RM0517
Reference manual

STM32H5E4/5F4 and STM32H5E5/5F5 Arm®-based 32-bit MCUs

Introduction

This document is addressed to application developers. It provides complete information on how to use the STM32H5Exxx and STM32H5Fxxx microcontrollers memory and peripherals.

For ordering information, mechanical, and electrical device characteristics, refer to the corresponding datasheets.

For information on the Arm® Cortex®-M33 core, refer to the corresponding Arm® Technical Reference Manuals available on http://infocenter.arm.com.

The STM32H5Exxx and STM32H5Fxxx microcontrollers include ST state-of-the-art patented technology.

Related documents

- STM32H5Exxx data brief (DS14971)
- STM32H5Fxxx data brief (DS14972)
- STM32H5Exxx/H5Fxxx errata sheet (ES0639)
- STM32 Cortex®-M33 MCUs programming manual (PM0264)

Contents

1 Documentation conventions 128

1.1 General information 128

1.2 List of abbreviations for registers 128

1.3 Register reset value 129

1.4 Glossary 129

2 Memory and bus architecture 130

2.1 System architecture 130

2.1.1 Fast C-bus 131

2.1.2 Slow C-bus 131

2.1.3 S-bus 131

2.1.4 DCACHE S-bus 132

2.1.5 GPDMA1 and GPDMA2 buses 132

2.1.6 SDMMC1 and SDMMC2 controllers DMA buses 132

2.1.7 OTG_HS bus 132

2.1.8 LTDC bus 132

2.1.9 Bus matrix 132

2.1.10 AHB/APB bridges 132

2.1.11 Ethernet MAC 133

2.2 TrustZone® security architecture 133

2.2.1 Default TrustZone® security state 133

2.2.2 TrustZone® peripheral classification 134

2.3 Memory organization 140

2.3.1 Introduction 140

2.3.2 Memory map and register boundary addresses 141

2.3.3 Embedded SRAMs 151

2.3.4 Flash memory overview 151

2.3.5 Boot modes 151

3 System security 153

3.1 Key security features 153

3.2 Secure install 154

3.3 Secure boot 155

3.3.1 Unique boot entry . . . 155
3.3.2 Immutable root of trust in system flash memory . . . 156
3.4 Secure update . . . 156
3.5 Resource isolation using hide protection levels . . . 156
3.6 Resource isolation using TrustZone . . . 157
3.6.1 TrustZone security architecture . . . 157
3.6.2 Armv8-M security extension of Cortex-M33 . . . 158
3.6.3 Memory and peripheral allocation using IDAU/SAU . . . 158
3.6.4 Memory and peripheral allocation using GTZC . . . 161
3.6.5 Managing security in TrustZone-aware peripherals . . . 164
3.6.6 Activating TrustZone security . . . 171
3.6.7 Deactivating TrustZone security . . . 171
3.7 Other resources isolation . . . 172
3.7.1 Temporal isolation using secure hide protection (HDP) . . . 172
3.7.2 Resource isolation using Cortex privileged mode . . . 172
3.8 Secure execution . . . 176
3.8.1 Memory protection unit (MPU) . . . 176
3.8.2 Embedded flash memory write protection . . . 177
3.8.3 Tamper detection and response . . . 177
3.9 Secure storage . . . 179
3.9.1 Hardware secret key management . . . 180
3.9.2 Unique ID . . . 181
3.10 Crypto engines . . . 181
3.10.1 Crypto engines features . . . 181
3.10.2 Secure AES coprocessor (SAES) . . . 182
3.10.3 On-the-fly decryption engine (OTFDEC1, OTFDEC2) . . . 183
3.11 Product life cycle . . . 184
3.11.1 Product configurations and security services . . . 185
3.11.2 Life cycle management . . . 186
3.11.3 Recommended product settings . . . 189
3.12 Software intellectual property protection and collaborative development . . . 189
3.12.1 Software intellectual property protection . . . 191
3.12.2 Software intellectual property protection with OTFDEC . . . 191
3.12.3 Other software intellectual property protections . . . 193

4 Boot modes 194
4.1 STM32H5Ex boot modes 195
4.2 STM32H5Fx boot modes 196

5 Global TrustZone® controller (GTZC) 197
5.1 Introduction 197
5.2 GTZC main features 197
5.3 GTZC implementation 199
5.4 GTZC functional description 201
5.4.1 GTZC block diagram 201
5.4.2 Illegal access definition 202
5.4.3 TrustZone security controller (TZSC) 203
5.4.4 Memory protection controller - block based (MPCBB) 204
5.4.5 TrustZone illegal access controller (TZIC) 205
5.4.6 Power-on/reset state 205
5.5 GTZC interrupts 205
5.6 GTZC1 TZSC registers 206
5.6.1 GTZC1 TZSC control register (GTZC1_TZSC_CR) 206
5.6.2 GTZC1 TZSC secure configuration register 1 (GTZC1_TZSC_SECCFGR1) 206
5.6.3 GTZC1 TZSC secure configuration register 2 (GTZC1_TZSC_SECCFGR2) 209
5.6.4 GTZC1 TZSC secure configuration register 3 (GTZC1_TZSC_SECCFGR3) 211
5.6.5 GTZC1 TZSC privilege configuration register 1 (GTZC1_TZSC_PRIVCFGR1) 214
5.6.6 GTZC1 TZSC privilege configuration register 2 (GTZC1_TZSC_PRIVCFGR2) 217
5.6.7 GTZC1 TZSC privilege configuration register 3 (GTZC1_TZSC_PRIVCFGR3) 219
5.6.8 GTZC1 TZSC memory x subregion z watermark configuration register (GTZC1_TZSC_MPCWMxACFGR) 222
5.6.9 GTZC1 TZSC memory x subregion z watermark configuration register (GTZC1_TZSC_MPCWMxBCFGR) 223
5.6.10 GTZC1 TZSC memory x subregion A watermark register (GTZC1_TZSC_MPCWMxAR) 224
5.6.11 GTZC1 TZSC memory x subregion B watermark register (GTZC1_TZSC_MPCWMxBR) 225
5.6.12 GTZC1 TZSC register map 226

5.7 GTZC1 TZIC registers 228
5.7.1 GTZC1 TZIC interrupt enable register 1 (GTZC1_TZIC_IER1) 228
5.7.2 GTZC1 TZIC interrupt enable register 2 (GTZC1_TZIC_IER2) 230
5.7.3 GTZC1 TZIC interrupt enable register 3 (GTZC1_TZIC_IER3) 233
5.7.4 GTZC1 TZIC interrupt enable register 4 (GTZC1_TZIC_IER4) 235
5.7.5 GTZC1 TZIC status register 1 (GTZC1_TZIC_SR1) 238
5.7.6 GTZC1 TZIC status register 2 (GTZC1_TZIC_SR2) 240
5.7.7 GTZC1 TZIC status register 3 (GTZC1_TZIC_SR3) 242
5.7.8 GTZC1 TZIC status register 4 (GTZC1_TZIC_SR4) 245
5.7.9 GTZC1 TZIC flag clear register 1 (GTZC1_TZIC_FCR1) 247
5.7.10 GTZC1 TZIC flag clear register 2 (GTZC1_TZIC_FCR2) 250
5.7.11 GTZC1 TZIC flag clear register 3 (GTZC1_TZIC_FCR3) 252
5.7.12 GTZC1 TZIC flag clear register 4 (GTZC1_TZIC_FCR4) 255
5.7.13 GTZC1 TZIC register map 258
5.8 GTZC1 MPCBBz registers (z = 1 to 3) 260
5.8.1 GTZC1 SRAMz MPCBB control register (GTZC1_MPCBBz_CR) (z = 1 to 3) 260
5.8.2 GTZC1 SRAMz MPCBB configuration lock register 1 (GTZC1_MPCBBz_CFGLOCK1) (z = 1 to 3) 261
5.8.3 GTZC1 SRAM1 MPCBB security configuration for super-block x register (GTZC1_MPCBB1_SECCFGRx) 261
5.8.4 GTZC1 SRAM2 MPCBB security configuration for super-block x register (GTZC1_MPCBB2_SECCFGRx) 262
5.8.5 GTZC1 SRAM3 MPCBB security configuration for super-block x register (GTZC1_MPCBB3_SECCFGRx) 262
5.8.6 GTZC1 SRAM1 MPCBB privileged configuration for super-block x register (GTZC1_MPCBB1_PRIVCFGRx) 263
5.8.7 GTZC1 SRAM2 MPCBB privileged configuration for super-block x register (GTZC1_MPCBB2_PRIVCFGRx) 263
5.8.8 GTZC1 SRAM3 MPCBB privileged configuration for super-block x register (GTZC1_MPCBB3_PRIVCFGRx) 264
5.8.9 GTZC1 MPCBBz register map (z = 1 to 3) 264

6 RAMs configuration controller (RAMCFG) 265
6.1 RAMCFG introduction 265
6.2 RAMCFG main features 265
6.3 RAMCFG functional description 265
6.3.1 Internal SRAM features 265
6.3.2 Error code correction (SRAM2, SRAM3, BKPSRAM) 266

6.3.3 Write protection (SRAM2) . . . 268
6.3.4 Software erase . . . 268
6.4 RAMCFG low-power modes . . . 269
6.5 RAMCFG interrupts . . . 269
6.6 RAMCFG registers . . . 269
6.6.1 RAMCFG memory x control register (RAMCFG_MxCR) . . . 269
6.6.2 RAMCFG memory x interrupt enable register (RAMCFG_MxIER) . . . 270
6.6.3 RAMCFG memory interrupt status register (RAMCFG_MxISR) . . . 271
6.6.4 RAMCFG memory x ECC single error address register (RAMCFG_MxSEAR) . . . 271
6.6.5 RAMCFG memory x ECC double error address register (RAMCFG_MxDEAR) . . . 272
6.6.6 RAMCFG memory x interrupt clear register x (RAMCFG_MxICR) . . . 272
6.6.7 RAMCFG memory 2 write protection register 1 (RAMCFG_M2WPR1) . . . 273
6.6.8 RAMCFG memory 2 write protection register 2 (RAMCFG_M2WPR2) . . . 273
6.6.9 RAMCFG memory x ECC key register (RAMCFG_MxECCKEYR) . . . 273
6.6.10 RAMCFG memory x erase key register (RAMCFG_MxERKEYR) . . . 274
6.6.11 RAMCFG memory 2 write protection register 3 (RAMCFG_M2WPR3) . . . 274
6.6.12 RAMCFG memory 2 write protection register 4 (RAMCFG_M2WPR4) . . . 275
6.6.13 RAMCFG register map . . . 276

7 Embedded flash memory (FLASH) . . . 277
7.1 FLASH introduction . . . 277
7.2 FLASH main features . . . 277
7.3 FLASH functional description . . . 278
7.3.1 FLASH block diagram . . . 278
7.3.2 FLASH signals . . . 279
7.3.3 Flash memory architecture and usage . . . 280
7.3.4 FLASH read operations . . . 282
7.3.5 FLASH program operations . . . 284
7.3.6 FLASH erase operations . . . 287
7.3.7 FLASH parallel operations . . . 291

7.3.8 FLASH error protections . . . 291
7.3.9 OTP and RO memory access . . . 292
7.3.10 Flash high-cycle data . . . 294
7.3.11 Flash bank swapping . . . 296
7.3.12 FLASH reset and clocks . . . 298
7.4 FLASH option bytes . . . 300
7.4.1 About option bytes . . . 300
7.4.2 Option bytes loading . . . 300
7.4.3 Option byte modification . . . 300
7.4.4 Description of user and system option bytes . . . 304
7.4.5 Description of data protection option bytes . . . 305
7.4.6 Description of boot address option bytes . . . 305
7.4.7 Specific rules for modifying option bytes . . . 306
7.5 Option byte key management . . . 308
7.5.1 OBK loading . . . 308
7.5.2 OBK access per HDPL level . . . 308
7.5.3 OBK programming sequence . . . 309
7.5.4 OBK programming finite state machine . . . 311
7.5.5 OBK swap sector . . . 312
7.5.6 OBK alternate sector erase . . . 314
7.6 FLASH security and protections . . . 314
7.6.1 TrustZone security protection . . . 315
7.6.2 Hide protection (HDP) . . . 317
7.6.3 Block-based secure flash memory area protection . . . 319
7.6.4 Block-based privileged flash memory area protection . . . 320
7.6.5 Flash memory register privileged and unprivileged modes . . . 321
7.6.6 Flash memory banks attributes in case of bank swap . . . 322
7.6.7 Flash memory configuration protection . . . 323
7.6.8 Write protection . . . 324
7.6.9 Flash high-cycle data protections . . . 324
7.6.10 Life cycle management . . . 326
7.6.11 Product state transitions . . . 327
7.6.12 OBK protection . . . 330
7.6.13 One-time-programmable and read-only memory protections . . . 331
7.7 System memory . . . 332
7.7.1 Introduction . . . 332
7.7.2 RSS user functions . . . 332

7.8 FLASH low-power modes 338
7.9 FLASH error management 339
7.9.1 Introduction 339
7.9.2 Nonsecure write protection error (WRPERR) 340
7.9.3 Secure write protection error (WRPERR) 341
7.9.4 Nonsecure programming sequence error (PGSERR) 341
7.9.5 Secure programming sequence error (PGSERR) 343
7.9.6 Nonsecure strobe error (STRBERR) 344
7.9.7 Secure strobe error (STRBERR) 344
7.9.8 Nonsecure inconsistency error (INCERR) 344
7.9.9 Secure inconsistency error (INCERR) 345
7.9.10 Error correction code error (ECCC, ECCD) 345
7.9.11 Illegal access (ILAFM/ILAP) 346
7.9.12 Option byte change error (OPTCHANGEERR) 347
7.9.13 Miscellaneous HardFault errors 347
7.9.14 OBK error cases (OBKERR, OBKWERR) 348
7.10 FLASH interrupts 348
7.11 FLASH registers 350
7.11.1 FLASH access control register (FLASH_ACR) 350
7.11.2 FLASH nonsecure key register (FLASH_NSKEYR) 351
7.11.3 FLASH secure key register (FLASH_SECKEYR) 351
7.11.4 FLASH option key register (FLASH_OPTKEYR) 352
7.11.5 FLASH nonsecure OBK key register (FLASH_NSOBKKEYR) 352
7.11.6 FLASH secure OBK key register (FLASH_SECOBKKEYR) 353
7.11.7 FLASH operation status register (FLASH_OPSR) 353
7.11.8 FLASH option control register (FLASH_OPTCR) 354
7.11.9 FLASH nonsecure status register (FLASH_NSSR) 355
7.11.10 FLASH secure status register (FLASH_SECSR) 357
7.11.11 FLASH nonsecure control register (FLASH_NSCR) 359
7.11.12 FLASH secure control register (FLASH_SECCR) 361
7.11.13 FLASH nonsecure clear control register (FLASH_NSCCR) 364
7.11.14 FLASH secure clear control register (FLASH_SECCCR) 365
7.11.15 FLASH privilege configuration register (FLASH_PRIVCFGR) 366
7.11.16 FLASH nonsecure OBK configuration register (FLASH_NSOBKCFGR) 366
7.11.17 FLASH secure OBK configuration register (FLASH_SECOBKCFGR) 367
7.11.18 FLASH HDP extension register (FLASH_HDPEXTR) 369

7.11.19 FLASH option status register (FLASH_OPTSR_CUR) 369
7.11.20 FLASH option status register (FLASH_OPTSR_PRG) 371
7.11.21 FLASH nonsecure EPOCH register (FLASH_NSEPOCHR_CUR) . . . 373
7.11.22 FLASH secure EPOCH register (FLASH_SECEPOCHR_CUR) 373
7.11.23 FLASH option status register 2 (FLASH_OPTSR2_CUR) 374
7.11.24 FLASH option status register 2 (FLASH_OPTSR2_PRG) 375
7.11.25 FLASH nonsecure boot register (FLASH_NSBOOTR_CUR) 376
7.11.26 FLASH nonsecure boot register (FLASH_NSBOOTR_PRG) 376
7.11.27 FLASH secure boot register (FLASH_SECBOOTR_CUR) 378
7.11.28 FLASH secure boot register (FLASH_BOOTR_PRG) 378
7.11.29 FLASH nonsecure OTP block lock (FLASH_OTPBLR_CUR) 379
7.11.30 FLASH nonsecure OTP block lock (FLASH_OTPBLR_PRG) 379
7.11.31 FLASH write sector group 2 protection for bank1 (FLASH_WRP12R_CUR) 380
7.11.32 FLASH write sector group 2 protection for bank1 (FLASH_WRP12R_PRG) 380
7.11.33 FLASH secure block based register for bank1 (FLASH_SECBB1Rx) . 381
7.11.34 FLASH privilege block based register for bank1 (FLASH_PRIVBB1Rx) 381
7.11.35 FLASH security watermark for bank1 (FLASH_SECWM1R_CUR) 382
7.11.36 FLASH security watermark for bank1 (FLASH_SECWM1R_PRG) . . . 382
7.11.37 FLASH write sector group 1 protection for bank1 (FLASH_WRP11R_CUR) 383
7.11.38 FLASH write sector group 1 protection for bank1 (FLASH_WRP11R_PRG) 383
7.11.39 FLASH data sector configuration bank1 (FLASH_EDATA1R_CUR) . . 384
7.11.40 FLASH data sector configuration bank1 (FLASH_EDATA1R_PRG) . . 384
7.11.41 FLASH HDP bank1 configuration (FLASH_HDP1R_CUR) 385
7.11.42 FLASH HDP bank1 configuration (FLASH_HDP1R_PRG) 385
7.11.43 FLASH ECC correction register (FLASH_ECCCORR) 386
7.11.44 FLASH ECC detection register (FLASH_ECCDETR) 387
7.11.45 FLASH ECC data (FLASH_ECCDR) 388
7.11.46 FLASH write sector group 2 protection for bank2 (FLASH_WRP22R_CUR) 389
7.11.47 FLASH write sector group 2 protection for bank2 (FLASH_WRP22R_PRG) 389
7.11.48 FLASH secure block-based register for bank2 (FLASH_SECBB2Rx) 390
7.11.49 FLASH privilege block-based register for bank2 (FLASH_PRIVBB2Rx) 390

7.11.50 FLASH security watermark for bank2 (FLASH_SECWM2R_CUR) . . . 391
7.11.51 FLASH security watermark for bank2 (FLASH_SECWM2R_PRG) . . . 391
7.11.52 FLASH write sector group 1 protection for bank2 (FLASH_WRP21R_CUR) . . . 392
7.11.53 FLASH write sector group 1 protection for bank2 (FLASH_WRP21R_PRG) . . . 392
7.11.54 FLASH data sectors configuration bank2 (FLASH_EDATA2R_CUR) . 393
7.11.55 FLASH data sector configuration bank2 (FLASH_EDATA2R_PRG) . . 394
7.11.56 FLASH HDP bank2 configuration (FLASH_HDP2R_CUR) . . . 394
7.11.57 FLASH HDP bank2 configuration (FLASH_HDP2R_PRG) . . . 395
7.12 FLASH register map and reset values . . . 396

8 Instruction cache (ICACHE) . . . 402
8.1 ICACHE introduction . . . 402
8.2 ICACHE main features . . . 402
8.3 ICACHE implementation . . . 403
8.4 ICACHE functional description . . . 403
8.4.1 ICACHE block diagram . . . 404
8.4.2 ICACHE reset and clocks . . . 404
8.4.3 ICACHE TAG memory . . . 405
8.4.4 Direct-mapped ICACHE (1-way cache) . . . 406
8.4.5 ICACHE enable . . . 407
8.4.6 Cacheable and noncacheable traffic . . . 407
8.4.7 Address remapping . . . 408
8.4.8 Cacheable accesses . . . 410
8.4.9 Dual-master cache . . . 411
8.4.10 ICACHE security . . . 411
8.4.11 ICACHE maintenance . . . 411
8.4.12 ICACHE performance monitoring . . . 412
8.4.13 ICACHE boot . . . 412
8.5 ICACHE low-power modes . . . 412
8.6 ICACHE error management and interrupts . . . 413
8.7 ICACHE registers . . . 413
8.7.1 ICACHE control register (ICACHE_CR) . . . 413
8.7.2 ICACHE status register (ICACHE_SR) . . . 414
8.7.3 ICACHE interrupt enable register (ICACHE_IER) . . . 415
8.7.4 ICACHE flag clear register (ICACHE_FCR) . . . 415

8.7.5 ICACHE hit monitor register (ICACHE_HMONR) 416
8.7.6 ICACHE miss monitor register (ICACHE_MMONR) 416
8.7.7 ICACHE region x configuration register (ICACHE_CRRx) 416
8.7.8 ICACHE register map 417

9 Data cache (DCACHE) 419
9.1 DCACHE introduction 419
9.2 DCACHE main features 419
9.3 DCACHE implementation 420
9.4 DCACHE functional description 420
9.4.1 DCACHE block diagram 421
9.4.2 DCACHE reset and clocks 421
9.4.3 DCACHE TAG memory 422
9.4.4 DCACHE enable 424
9.4.5 Cacheable and noncacheable traffic 424
9.4.6 Cacheable accesses 425
9.4.7 DCACHE security 427
9.4.8 DCACHE maintenance 427
9.4.9 DCACHE performance monitoring 429
9.4.10 DCACHE boot 429
9.5 DCACHE low-power modes 430
9.6 DCACHE error management and interrupts 430
9.7 DCACHE registers 431
9.7.1 DCACHE control register (DCACHE_CR) 431
9.7.2 DCACHE status register (DCACHE_SR) 432
9.7.3 DCACHE interrupt enable register (DCACHE_IER) 433
9.7.4 DCACHE flag clear register (DCACHE_FCR) 434
9.7.5 DCACHE read-hit monitor register (DCACHE_RHMONR) 434
9.7.6 DCACHE read-miss monitor register (DCACHE_RMMONR) 435
9.7.7 DCACHE write-hit monitor register (DCACHE_WHMONR) 435
9.7.8 DCACHE write-miss monitor register (DCACHE_WMMONR) 435
9.7.9 DCACHE command range start address register (DCACHE_CMDRSADDRR) 436
9.7.10 DCACHE command range end address register (DCACHE_CMDREADDRR) 436
9.7.11 DCACHE register map 436

10 Power control (PWR) 438
10.1 PWR introduction 438
10.2 PWR main features 438
10.3 PWR pins and internal signals 438
10.4 PWR power supplies and supply domains 440
10.4.1 External power supplies 441
10.4.2 Internal regulators 443
10.4.3 Power-up and power-down power sequences 444
10.4.4 Independent analog peripherals supply 444
10.4.5 Independent I/O supply rail 445
10.4.6 Independent USB transceivers supply 445
10.4.7 Backup domain 445
10.5 PWR system supply voltage regulation 447
10.5.1 SMPS and LDO embedded regulators 447
10.5.2 V_{CORE} supply versus reset, voltage scaling, and low-power modes . . 447
10.5.3 Embedded voltage regulator operating modes 447
10.6 PWR power supply and temperature supervision 448
10.6.1 Power-on reset (POR)/power-down reset (PDR) 448
10.6.2 Brownout reset (BOR) 449
10.6.3 Programmable voltage detector (PVD) 450
10.6.4 Analog voltage detector (AVD) 451
10.6.5 VDDIO2 voltage monitor (IO2VM) 452
10.6.6 VDDUSB voltage monitor (UVM) 452
10.6.7 Backup domain voltage monitoring 452
10.6.8 Temperature monitoring 453
10.7 PWR management 454
10.7.1 Voltage scaling 454
10.7.2 Power management examples 455
10.8 Power modes 456
10.8.1 Slowing down system clocks 460
10.8.2 Peripheral clock gating 460
10.8.3 Low-power modes 460
10.8.4 Sleep mode 461
10.8.5 Stop mode 462
10.8.6 Standby mode 465
10.8.7 Power modes output pins 467

10.9 PWR security and privileged protection 468
10.9.1 PWR security protection 468
10.9.2 PWR privileged protection 469
10.10 PWR interrupts 470
10.11 PWR registers 470
10.11.1 PWR power mode control register (PWR_PMCR) 470
10.11.2 PWR status register (PWR_PMSR) 472
10.11.3 PWR voltage scaling control register (PWR_VOSCR) 473
10.11.4 PWR voltage scaling status register (PWR_VOSSR) 474
10.11.5 PWR backup domain control register (PWR_BDCR) 474
10.11.6 PWR backup domain control register (PWR_DBPCR) 476
10.11.7 PWR backup domain status register (PWR_BDSR) 476
10.11.8 PWR USB Type-C® power delivery register (PWR_UCPDR) 477
10.11.9 PWR supply configuration control register (PWR_SCCR) 478
10.11.10 PWR voltage monitor status register (PWR_VMCR) 478
10.11.11 PWR USB supply control register (PWR_USBSCR) 479
10.11.12 PWR voltage monitor status register (PWR_VMSR) 480
10.11.13 PWR wake-up status clear register (PWR_WUSCR) 481
10.11.14 PWR wake-up status register (PWR_WUSR) 481
10.11.15 PWR wake-up configuration register (PWR_WUCR) 482
10.11.16 PWR I/O retention register (PWR_IORETR) 483
10.11.17 PWR security configuration register (PWR_SECCFGR) 484
10.11.18 PWR privilege configuration register (PWR_PRIVCFGR) 485
10.11.19 PWR register map 485

11 Reset and clock control (RCC) 488

11.1 RCC introduction 488
11.2 RCC pins and internal signals 488
11.3 RCC reset functional description 488
11.3.1 Power reset 488
11.3.2 System reset 489
11.3.3 Backup domain reset 490
11.3.4 Reset source identification 490
11.4 RCC clock functional description 491
11.4.1 HSE clock 493
11.4.2 HSI clock 494

11.4.3 CSI oscillator . . . 495
11.4.4 HSI48 clock . . . 496
11.4.5 PLL description . . . 496
11.4.6 LSE clock . . . 500
11.4.7 LSI clock . . . 501
11.4.8 System clock (SYSCLK) selection . . . 501
11.4.9 Handling clock generators in Stop and Standby modes . . . 502
11.4.10 Clock security system (CSS) . . . 503
11.4.11 Clock output generation (MCO1/MCO2) . . . 504
11.4.12 Kernel clock selection . . . 504
11.4.13 RTC and TAMP clock . . . 513
11.4.14 Timer clock . . . 514
11.4.15 Watchdog clock . . . 514
11.4.16 Peripheral clock gating and autonomous mode . . . 514
11.5 RCC security and privilege functional description . . . 515
11.5.1 RCC TrustZone security protection modes . . . 515
11.5.2 RCC privilege protection modes . . . 518
11.6 RCC low-power modes . . . 518
11.7 RCC interrupts . . . 519
11.8 RCC registers . . . 521
11.8.1 RCC clock control register (RCC_CR) . . . 521
11.8.2 RCC HSI calibration register (RCC_HSICFGR) . . . 524
11.8.3 RCC clock recovery RC register (RCC_CRRCR) . . . 525
11.8.4 RCC CSI calibration register (RCC_CSICFGR) . . . 525
11.8.5 RCC clock configuration register1 (RCC_CFGR1) . . . 526
11.8.6 RCC CPU domain clock configuration register 2 (RCC_CFGR2) . . . 528
11.8.7 RCC PLL clock source selection register (RCC_PLL1CFGR) . . . 530
11.8.8 RCC PLL clock source selection register (RCC_PLL2CFGR) . . . 532
11.8.9 RCC PLL clock source selection register (RCC_PLL3CFGR) . . . 534
11.8.10 RCC PLL1 dividers register (RCC_PLL1DIVR) . . . 535
11.8.11 RCC PLL1 fractional divider register (RCC_PLL1FRACR) . . . 537
11.8.12 RCC PLL1 dividers register (RCC_PLL2DIVR) . . . 537
11.8.13 RCC PLL2 fractional divider register (RCC_PLL2FRACR) . . . 538
11.8.14 RCC PLL3 dividers register (RCC_PLL3DIVR) . . . 539
11.8.15 RCC PLL3 fractional divider register (RCC_PLL3FRACR) . . . 540
11.8.16 RCC clock source interrupt enable register (RCC_CIER) . . . 541
11.8.17 RCC clock source interrupt flag register (RCC_CIFR) . . . 542

11.8.18 RCC clock source interrupt clear register (RCC_CICR) 544
11.8.19 RCC AHB1 reset register (RCC_AHB1RSTR) 545
11.8.20 RCC AHB2 peripheral reset register (RCC_AHB2RSTR) 546
11.8.21 RCC AHB4 peripheral reset register (RCC_AHB4RSTR) 549
11.8.22 RCC APB1 peripheral low reset register (RCC_APB1LRSTR) 550
11.8.23 RCC APB1 peripheral high reset register (RCC_APB1HRSTR) 553
11.8.24 RCC APB2 peripheral reset register (RCC_APB2RSTR) 554
11.8.25 RCC APB3 peripheral reset register (RCC_APB3RSTR) 556
11.8.26 RCC AHB1 peripheral clock register (RCC_AHB1ENR) 557
11.8.27 RCC AHB2 peripheral clock register (RCC_AHB2ENR) 559
11.8.28 RCC AHB4 peripheral clock register (RCC_AHB4ENR) 562
11.8.29 RCC APB1 peripheral clock register (RCC_APB1LENR) 563
11.8.30 RCC APB1 peripheral clock register (RCC_APB1HENR) 566
11.8.31 RCC APB2 peripheral clock register (RCC_APB2ENR) 567
11.8.32 RCC APB3 peripheral clock register (RCC_APB3ENR) 569
11.8.33 RCC AHB1 sleep clock register (RCC_AHB1LPENR) 570
11.8.34 RCC AHB2 sleep clock register (RCC_AHB2LPENR) 573
11.8.35 RCC AHB4 sleep clock register (RCC_AHB4LPENR) 576
11.8.36 RCC APB1 sleep clock register (RCC_APB1LLPENR) 577
11.8.37 RCC APB1 sleep clock register (RCC_APB1HLPENR) 580
11.8.38 RCC APB2 sleep clock register (RCC_APB2LPENR) 581
11.8.39 RCC APB3 sleep clock register (RCC_APB3LPENR) 582
11.8.40 RCC kernel clock configuration register (RCC_CCIPR1) 584
11.8.41 RCC kernel clock configuration register (RCC_CCIPR2) 586
11.8.42 RCC kernel clock configuration register (RCC_CCIPR3) 588
11.8.43 RCC kernel clock configuration register (RCC_CCIPR4) 590
11.8.44 RCC kernel clock configuration register (RCC_CCIPR5) 592
11.8.45 RCC backup domain control register (RCC_BDCR) 594
11.8.46 RCC reset status register (RCC_RSR) 597
11.8.47 RCC secure configuration register (RCC_SECCFGR) 598
11.8.48 RCC privilege configuration register (RCC_PRIVCFGR) 600
11.8.49 RCC register map 600

12 Clock recovery system (CRS) 606

12.1 CRS introduction 606
12.2 CRS main features 606
12.3 CRS implementation 606

12.4 CRS functional description 607
12.4.1 CRS block diagram 607
12.4.2 CRS internal signals 607
12.4.3 Synchronization input 608
12.4.4 Frequency error measurement 608
12.4.5 Frequency error evaluation and automatic trimming 609
12.4.6 CRS initialization and configuration 610
12.5 CRS in low-power modes 611
12.6 CRS interrupts 611
12.7 CRS registers 611
12.7.1 CRS control register (CRS_CR) 611
12.7.2 CRS configuration register (CRS_CFGR) 613
12.7.3 CRS interrupt and status register (CRS_ISR) 614
12.7.4 CRS interrupt flag clear register (CRS_ICR) 616
12.7.5 CRS register map 616

13 General-purpose I/Os (GPIO) 618
13.1 Introduction 618
13.2 GPIO main features 618
13.3 GPIO functional description 618
13.3.1 General-purpose I/O (GPIO) 620
13.3.2 I/O pin alternate function multiplexer and mapping 621
13.3.3 I/O port control registers 622
13.3.4 I/O port data registers 622
13.3.5 I/O data bitwise handling 622
13.3.6 GPIO locking mechanism 622
13.3.7 I/O alternate function input/output 623
13.3.8 External interrupt/wakeup lines 623
13.3.9 Input configuration 623
13.3.10 Output configuration 624
13.3.11 Alternate function configuration 624
13.3.12 Analog configuration 625
13.3.13 Using the HSE or LSE oscillator pins as GPIOs 625
13.3.14 Using the GPIO pins in the RTC supply domain 626
13.3.15 I/Os state retention during standby mode 626
13.3.16 TrustZone security 626

13.3.17 Privileged and unprivileged modes . . . 627
13.3.18 High-speed low-voltage mode (HSLV) . . . 627
13.3.19 I/O compensation cell . . . 628
13.4 GPIO registers . . . 628
13.4.1 GPIO port mode register (GPIOx_MODER) (x = A to K) . . . 628
13.4.2 GPIO port output type register (GPIOx_OTYPER) (x = A to K) . . . 629
13.4.3 GPIO port output speed register (GPIOx_OSPEEDR) (x = A to K) . . . 629
13.4.4 GPIO port pull-up/pull-down register (GPIOx_PUPDR) (x = A to K) . . 630
13.4.5 GPIO port input data register (GPIOx_IDR) (x = A to K) . . . 630
13.4.6 GPIO port output data register (GPIOx_ODR) (x = A to K) . . . 631
13.4.7 GPIO port bit set/reset register (GPIOx_BSRR) (x = A to K) . . . 631
13.4.8 GPIO port configuration lock register (GPIOx_LCKR) (x = A to K) . . . 632
13.4.9 GPIO alternate function low register (GPIOx_AFRL) (x = A to K) . . . 633
13.4.10 GPIO alternate function high register (GPIOx_AFRH) (x = A to K) . . . 633
13.4.11 GPIO port bit reset register (GPIOx_BRR) (x = A to K) . . . 634
13.4.12 GPIO high-speed low-voltage register (GPIOx_HSLVR) (x = A to K) . 635
13.4.13 GPIO secure configuration register (GPIOx_SECCFGR) (x = A to K) . 635
13.4.14 GPIO register map . . . 636

14 System configuration, boot, and security (SBS) . . . 638
14.1 SBS introduction . . . 638
14.2 SBS main features . . . 638
14.3 SBS functional description . . . 639
14.3.1 SBS block diagram . . . 639
14.3.2 SBS signals . . . 640
14.3.3 SBS reset and clocks . . . 641
14.3.4 SBS system configuration . . . 641
14.3.5 SBS boot control . . . 643
14.3.6 SBS debug control . . . 645
14.3.7 SBS hardware secure storage control . . . 648
14.4 SBS interrupts . . . 649
14.5 SBS registers . . . 649
14.5.1 SBS temporal isolation control register (SBS_HDPLCR) . . . 649
14.5.2 SBS temporal isolation status register (SBS_HDPLSR) . . . 650
14.5.3 SBS next HDPL control register (SBS_NEXTHDPLCR) . . . 650
14.5.4 SBS debug control register (SBS_DBGCR) . . . 651

14.5.5 SBS debug lock register (SBS_DBGLOCKR) 651
14.5.6 SBS RSS command register (SBS_RSSCMDR) 652
14.5.7 SBS EPOCH selection control register (SBS_EPOCHSELCR) 652
14.5.8 SBS security mode configuration control register (SBS_SECCFGR) . 653
14.5.9 SBS product mode and configuration register (SBS_PMCR) 654
14.5.10 SBS FPU interrupt mask register (SBS_FPUIMR) 655
14.5.11 SBS memory erase status register (SBS_MESR) 656
14.5.12 SBS compensation cell for I/Os control and status register (SBS_CCCSR) 656
14.5.13 SBS compensation cell for I/Os value register (SBS_CCVALR) 657
14.5.14 SBS compensation cell for I/Os software code register (SBS_CCSWCR) 658
14.5.15 SBS Class B register (SBS_CFGR2) 659
14.5.16 SBS CPU nonsecure lock register (SBS_CNSLCKR) 660
14.5.17 SBS CPU secure lock register (SBS_CSLCKR) 661
14.5.18 SBS flift ECC NMI mask register (SBS_ECCNMIR) 662
14.5.19 SBS OTG_HS PHY tune register 2 (SBS_OTGHSPHYTUNER2) . . . 662
14.5.20 SBS register map 663

15 Peripherals interconnect matrix 666

15.1 Interconnect matrix introduction 666
15.2 Connection summary 666
15.3 Interconnection details 668
15.3.1 Master to slave interconnection for timers 668
15.3.2 Triggers to ADCs 668
15.3.3 ADC analog watchdogs as triggers to timers and PLAY1 669
15.3.4 Triggers to DAC 670
15.3.5 Clock sources to timers 670
15.3.6 Triggers to low-power timers 671
15.3.7 RTC wake-up as input to timers 672
15.3.8 System errors as break signals to timers 672
15.3.9 I3C as trigger to timers 673
15.3.10 Triggers to GPDMA1/2 673
15.3.11 Internal analog signals to analog peripherals 674
15.3.12 Clock source for the DAC sample and hold mode 674
15.3.13 Internal tamper sources 674
15.3.14 Output from tamper to RTC 674

15.3.15 Timer break from MDF1 . . . 675
15.3.16 Comparators as inputs, trigger, or break signals to timers1 . . . 675
15.3.17 Triggers on MDF1 or ADF1 . . . 676
15.3.18 Blanking sources to comparators . . . 677
15.3.19 OTG_FS/OTG_HS SOF as trigger to timers . . . 677
15.3.20 Ethernet as trigger to timers . . . 678
15.3.21 Timers as trigger to Ethernet . . . 678
15.3.22 PLAY1 as input to timers . . . 678
15.3.23 ADC data filtering by the MDF1/ADF1 . . . 679
15.3.24 Inputs to PLAY1 . . . 679
15.3.25 Triggers to DTS . . . 680
15.3.26 Encryption keys to AES/SAES . . . 680

16 General purpose direct memory access controller (GPDMA) . . . 681

16.1 GPDMA introduction . . . 681
16.2 GPDMA main features . . . 681
16.3 GPDMA implementation . . . 682
16.3.1 GPDMA instances . . . 682
16.3.2 GPDMA channels . . . 682
16.3.3 GPDMA in low-power modes . . . 683
16.3.4 GPDMA requests . . . 683
16.3.5 GPDMA block requests . . . 688
16.3.6 GPDMA channels with peripheral early termination . . . 688
16.3.7 GPDMA triggers . . . 689
16.4 GPDMA functional description . . . 692
16.4.1 GPDMA block diagram . . . 692
16.4.2 GPDMA channel state and direct programming without any linked-list 692
16.4.3 GPDMA channel suspend and resume . . . 693
16.4.4 GPDMA channel abort and restart . . . 694
16.4.5 GPDMA linked-list data structure . . . 695
16.4.6 Linked-list item transfer execution . . . 698
16.4.7 GPDMA channel state and linked-list programming in run-to-completion mode . . . 698
16.4.8 GPDMA channel state and linked-list programming in link step mode 702
16.4.9 GPDMA channel state and linked-list programming . . . 709
16.4.10 GPDMA FIFO-based transfers . . . 711
16.4.11 GPDMA transfer request and arbitration . . . 718

16.4.12 GPDMA triggered transfer 722
16.4.13 GPDMA circular buffering with linked-list programming 723
16.4.14 GPDMA transfer in peripheral flow-control mode 725
16.4.15 GPDMA secure/nonsecure channel 726
16.4.16 GPDMA privileged/unprivileged channel 727
16.4.17 GPDMA error management 727
16.5 GPDMA in debug mode 729
16.6 GPDMA in low-power modes 729
16.7 GPDMA interrupts 730
16.8 GPDMA registers 731
16.8.1 GPDMA secure configuration register (GPDMA_SECCFGR) 731
16.8.2 GPDMA privileged configuration register (GPDMA_PRIVCFGR) 732
16.8.3 GPDMA configuration lock register (GPDMA_RCFGLOCKR) 732
16.8.4 GPDMA nonsecure masked interrupt status register (GPDMA_MISR) 733
16.8.5 GPDMA secure masked interrupt status register (GPDMA_SMISR) . . 734
16.8.6 GPDMA channel x linked-list base address register (GPDMA_CxLBAR) 734
16.8.7 GPDMA channel x flag clear register (GPDMA_CxFCR) 735
16.8.8 GPDMA channel x status register (GPDMA_CxSR) 736
16.8.9 GPDMA channel x control register (GPDMA_CxCR) 737
16.8.10 GPDMA channel x transfer register 1 (GPDMA_CxTR1) 739
16.8.11 GPDMA channel x transfer register 2 (GPDMA_CxTR2) 743
16.8.12 GPDMA channel x block register 1 (GPDMA_CxBR1) 747
16.8.13 GPDMA channel x alternate block register 1 (GPDMA_CxBR1) 748
16.8.14 GPDMA channel x source address register (GPDMA_CxSAR) 751
16.8.15 GPDMA channel x destination address register (GPDMA_CxDAR) . . 752
16.8.16 GPDMA channel x transfer register 3 (GPDMA_CxTR3) 753
16.8.17 GPDMA channel x block register 2 (GPDMA_CxBR2) 754
16.8.18 GPDMA channel x linked-list address register (GPDMA_CxLLR) 755
16.8.19 GPDMA channel x alternate linked-list address register (GPDMA_CxLLR) 757
16.8.20 GPDMA register map 758

17 Chrom-ART2 accelerator controller (DMA2D) 761
17.1 DMA2D introduction 761
17.2 DMA2D main features 762

17.3 DMA2D functional description 763
17.3.1 General description 763
17.3.2 DMA2D internal signals 763
17.3.3 DMA2D pipeline 765
17.3.4 DMA2D control and global operating mode 767
17.3.5 DMA2D fetching stage 767
17.3.6 DMA2D input pixel format conversion stage 770
17.3.7 DMA2D foreground and background CLUT interface 772
17.3.8 DMA2D pixel skipper stage 773
17.3.9 DMA2D stenciling stage (pre-blend or post-blend) 774
17.3.10 DMA2D scaling stage (pre-blend or post-blend) 775
17.3.11 DMA2D buffer/rotate stage 776
17.3.12 DMA2D YCBCR PFC stage / JPEG decoding 780
17.3.13 DMA2D blender stage 781
17.3.14 DMA2D output PFC stage 782
17.3.15 DMA2D write stage 782
17.3.16 DMA2D output FIFO byte reordering 783
17.3.17 Watermark 785
17.3.18 DMA2D AHB master port timer 785
17.3.19 DMA2D configuration 785
17.3.20 DMA2D configuration error detection 788
17.3.21 DMA2D transfer control (start, suspend, abort, and completion) 791
17.3.22 DMA2D error management 791
17.3.23 General purpose flags 792
17.3.24 Command list management 793
17.4 DMA2D interrupts 800
17.5 DMA2D registers 801
17.5.1 DMA2D control register (DMA2D_CR) 801
17.5.2 DMA2D interrupt status register (DMA2D_ISR) 802
17.5.3 DMA2D interrupt enable register (DMA2D_IER) 804
17.5.4 DMA2D interrupt flag clear register (DMA2D_IFCR) 806
17.5.5 DMA2D foreground memory address register (DMA2D_FGMAR) . . . 807
17.5.6 DMA2D foreground offset register (DMA2D_FGOR) 808
17.5.7 DMA2D foreground memory skip register (DMA2D_FGMSR) 808
17.5.8 DMA2D foreground PFC control register (DMA2D_FGPFCCR) 809
17.5.9 DMA2D foreground color register (DMA2D_FGCOLR) 811

17.5.10 DMA2D foreground CLUT memory address register (DMA2D_FGCMAR) 812
17.5.11 DMA2D background memory address register (DMA2D_BGMAR) . . 812
17.5.12 DMA2D background offset register (DMA2D_BGOR) 813
17.5.13 DMA2D background memory skip register (DMA2D_BGMSR) 813
17.5.14 DMA2D background PFC control register (DMA2D_BGPFCCR) 814
17.5.15 DMA2D background color register (DMA2D_BGCOLR) 816
17.5.16 DMA2D background CLUT memory address register (DMA2D_BGCMAR) 816
17.5.17 DMA2D output PFC control register (DMA2D_OPFCCR) 817
17.5.18 DMA2D output color register (DMA2D_OCOLR) 818
17.5.19 DMA2D output memory address register (DMA2D_OMAR) 819
17.5.20 DMA2D output offset register (DMA2D_OOR) 819
17.5.21 DMA2D number of line register (DMA2D_NLR) 820
17.5.22 DMA2D line watermark register (DMA2D_LWR) 820
17.5.23 DMA2D AHB master timer configuration register (DMA2D_AMTCR) 821
17.5.24 DMA2D stencil buffer configuration register (DMA2D_SBCR) 821
17.5.25 DMA2D stencil buffer memory address register (DMA2D_SBMAR) . . 822
17.5.26 DMA2D stencil buffer offset register (DMA2D_SBOR) 822
17.5.27 DMA2D stencil buffer memory skip register (DMA2D_SBMSR) 823
17.5.28 DMA2D tile buffer configuration register (DMA2D_TBCR) 824
17.5.29 DMA2D scaler configuration register (DMA2D_SCR) 825
17.5.30 DMA2D scaler number of line register (DMA2D_SNLR) 825
17.5.31 DMA2D scaler step register (DMA2D_SSR) 826
17.5.32 DMA2D scaler phase register (DMA2D_SPR) 826
17.5.33 DMA2D general purpose flag configuration register (DMA2D_GPFCR) 827
17.5.34 DMA2D general purpose flag register (DMA2D_GPFR) 828
17.5.35 DMA2D general purpose flag set register (DMA2D_GPFSR) 829
17.5.36 DMA2D general purpose flag reset register (DMA2D_GPFRR) 829
17.5.37 DMA2D command list configuration register (DMA2D_CLCR) 830
17.5.38 DMA2D command list status register (DMA2D_CLSR) 831
17.5.39 DMA2D ring buffer base address register (DMA2D_RBBAR) 833
17.5.40 DMA2D ring buffer head pointer register (DMA2D_RBHPR) 833
17.5.41 DMA2D ring buffer write pointer register (DMA2D_RBWPR) 834
17.5.42 DMA2D linear buffer current base address register (DMA2D_LBCBAR) 834

17.5.43 DMA2D linear buffer current size register (DMA2D_LBCSR) 834
17.5.44 DMA2D linear buffer current address register (DMA2D_LBCAR) 835
17.5.45 DMA2D foreground CLUTx (DMA2D_FGCLUTx) 835
17.5.46 DMA2D background CLUTx (DMA2D_BGCLUTx) 836
17.5.47 DMA2D register map 837

18 Graphic timer (GFXTIM) 841

18.1 GFXTIM introduction 841
18.2 GFXTIM main features 841
18.3 GFXTIM functional description 841
18.3.1 Block diagram 841
18.3.2 GFXTIM pins and internal signals 842
18.3.3 Clock generator 843
18.3.4 Example of clock generator configuration 845
18.3.5 Absolute timers 849
18.3.6 Relative timers 850
18.3.7 Tearing-effect detection 851
18.3.8 Event generator 851
18.3.9 Watchdog timer 852
18.4 GFXTIM interrupts 853
18.5 GFXTIM registers 854
18.5.1 GFXTIM configuration register (GFXTIM_CR) 854
18.5.2 GFXTIM clock generator configuration register (GFXTIM_CGCR) . . . 855
18.5.3 GFXTIM timers configuration register (GFXTIM_TCR) 857
18.5.4 GFXTIM timers disable register (GFXTIM_TDR) 858
18.5.5 GFXTIM events control register (GFXTIM_EVCR) 859
18.5.6 GFXTIM events selection register (GFXTIM_EVSR) 859
18.5.7 GFXTIM watchdog timer configuration register (GFXTIM_WDGTCR) 861
18.5.8 GFXTIM interrupt status register (GFXTIM_ISR) 863
18.5.9 GFXTIM interrupt clear register (GFXTIM_ICR) 864
18.5.10 GFXTIM interrupt enable register (GFXTIM_IER) 866
18.5.11 GFXTIM timers status register (GFXTIM_TSR) 868
18.5.12 GFXTIM line-clock counter reload register (GFXTIM_LCCRR) 869
18.5.13 GFXTIM frame-clock counter reload register (GFXTIM_FCCRR) 869
18.5.14 GFXTIM absolute time register (GFXTIM_ATR) 869
18.5.15 GFXTIM absolute frame counter register (GFXTIM_AFCR) 870

18.5.16 GFXTIM absolute line counter register (GFXTIM_ALCR) 870
18.5.17 GFXTIM absolute frame counter compare 1 register (GFXTIM_AFCC1R) 871
18.5.18 GFXTIM absolute line counter compare 1 register (GFXTIM_ALCC1R) 871
18.5.19 GFXTIM absolute line counter compare 2 register (GFXTIM_ALCC2R) 871
18.5.20 GFXTIM relative frame counter 1 register (GFXTIM_RFC1R) 872
18.5.21 GFXTIM relative frame counter 1 reload register (GFXTIM_RFC1RR) 872
18.5.22 GFXTIM relative frame counter 2 register (GFXTIM_RFC2R) 873
18.5.23 GFXTIM relative frame counter 2 reload register (GFXTIM_RFC2RR) 873
18.5.24 GFXTIM watchdog counter register (GFXTIM_WDGCR) 873
18.5.25 GFXTIM watchdog reload register (GFXTIM_WDGRR) 874
18.5.26 GFXTIM watchdog pre-alarm register (GFXTIM_WDGPAR) 874
18.5.27 GFXTIM register map 874

19 Nested vectored interrupt controller (NVIC) 877

19.1 NVIC main features 877
19.2 SysTick calibration value register 877
19.3 Interrupt and exception vectors 878

20 Extended interrupts and event controller (EXTI) 884

20.1 EXTI main features 884
20.2 EXTI block diagram 885
20.2.1 EXTI connections between peripherals and CPU 886
20.2.2 EXTI interrupt/event mapping 886
20.3 EXTI functional description 888
20.3.1 EXTI configurable event input wake-up 889
20.3.2 EXTI direct event input wake-up 890
20.3.3 EXTI multiplexer selection 890
20.4 EXTI functional behavior 891
20.5 EXTI event protection 891
20.5.1 EXTI security protection 892
20.5.2 EXTI privilege protection 892
20.6 EXTI registers 893
20.6.1 EXTI rising trigger selection register (EXTI_RTSR1) 893

20.6.2 EXTI falling trigger selection register (EXTI_FTSR1) 894
20.6.3 EXTI software interrupt event register (EXTI_SWIER1) 894
20.6.4 EXTI rising edge pending register (EXTI_RPR1) 895
20.6.5 EXTI falling edge pending register (EXTI_FPR1) 896
20.6.6 EXTI security configuration register (EXTI_SECCFGR1) 896
20.6.7 EXTI privilege configuration register (EXTI_PRIVCFGR1) 897
20.6.8 EXTI rising trigger selection register 2 (EXTI_RTSR2) 897
20.6.9 EXTI falling trigger selection register 2 (EXTI_FTSR2) 899
20.6.10 EXTI software interrupt event register 2 (EXTI_SWIER2) 901
20.6.11 EXTI rising edge pending register 2 (EXTI_RPR2) 904
20.6.12 EXTI falling edge pending register 2 (EXTI_FPR2) 906
20.6.13 EXTI security configuration register 2 (EXTI_SECCFGR2) 908
20.6.14 EXTI privilege configuration register 2 (EXTI_PRIVCFGR2) 909
20.6.15 EXTI rising trigger selection register 3 (EXTI_RTSR3) 909
20.6.16 EXTI falling trigger selection register 3 (EXTI_FTSR3) 910
20.6.17 EXTI software interrupt event register 3 (EXTI_SWIER3) 911
20.6.18 EXTI rising edge pending register 3 (EXTI_RPR3) 912
20.6.19 EXTI falling edge pending register 3 (EXTI_FPR3) 913
20.6.20 EXTI security configuration register 3 (EXTI_SECCFGR3) 914
20.6.21 EXTI privilege configuration register 3 (EXTI_PRIVCFGR3) 915
20.6.22 EXTI external interrupt selection register (EXTI_EXTICR1) 915
20.6.23 EXTI external interrupt selection register (EXTI_EXTICR2) 918
20.6.24 EXTI external interrupt selection register (EXTI_EXTICR3) 920
20.6.25 EXTI external interrupt selection register (EXTI_EXTICR4) 923
20.6.26 EXTI lock register (EXTI_LOCKR) 925
20.6.27 EXTI CPU wake-up with interrupt mask register (EXTI_IMR1) 926
20.6.28 EXTI CPU wake-up with event mask register (EXTI_EMR1) 926
20.6.29 EXTI CPU wake-up with interrupt mask register 2 (EXTI_IMR2) 927
20.6.30 EXTI CPU wake-up with event mask register 2 (EXTI_EMR2) 928
20.6.31 EXTI CPU wake-up with interrupt mask register 3 (EXTI_IMR3) 929
20.6.32 EXTI CPU wake-up with event mask register 3 (EXTI_EMR3) 930
20.6.33 EXTI register map 930

21 Cyclic redundancy check calculation unit (CRC) 934

21.1 CRC introduction 934
21.2 CRC main features 934
21.3 CRC functional description 935

21.3.1 CRC block diagram . . . 935
21.3.2 CRC internal signals . . . 935
21.3.3 CRC operation . . . 935
21.4 CRC registers . . . 937
21.4.1 CRC data register (CRC_DR) . . . 937
21.4.2 CRC independent data register (CRC_IDR) . . . 937
21.4.3 CRC control register (CRC_CR) . . . 938
21.4.4 CRC initial value (CRC_INIT) . . . 939
21.4.5 CRC polynomial (CRC_POL) . . . 939
21.4.6 CRC register map . . . 940

22 CORDIC coprocessor (CORDIC) . . . 941
22.1 CORDIC introduction . . . 941
22.2 CORDIC main features . . . 941
22.3 CORDIC functional description . . . 941
22.3.1 General description . . . 941
22.3.2 CORDIC functions . . . 941
22.3.3 Fixed point representation . . . 948
22.3.4 Scaling factor . . . 948
22.3.5 Precision . . . 949
22.3.6 Zero-overhead mode . . . 952
22.3.7 Polling mode . . . 953
22.3.8 Interrupt mode . . . 954
22.3.9 DMA mode . . . 954
22.4 CORDIC registers . . . 955
22.4.1 CORDIC control/status register (CORDIC_CSR) . . . 955
22.4.2 CORDIC argument register (CORDIC_WDATA) . . . 957
22.4.3 CORDIC result register (CORDIC_RDATA) . . . 958
22.4.4 CORDIC register map . . . 958

23 Filter math accelerator (FMAC) . . . 959
23.1 FMAC introduction . . . 959
23.2 FMAC main features . . . 959
23.3 FMAC functional description . . . 960
23.3.1 General description . . . 960
23.3.2 Local memory and buffers . . . 961

23.3.3 Input buffers . . . 961
23.3.4 Output buffer . . . 964
23.3.5 Initialization functions . . . 966
23.3.6 Filter functions . . . 967
23.3.7 Fixed point representation . . . 971
23.3.8 Implementing FIR filters with the FMAC . . . 971
23.3.9 Implementing IIR filters with the FMAC . . . 973
23.3.10 Examples of filter initialization . . . 975
23.3.11 Examples of filter operation . . . 976
23.3.12 Filter design tips . . . 978
23.4 FMAC registers . . . 979
23.4.1 FMAC X1 buffer configuration register (FMAC_X1BUFCFG) . . . 979
23.4.2 FMAC X2 buffer configuration register (FMAC_X2BUFCFG) . . . 979
23.4.3 FMAC Y buffer configuration register (FMAC_YBUFCFG) . . . 980
23.4.4 FMAC parameter register (FMAC_PARAM) . . . 981
23.4.5 FMAC control register (FMAC_CR) . . . 982
23.4.6 FMAC status register (FMAC_SR) . . . 983
23.4.7 FMAC write data register (FMAC_WDATA) . . . 984
23.4.8 FMAC read data register (FMAC_RDATA) . . . 985
23.4.9 FMAC register map . . . 985

24 Programmable logic array (PLAY) . . . 987
24.1 PLAY introduction . . . 987
24.2 PLAY main features . . . 987
24.3 PLAY functional description . . . 987
24.3.1 PLAY block diagram . . . 988
24.3.2 PLAY pins and internal signals . . . 988
24.3.3 PLAY reset and clocks . . . 991
24.3.4 Input selection . . . 991
24.3.5 Input filtering and edge detection . . . 992
24.3.6 Software programmable inputs . . . 994
24.3.7 Logic elements . . . 994
24.3.8 Input interconnect . . . 998
24.3.9 Output interconnect . . . 1003
24.3.10 Flags . . . 1004
24.3.11 Miscellaneous status bits . . . 1005
24.4 PLAY in low-power modes . . . 1005

24.5 PLAY interrupts 1005
24.6 PLAY registers 1006
24.6.1 PLAY configuration control register (PLAY_CFGCR) 1007
24.6.2 PLAY security attributes configuration register (PLAY_SECCFGR) . 1007
24.6.3 PLAY privilege attributes configuration register (PLAY_PRIVCFGR) 1008
24.6.4 PLAY filter x configuration register (PLAY_FILTxCFG) 1009
24.6.5 PLAY logic element x configuration register 1 (PLAY_LExCFG1) . . . 1010
24.6.6 PLAY logic element x configuration register 2 (PLAY_LExCFG2) . . . 1010
24.6.7 PLAY output x configuration register (PLAY_OUTxCFG) 1011
24.6.8 PLAY software input status register (PLAY_SWIN) 1012
24.6.9 PLAY software input set register (PLAY_SWINSET) 1012
24.6.10 PLAY software input clear register (PLAY_SWINCLR) 1013
24.6.11 PLAY output status register (PLAY_OSR) 1014
24.6.12 PLAY flag status register (PLAY_FLSTAT) 1014
24.6.13 PLAY flag set register (PLAY_FLSET) 1015
24.6.14 PLAY flag clear register (PLAY_FLCLR) 1016
24.6.15 PLAY flag interrupt enable register (PLAY_FLIER) 1016
24.6.16 PLAY flag control register (PLAY_FLCTL) 1017
24.6.17 PLAY miscellaneous status register (PLAY_MSR) 1018
24.6.18 PLAY interrupt status register (PLAY_ISR) 1018
24.6.19 PLAY interrupt clear register (PLAY_ICR) 1019
24.6.20 PLAY interrupt enable register (PLAY_IER) 1020
24.7 PLAY register map 1020

25 Flexible memory controller (FMC) 1023
25.1 FMC introduction 1023
25.2 FMC main features 1023
25.3 FMC block diagram 1024
25.4 AHB interface 1025
25.4.1 Supported memories and transactions 1026
25.5 External device address mapping 1027
25.5.1 NOR/PSRAM address mapping 1028
25.5.2 NAND flash memory address mapping 1028
25.5.3 SDRAM address mapping 1029
25.6 NOR flash/PSRAM controller 1032
25.6.1 External memory interface signals 1034

25.6.2 Supported memories and transactions 1036
25.6.3 General timing rules 1037
25.6.4 NOR flash/PSRAM controller asynchronous transactions 1037
25.6.5 Synchronous transactions 1055
25.6.6 NOR/PSRAM controller registers 1062
25.7 NAND flash controller 1070
25.7.1 External memory interface signals 1070
25.7.2 NAND flash supported memories and transactions 1071
25.7.3 Timing diagrams for NAND flash memory 1072
25.7.4 NAND flash operations 1073
25.7.5 NAND flash prewait functionality 1073
25.7.6 Computation of the error correction code (ECC) in NAND flash memory 1074
25.7.7 NAND flash controller registers 1075
25.8 SDRAM controller 1081
25.8.1 SDRAM controller main features 1081
25.8.2 SDRAM External memory interface signals 1081
25.8.3 SDRAM controller functional description 1082
25.8.4 Low-power modes 1088
25.8.5 SDRAM controller registers 1092
25.8.6 FMC register map 1098

26 Extended-SPI interface (OCTOSPI) 1101
26.1 OCTOSPI introduction 1101
26.2 OCTOSPI main features 1101
26.3 OCTOSPI implementation 1102
26.4 OCTOSPI functional description 1103
26.4.1 OCTOSPI block diagram 1103
26.4.2 OCTOSPI pins and internal signals 1104
26.4.3 OCTOSPI interface to memory modes 1105
26.4.4 OCTOSPI regular-command protocol 1105
26.4.5 OCTOSPI regular-command protocol signal interface 1109
26.4.6 HyperBus protocol 1112
26.4.7 Specific features 1116
26.4.8 OCTOSPI operating mode introduction 1117
26.4.9 OCTOSPI indirect mode 1118
26.4.10 OCTOSPI automatic status-polling mode 1119

26.4.11 OCTOSPI memory-mapped mode 1120
26.4.12 OCTOSPI configuration introduction 1121
26.4.13 OCTOSPI system configuration 1121
26.4.14 OCTOSPI device configuration 1122
26.4.15 OCTOSPI regular-command mode configuration 1124
26.4.16 OCTOSPI HyperBus protocol configuration 1127
26.4.17 OCTOSPI error management 1127
26.4.18 OCTOSPI BUSY and ABORT 1128
26.4.19 OCTOSPI reconfiguration or deactivation 1128
26.4.20 NCS behavior 1129
26.4.21 Software control of two external memories 1129
26.4.22 Hardware-controlled extended memory support 1130
26.5 Address alignment and data number 1131
26.6 OCTOSPI interrupts 1132
26.7 OCTOSPI registers 1133
26.7.1 OCTOSPI control register (OCTOSPI_CR) 1133
26.7.2 OCTOSPI device configuration register 1 (OCTOSPI_DCR1) 1136
26.7.3 OCTOSPI device configuration register 2 (OCTOSPI_DCR2) 1138
26.7.4 OCTOSPI device configuration register 3 (OCTOSPI_DCR3) 1139
26.7.5 OCTOSPI device configuration register 4 (OCTOSPI_DCR4) 1140
26.7.6 OCTOSPI status register (OCTOSPI_SR) 1140
26.7.7 OCTOSPI flag clear register (OCTOSPI_FCR) 1141
26.7.8 OCTOSPI data length register (OCTOSPI_DLR) 1142
26.7.9 OCTOSPI address register (OCTOSPI_AR) 1143
26.7.10 OCTOSPI data register (OCTOSPI_DR) 1143
26.7.11 OCTOSPI polling status mask register (OCTOSPI_PSMKR) 1144
26.7.12 OCTOSPI polling status match register (OCTOSPI_PSMAR) 1144
26.7.13 OCTOSPI polling interval register (OCTOSPI_PIR) 1145
26.7.14 OCTOSPI communication configuration register (OCTOSPI_CCR) . 1145
26.7.15 OCTOSPI timing configuration register (OCTOSPI_TCR) 1147
26.7.16 OCTOSPI instruction register (OCTOSPI_IR) 1148
26.7.17 OCTOSPI alternate bytes register (OCTOSPI_ABR) 1148
26.7.18 OCTOSPI low-power timeout register (OCTOSPI_LPTR) 1149
26.7.19 OCTOSPI wrap communication configuration register (OCTOSPI_WPCCR) 1149
26.7.20 OCTOSPI wrap timing configuration register (OCTOSPI_WPTCR) . 1151
26.7.21 OCTOSPI wrap instruction register (OCTOSPI_WPIR) 1152

26.7.22 OCTOSPI wrap alternate bytes register (OCTOSPI_WPABR) 1152
26.7.23 OCTOSPI write communication configuration register (OCTOSPI_WCCR) 1153
26.7.24 OCTOSPI write timing configuration register (OCTOSPI_WTCR) . . . 1155
26.7.25 OCTOSPI write instruction register (OCTOSPI_WIR) 1155
26.7.26 OCTOSPI write alternate bytes register (OCTOSPI_WABR) 1156
26.7.27 OCTOSPI HyperBus latency configuration register (OCTOSPI_HLCR) 1156
26.7.28 OCTOSPI register map 1157

27 Extended-SPI I/O manager (OCTOSPIM) 1160

27.1 Introduction 1160
27.2 OCTOSPIM main features 1160
27.3 OCTOSPIM implementation 1160
27.4 OCTOSPIM functional description 1160
27.4.1 OCTOSPIM block diagram 1160
27.4.2 OCTOSPIM input/output pins 1161
27.4.3 OCTOSPIM matrix 1161
27.4.4 OCTOSPIM multiplexed mode 1162
27.5 Use cases description 1162
27.5.1 Two OCTOSPIs direct mode 1163
27.5.2 OCTOSPI swapped mode 1163
27.5.3 Two OCTOSPIs multiplexed mode to Port 1 accessing two external memories 1164
27.5.4 Two OCTOSPIs multiplexed mode to Port 2 accessing two external memories 1165
27.5.5 OCTOSPI1 and OCTOSPI2 drive a single external memory 1166
27.5.6 A single OCTOSPI drives two external memories 1166
27.6 OCTOSPIM registers 1168
27.6.1 OCTOSPIM control register (OCTOSPIM_CR) 1168
27.6.2 OCTOSPIM register map 1169

28 Secure digital input/output MultiMediaCard interface (SDMMC) . . 1170

28.1 SDMMC main features 1170
28.2 SDMMC implementation 1170
28.3 SDMMC bus topology 1171
28.4 SDMMC operation modes 1173

28.5 SDMMC functional description 1174
28.5.1 SDMMC block diagram 1174
28.5.2 SDMMC pins and internal signals 1174
28.5.3 General description 1175
28.5.4 SDMMC adapter 1177
28.5.5 SDMMC AHB slave interface 1199
28.5.6 SDMMC AHB master interface 1200
28.5.7 AHB and SDMMC_CK clock relation 1203
28.6 Card functional description 1203
28.6.1 SD I/O mode 1203
28.6.2 CMD12 send timing 1211
28.6.3 Sleep (CMD5) 1215
28.6.4 Interrupt mode (Wait-IRQ) 1216
28.6.5 Boot operation 1217
28.6.6 Response R1b handling 1220
28.6.7 Reset and card cycle power 1221
28.7 Hardware flow control 1222
28.8 Ultra-high-speed phase I (UHS-I) voltage switch 1222
28.9 SDMMC interrupts 1226
28.10 SDMMC registers 1227
28.10.1 SDMMC power control register (SDMMC_POWER) 1227
28.10.2 SDMMC clock control register (SDMMC_CLKCR) 1228
28.10.3 SDMMC argument register (SDMMC_ARGR) 1230
28.10.4 SDMMC command register (SDMMC_CMDR) 1230
28.10.5 SDMMC command response register (SDMMC_RESPCMDR) 1232
28.10.6 SDMMC response x register (SDMMC_RESPxR) 1233
28.10.7 SDMMC data timer register (SDMMC_DTIMER) 1233
28.10.8 SDMMC data length register (SDMMC_DLENR) 1234
28.10.9 SDMMC data control register (SDMMC_DCTRL) 1235
28.10.10 SDMMC data counter register (SDMMC_DCNTR) 1236
28.10.11 SDMMC status register (SDMMC_STAR) 1237
28.10.12 SDMMC interrupt clear register (SDMMC_ICR) 1240
28.10.13 SDMMC mask register (SDMMC_MASKR) 1242
28.10.14 SDMMC acknowledgment timer register (SDMMC_ACKTIMER) . . . 1245
28.10.15 SDMMC DMA control register (SDMMC_IDMACTRLR) 1245
28.10.16 SDMMC IDMA buffer size register (SDMMC_IDMABSIZER) 1246

28.10.17 SDMMC IDMA buffer base address register (SDMMC_IDMABASER) . . . 1247
28.10.18 SDMMC IDMA linked list address register (SDMMC_IDMALAR) . . . 1247
28.10.19 SDMMC IDMA linked list memory base register (SDMMC_IDMABAR) . . . 1248
28.10.20 SDMMC data FIFO registers x (SDMMC_FIFORx) . . . 1249
28.10.21 SDMMC register map . . . 1249

29 Delay block (DLYB) . . . 1252
29.1 DLYB introduction . . . 1252
29.2 DLYB main features . . . 1252
29.3 DLYB implementation . . . 1252
29.4 DLYB functional description . . . 1252
29.4.1 DLYB diagram . . . 1252
29.4.2 DLYB pins and internal signals . . . 1253
29.4.3 General description . . . 1253
29.4.4 Delay line length configuration procedure . . . 1254
29.4.5 Output clock phase configuration procedure . . . 1255
29.5 DLYB registers . . . 1255
29.5.1 DLYB control register (DLYB_CR) . . . 1255
29.5.2 DLYB configuration register (DLYB_CFGR) . . . 1256
29.5.3 DLYB register map . . . 1257

30 Analog-to-digital converters (ADC1/2/3) . . . 1258
30.1 ADC introduction . . . 1258
30.2 ADC main features . . . 1258
30.3 ADC implementation . . . 1260
30.4 ADC functional description . . . 1261
30.4.1 ADC block diagram . . . 1261
30.4.2 ADC pins and internal signals . . . 1262
30.4.3 ADC clocks . . . 1265
30.4.4 ADC connectivity . . . 1267
30.4.5 Slave AHB interface . . . 1270
30.4.6 ADC Deep-power-down mode (DEEPPWD) and ADC voltage regulator (ADVREGEN) . . . 1270
30.4.7 Single-ended and differential input channels . . . 1271
30.4.8 Calibration (ADCAL, ADCALDIF, ADC_CALFACT) . . . 1271

30.4.9 ADC on-off control (ADEN, ADDIS, ADRDY) 1274
30.4.10 Constraints when writing the ADC control bits 1275
30.4.11 Channel selection (ADC_SQRy, ADC_JSQR) 1276
30.4.12 Channel-wise programmable sampling time (SMPR1, SMPR2) 1277
30.4.13 Single conversion mode (CONT = 0) 1279
30.4.14 Continuous conversion mode (CONT = 1) 1279
30.4.15 Starting conversions (ADSTART, JADSTART) 1280
30.4.16 ADC timing 1281
30.4.17 Stopping an ongoing conversion (ADSTP, JADSTP) 1282
30.4.18 Conversion on external trigger and trigger polarity (EXTSEL, EXTEN,JEXTSEL, JEXTEN) 1283
30.4.19 Injected channel management 1285
30.4.20 Discontinuous mode (DISCEN, DISCNUM, JDISCEN) 1286
30.4.21 Queue of context for injected conversions 1287
30.4.22 Programmable resolution (RES) - fast conversion mode 1295
30.4.23 End of conversion, end of sampling phase (EOC, JEOC, EOSMP) . 1296
30.4.24 End of conversion sequence (EOS, JEOS) 1296
30.4.25 Timing diagrams example (single/continuous modes, hardware/software triggers) 1297
30.4.26 Data management 1299
30.4.27 Managing conversions using the ADF/MDF 1305
30.4.28 Dynamic low-power features 1306
30.4.29 Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx) 1311
30.4.30 Oversampler 1315
30.4.31 Dual ADC modes 1322
30.4.32 Temperature sensor 1335
30.4.33 VBAT supply monitoring 1337
30.4.34 Monitoring the internal voltage reference 1338
30.4.35 Monitoring the supply voltage 1339
30.5 ADC interrupts 1340
30.6 ADC registers (for each ADC) 1341
30.6.1 ADC interrupt and status register (ADC_ISR) 1341
30.6.2 ADC interrupt enable register (ADC_IER) 1343
30.6.3 ADC control register (ADC_CR) 1345
30.6.4 ADC configuration register (ADC_CFGR) 1348
30.6.5 ADC configuration register 2 (ADC_CFGR2) 1353
30.6.6 ADC sample time register 1 (ADC_SMPR1) 1355

30.6.7 ADC sample time register 2 (ADC_SMPR2) 1356
30.6.8 ADC watchdog threshold register 1 (ADC_TR1) 1357
30.6.9 ADC watchdog threshold register 2 (ADC_TR2) 1358
30.6.10 ADC watchdog threshold register 3 (ADC_TR3) 1359
30.6.11 ADC regular sequence register 1 (ADC_SQR1) 1359
30.6.12 ADC regular sequence register 2 (ADC_SQR2) 1360
30.6.13 ADC regular sequence register 3 (ADC_SQR3) 1361
30.6.14 ADC regular sequence register 4 (ADC_SQR4) 1362
30.6.15 ADC regular data register (ADC_DR) 1363
30.6.16 ADC injected sequence register (ADC_JSQR) 1363
30.6.17 ADC offset y register (ADC_OFRy) 1366
30.6.18 ADC injected channel y data register (ADC_JDRy) 1367
30.6.19 ADC analog watchdog 2 configuration register (ADC_AWD2CR) . . . 1368
30.6.20 ADC analog watchdog 3 configuration register (ADC_AWD3CR) . . . 1368
30.6.21 ADC Differential mode selection register (ADC_DIFSEL) 1369
30.6.22 ADC calibration factors (ADC_CALFACT) 1370
30.6.23 ADC option register (ADC_OR) 1370
30.7 ADC common registers 1371
30.7.1 ADC common status register (ADC_CSR) 1371
30.7.2 ADC common control register (ADC_CCR) 1373
30.7.3 ADC common regular data register for dual mode (ADC_CDR) 1376
30.8 ADC register map 1377

31 Digital temperature sensor (DTS) 1381
31.1 DTS introduction 1381
31.2 DTS main features 1381
31.3 DTS functional description 1382
31.3.1 DTS block diagram 1382
31.3.2 DTS internal signals 1382
31.3.3 DTS block operation 1383
31.3.4 Operating modes 1383
31.3.5 Calibration 1383
31.3.6 Prescaler 1383
31.3.7 Temperature measurement principles 1384
31.3.8 Sampling time 1385
31.3.9 Quick measurement mode 1385
31.3.10 Trigger input 1386

31.3.11 On-off control and ready flag 1386
31.3.12 Temperature measurement sequence 1387
31.4 DTS low-power modes 1388
31.5 DTS interrupts 1388
31.5.1 Temperature window comparator 1388
31.5.2 Synchronous interrupt 1388
31.5.3 Asynchronous wake-up 1388
31.6 DTS registers 1389
31.6.1 Temperature sensor configuration register 1 (DTS_CFGR1) 1389
31.6.2 Temperature sensor T0 value register 1 (DTS_T0VALR1) 1391
31.6.3 Temperature sensor ramp value register (DTS_RAMPVALR) 1391
31.6.4 Temperature sensor interrupt threshold register 1 (DTS_ITR1) 1392
31.6.5 Temperature sensor data register (DTS_DR) 1392
31.6.6 Temperature sensor status register (DTS_SR) 1393
31.6.7 Temperature sensor interrupt enable register (DTS_ITENR) 1394
31.6.8 Temperature sensor clear interrupt flag register (DTS_ICIFR) 1395
31.6.9 Temperature sensor option register (DTS_OR) 1396
31.6.10 DTS register map 1397

32 Digital-to-analog converter (DAC) 1399
32.1 DAC introduction 1399
32.2 DAC main features 1399
32.3 DAC implementation 1400
32.4 DAC functional description 1401
32.4.1 DAC block diagram 1401
32.4.2 DAC pins and internal signals 1402
32.4.3 DAC clocks 1403
32.4.4 DAC channel enable 1403
32.4.5 DAC data format 1404
32.4.6 DAC conversion 1405
32.4.7 DAC output voltage 1407
32.4.8 DAC trigger selection 1407
32.4.9 DMA requests 1407
32.4.10 Noise generation 1408
32.4.11 Triangle-wave generation 1410
32.4.12 DAC channel modes 1411

32.4.13 DAC channel buffer calibration 1414
32.4.14 DAC channel conversion modes 1415
32.4.15 Dual DAC channel conversion modes (if dual channels are available) 1416
32.5 DAC in low-power modes 1420
32.6 DAC interrupts 1420
32.7 DAC registers 1421
32.7.1 DAC control register (DAC_CR) 1421
32.7.2 DAC software trigger register (DAC_SWTRGR) 1424
32.7.3 DAC channel1 12-bit right-aligned data holding register (DAC_DHR12R1) 1425
32.7.4 DAC channel1 12-bit left aligned data holding register (DAC_DHR12L1) 1426
32.7.5 DAC channel1 8-bit right aligned data holding register (DAC_DHR8R1) 1426
32.7.6 DAC channel2 12-bit right aligned data holding register (DAC_DHR12R2) 1427
32.7.7 DAC channel2 12-bit left aligned data holding register (DAC_DHR12L2) 1427
32.7.8 DAC channel2 8-bit right-aligned data holding register (DAC_DHR8R2) 1428
32.7.9 Dual DAC 12-bit right-aligned data holding register (DAC_DHR12RD) 1428
32.7.10 Dual DAC 12-bit left aligned data holding register (DAC_DHR12LD) 1429
32.7.11 Dual DAC 8-bit right aligned data holding register (DAC_DHR8RD) 1429
32.7.12 DAC channel1 data output register (DAC_DOR1) 1430
32.7.13 DAC channel2 data output register (DAC_DOR2) 1430
32.7.14 DAC status register (DAC_SR) 1431
32.7.15 DAC calibration control register (DAC_CCR) 1432
32.7.16 DAC mode control register (DAC_MCR) 1433
32.7.17 DAC channel1 sample and hold sample time register (DAC_SHSR1) 1434
32.7.18 DAC channel2 sample and hold sample time register (DAC_SHSR2) 1435
32.7.19 DAC sample and hold time register (DAC_SHHR) 1435
32.7.20 DAC sample and hold refresh time register (DAC_SHRR) 1436
32.7.21 DAC register map 1437

33 Voltage reference buffer (VREFBUF) 1439
33.1 VREFBUF introduction 1439
33.2 VREFBUF implementation 1439
33.3 VREFBUF functional description 1439
33.4 VREFBUF trimming 1440
33.5 VREFBUF registers 1441
33.5.1 VREFBUF control and status register (VREFBUF_CSR) 1441
33.5.2 VREFBUF calibration control register (VREFBUF_CCR) 1442
33.5.3 VREFBUF register map 1442

34 Operational amplifiers (OPAMP) 1443
34.1 OPAMP introduction 1443
34.2 OPAMP main features 1443
34.3 OPAMP functional description 1443
34.3.1 OPAMP reset and clocks 1443
34.3.2 Initial configuration 1444
34.3.3 Signal routing 1444
34.3.4 OPAMP modes 1444
34.3.5 Calibration 1451
34.4 OPAMP low-power modes 1453
34.5 OPAMP PGA gain 1453
34.6 OPAMP registers 1453
34.6.1 OPAMP1 control/status register (OPAMP1_CSR) 1453
34.6.2 OPAMP1 trimming register in normal mode (OPAMP1_OTR) 1455
34.6.3 OPAMP1 trimming register in high-speed mode (OPAMP1_HSOTR) 1456
34.6.4 OPAMP register map 1456

35 Comparator (COMP) 1457
35.1 Introduction 1457
35.2 COMP main features 1457
35.3 COMP functional description 1458
35.3.1 COMP block diagram 1458
35.3.2 COMP pins and internal signals 1458
35.3.3 COMP reset and clocks 1462
35.3.4 Comparator LOCK mechanism 1462

35.3.5 Window comparator . . . 1462
35.3.6 Hysteresis . . . 1463
35.3.7 Comparator output blanking function . . . 1463
35.3.8 COMP startup stabilization time . . . 1464
35.3.9 COMP power and speed modes . . . 1464
35.4 COMP low-power modes . . . 1465
35.5 COMP interrupts . . . 1465
35.5.1 Wake-up interrupt through EXTI . . . 1465
35.5.2 Interrupt through EXTI . . . 1466
35.5.3 Interrupt through the NVIC of the CPU . . . 1466
35.6 SCALER function . . . 1466
35.7 COMP registers . . . 1467
35.7.1 Comparator status register (COMP_SR) . . . 1467
35.7.2 Comparator interrupt clear flag register (COMP_ICFR) . . . 1468
35.7.3 Comparator configuration register 1 (COMP_CFGR1) . . . 1468
35.7.4 Comparator configuration register 2 (COMP_CFGR2) . . . 1470
35.7.5 COMP register map . . . 1472

36 Multi-function digital filter (MDF) . . . 1473
36.1 MDF introduction . . . 1473
36.2 MDF main features . . . 1474
36.3 MDF implementation . . . 1474
36.4 MDF functional description . . . 1476
36.4.1 MDF block diagram . . . 1476
36.4.2 MDF pins and internal signals . . . 1477
36.4.3 Serial input interfaces (SITF) . . . 1478
36.4.4 ADC slave interface (ADCITF) . . . 1484
36.4.5 Clock generator (CKGEN) . . . 1485
36.4.6 Bitstream matrix (BSMX) . . . 1487
36.4.7 Short-circuit detectors (SCD) . . . 1488
36.4.8 Digital filter processing (DFLT) . . . 1490
36.4.9 Out-of-limit detector (OLD) . . . 1500
36.4.10 Digital filter acquisition modes . . . 1503
36.4.11 Start-up sequence examples . . . 1513
36.4.12 Break interface . . . 1514
36.4.13 Data transfer to memory . . . 1515

36.4.14 Register protection 1520
36.5 MDF low-power modes 1522
36.6 MDF interrupts 1522
36.7 MDF application informations 1524
36.7.1 MDF configuration examples for audio capture 1524
36.7.2 Programming examples 1525
36.7.3 Connection examples 1527
36.7.4 Global frequency response 1528
36.7.5 Total MDF gain 1529
36.8 MDF registers 1533
36.8.1 MDF global control register (MDF_GCR) 1533
36.8.2 MDF clock generator control register (MDF_CKGCR) 1534
36.8.3 MDF serial interface control register x (MDF_SITFxCR) 1536
36.8.4 MDF bitstream matrix control register x (MDF_BSMXxCR) 1537
36.8.5 MDF digital filter control register x (MDF_DFLTxCR) 1538
36.8.6 MDF digital filter configuration register x (MDF_DFLTxCICR) 1540
36.8.7 MDF reshape filter configuration register x (MDF_DFLTxRSFR) . . . 1542
36.8.8 MDF integrator configuration register x (MDF_DFLTxINTR) 1543
36.8.9 MDF out-of limit detector control register x (MDF_OLDxCR) 1543
36.8.10 MDF OLDx low threshold register x (MDF_OLDxTHLR) 1545
36.8.11 MDF OLDx high threshold register x (MDF_OLDxTHHR) 1545
36.8.12 MDF delay control register x (MDF_DLYxCR) 1546
36.8.13 MDF short circuit detector control register x (MDF_SCDxCR) 1546
36.8.14 MDF DFLT0 interrupt enable register 0 (MDF_DFLT0IER) 1547
36.8.15 MDF DFLTx interrupt enable register x (MDF_DFLTxIER) 1549
36.8.16 MDF DFLT0 interrupt status register 0 (MDF_DFLT0ISR) 1550
36.8.17 MDF DFLTx interrupt status register x (MDF_DFLTxISR) 1552
36.8.18 MDF offset error compensation control register x (MDF_OECxCR) . 1553
36.8.19 MDF snapshot data register x (MDF_SNPSxDR) 1554
36.8.20 MDF digital filter data register x (MDF_DFLTxDR) 1554
36.8.21 MDF register map 1555

37 Audio digital filter (ADF) 1557
37.1 ADF introduction 1557
37.2 ADF main features 1557
37.3 ADF implementation 1558

37.4 ADF functional description 1559
37.4.1 ADF block diagram 1559
37.4.2 ADF pins and internal signals 1559
37.4.3 Serial input interface (SITF) 1560
37.4.4 ADC slave interface (ADCITF) 1565
37.4.5 Clock generator (CKGEN) 1565
37.4.6 Bitstream matrix (BSMX) 1567
37.4.7 Digital filter processing (DFLT) 1568
37.4.8 Digital filter acquisition modes 1578
37.4.9 Start-up sequence examples 1586
37.4.10 Sound activity detection (SAD) 1587
37.4.11 Data transfer to memory 1595
37.4.12 Register protection 1598
37.5 ADF low-power modes 1599
37.6 ADF interrupts 1599
37.7 ADF application information 1601
37.7.1 ADF configuration examples for audio capture 1601
37.7.2 Programming examples 1602
37.7.3 Connection examples 1604
37.7.4 Global frequency response 1605
37.7.5 Total ADF gain 1606
37.7.6 How to compute SAD thresholds 1609
37.8 ADF registers 1613
37.8.1 ADF global control register (ADF_GCR) 1613
37.8.2 ADF clock generator control register (ADF_CKGCR) 1613
37.8.3 ADF serial interface control register 0 (ADF_SITF0CR) 1615
37.8.4 ADF bitstream matrix control register 0 (ADF_BSMX0CR) 1617
37.8.5 ADF digital filter control register 0 (ADF_DFLT0CR) 1617
37.8.6 ADF digital filer configuration register 0 (ADF_DFLT0CICR) 1619
37.8.7 ADF reshape filter configuration register 0 (ADF_DFLT0RSFR) 1620
37.8.8 ADF delay control register 0 (ADF_DLY0CR) 1621
37.8.9 ADF DFLT0 interrupt enable register (ADF_DFLT0IER) 1622
37.8.10 ADF DFLT0 interrupt status register 0 (ADF_DFLT0ISR) 1623
37.8.11 ADF SAD control register (ADF_SADCR) 1624
37.8.12 ADF SAD configuration register (ADF_SADCFGR) 1626
37.8.13 ADF SAD sound level register (ADF_SADSDLVR) 1627

37.8.14 ADF SAD ambient noise level register (ADF_SADANLVR) 1628
37.8.15 ADF digital filter data register 0 (ADF_DFLT0DR) 1628
37.8.16 ADF register map 1628

38 Digital camera interface (DCMI) 1631
38.1 DCMI introduction 1631
38.2 DCMI main features 1631
38.3 DCMI functional description 1631
38.3.1 DCMI block diagram 1632
38.3.2 DCMI pins and internal signals 1632
38.3.3 DCMI clocks 1633
38.3.4 DCMI DMA interface 1633
38.3.5 DCMI physical interface 1633
38.3.6 DCMI synchronization 1635
38.3.7 DCMI capture modes 1637
38.3.8 DCMI crop feature 1638
38.3.9 DCMI JPEG format 1639
38.3.10 DCMI FIFO 1639
38.3.11 DCMI data format description 1640
38.4 DCMI interrupts 1642
38.5 DCMI registers 1642
38.5.1 DCMI control register (DCMI_CR) 1642
38.5.2 DCMI status register (DCMI_SR) 1645
38.5.3 DCMI raw interrupt status register (DCMI_RIS) 1645
38.5.4 DCMI interrupt enable register (DCMI_IER) 1646
38.5.5 DCMI masked interrupt status register (DCMI_MIS) 1647
38.5.6 DCMI interrupt clear register (DCMI_ICR) 1648
38.5.7 DCMI embedded synchronization code register (DCMI_ESCR) 1649
38.5.8 DCMI embedded synchronization unmask register (DCMI_ESUR) . 1649
38.5.9 DCMI crop window start (DCMI_CWSTRT) 1650
38.5.10 DCMI crop window size (DCMI_CWSIZE) 1651
38.5.11 DCMI data register (DCMI_DR) 1651
38.5.12 DCMI register map 1652

39 Parallel synchronous slave interface (PSSI) 1653
39.1 PSSI introduction 1653

39.2 PSSI main features 1653
39.3 PSSI functional description 1653
39.3.1 PSSI block diagram 1654
39.3.2 PSSI pins and internal signals 1654
39.3.3 PSSI clock 1655
39.3.4 PSSI data management 1655
39.3.5 PSSI optional control signals 1657
39.4 PSSI interrupts 1660
39.5 PSSI registers 1661
39.5.1 PSSI control register (PSSI_CR) 1661
39.5.2 PSSI status register (PSSI_SR) 1662
39.5.3 PSSI raw interrupt status register (PSSI_RIS) 1663
39.5.4 PSSI interrupt enable register (PSSI_IER) 1664
39.5.5 PSSI masked interrupt status register (PSSI_MIS) 1664
39.5.6 PSSI interrupt clear register (PSSI_ICR) 1665
39.5.7 PSSI data register (PSSI_DR) 1665
39.5.8 PSSI register map 1666

40 LCD-TFT display controller (LTDC) 1667

40.1 Introduction 1667
40.2 LTDC main features 1667
40.3 LTDC functional description 1668
40.3.1 LTDC block diagram 1668
40.3.2 LTDC pins and internal signals 1668
40.3.3 LTDC reset and clocks 1669
40.4 LTDC programmable parameters 1671
40.4.1 LTDC global configuration parameters 1671
40.4.2 Layer programmable parameters 1673
40.5 LTDC interrupts 1677
40.6 LTDC programming procedure 1678
40.7 LTDC registers 1679
40.7.1 LTDC synchronization size configuration register (LTDC_SSCR) . . . 1679
40.7.2 LTDC back porch configuration register (LTDC_BPCR) 1679
40.7.3 LTDC active width configuration register (LTDC_AWCR) 1680
40.7.4 LTDC total width configuration register (LTDC_TWCR) 1681
40.7.5 LTDC global control register (LTDC_GCR) 1681

40.7.6 LTDC shadow reload configuration register (LTDC_SRCR) 1683
40.7.7 LTDC background color configuration register (LTDC_BCCR) 1683
40.7.8 LTDC interrupt enable register (LTDC_IER) 1684
40.7.9 LTDC interrupt status register (LTDC_ISR) 1685
40.7.10 LTDC interrupt clear register (LTDC_ICR) 1685
40.7.11 LTDC line interrupt position configuration register (LTDC_LIPCR) . . 1686
40.7.12 LTDC current position status register (LTDC_CPSR) 1686
40.7.13 LTDC current display status register (LTDC_CDSR) 1687
40.7.14 LTDC layer x control register (LTDC_LxCR) 1687
40.7.15 LTDC layer x window horizontal position configuration register (LTDC_LxWHPCR) 1688
40.7.16 LTDC layer x window vertical position configuration register (LTDC_LxWVPCR) 1689
40.7.17 LTDC layer x color keying configuration register (LTDC_LxCKCR) 1690
40.7.18 LTDC layer x pixel format configuration register (LTDC_LxPFCR) 1690
40.7.19 LTDC layer x constant alpha configuration register (LTDC_LxCACR) 1691
40.7.20 LTDC layer x default color configuration register (LTDC_LxDCCR) 1691
40.7.21 LTDC layer x blending factors configuration register (LTDC_LxBFCR) 1692
40.7.22 LTDC layer x color frame buffer address register (LTDC_LxCFBAR) 1693
40.7.23 LTDC layer x color frame buffer length register (LTDC_LxCFBLR) 1693
40.7.24 LTDC layer x color frame buffer line number register (LTDC_LxCFBLNR) 1694
40.7.25 LTDC layer x CLUT write register (LTDC_LxCLUTWR) 1694
40.7.26 LTDC register map 1695

41 JPEG codec (JPEG) 1698

41.1 JPEG introduction 1698
41.2 JPEG codec main features 1698
41.3 JPEG codec block functional description 1699
41.3.1 General description 1699
41.3.2 JPEG internal signals 1699
41.3.3 JPEG decoding procedure 1700
41.3.4 JPEG encoding procedure 1702

41.4 JPEG codec interrupts 1705
41.5 JPEG codec registers 1705
41.5.1 JPEG codec control register (JPEG_CONFR0) 1705
41.5.2 JPEG codec configuration register 1 (JPEG_CONFR1) 1706
41.5.3 JPEG codec configuration register 2 (JPEG_CONFR2) 1707
41.5.4 JPEG codec configuration register 3 (JPEG_CONFR3) 1707
41.5.5 JPEG codec configuration register x (JPEG_CONFRx) 1708
41.5.6 JPEG control register (JPEG_CR) 1709
41.5.7 JPEG status register (JPEG_SR) 1710
41.5.8 JPEG clear flag register (JPEG_CFR) 1711
41.5.9 JPEG data input register (JPEG_DIR) 1712
41.5.10 JPEG data output register (JPEG_DOR) 1712
41.5.11 JPEG quantization memory x (JPEG_QMEMx_y) 1713
41.5.12 JPEG Huffman min (JPEG_HUFFMINx_y) 1713
41.5.13 JPEG Huffman min x (JPEG_HUFFMINx_y) 1714
41.5.14 JPEG Huffman base (JPEG_HUFFBASEx) 1714
41.5.15 JPEG Huffman symbol (JPEG_HUFFSYMBx) 1715
41.5.16 JPEG DHT memory (JPEG_DHTMEMx) 1716
41.5.17 JPEG Huffman encoder ACx (JPEG_HUFFENC_ACx_y) 1716
41.5.18 JPEG Huffman encoder DCx (JPEG_HUFFENC_DCx_y) 1717
41.5.19 JPEG codec register map 1718

42 Coupling and chaining bridge (CCB) 1720
42.1 CCB introduction 1720
42.2 CCB main features 1720
42.3 CCB implementation 1721
42.4 CCB functional description 1721
42.4.1 CCB block diagram 1721
42.4.2 CCB internal signals 1722
42.4.3 CCB reset and clocks 1722
42.4.4 CCB coupling and chaining 1722
42.4.5 CCB error management 1725
42.5 CCB coupling and chaining operations 1725
42.5.1 Preliminary steps before any protected operation 1727
42.5.2 ECDSA signature 1728
42.5.3 ECC scalar multiplication 1735

42.5.4 RSA modular exponentiation . . . 1738
42.6 CCB interrupts . . . 1740
42.7 CCB registers . . . 1741
42.7.1 CCB control register (CCB_CR) . . . 1741
42.7.2 CCB status register (CCB_SR) . . . 1742
42.7.3 CCB reference tag register (CCB_REFTAGRx) . . . 1744
42.7.4 CCB register map . . . 1745

43 True random number generator (RNG) . . . 1746
43.1 RNG introduction . . . 1746
43.2 RNG main features . . . 1746
43.3 RNG functional description . . . 1747
43.3.1 RNG block diagram . . . 1747
43.3.2 RNG internal signals . . . 1747
43.3.3 Random number generation . . . 1748
43.3.4 RNG initialization . . . 1750
43.3.5 RNG operation . . . 1751
43.3.6 RNG clocking . . . 1753
43.3.7 Error management . . . 1753
43.3.8 RNG low-power use . . . 1755
43.4 RNG interrupts . . . 1755
43.5 RNG processing time . . . 1756
43.6 RNG entropy source validation . . . 1756
43.6.1 Introduction . . . 1756
43.6.2 Validation conditions . . . 1756
43.7 RNG registers . . . 1758
43.7.1 RNG control register (RNG_CR) . . . 1758
43.7.2 RNG status register (RNG_SR) . . . 1760
43.7.3 RNG data register (RNG_DR) . . . 1761
43.7.4 RNG noise source control register (RNG_NSCR) . . . 1762
43.7.5 RNG health test control register x (RNG_HTCRx) . . . 1762
43.7.6 RNG health test status register 0 (RNG_HTSR0) . . . 1763
43.7.7 RNG health test status register 1 (RNG_HTSR1) . . . 1763
43.7.8 RNG noise source mask register (RNG_NSMR) . . . 1764
43.7.9 RNG register map . . . 1765

44 AES hardware accelerator (AES) 1766

44.1 AES introduction 1766

44.2 AES main features 1766

44.3 AES implementation 1767

44.4 AES functional description 1767

44.4.1 AES block diagram 1767

44.4.2 AES internal signals 1768

44.4.3 AES reset and clocks 1768

44.4.4 AES symmetric cipher implementation 1768

44.4.5 AES encryption or decryption typical usage 1769

44.4.6 AES authenticated encryption, decryption, and cipher-based message authentication 1771

44.4.7 AES ciphertext stealing and data padding 1771

44.4.8 AES suspend and resume operations 1772

44.4.9 AES basic chaining modes (ECB, CBC) 1773

44.4.10 AES counter (CTR) mode 1776

44.4.11 AES Galois/counter mode (GCM) 1779

44.4.12 AES Galois message authentication code (GMAC) 1783

44.4.13 AES counter with CBC-MAC (CCM) 1784

44.4.14 AES key sharing with secure AES co-processor 1789

44.4.15 AES data registers and data swapping 1790

44.4.16 AES key registers 1792

44.4.17 AES initialization vector registers 1792

44.4.18 AES error management 1793

44.5 AES interrupts 1794

44.6 AES DMA requests 1794

44.7 AES processing latency 1795

44.8 AES registers 1797

44.8.1 AES control register (AES_CR) 1797

44.8.2 AES status register (AES_SR) 1799

44.8.3 AES data input register (AES_DINR) 1800

44.8.4 AES data output register (AES_DOUTR) 1801

44.8.5 AES key register 0 (AES_KEYR0) 1801

44.8.6 AES key register 1 (AES_KEYR1) 1802

44.8.7 AES key register 2 (AES_KEYR2) 1802

44.8.8 AES key register 3 (AES_KEYR3) 1802

44.8.9 AES initialization vector register 0 (AES_IVR0) 1803
44.8.10 AES initialization vector register 1 (AES_IVR1) 1803
44.8.11 AES initialization vector register 2 (AES_IVR2) 1803
44.8.12 AES initialization vector register 3 (AES_IVR3) 1804
44.8.13 AES key register 4 (AES_KEYR4) 1804
44.8.14 AES key register 5 (AES_KEYR5) 1804
44.8.15 AES key register 6 (AES_KEYR6) 1805
44.8.16 AES key register 7 (AES_KEYR7) 1805
44.8.17 AES suspend registers (AES_SUSPRx) 1805
44.8.18 AES interrupt enable register (AES_IER) 1806
44.8.19 AES interrupt status register (AES_ISR) 1807
44.8.20 AES interrupt clear register (AES_ICR) 1808
44.8.21 AES register map 1808

45 Secure AES coprocessor (SAES) 1811

45.1 SAES introduction 1811
45.2 SAES main features 1811
45.3 SAES implementation 1812
45.4 SAES functional description 1812
45.4.1 SAES block diagram 1812
45.4.2 SAES internal signals 1813
45.4.3 SAES reset and clocks 1814
45.4.4 SAES symmetric cipher implementation 1814
45.4.5 SAES encryption or decryption typical usage 1815
45.4.6 SAES authenticated encryption, decryption, and cipher-based message authentication 1817
45.4.7 SAES ciphertext stealing and data padding 1818
45.4.8 SAES suspend and resume operations 1818
45.4.9 SAES basic chaining modes (ECB, CBC) 1819
45.4.10 SAES counter (CTR) mode 1823
45.4.11 SAES Galois/counter mode (GCM) 1825
45.4.12 SAES Galois message authentication code (GMAC) 1829
45.4.13 SAES counter with CBC-MAC (CCM) 1831
45.4.14 SAES operation with wrapped keys 1836
45.4.15 SAES operation with shared keys 1840
45.4.16 SAES data registers and data swapping 1841
45.4.17 SAES key registers 1844

45.4.18 SAES initialization vector registers . . . 1845
45.4.19 SAES error management . . . 1846
45.5 SAES interrupts . . . 1848
45.6 SAES DMA requests . . . 1848
45.7 SAES processing latency . . . 1849
45.8 SAES registers . . . 1851
45.8.1 SAES control register (SAES_CR) . . . 1851
45.8.2 SAES status register (SAES_SR) . . . 1854
45.8.3 SAES data input register (SAES_DINR) . . . 1855
45.8.4 SAES data output register (SAES_DOUTR) . . . 1856
45.8.5 SAES key register 0 (SAES_KEYR0) . . . 1856
45.8.6 SAES key register 1 (SAES_KEYR1) . . . 1857
45.8.7 SAES key register 2 (SAES_KEYR2) . . . 1857
45.8.8 SAES key register 3 (SAES_KEYR3) . . . 1857
45.8.9 SAES initialization vector register 0 (SAES_IVR0) . . . 1858
45.8.10 SAES initialization vector register 1 (SAES_IVR1) . . . 1858
45.8.11 SAES initialization vector register 2 (SAES_IVR2) . . . 1858
45.8.12 SAES initialization vector register 3 (SAES_IVR3) . . . 1859
45.8.13 SAES key register 4 (SAES_KEYR4) . . . 1859
45.8.14 SAES key register 5 (SAES_KEYR5) . . . 1859
45.8.15 SAES key register 6 (SAES_KEYR6) . . . 1860
45.8.16 SAES key register 7 (SAES_KEYR7) . . . 1860
45.8.17 SAES suspend registers (SAES_SUSPRx) . . . 1860
45.8.18 SAES interrupt enable register (SAES_IER) . . . 1861
45.8.19 SAES interrupt status register (SAES_ISR) . . . 1862
45.8.20 SAES interrupt clear register (SAES_ICR) . . . 1863
45.8.21 SAES register map . . . 1864

46 Hash processor (HASH) . . . 1866
46.1 HASH introduction . . . 1866
46.2 HASH main features . . . 1866
46.3 HASH implementation . . . 1867
46.4 HASH functional description . . . 1867
46.4.1 HASH block diagram . . . 1867
46.4.2 HASH internal signals . . . 1868
46.4.3 About secure hash algorithms . . . 1868

46.4.4 Message data feeding . . . 1869
46.4.5 Message digest computing . . . 1870
46.4.6 Message padding . . . 1873
46.4.7 HMAC operation . . . 1874
46.4.8 HASH suspend/resume operations . . . 1876
46.4.9 HASH DMA interface . . . 1878
46.4.10 HASH error management . . . 1879
46.4.11 HASH processing time . . . 1879
46.5 HASH interrupts . . . 1879
46.6 HASH registers . . . 1880
46.6.1 HASH control register (HASH_CR) . . . 1880
46.6.2 HASH data input register (HASH_DIN) . . . 1882
46.6.3 HASH start register (HASH_STR) . . . 1883
46.6.4 HASH digest registers . . . 1884
46.6.5 HASH interrupt enable register (HASH_IMR) . . . 1886
46.6.6 HASH status register (HASH_SR) . . . 1886
46.6.7 HASH context swap registers . . . 1888
46.6.8 HASH register map . . . 1888

47 Public key accelerator (PKA) . . . 1890
47.1 PKA introduction . . . 1890
47.2 PKA main features . . . 1890
47.3 PKA functional description . . . 1891
47.3.1 PKA block diagram . . . 1891
47.3.2 PKA internal signals . . . 1891
47.3.3 PKA reset and clocks . . . 1892
47.3.4 PKA public key acceleration . . . 1892
47.3.5 Typical applications for PKA . . . 1894
47.3.6 PKA procedure to perform an operation . . . 1896
47.3.7 Private keys protection using CCB . . . 1897
47.3.8 PKA error management . . . 1901
47.4 PKA operating modes . . . 1901
47.4.1 Introduction . . . 1901
47.4.2 Montgomery parameter computation . . . 1903
47.4.3 Modular addition . . . 1903
47.4.4 Modular subtraction . . . 1904

47.4.5 Modular and Montgomery multiplication 1904
47.4.6 Modular exponentiation 1905
47.4.7 Modular inversion 1907
47.4.8 Modular reduction 1907
47.4.9 Arithmetic addition 1908
47.4.10 Arithmetic subtraction 1908
47.4.11 Arithmetic multiplication 1909
47.4.12 Arithmetic comparison 1909
47.4.13 RSA CRT exponentiation 1909
47.4.14 Point on elliptic curve Fp check 1910
47.4.15 ECC Fp scalar multiplication 1911
47.4.16 ECDSA sign 1912
47.4.17 ECDSA verification 1914
47.4.18 ECC complete addition 1915
47.4.19 ECC double base ladder 1915
47.4.20 ECC projective to affine 1916
47.5 Example of configurations and processing times 1917
47.5.1 Supported elliptic curves 1917
47.5.2 Computation times 1919
47.6 PKA interrupts 1921
47.7 PKA registers 1922
47.7.1 PKA control register (PKA_CR) 1922
47.7.2 PKA status register (PKA_SR) 1924
47.7.3 PKA clear flag register (PKA_CLRFR) 1926
47.7.4 PKA RAM 1927
47.7.5 PKA register map 1928

48 On-the-fly decryption engine (OTFDEC) 1929
48.1 OTFDEC introduction 1929
48.2 OTFDEC main features 1929
48.3 OTFDEC functional description 1930
48.3.1 OTFDEC block diagram 1930
48.3.2 OTFDEC internal signals 1930
48.3.3 OTFDEC on-the-fly decryption 1931
48.3.4 OTFDEC usage of AES in counter mode decryption 1932
48.3.5 Flow control management 1933

48.3.6 OTFDEC error management . . . 1933
48.4 OTFDEC interrupts . . . 1934
48.5 OTFDEC application information . . . 1934
48.5.1 OTFDEC initialization process . . . 1934
48.5.2 OTFDEC and power management . . . 1936
48.5.3 Encrypting for OTFDEC . . . 1936
48.5.4 OTFDEC key CRC source code . . . 1937
48.6 OTFDEC registers . . . 1938
48.6.1 OTFDEC control register (OTFDEC_CR) . . . 1938
48.6.2 OTFDEC privileged access control configuration register (OTFDEC_PRIVCFGR) . . . 1939
48.6.3 OTFDEC region x configuration register (OTFDEC_RxCFGR) . . . 1939
48.6.4 OTFDEC region x start address register (OTFDEC_RxSTARTADDR) . . . 1941
48.6.5 OTFDEC region x end address register (OTFDEC_RxENDADDR) . 1941
48.6.6 OTFDEC region x nonce register 0 (OTFDEC_RxNONCER0) . . . 1942
48.6.7 OTFDEC region x nonce register 1 (OTFDEC_RxNONCER1) . . . 1943
48.6.8 OTFDEC region x key register 0 (OTFDEC_RxKEYR0) . . . 1943
48.6.9 OTFDEC region x key register 1 (OTFDEC_RxKEYR1) . . . 1944
48.6.10 OTFDEC region x key register 2 (OTFDEC_RxKEYR2) . . . 1944
48.6.11 OTFDEC region x key register 3 (OTFDEC_RxKEYR3) . . . 1945
48.6.12 OTFDEC interrupt status register (OTFDEC_ISR) . . . 1945
48.6.13 OTFDEC interrupt clear register (OTFDEC_ICR) . . . 1946
48.6.14 OTFDEC interrupt enable register (OTFDEC_IER) . . . 1947
48.6.15 OTFDEC register map . . . 1948

49 Advanced-control timers (TIM1/TIM8) . . . 1952
49.1 TIM1/TIM8 introduction . . . 1952
49.2 TIM1/TIM8 main features . . . 1952
49.3 TIM1/TIM8 functional description . . . 1953
49.3.1 Block diagram . . . 1953
49.3.2 TIM1/TIM8 pins and internal signals . . . 1954
49.3.3 Time-base unit . . . 1958
49.3.4 Counter modes . . . 1961
49.3.5 Repetition counter . . . 1973
49.3.6 External trigger input . . . 1974
49.3.7 Clock selection . . . 1975

49.3.8 Capture/compare channels . . . 1979
49.3.9 Input capture mode . . . 1982
49.3.10 PWM input mode . . . 1983
49.3.11 Forced output mode . . . 1984
49.3.12 Output compare mode . . . 1984
49.3.13 PWM mode . . . 1986
49.3.14 Asymmetric PWM mode . . . 1994
49.3.15 Combined PWM mode . . . 1995
49.3.16 Combined 3-phase PWM mode . . . 1996
49.3.17 Complementary outputs and dead-time insertion . . . 1997
49.3.18 Using the break function . . . 2000
49.3.19 Bidirectional break inputs . . . 2006
49.3.20 Clearing the tim_ocxref signal on an external event . . . 2007
49.3.21 6-step PWM generation . . . 2009
49.3.22 One-pulse mode . . . 2010
49.3.23 Retriggerable One-pulse mode . . . 2012
49.3.24 Pulse on compare mode . . . 2013
49.3.25 Encoder interface mode . . . 2015
49.3.26 Direction bit output . . . 2032
49.3.27 UIF bit remapping . . . 2033
49.3.28 Timer input XOR function . . . 2033
49.3.29 Interfacing with Hall sensors . . . 2033
49.3.30 Timer synchronization . . . 2035
49.3.31 ADC triggers . . . 2040
49.3.32 DMA burst mode . . . 2040
49.3.33 TIM1/TIM8 DMA requests . . . 2041
49.3.34 Debug mode . . . 2041
49.4 TIM1/TIM8 low-power modes . . . 2042
49.5 TIM1/TIM8 interrupts . . . 2042
49.6 TIM1/TIM8 registers . . . 2043
49.6.1 TIMx control register 1 (TIMx_CR1)(x = 1, 8) . . . 2043
49.6.2 TIMx control register 2 (TIMx_CR2)(x = 1, 8) . . . 2044
49.6.3 TIMx slave mode control register (TIMx_SMCR)(x = 1, 8) . . . 2048
49.6.4 TIMx DMA/interrupt enable register (TIMx_DIER)(x = 1, 8) . . . 2052
49.6.5 TIMx status register (TIMx_SR)(x = 1, 8) . . . 2053
49.6.6 TIMx event generation register (TIMx_EGR)(x = 1, 8) . . . 2056

49.6.7 TIMx capture/compare mode register 1 (TIMx_CCMR1) (x = 1, 8) . . . 2057
49.6.8 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 1, 8) . . . 2059
49.6.9 TIMx capture/compare mode register 2 (TIMx_CCMR2) (x = 1, 8) . . . 2062
49.6.10 TIMx capture/compare mode register 2 [alternate] (TIMx_CCMR2)(x = 1, 8) . . . 2063
49.6.11 TIMx capture/compare enable register (TIMx_CCER)(x = 1, 8) . . . 2066
49.6.12 TIMx counter (TIMx_CNT)(x = 1, 8) . . . 2070
49.6.13 TIMx prescaler (TIMx_PSC)(x = 1, 8) . . . 2070
49.6.14 TIMx autoreload register (TIMx_ARR)(x = 1, 8) . . . 2071
49.6.15 TIMx repetition counter register (TIMx_RCR)(x = 1, 8) . . . 2071
49.6.16 TIMx capture/compare register 1 (TIMx_CCR1)(x = 1, 8) . . . 2072
49.6.17 TIMx capture/compare register 2 (TIMx_CCR2)(x = 1, 8) . . . 2072
49.6.18 TIMx capture/compare register 3 (TIMx_CCR3)(x = 1, 8) . . . 2073
49.6.19 TIMx capture/compare register 4 (TIMx_CCR4)(x = 1, 8) . . . 2074
49.6.20 TIMx break and dead-time register (TIMx_BDTR)(x = 1, 8) . . . 2075
49.6.21 TIMx capture/compare register 5 (TIMx_CCR5)(x = 1, 8) . . . 2079
49.6.22 TIMx capture/compare register 6 (TIMx_CCR6)(x = 1, 8) . . . 2080
49.6.23 TIMx capture/compare mode register 3 (TIMx_CCMR3) (x = 1, 8) . . . 2081
49.6.24 TIMx timer deadtime register 2 (TIMx_DTR2)(x = 1, 8) . . . 2082
49.6.25 TIMx timer encoder control register (TIMx_ECR)(x = 1, 8) . . . 2083
49.6.26 TIMx timer input selection register (TIMx_TISEL)(x = 1, 8) . . . 2084
49.6.27 TIMx alternate function option register 1 (TIMx_AF1)(x = 1, 8) . . . 2085
49.6.28 TIMx alternate function register 2 (TIMx_AF2)(x = 1, 8) . . . 2088
49.6.29 TIMx DMA control register (TIMx_DCR)(x = 1, 8) . . . 2090
49.6.30 TIMx DMA address for full transfer (TIMx_DMAR)(x = 1, 8) . . . 2092
49.6.31 TIMx register map . . . 2092

50 General-purpose timers (TIM2/TIM3/TIM4/TIM5) . . . 2095

50.1 TIM2/TIM3/TIM4/TIM5 introduction . . . 2095
50.2 TIM2/TIM3/TIM4/TIM5 main features . . . 2095
50.3 TIM2/TIM3/TIM4/TIM5 implementation . . . 2096
50.4 TIM2/TIM3/TIM4/TIM5 functional description . . . 2097
50.4.1 Block diagram . . . 2097
50.4.2 TIM2/TIM3/TIM4/TIM5 pins and internal signals . . . 2098

50.4.3 Time-base unit 2102
50.4.4 Counter modes 2104
50.4.5 Clock selection 2115
50.4.6 Capture/compare channels 2119
50.4.7 Input capture mode 2121
50.4.8 PWM input mode 2122
50.4.9 Forced output mode 2123
50.4.10 Output compare mode 2123
50.4.11 PWM mode 2125
50.4.12 Asymmetric PWM mode 2133
50.4.13 Combined PWM mode 2134
50.4.14 Clearing the tim_ocxref signal on an external event 2135
50.4.15 One-pulse mode 2137
50.4.16 Retriggerable one-pulse mode 2138
50.4.17 Pulse on compare mode 2139
50.4.18 Encoder interface mode 2141
50.4.19 Direction bit output 2159
50.4.20 UIF bit remapping 2160
50.4.21 Timer input XOR function 2160
50.4.22 Timers and external trigger synchronization 2160
50.4.23 Timer synchronization 2164
50.4.24 ADC triggers 2169
50.4.25 DMA burst mode 2170
50.4.26 TIM2/TIM3/TIM4/TIM5 DMA requests 2171
50.4.27 Debug mode 2171
50.4.28 TIM2/TIM3/TIM4/TIM5 low-power modes 2171
50.4.29 TIM2/TIM3/TIM4/TIM5 interrupts 2172
50.5 TIM2/TIM3/TIM4/TIM5 registers 2173
50.5.1 TIMx control register 1 (TIMx_CR1)(x = 2 to 5) 2173
50.5.2 TIMx control register 2 (TIMx_CR2)(x = 2 to 5) 2174
50.5.3 TIMx slave mode control register (TIMx_SMCR)(x = 2 to 5) 2176
50.5.4 TIMx DMA/Interrupt enable register (TIMx_DIER)(x = 2 to 5) 2180
50.5.5 TIMx status register (TIMx_SR)(x = 2 to 5) 2181
50.5.6 TIMx event generation register (TIMx_EGR)(x = 2 to 5) 2183
50.5.7 TIMx capture/compare mode register 1 (TIMx_CCMR1)(x = 2 to 5) . 2184
50.5.8 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 2 to 5) 2186

50.5.9 TIMx capture/compare mode register 2 (TIMx_CCMR2)(x = 2 to 5) . 2188
50.5.10 TIMx capture/compare mode register 2 [alternate] (TIMx_CCMR2)(x = 2 to 5) 2189
50.5.11 TIMx capture/compare enable register (TIMx_CCER)(x = 2 to 5) . . . 2192
50.5.12 TIMx counter (TIMx_CNT)(x = 3, 4) 2193
50.5.13 TIMx counter (TIMx_CNT)(x = 2, 5) 2194
50.5.14 TIMx prescaler (TIMx_PSC)(x = 2 to 5) 2194
50.5.15 TIMx autoreload register (TIMx_ARR)(x = 3, 4) 2195
50.5.16 TIMx autoreload register (TIMx_ARR)(x = 2, 5) 2195
50.5.17 TIMx capture/compare register 1 (TIMx_CCR1)(x = 3, 4) 2196
50.5.18 TIMx capture/compare register 1 (TIMx_CCR1)(x = 2, 5) 2197
50.5.19 TIMx capture/compare register 2 (TIMx_CCR2)(x = 3, 4) 2197
50.5.20 TIMx capture/compare register 2 (TIMx_CCR2)(x = 2, 5) 2198
50.5.21 TIMx capture/compare register 3 (TIMx_CCR3)(x = 3, 4) 2199
50.5.22 TIMx capture/compare register 3 (TIMx_CCR3)(x = 2, 5) 2200
50.5.23 TIMx capture/compare register 4 (TIMx_CCR4)(x = 3, 4) 2201
50.5.24 TIMx capture/compare register 4 (TIMx_CCR4)(x = 2, 5) 2202
50.5.25 TIMx timer encoder control register (TIMx_ECR)(x = 2 to 5) 2203
50.5.26 TIMx timer input selection register (TIMx_TISEL)(x = 2 to 5) 2204
50.5.27 TIMx alternate function register 1 (TIMx_AF1)(x = 2 to 5) 2205
50.5.28 TIMx alternate function register 2 (TIMx_AF2)(x = 2 to 5) 2206
50.5.29 TIMx DMA control register (TIMx_DCR)(x = 2 to 5) 2207
50.5.30 TIMx DMA address for full transfer (TIMx_DMAR)(x = 2 to 5) 2208
50.5.31 TIMx register map 2209

51 Basic timers (TIM6/TIM7) 2212

51.1 TIM6/TIM7 introduction 2212
51.2 TIM6/TIM7 main features 2212
51.3 TIM6/TIM7 functional description 2213
51.3.1 TIM6/TIM7 block diagram 2213
51.3.2 TIM6/TIM7 internal signals 2213
51.3.3 TIM6/TIM7 clocks 2214
51.3.4 Time-base unit 2214
51.3.5 Counting mode 2216
51.3.6 UIF bit remapping 2223
51.3.7 ADC triggers 2224
51.3.8 TIM6/TIM7 DMA requests 2224

51.3.9 Debug mode . . . 2224
51.3.10 TIM6/TIM7 low-power modes . . . 2224
51.3.11 TIM6/TIM7 interrupts . . . 2224
51.4 TIM6/TIM7 registers . . . 2225
51.4.1 TIMx control register 1 (TIMx_CR1)(x = 6 to 7) . . . 2225
51.4.2 TIMx control register 2 (TIMx_CR2)(x = 6 to 7) . . . 2227
51.4.3 TIMx DMA/Interrupt enable register (TIMx_DIER)(x = 6 to 7) . . . 2227
51.4.4 TIMx status register (TIMx_SR)(x = 6 to 7) . . . 2228
51.4.5 TIMx event generation register (TIMx_EGR)(x = 6 to 7) . . . 2228
51.4.6 TIMx counter (TIMx_CNT)(x = 6 to 7) . . . 2228
51.4.7 TIMx prescaler (TIMx_PSC)(x = 6 to 7) . . . 2229
51.4.8 TIMx autoreload register (TIMx_ARR)(x = 6 to 7) . . . 2229
51.4.9 TIMx register map . . . 2230

52 General-purpose timers (TIM12/TIM13/TIM14) . . . 2231
52.1 TIM12/TIM13/TIM14 introduction . . . 2231
52.2 TIM12 main features . . . 2231
52.3 TIM13/TIM14 main features . . . 2232
52.4 TIM12/TIM13/TIM14 functional description . . . 2233
52.4.1 Block diagram . . . 2233
52.4.2 TIM12/TIM13/TIM14 pins and internal signals . . . 2234
52.4.3 Time-base unit . . . 2237
52.4.4 Counter modes . . . 2239
52.4.5 Clock selection . . . 2242
52.4.6 Capture/compare channels . . . 2244
52.4.7 Input capture mode . . . 2246
52.4.8 PWM input mode (TIM12 only) . . . 2247
52.4.9 Forced output mode . . . 2248
52.4.10 Output compare mode . . . 2249
52.4.11 PWM mode . . . 2250
52.4.12 Combined PWM mode (TIM12 only) . . . 2255
52.4.13 One-pulse mode . . . 2256
52.4.14 Retriggerable one pulse mode (TIM12 only) . . . 2258
52.4.15 UIF bit remapping . . . 2259
52.4.16 Timer input XOR function . . . 2259
52.4.17 TIM12 external trigger synchronization . . . 2259
52.4.18 Slave mode – combined reset + trigger mode . . . 2262

52.4.19 Slave mode – combined reset + gated mode 2262
52.4.20 Timer synchronization (TIM12 only) 2262
52.4.21 Using timer output as trigger for other timers (TIM13/TIM14 only) 2262
52.4.22 ADC triggers (TIM12 only) 2262
52.4.23 Debug mode 2262
52.5 TIM12/TIM13/TIM14 low-power modes 2263
52.6 TIM12/TIM13/TIM14 interrupts 2263
52.7 TIM12 registers 2263
52.7.1 TIM12 control register 1 (TIM12_CR1) 2263
52.7.2 TIM12 control register 2 (TIM12_CR2) 2265
52.7.3 TIM12 slave mode control register (TIM12_SMCR) 2265
52.7.4 TIM12 interrupt enable register (TIM12_DIER) 2267
52.7.5 TIM12 status register (TIM12_SR) 2268
52.7.6 TIM12 event generation register (TIM12_EGR) 2269
52.7.7 TIM12 capture/compare mode register 1 (TIM12_CCMR1) 2270
52.7.8 TIM12 capture/compare mode register 1 [alternate] (TIM12_CCMR1) 2271
52.7.9 TIM12 capture/compare enable register (TIM12_CCER) 2274
52.7.10 TIM12 counter (TIM12_CNT) 2275
52.7.11 TIM12 prescaler (TIM12_PSC) 2276
52.7.12 TIM12 autoreload register (TIM12_ARR) 2276
52.7.13 TIM12 capture/compare register 1 (TIM12_CCR1) 2277
52.7.14 TIM12 capture/compare register 2 (TIM12_CCR2) 2277
52.7.15 TIM12 timer input selection register (TIM12_TISEL) 2278
52.7.16 TIM12 register map 2279
52.8 TIM13/TIM14 registers 2281
52.8.1 TIMx control register 1 (TIMx_CR1)(x = 13, 14) 2281
52.8.2 TIMx interrupt enable register (TIMx_DIER)(x = 13, 14) 2282
52.8.3 TIMx status register (TIMx_SR)(x = 13, 14) 2282
52.8.4 TIMx event generation register (TIMx_EGR)(x = 13, 14) 2283
52.8.5 TIMx capture/compare mode register 1 (TIMx_CCMR1)(x = 13, 14) 2284
52.8.6 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 13, 14) 2285
52.8.7 TIMx capture/compare enable register (TIMx_CCER)(x = 13, 14) 2287
52.8.8 TIMx counter (TIMx_CNT)(x = 13, 14) 2288

52.8.9 TIMx prescaler (TIMx_PSC)(x = 13, 14) 2289
52.8.10 TIMx autoreload register (TIMx_ARR)(x = 13, 14) 2289
52.8.11 TIMx capture/compare register 1 (TIMx_CCR1)(x = 13, 14) 2290
52.8.12 TIMx timer input selection register (TIMx_TISEL)(x = 13, 14) 2290
52.8.13 TIM13/TIM14 register map 2291

53 General purpose timers (TIM15/TIM16/TIM17) 2293

53.1 TIM15/TIM16/TIM17 introduction 2293
53.2 TIM15 main features 2293
53.3 TIM16/TIM17 main features 2294
53.4 TIM15/TIM16/TIM17 functional description 2295
53.4.1 Block diagram 2295
53.4.2 TIM15/TIM16/TIM17 pins and internal signals 2296
53.4.3 Time-base unit 2300
53.4.4 Counter modes 2302
53.4.5 Repetition counter 2306
53.4.6 Clock selection 2307
53.4.7 Capture/compare channels 2309
53.4.8 Input capture mode 2311
53.4.9 PWM input mode (only for TIM15) 2313
53.4.10 Forced output mode 2314
53.4.11 Output compare mode 2314
53.4.12 PWM mode 2316
53.4.13 Combined PWM mode (TIM15 only) 2321
53.4.14 Complementary outputs and dead-time insertion 2322
53.4.15 Using the break function 2325
53.4.16 Bidirectional break input 2329
53.4.17 Clearing the tim_ocxref signal on an external event 2330
53.4.18 6-step PWM generation 2331
53.4.19 One-pulse mode 2333
53.4.20 Retriggerable one pulse mode (TIM15 only) 2334
53.4.21 UIF bit remapping 2335
53.4.22 Timer input XOR function (TIM15 only) 2335
53.4.23 External trigger synchronization (TIM15 only) 2335
53.4.24 Slave mode – combined reset + trigger mode (TIM15 only) 2338
53.4.25 Slave mode – combined reset + gated mode (TIM15 only) 2338
53.4.26 Timer synchronization (TIM15 only) 2339

53.4.27 Using timer output as trigger for other timers (TIM16/TIM17 only) . . 2339
53.4.28 ADC triggers (TIM15 only) 2339
53.4.29 DMA burst mode 2339
53.4.30 TIM15/TIM16/TIM17 DMA requests 2340
53.4.31 Debug mode 2340
53.5 TIM15/TIM16/TIM17 low-power modes 2341
53.6 TIM15/TIM16/TIM17 interrupts 2341
53.7 TIM15 registers 2341
53.7.1 TIM15 control register 1 (TIM15_CR1) 2342
53.7.2 TIM15 control register 2 (TIM15_CR2) 2343
53.7.3 TIM15 slave mode control register (TIM15_SMCR) 2345
53.7.4 TIM15 DMA/interrupt enable register (TIM15_DIER) 2347
53.7.5 TIM15 status register (TIM15_SR) 2348
53.7.6 TIM15 event generation register (TIM15_EGR) 2350
53.7.7 TIM15 capture/compare mode register 1 (TIM15_CCMR1) 2351
53.7.8 TIM15 capture/compare mode register 1 [alternate] (TIM15_CCMR1) 2352
53.7.9 TIM15 capture/compare enable register (TIM15_CCER) 2355
53.7.10 TIM15 counter (TIM15_CNT) 2358
53.7.11 TIM15 prescaler (TIM15_PSC) 2358
53.7.12 TIM15 autoreload register (TIM15_ARR) 2359
53.7.13 TIM15 repetition counter register (TIM15_RCR) 2359
53.7.14 TIM15 capture/compare register 1 (TIM15_CCR1) 2360
53.7.15 TIM15 capture/compare register 2 (TIM15_CCR2) 2361
53.7.16 TIM15 break and dead-time register (TIM15_BDTR) 2361
53.7.17 TIM15 timer deadtime register 2 (TIM15_DTR2) 2364
53.7.18 TIM15 input selection register (TIM15_TISEL) 2365
53.7.19 TIM15 alternate function register 1 (TIM15_AF1) 2366
53.7.20 TIM15 alternate function register 2 (TIM15_AF2) 2368
53.7.21 TIM15 DMA control register (TIM15_DCR) 2369
53.7.22 TIM15 DMA address for full transfer (TIM15_DMAR) 2370
53.7.23 TIM15 register map 2370
53.8 TIM16/TIM17 registers 2373
53.8.1 TIMx control register 1 (TIMx_CR1)(x = 16 to 17) 2373
53.8.2 TIMx control register 2 (TIMx_CR2)(x = 16 to 17) 2374
53.8.3 TIMx DMA/interrupt enable register (TIMx_DIER)(x = 16 to 17) 2375
53.8.4 TIMx status register (TIMx_SR)(x = 16 to 17) 2376

53.8.5 TIMx event generation register (TIMx_EGR)(x = 16 to 17) 2377
53.8.6 TIMx capture/compare mode register 1 (TIMx_CCMR1) (x = 16 to 17) 2378
53.8.7 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 16 to 17) 2379
53.8.8 TIMx capture/compare enable register (TIMx_CCER)(x = 16 to 17) . 2381
53.8.9 TIMx counter (TIMx_CNT)(x = 16 to 17) 2384
53.8.10 TIMx prescaler (TIMx_PSC)(x = 16 to 17) 2384
53.8.11 TIMx auto-reautoreload register (TIMx_ARR)(x = 16 to 17) 2385
53.8.12 TIMx repetition counter register (TIMx_RCR)(x = 16 to 17) 2385
53.8.13 TIMx capture/compare register 1 (TIMx_CCR1)(x = 16 to 17) 2386
53.8.14 TIMx break and dead-time register (TIMx_BDTR)(x = 16 to 17) 2387
53.8.15 TIMx timer deadtime register 2 (TIMx_DTR2)(x = 16 to 17) 2390
53.8.16 TIMx input selection register (TIMx_TISEL)(x = 16 to 17) 2391
53.8.17 TIMx alternate function register 1 (TIMx_AF1)(x = 16 to 17) 2391
53.8.18 TIMx alternate function register 2 (TIMx_AF2)(x = 16 to 17) 2394
53.8.19 TIM17 option register 1 (TIM17_OR1) 2394
53.8.20 TIMx DMA control register (TIMx_DCR)(x = 16 to 17) 2395
53.8.21 TIM16/TIM17 DMA address for full transfer (TIMx_DMAR)(x = 16 to 17) 2396
53.8.22 TIM16/TIM17 register map 2397

54 Low-power timer (LPTIM) 2400

54.1 LPTIM introduction 2400
54.2 LPTIM main features 2400
54.3 LPTIM implementation 2401
54.4 LPTIM functional description 2402
54.4.1 LPTIM block diagram 2402
54.4.2 LPTIM pins and internal signals 2403
54.4.3 LPTIM input and trigger mapping 2405
54.4.4 LPTIM reset and clocks 2406
54.4.5 Glitch filter 2407
54.4.6 Prescaler 2408
54.4.7 Trigger multiplexer 2408
54.4.8 Operating mode 2409
54.4.9 Timeout function 2411
54.4.10 Waveform generation 2411
54.4.11 Register update 2412

54.4.12 Counter mode . . . 2413
54.4.13 Timer enable . . . 2413
54.4.14 Timer counter reset . . . 2414
54.4.15 Encoder mode . . . 2414
54.4.16 Repetition counter . . . 2416
54.4.17 Capture/compare channels . . . 2417
54.4.18 Input capture mode . . . 2418
54.4.19 PWM mode . . . 2420
54.4.20 DMA requests . . . 2422
54.4.21 Debug mode . . . 2423
54.5 LPTIM low-power modes . . . 2423
54.6 LPTIM interrupts . . . 2423
54.7 LPTIM registers . . . 2424
54.7.1 LPTIM4 interrupt and status register (LPTIM4_ISR) . . . 2425
54.7.2 LPTIMx interrupt and status register [alternate] (LPTIMx_ISR) (x = 1 to 3, 5, 6) . . . 2426
54.7.3 LPTIMx interrupt and status register [alternate] (LPTIMx_ISR) (x = 1 to 3, 5, 6) . . . 2428
54.7.4 LPTIM4 interrupt clear register (LPTIM4_ICR) . . . 2430
54.7.5 LPTIMx interrupt clear register [alternate] (LPTIMx_ICR) (x = 1 to 3, 5, 6) . . . 2431
54.7.6 LPTIMx interrupt clear register [alternate] (LPTIMx_ICR) (x = 1 to 3, 5, 6) . . . 2432
54.7.7 LPTIM4 interrupt enable register (LPTIM4_DIER) . . . 2433
54.7.8 LPTIMx interrupt enable register [alternate] (LPTIMx_DIER) (x = 1 to 3, 5, 6) . . . 2435
54.7.9 LPTIMx interrupt enable register [alternate] (LPTIMx_DIER) (x = 1 to 3, 5, 6) . . . 2436
54.7.10 LPTIM configuration register (LPTIM_CFGR) . . . 2438
54.7.11 LPTIM control register (LPTIM_CR) . . . 2441
54.7.12 LPTIM compare register 1 (LPTIM_CCR1) . . . 2442
54.7.13 LPTIM autoreload register (LPTIM_ARR) . . . 2443
54.7.14 LPTIM counter register (LPTIM_CNT) . . . 2443
54.7.15 LPTIM configuration register 2 (LPTIM_CFGR2) . . . 2444
54.7.16 LPTIM repetition register (LPTIM_RCR) . . . 2445
54.7.17 LPTIM capture/compare mode register 1 (LPTIM_CCMR1) . . . 2445
54.7.18 LPTIM compare register 2 (LPTIM_CCR2) . . . 2448
54.7.19 LPTIM register map . . . 2448

55 Independent watchdog (IWDG) 2451
55.1 IWDG introduction 2451
55.2 IWDG main features 2451
55.3 IWDG implementation 2451
55.4 IWDG functional description 2452
55.4.1 IWDG block diagram 2452
55.4.2 IWDG internal signals 2453
55.4.3 Software and hardware watchdog modes 2453
55.4.4 Window option 2454
55.4.5 Debug 2457
55.4.6 Register access protection 2457
55.5 IWDG low power modes 2458
55.6 IWDG interrupts 2458
55.7 IWDG registers 2460
55.7.1 IWDG key register (IWDG_KR) 2461
55.7.2 IWDG prescaler register (IWDG_PR) 2461
55.7.3 IWDG reload register (IWDG_RLR) 2462
55.7.4 IWDG status register (IWDG_SR) 2462
55.7.5 IWDG window register (IWDG_WINR) 2464
55.7.6 IWDG early wake-up interrupt register (IWDG_EWCR) 2464
55.7.7 IWDG register map 2466

56 System window watchdog (WWDG) 2467
56.1 WWDG introduction 2467
56.2 WWDG main features 2467
56.3 WWDG implementation 2467
56.4 WWDG functional description 2468
56.4.1 WWDG block diagram 2468
56.4.2 WWDG internal signals 2468
56.4.3 Enabling the watchdog 2469
56.4.4 Controlling the down-counter 2469
56.4.5 How to program the watchdog timeout 2469
56.4.6 Debug mode 2470
56.5 WWDG interrupts 2471
56.6 WWDG registers 2471

56.6.1 WWDG control register (WWDG_CR) 2471
56.6.2 WWDG configuration register (WWDG_CFR) 2472
56.6.3 WWDG status register (WWDG_SR) 2473
56.6.4 WWDG register map 2473

57 Real-time clock (RTC) 2474
57.1 RTC introduction 2474
57.2 RTC main features 2474
57.3 RTC functional description 2475
57.3.1 RTC block diagram 2475
57.3.2 RTC pins and internal signals 2477
57.3.3 GPIOs controlled by the RTC and TAMP 2478
57.3.4 RTC secure protection modes 2482
57.3.5 RTC privilege protection modes 2484
57.3.6 Clock and prescalers 2485
57.3.7 Real-time clock and calendar 2486
57.3.8 Calendar ultra-low power mode 2486
57.3.9 Programmable alarms 2487
57.3.10 Periodic auto-wake-up 2487
57.3.11 RTC initialization and configuration 2488
57.3.12 Reading the calendar 2491
57.3.13 Resetting the RTC 2492
57.3.14 RTC synchronization 2492
57.3.15 RTC reference clock detection 2492
57.3.16 RTC smooth digital calibration 2493
57.3.17 Timestamp function 2495
57.3.18 Calibration clock output 2496
57.3.19 Tamper and alarm output 2497
57.4 RTC low-power modes 2497
57.5 RTC interrupts 2498
57.6 RTC registers 2499
57.6.1 RTC time register (RTC_TR) 2499
57.6.2 RTC date register (RTC_DR) 2500
57.6.3 RTC subsecond register (RTC_SSR) 2501
57.6.4 RTC initialization control and status register (RTC_ICSR) 2502
57.6.5 RTC prescaler register (RTC_PRER) 2504

57.6.6 RTC wake-up timer register (RTC_WUTR) 2505
57.6.7 RTC control register (RTC_CR) 2505
57.6.8 RTC privilege mode control register (RTC_PRIVCFGR) 2509
57.6.9 RTC secure configuration register (RTC_SECCFGR) 2511
57.6.10 RTC write protection register (RTC_WPR) 2512
57.6.11 RTC calibration register (RTC_CALR) 2513
57.6.12 RTC shift control register (RTC_SHIFTR) 2514
57.6.13 RTC timestamp time register (RTC_TSTR) 2515
57.6.14 RTC timestamp date register (RTC_TSDR) 2516
57.6.15 RTC timestamp subsecond register (RTC_TSSSR) 2517
57.6.16 RTC alarm A register (RTC_ALRMAR) 2517
57.6.17 RTC alarm A subsecond register (RTC_ALRMASSR) 2519
57.6.18 RTC alarm B register (RTC_ALRMBR) 2520
57.6.19 RTC alarm B subsecond register (RTC_ALRMBSSR) 2521
57.6.20 RTC status register (RTC_SR) 2522
57.6.21 RTC nonsecure masked interrupt status register (RTC_MISR) 2523
57.6.22 RTC secure masked interrupt status register (RTC_SMISR) 2524
57.6.23 RTC status clear register (RTC_SCR) 2525
57.6.24 RTC option register (RTC_OR) 2526
57.6.25 RTC alarm A binary mode register (RTC_ALRABINR) 2527
57.6.26 RTC alarm B binary mode register (RTC_ALRBBINR) 2527
57.6.27 RTC register map 2529

58 Tamper and backup registers (TAMP) 2532

58.1 TAMP introduction 2532
58.2 TAMP main features 2533
58.3 TAMP functional description 2534
58.3.1 TAMP block diagram 2534
58.3.2 TAMP pins and internal signals 2535
58.3.3 GPIOs controlled by the RTC and TAMP 2538
58.3.4 TAMP register write protection 2538
58.3.5 TAMP secure protection modes 2538
58.3.6 Backup registers protection zones 2539
58.3.7 TAMP privilege protection modes 2539
58.3.8 Boot hardware key (BHK) 2540
58.3.9 Tamper detection 2540
58.3.10 TAMP backup registers and other device secrets erase 2540

58.3.11 Tamper detection configuration and initialization 2542
58.4 TAMP low-power modes 2549
58.5 TAMP interrupts 2549
58.6 TAMP registers 2549
58.6.1 TAMP control register 1 (TAMP_CR1) 2550
58.6.2 TAMP control register 2 (TAMP_CR2) 2552
58.6.3 TAMP control register 3 (TAMP_CR3) 2554
58.6.4 TAMP filter control register (TAMP_FLTCR) 2555
58.6.5 TAMP active tamper control register 1 (TAMP_ATCR1) 2557
58.6.6 TAMP active tamper seed register (TAMP_ATSEEDR) 2559
58.6.7 TAMP active tamper output register (TAMP_ATOR) 2559
58.6.8 TAMP active tamper control register 2 (TAMP_ATCR2) 2560
58.6.9 TAMP secure configuration register (TAMP_SECCFGR) 2563
58.6.10 TAMP privilege configuration register (TAMP_PRIVCFGR) 2565
58.6.11 TAMP interrupt enable register (TAMP_IER) 2566
58.6.12 TAMP status register (TAMP_SR) 2568
58.6.13 TAMP nonsecure masked interrupt status register (TAMP_MISR) . . 2570
58.6.14 TAMP secure masked interrupt status register (TAMP_SMISR) 2571
58.6.15 TAMP status clear register (TAMP_SCR) 2573
58.6.16 TAMP monotonic counter 1 register (TAMP_COUNT1R) 2575
58.6.17 TAMP option register (TAMP_OR) 2575
58.6.18 TAMP resources protection configuration register (TAMP_RPCFGR) 2576
58.6.19 TAMP backup x register (TAMP_BKPxR) 2577
58.6.20 TAMP register map 2578

59 Inter-integrated circuit interface (I2C) 2580
59.1 I2C introduction 2580
59.2 I2C main features 2580
59.3 I2C implementation 2581
59.4 I2C functional description 2581
59.4.1 I2C block diagram 2582
59.4.2 I2C pins and internal signals 2582
59.4.3 I2C clock requirements 2583
59.4.4 I2C mode selection 2583
59.4.5 I2C initialization 2584
59.4.6 I2C reset 2588

59.4.7 I2C data transfer . . . 2589
59.4.8 I2C target mode . . . 2591
59.4.9 I2C controller mode . . . 2600
59.4.10 I2C_TIMINGR register configuration examples . . . 2611
59.4.11 SMBus specific features . . . 2613
59.4.12 SMBus initialization . . . 2615
59.4.13 SMBus I2C_TIMEOUTR register configuration examples . . . 2617
59.4.14 SMBus target mode . . . 2618
59.4.15 SMBus controller mode . . . 2621
59.4.16 Wake-up from Stop mode on address match . . . 2624
59.4.17 Error conditions . . . 2625
59.5 I2C in low-power modes . . . 2627
59.6 I2C interrupts . . . 2627
59.7 I2C DMA requests . . . 2628
59.7.1 Transmission using DMA . . . 2628
59.7.2 Reception using DMA . . . 2628
59.8 I2C debug modes . . . 2628
59.9 I2C registers . . . 2629
59.9.1 I2C control register 1 (I2C_CR1) . . . 2629
59.9.2 I2C control register 2 (I2C_CR2) . . . 2632
59.9.3 I2C own address 1 register (I2C_OAR1) . . . 2634
59.9.4 I2C own address 2 register (I2C_OAR2) . . . 2634
59.9.5 I2C timing register (I2C_TIMINGR) . . . 2635
59.9.6 I2C timeout register (I2C_TIMEOUTR) . . . 2636
59.9.7 I2C interrupt and status register (I2C_ISR) . . . 2637
59.9.8 I2C interrupt clear register (I2C_ICR) . . . 2640
59.9.9 I2C PEC register (I2C_PECR) . . . 2641
59.9.10 I2C receive data register (I2C_RXDR) . . . 2641
59.9.11 I2C transmit data register (I2C_TXDR) . . . 2642
59.9.12 I2C register map . . . 2643

60 Improved inter-integrated circuit (I3C) . . . 2644
60.1 I3C introduction . . . 2644
60.2 I3C main features . . . 2644
60.3 I3C implementation . . . 2646
60.3.1 I3C instantiation . . . 2646

60.3.2 I3C wake-up from low-power mode(s) . . . 2646
60.3.3 I3C FIFOs . . . 2646
60.3.4 I3C triggers . . . 2646
60.3.5 I3C interrupt(s) . . . 2646
60.3.6 I3C MIPI® support . . . 2647
60.4 I3C block diagram . . . 2648
60.5 I3C pins and internal signals . . . 2648
60.6 I3C reset and clocks . . . 2649
60.6.1 I3C reset . . . 2649
60.6.2 I3C clocks and requirements . . . 2649
60.7 I3C peripheral state and programming . . . 2651
60.7.1 I3C peripheral state . . . 2651
60.7.2 I3C controller state and programming sequence . . . 2652
60.7.3 I3C target state and programming sequence . . . 2657
60.8 I3C registers and programming . . . 2661
60.8.1 I3C register set, as controller/target . . . 2661
60.8.2 I3C registers and fields use versus peripheral state, as controller . . . 2662
60.8.3 I3C registers and fields usage versus peripheral state, as target . . . 2665
60.9 I3C bus transfers and programming . . . 2667
60.9.1 I3C command set (CCCs), as controller/target . . . 2667
60.9.2 I3C broadcast/direct CCC transfer (except ENTDAA, RSTACT), as controller . . . 2671
60.9.3 I3C broadcast ENTDAA CCC transfer, as controller . . . 2673
60.9.4 I3C broadcast/direct RSTACT CCC transfer, as controller . . . 2673
60.9.5 I3C broadcast/direct CCC transfer (except ENTDAA, DEFTGTS, DEFGRPA), as target . . . 2675
60.9.6 I3C broadcast ENTDAA CCC transfer, as target . . . 2677
60.9.7 I3C broadcast DEFTGTS CCC transfer, as target . . . 2678
60.9.8 I3C broadcast DEFGRPA CCC transfer, as target . . . 2679
60.9.9 I3C direct GETSTATUS CCC response, as target . . . 2680
60.9.10 I3C private read/write transfer, as controller . . . 2681
60.9.11 I3C private read/write transfer, as target . . . 2682
60.9.12 Legacy I2C read/write transfer, as controller . . . 2683
60.9.13 I3C IBI transfer, as controller/target . . . 2684
60.9.14 I3C hot-join request transfer, as controller/target . . . 2686
60.9.15 I3C controller-role request transfer, as controller/target . . . 2687
60.10 I3C FIFOs management, as controller . . . 2688

60.10.1 C-FIFO management, as controller 2688
60.10.2 TX-FIFO management, as controller 2689
60.10.3 RX-FIFO management, as controller 2692
60.10.4 S-FIFO management, as controller 2694
60.11 I3C FIFOs management, as target 2696
60.11.1 RX-FIFO management, as target 2696
60.11.2 TX-FIFO management, as target 2697
60.12 I3C error management 2700
60.12.1 Controller error management 2700
60.12.2 Target error management 2702
60.13 I3C in low-power modes 2703
60.14 I3C interrupts 2704
60.15 I3C registers 2704
60.15.1 I3C message control register (I3C_CR) 2704
60.15.2 I3C message control register [alternate] (I3C_CR) 2706
60.15.3 I3C configuration register (I3C_CFGR) 2708
60.15.4 I3C receive data byte register (I3C_RDR) 2713
60.15.5 I3C receive data word register (I3C_RDWR) 2714
60.15.6 I3C transmit data byte register (I3C_TDR) 2715
60.15.7 I3C transmit data word register (I3C_TDWR) 2716
60.15.8 I3C IBI payload data register (I3C_IBIDR) 2717
60.15.9 I3C target transmit configuration register (I3C_TGTTDR) 2718
60.15.10 I3C status register (I3C_SR) 2719
60.15.11 I3C status error register (I3C_SER) 2720
60.15.12 I3C received message register (I3C_RMR) 2722
60.15.13 I3C event register (I3C_EVR) 2723
60.15.14 I3C interrupt enable register (I3C_IER) 2727
60.15.15 I3C clear event register (I3C_CEVR) 2729
60.15.16 I3C masked interrupt status register (I3C_MISR) 2731
60.15.17 I3C own device characteristics register (I3C_DEVR0) 2732
60.15.18 I3C device x characteristics register (I3C_DEVRx) 2734
60.15.19 I3C maximum read length register (I3C_MAXRLR) 2736
60.15.20 I3C maximum write length register (I3C_MAXWLR) 2737
60.15.21 I3C timing register 0 (I3C_TIMINGR0) 2738
60.15.22 I3C timing register 1 (I3C_TIMINGR1) 2739
60.15.23 I3C timing register 2 (I3C_TIMINGR2) 2741

60.15.24 I3C bus characteristics register (I3C_BCR) 2742
60.15.25 I3C device characteristics register (I3C_DCR) 2743
60.15.26 I3C get capability register (I3C_GETCAPR) 2744
60.15.27 I3C controller-role capability register (I3C_CRCAPR) 2745
60.15.28 I3C get max data speed register (I3C_GETMXDSR) 2746
60.15.29 I3C extended provisioned ID register (I3C_EPIDR) 2748
60.15.30 I3C register map 2749

61 Universal synchronous/asynchronous receiver transmitter (USART/UART) 2752

61.1 USART introduction 2752
61.2 USART main features 2752
61.3 USART extended features 2753
61.4 USART implementation 2753
61.5 USART functional description 2755
61.5.1 USART block diagram 2755
61.5.2 USART pins and internal signals 2755
61.5.3 USART clocks 2757
61.5.4 USART character description 2757
61.5.5 USART FIFOs and thresholds 2760
61.5.6 USART transmitter 2760
61.5.7 USART receiver 2763
61.5.8 USART baud rate generation 2770
61.5.9 Tolerance of the USART receiver to clock deviation 2772
61.5.10 USART auto baud rate detection 2773
61.5.11 USART multiprocessor communication 2775
61.5.12 USART Modbus communication 2777
61.5.13 USART parity control 2778
61.5.14 USART LIN (local interconnection network) mode 2779
61.5.15 USART synchronous mode 2781
61.5.16 USART single-wire half-duplex communication 2785
61.5.17 USART receiver timeout 2785
61.5.18 USART smartcard mode 2786
61.5.19 USART IrDA SIR ENDEC block 2790
61.5.20 Continuous communication using USART and DMA 2793
61.5.21 RS232 hardware flow control and RS485 driver enable 2795
61.5.22 USART low-power management 2798

61.6 USART in low-power modes 2801
61.7 USART interrupts 2801
61.8 USART registers 2804
61.8.1 USART control register 1 (USART_CR1) 2804
61.8.2 USART control register 1 [alternate] (USART_CR1) 2808
61.8.3 USART control register 2 (USART_CR2) 2811
61.8.4 USART control register 3 (USART_CR3) 2815
61.8.5 USART control register 3 [alternate] (USART_CR3) 2819
61.8.6 USART baud rate register (USART_BRR) 2822
61.8.7 USART guard time and prescaler register (USART_GTPR) 2823
61.8.8 USART receiver timeout register (USART_RTOR) 2824
61.8.9 USART request register (USART_RQR) 2825
61.8.10 USART interrupt and status register (USART_ISR) 2826
61.8.11 USART interrupt and status register [alternate] (USART_ISR) 2832
61.8.12 USART interrupt flag clear register (USART_ICR) 2837
61.8.13 USART receive data register (USART_RDR) 2838
61.8.14 USART transmit data register (USART_TDR) 2839
61.8.15 USART prescaler register (USART_PRESC) 2839
61.8.16 USART register map 2840

62 Low-power universal asynchronous receiver transmitter (LPUART) 2842
62.1 LPUART introduction 2842
62.2 LPUART main features 2842
62.3 LPUART implementation 2843
62.4 LPUART functional description 2845
62.4.1 LPUART block diagram 2845
62.4.2 LPUART pins and internal signals 2846
62.4.3 LPUART clocks 2847
62.4.4 LPUART character description 2847
62.4.5 LPUART FIFOs and thresholds 2849
62.4.6 LPUART transmitter 2849
62.4.7 LPUART receiver 2853
62.4.8 LPUART baud rate generation 2857
62.4.9 Tolerance of the LPUART receiver to clock deviation 2858
62.4.10 LPUART multiprocessor communication 2859
62.4.11 LPUART parity control 2861

62.4.12 LPUART single-wire half-duplex communication 2862
62.4.13 Continuous communication using DMA and LPUART 2862
62.4.14 RS232 hardware flow control and RS485 driver enable 2865
62.4.15 LPUART low-power management 2867
62.5 LPUART in low-power modes 2870
62.6 LPUART interrupts 2871
62.7 LPUART registers 2872
62.7.1 LPUART control register 1 (LPUART_CR1) 2872
62.7.2 LPUART control register 1 [alternate] (LPUART_CR1) 2875
62.7.3 LPUART control register 2 (LPUART_CR2) 2878
62.7.4 LPUART control register 3 (LPUART_CR3) 2880
62.7.5 LPUART control register 3 [alternate] (LPUART_CR3) 2883
62.7.6 LPUART baud rate register (LPUART_BRR) 2885
62.7.7 LPUART request register (LPUART_RQR) 2885
62.7.8 LPUART interrupt and status register (LPUART_ISR) 2886
62.7.9 LPUART interrupt and status register [alternate] (LPUART_ISR) . . . 2891
62.7.10 LPUART interrupt flag clear register (LPUART_ICR) 2894
62.7.11 LPUART receive data register (LPUART_RDR) 2895
62.7.12 LPUART transmit data register (LPUART_TDR) 2895
62.7.13 LPUART prescaler register (LPUART_PRESC) 2896
62.7.14 LPUART register map 2897

63 Serial peripheral interface (SPI) 2899
63.1 SPI introduction 2899
63.2 SPI main features 2899
63.3 SPI implementation 2900
63.4 SPI functional description 2901
63.4.1 SPI block diagram 2901
63.4.2 SPI pins and internal signals 2902
63.4.3 SPI communication general aspects 2903
63.4.4 Communications between one master and one slave 2903
63.4.5 Standard multislave communication 2906
63.4.6 Multimaster communication 2909
63.4.7 Slave select (NSS pin) management 2910
63.4.8 Ready pin (RDY) management 2914
63.4.9 Communication formats 2914

63.4.10 Configuring the SPI . . . 2916
63.4.11 Enabling the SPI . . . 2917
63.4.12 SPI data transmission and reception procedures . . . 2918
63.4.13 Disabling the SPI . . . 2922
63.4.14 Communication using DMA (direct memory addressing) . . . 2923
63.5 SPI specific modes and control . . . 2925
63.5.1 TI mode . . . 2925
63.5.2 SPI error flags . . . 2925
63.5.3 CRC computation . . . 2929
63.6 SPI in low-power modes . . . 2930
63.7 SPI interrupts . . . 2930
63.8 I2S main features . . . 2932
63.9 I2S functional description . . . 2932
63.9.1 I2S general description . . . 2932
63.9.2 Pin sharing with SPI function . . . 2933
63.9.3 Bitfields usable in I2S/PCM mode . . . 2933
63.9.4 Slave and master modes . . . 2934
63.9.5 Supported audio protocols . . . 2934
63.9.6 Additional serial interface flexibility . . . 2940
63.9.7 Startup sequence . . . 2942
63.9.8 Stop sequence . . . 2944
63.9.9 Clock generator . . . 2945
63.9.10 Internal FIFOs . . . 2947
63.9.11 FIFO status flags . . . 2948
63.9.12 Handling of underrun situation . . . 2948
63.9.13 Handling of overrun situation . . . 2949
63.9.14 Frame error detection . . . 2950
63.9.15 DMA interface . . . 2952
63.9.16 Programing examples . . . 2952
63.10 I2S interrupts . . . 2954
63.11 SPI/I2S registers . . . 2955
63.11.1 SPI/I2S control register 1 (SPI_CR1) . . . 2955
63.11.2 SPI/I2S control register 2 (SPI_CR2) . . . 2957
63.11.3 SPI/I2S configuration register 1 (SPI_CFG1) . . . 2957
63.11.4 SPI/I2S configuration register 2 (SPI_CFG2) . . . 2961
63.11.5 SPI/I2S interrupt enable register (SPI_IER) . . . 2963

63.11.6 SPI/I2S status register (SPI_SR) 2964
63.11.7 SPI/I2S interrupt/status flags clear register (SPI_IFCR) 2967
63.11.8 SPI/I2S transmit data register (SPI_TXDR) 2968
63.11.9 SPI/I2S receive data register (SPI_RXDR) 2968
63.11.10 SPI/I2S polynomial register (SPI_CRCPOLY) 2969
63.11.11 SPI/I2S transmitter CRC register (SPI_TXCRC) 2969
63.11.12 SPI/I2S receiver CRC register (SPI_RXCRC) 2970
63.11.13 SPI/I2S underrun data register (SPI_UDRDR) 2971
63.11.14 SPI/I2S configuration register (SPI_I2SCFGR) 2971
63.11.15 SPI/I2S register map 2973

64 Serial audio interface (SAI) 2975

64.1 SAI introduction 2975
64.2 SAI main features 2975
64.3 SAI implementation 2976
64.4 SAI functional description 2977
64.4.1 SAI block diagram 2977
64.4.2 SAI pins and internal signals 2978
64.4.3 Main SAI modes 2979
64.4.4 SAI synchronization mode 2980
64.4.5 Audio data size 2981
64.4.6 Frame synchronization 2981
64.4.7 Slot configuration 2984
64.4.8 SAI clock generator 2986
64.4.9 Internal FIFOs 2989
64.4.10 PDM interface 2991
64.4.11 AC’97 link controller 2999
64.4.12 SPDIF output 3001
64.4.13 Specific features 3004
64.4.14 Error flags 3008
64.4.15 Disabling the SAI 3011
64.4.16 SAI DMA interface 3011
64.5 SAI interrupts 3012
64.6 SAI registers 3014
64.6.1 SAI global configuration register (SAI_GCR) 3014
64.6.2 SAI configuration register 1 (SAI_ACR1) 3014

64.6.3 SAI configuration register 2 (SAI_ACR2) . . . 3017
64.6.4 SAI frame configuration register (SAI_AFRCR) . . . 3019
64.6.5 SAI slot register (SAI_ASLOTR) . . . 3020
64.6.6 SAI interrupt mask register (SAI_AIM) . . . 3021
64.6.7 SAI status register (SAI_ASR) . . . 3023
64.6.8 SAI clear flag register (SAI_ACLRFR) . . . 3025
64.6.9 SAI data register (SAI_ADR) . . . 3026
64.6.10 SAI configuration register 1 (SAI_BCR1) . . . 3026
64.6.11 SAI configuration register 2 (SAI_BCR2) . . . 3029
64.6.12 SAI frame configuration register (SAI_BFRCR) . . . 3031
64.6.13 SAI slot register (SAI_BSLOTR) . . . 3032
64.6.14 SAI interrupt mask register (SAI_BIM) . . . 3033
64.6.15 SAI status register (SAI_BSR) . . . 3034
64.6.16 SAI clear flag register (SAI_BCLRFR) . . . 3036
64.6.17 SAI data register (SAI_BDR) . . . 3037
64.6.18 SAI PDM control register (SAI_PDMCR) . . . 3038
64.6.19 SAI PDM delay register (SAI_PDMDLY) . . . 3039
64.6.20 SAI register map . . . 3041

65 FD controller area network (FDCAN) . . . 3043

65.1 FDCAN introduction . . . 3043
65.2 FDCAN main features . . . 3045
65.3 FDCAN functional description . . . 3046
65.3.1 FDCAN block diagram . . . 3046
65.3.2 FDCAN pins and internal signals . . . 3047
65.3.3 Bit timing . . . 3048
65.3.4 Operating modes . . . 3049
65.3.5 Error management . . . 3058
65.3.6 Message RAM . . . 3059
65.3.7 FIFO acknowledge handling . . . 3068
65.3.8 FDCAN Rx FIFO element . . . 3068
65.3.9 FDCAN Tx buffer element . . . 3070
65.3.10 FDCAN Tx event FIFO element . . . 3072
65.3.11 FDCAN standard message ID filter element . . . 3073
65.3.12 FDCAN extended message ID filter element . . . 3074
65.4 FDCAN registers . . . 3076
65.4.1 FDCAN core release register (FDCAN_CREL) . . . 3076

65.4.2 FDCAN endian register (FDCAN_ENDN) 3076
65.4.3 FDCAN data bit timing and prescaler register (FDCAN_DBTP) 3076
65.4.4 FDCAN test register (FDCAN_TEST) 3077
65.4.5 FDCAN RAM watchdog register (FDCAN_RWD) 3078
65.4.6 FDCAN CC control register (FDCAN_CCCR) 3079
65.4.7 FDCAN nominal bit timing and prescaler register (FDCAN_NBTP) . 3080
65.4.8 FDCAN timestamp counter configuration register (FDCAN_TSCC) . 3082
65.4.9 FDCAN timestamp counter value register (FDCAN_TSCV) 3082
65.4.10 FDCAN timeout counter configuration register (FDCAN_TOCC) . . . 3083
65.4.11 FDCAN timeout counter value register (FDCAN_TOCV) 3084
65.4.12 FDCAN error counter register (FDCAN_ECR) 3084
65.4.13 FDCAN protocol status register (FDCAN_PSR) 3085
65.4.14 FDCAN transmitter delay compensation register (FDCAN_TDCR) . . 3087
65.4.15 FDCAN interrupt register (FDCAN_IR) 3087
65.4.16 FDCAN interrupt enable register (FDCAN_IE) 3090
65.4.17 FDCAN interrupt line select register (FDCAN_ILS) 3092
65.4.18 FDCAN interrupt line enable register (FDCAN_ILE) 3093
65.4.19 FDCAN global filter configuration register (FDCAN_RXGFC) 3093
65.4.20 FDCAN extended ID and mask register (FDCAN_XIDAM) 3095
65.4.21 FDCAN high-priority message status register (FDCAN_HPMS) 3095
65.4.22 FDCAN Rx FIFO 0 status register (FDCAN_RXF0S) 3096
65.4.23 CAN Rx FIFO 0 acknowledge register (FDCAN_RXF0A) 3097
65.4.24 FDCAN Rx FIFO 1 status register (FDCAN_RXF1S) 3097
65.4.25 FDCAN Rx FIFO 1 acknowledge register (FDCAN_RXF1A) 3098
65.4.26 FDCAN Tx buffer configuration register (FDCAN_TXBC) 3098
65.4.27 FDCAN Tx FIFO/queue status register (FDCAN_TXFQS) 3099
65.4.28 FDCAN Tx buffer request pending register (FDCAN_TXBRP) 3099
65.4.29 FDCAN Tx buffer add request register (FDCAN_TXBAR) 3100
65.4.30 FDCAN Tx buffer cancellation request register (FDCAN_TXBCR) . . 3101
65.4.31 FDCAN Tx buffer transmission occurred register (FDCAN_TXBTO) 3101
65.4.32 FDCAN Tx buffer cancellation finished register (FDCAN_TXBCF) . . 3102
65.4.33 FDCAN Tx buffer transmission interrupt enable register (FDCAN_TXBTIE) 3102
65.4.34 FDCAN Tx buffer cancellation finished interrupt enable register (FDCAN_TXBCIE) 3103
65.4.35 FDCAN Tx event FIFO status register (FDCAN_TXEFS) 3103
65.4.36 FDCAN Tx event FIFO acknowledge register (FDCAN_TXEFA) . . . 3104
65.4.37 FDCAN CFG clock divider register (FDCAN_CKDIV) 3104

65.4.38 FDCAN register map 3105

66 USB on-the-go full-speed (OTG_FS) 3109

66.1 OTG_FS introduction 3109

66.2 OTG_FS main features 3110

66.2.1 General features 3110

66.2.2 Host-mode features 3111

66.2.3 Peripheral-mode features 3111

66.3 OTG_FS implementation 3112

66.4 OTG_FS functional description 3113

66.4.1 OTG_FS block diagram 3113

66.4.2 OTG_FS pin and internal signals 3113

66.4.3 OTG_FS core 3114

66.4.4 Embedded full-speed OTG PHY connected to OTG_FS 3114

66.5 OTG_FS dual role device (DRD) 3115

66.6 OTG_FS as a USB peripheral 3115

66.6.1 Peripheral states 3116

66.6.2 Peripheral endpoints 3117

66.7 OTG_FS as a USB host 3119

66.7.1 USB host states 3120

66.7.2 Host channels 3121

66.7.3 Host scheduler 3122

66.8 OTG_FS SOF trigger 3123

66.8.1 Host SOFs 3124

66.8.2 Peripheral SOFs 3124

66.9 OTG_FS low-power modes 3124

66.10 OTG_FS Dynamic update of the OTG_HFIR register 3125

66.11 OTG_FS data FIFOs 3126

66.11.1 Peripheral FIFO architecture 3127

66.11.2 Host FIFO architecture 3128

66.11.3 FIFO RAM allocation 3129

66.12 OTG_FS system performance 3131

66.13 OTG_FS interrupts 3131

66.14 OTG_FS control and status registers 3133

66.14.1 CSR memory map 3133

66.15 OTG_FS registers 3138
66.15.1 OTG control and status register (OTG_GOTGCTL) 3138
66.15.2 OTG interrupt register (OTG_GOTGINT) 3140
66.15.3 OTG AHB configuration register (OTG_GAHBCFG) 3141
66.15.4 OTG USB configuration register (OTG_GUSBCFG) 3142
66.15.5 OTG reset register (OTG_GRSTCTL) 3143
66.15.6 OTG core interrupt register [alternate] (OTG_GINTSTS) 3146
66.15.7 OTG core interrupt register [alternate] (OTG_GINTSTS) 3150
66.15.8 OTG interrupt mask register [alternate] (OTG_GINTMSK) 3154
66.15.9 OTG interrupt mask register [alternate] (OTG_GINTMSK) 3155
66.15.10 OTG receive status debug read [alternate] (OTG_GRXSTSR) 3157
66.15.11 OTG receive status debug read register [alternate] (OTG_GRXSTSR) 3158
66.15.12 OTG status read and pop registers [alternate] (OTG_GRXSTSP) . . 3159
66.15.13 OTG status read and pop registers [alternate] (OTG_GRXSTSP) . . 3160
66.15.14 OTG receive FIFO size register (OTG_GRXFSIZ) 3161
66.15.15 OTG host non-periodic transmit FIFO size register [alternate] (OTG_HNPTXFSIZ) 3162
66.15.16 Endpoint 0 Transmit FIFO size [alternate] (OTG_DIEPTXF0) 3162
66.15.17 OTG non-periodic transmit FIFO/queue status register (OTG_HNPTXSTS) 3163
66.15.18 OTG general core configuration register (OTG_GCCFG) 3164
66.15.19 OTG core ID register (OTG_CID) 3165
66.15.20 OTG core LPM configuration register (OTG_GLPMCFG) 3165
66.15.21 OTG host periodic transmit FIFO size register (OTG_HPTXFSIZ) 3170
66.15.22 OTG device IN endpoint transmit FIFO x size register (OTG_DIEPTXFx) 3170
66.15.23 Host-mode registers 3170
66.15.24 OTG host configuration register (OTG_HCFG) 3171
66.15.25 OTG host frame interval register (OTG_HFIR) 3171
66.15.26 OTG host frame number/frame time remaining register (OTG_HFNUM) 3172
66.15.27 OTG_Host periodic transmit FIFO/queue status register (OTG_HPTXSTS) 3173
66.15.28 OTG host all channels interrupt register (OTG_HAINT) 3174
66.15.29 OTG host all channels interrupt mask register (OTG_HAINTMSK) 3174
66.15.30 OTG host port control and status register (OTG_HPRT) 3175

66.15.31 OTG host channel x characteristics register (OTG_HCCHARx) 3177
66.15.32 OTG host channel x interrupt register (OTG_HCINTx) 3178
66.15.33 OTG host channel x interrupt mask register (OTG_HCINTMSKx) . . 3179
66.15.34 OTG host channel x transfer size register (OTG_HCTSIZx) 3180
66.15.35 Device-mode registers 3181
66.15.36 OTG device configuration register (OTG_DCFG) 3181
66.15.37 OTG device control register (OTG_DCTL) 3182
66.15.38 OTG device status register (OTG_DSTS) 3185
66.15.39 OTG device IN endpoint common interrupt mask register (OTG_DIEPMSK) 3186
66.15.40 OTG device OUT endpoint common interrupt mask register (OTG_DOEPMSK) 3187
66.15.41 OTG device all endpoints interrupt register (OTG_DAINT) 3188
66.15.42 OTG all endpoints interrupt mask register (OTG_DAINTMSK) 3189
66.15.43 OTG device IN endpoint FIFO empty interrupt mask register (OTG_DIEPEMPMSK) 3189
66.15.44 OTG device each endpoint interrupt register (OTG_DEACHINT) . . . 3190
66.15.45 OTG device each endpoint interrupt mask register (OTG_DEACHINTMSK) 3190
66.15.46 OTG device each IN endpoint-1 interrupt mask register (OTG_DIEPEACHM) 3191
66.15.47 OTG device each OUT endpoint-1 interrupt mask register (OTG_DOEPEACHMSK1) 3192
66.15.48 OTG device control IN endpoint 0 control register (OTG_DIEPCTL0) 3193
66.15.49 OTG device IN endpoint x control register [alternate] (OTG_DIEPCTLx) 3195
66.15.50 OTG device IN endpoint x control register [alternate] (OTG_DIEPCTLx) 3197
66.15.51 OTG device IN endpoint x interrupt register (OTG_DIEPINTx) 3199
66.15.52 OTG device IN endpoint 0 transfer size register (OTG_DIEPTSIZ0) 3200
66.15.53 OTG device IN endpoint transmit FIFO status register (OTG_DTXFSTSx) 3201
66.15.54 OTG device IN endpoint x transfer size register (OTG_DIEPTSIZx) . 3201
66.15.55 OTG device control OUT endpoint 0 control register (OTG_DOEPCTL0) 3202
66.15.56 OTG device OUT endpoint x interrupt register (OTG_DOEPINTx) . . 3204
66.15.57 OTG device OUT endpoint 0 transfer size register (OTG_DOEPTSIZ0) 3205

66.15.58 OTG device OUT endpoint x control register [alternate] (OTG_DOEPCTLx) . . . 3206
66.15.59 OTG device OUT endpoint x control register [alternate] (OTG_DOEPCTLx) . . . 3208
66.15.60 OTG device OUT endpoint x transfer size register (OTG_DOEPTSIZx) . . . 3210
66.15.61 OTG power and clock gating control register (OTG_PCGCCTL) . . . 3211
66.15.62 OTG power and clock gating control register 1 (OTG_PCGCCTL1) . 3212
66.15.63 OTG_FS register map . . . 3213
66.16 OTG_FS programming model . . . 3221
66.16.1 Core initialization . . . 3221
66.16.2 Host initialization . . . 3222
66.16.3 Device initialization . . . 3222
66.16.4 Host programming model . . . 3223
66.16.5 Device programming model . . . 3244
66.16.6 Worst case response time . . . 3265
66.16.7 OTG programming model . . . 3267

67 USB on-the-go high-speed (OTG_HS) . . . 3268
67.1 OTG_HS introduction . . . 3268
67.2 OTG_HS main features . . . 3269
67.2.1 General features . . . 3269
67.2.2 Host-mode features . . . 3270
67.2.3 Peripheral-mode features . . . 3270
67.3 OTG_HS implementation . . . 3270
67.4 OTG_HS functional description . . . 3271
67.4.1 OTG_HS block diagram . . . 3271
67.4.2 OTG_HS pin and internal signals . . . 3271
67.4.3 OTG_HS core . . . 3272
67.4.4 High-speed OTG PHY connected to OTG_HS . . . 3272
67.4.5 Battery charging detection . . . 3272
67.5 OTG_HS dual role device (DRD) . . . 3273
67.6 OTG_HS as a USB peripheral . . . 3273
67.6.1 Peripheral states . . . 3274
67.6.2 Peripheral endpoints . . . 3275
67.7 OTG_HS as a USB host . . . 3277
67.7.1 USB host states . . . 3278

67.7.2 Host channels . . . 3279
67.7.3 Host scheduler . . . 3280
67.8 OTG_HS SOF trigger . . . 3281
67.8.1 Host SOFs . . . 3282
67.8.2 Peripheral SOFs . . . 3282
67.9 OTG_HS low-power modes . . . 3282
67.10 OTG_HS Dynamic update of the OTG_HFIR register . . . 3283
67.11 OTG_HS data FIFOs . . . 3284
67.11.1 Peripheral FIFO architecture . . . 3284
67.11.2 Host FIFO architecture . . . 3285
67.11.3 FIFO RAM allocation . . . 3287
67.12 **OTG_HS** interrupts . . . 3288
67.13 **OTG_HS** control and status registers . . . 3290
67.13.1 CSR memory map . . . 3290
67.14 **OTG_HS** registers . . . 3295
67.14.1 OTG control and status register (OTG_GOTGCTL) . . . 3295
67.14.2 OTG interrupt register (OTG_GOTGINT) . . . 3297
67.14.3 OTG AHB configuration register (OTG_GAHBCFG) . . . 3298
67.14.4 OTG USB configuration register (OTG_GUSBCFG) . . . 3299
67.14.5 OTG reset register (OTG_GRSTCTL) . . . 3301
67.14.6 OTG core interrupt register [alternate] (OTG_GINTSTS) . . . 3304
67.14.7 OTG core interrupt register [alternate] (OTG_GINTSTS) . . . 3308
67.14.8 OTG interrupt mask register [alternate] (OTG_GINTMSK) . . . 3313
67.14.9 OTG interrupt mask register [alternate] (OTG_GINTMSK) . . . 3314
67.14.10 OTG receive status debug read register [alternate] (OTG_GRXSTSR) . . . 3316
67.14.11 OTG receive status debug read register [alternate] (OTG_GRXSTSR) . . . 3317
67.14.12 OTG status read and pop registers (OTG_GRXSTSP) . . . 3318
67.14.13 OTG status read and pop registers [alternate] (OTG_GRXSTSP) . . . 3319
67.14.14 OTG receive FIFO size register (OTG_GRXFSIZ) . . . 3320
67.14.15 OTG host non-periodic transmit FIFO size register [alternate] (OTG_HNPTXFSIZ) . . . 3321
67.14.16 Endpoint 0 transmit FIFO size [alternate] (OTG_DIEPTXF0) . . . 3321
67.14.17 OTG non-periodic transmit FIFO/queue status register (OTG_HNPTXSTS) . . . 3322
67.14.18 OTG general core configuration register (OTG_GCCFG) . . . 3323

67.14.19 OTG core ID register (OTG_CID) 3324
67.14.20 OTG core LPM configuration register (OTG_GLPMCFG) 3325
67.14.21 OTG host periodic transmit FIFO size register (OTG_HPTXFSIZ) 3329
67.14.22 OTG device IN endpoint transmit FIFO x size register (OTG_DIEPTXFx) 3329
67.14.23 Host-mode registers 3329
67.14.24 OTG host configuration register (OTG_HCFG) 3330
67.14.25 OTG host frame interval register (OTG_HFIR) 3330
67.14.26 OTG host frame number/frame time remaining register (OTG_HFNUM) 3331
67.14.27 OTG_Host periodic transmit FIFO/queue status register (OTG_HPTXSTS) 3332
67.14.28 OTG host all channels interrupt register (OTG_HAINT) 3333
67.14.29 OTG host all channels interrupt mask register (OTG_HAINTMSK) 3333
67.14.30 OTG host port control and status register (OTG_HPRT) 3334
67.14.31 OTG host channel x characteristics register (OTG_HCCHARx) 3336
67.14.32 OTG host channel x split control register (OTG_HCSPLTx) 3337
67.14.33 OTG host channel x interrupt register (OTG_HCINTx) 3338
67.14.34 OTG host channel x interrupt mask register (OTG_HCINTMSKx) . . 3339
67.14.35 OTG host channel x transfer size register (OTG_HCTSIZx) 3340
67.14.36 OTG host channel x DMA address register(OTG_HCDMAx) 3341
67.14.37 Device-mode registers 3341
67.14.38 OTG device configuration register (OTG_DCFG) 3341
67.14.39 OTG device control register (OTG_DCTL) 3343
67.14.40 OTG device status register (OTG_DSTS) 3345
67.14.41 OTG device IN endpoint common interrupt mask register (OTG_DIEPMSK) 3346
67.14.42 OTG device OUT endpoint common interrupt mask register (OTG_DOEPMSK) 3347
67.14.43 OTG device all endpoints interrupt register (OTG_DAINT) 3348
67.14.44 OTG all endpoints interrupt mask register (OTG_DAINTMSK) 3349
67.14.45 OTG device threshold control register (OTG_DTHRCTL) 3349
67.14.46 OTG device IN endpoint FIFO empty interrupt mask register (OTG_DIEPEMPMSK) 3350
67.14.47 OTG device IN endpoint x control register [alternate] (OTG_DIEPCTLx) 3351

67.14.48 OTG device IN endpoint x control register [alternate] (OTG_DIEPCTLx) . . . 3353
67.14.49 OTG device IN endpoint x interrupt register (OTG_DIEPINTx) 3355
67.14.50 OTG device IN endpoint 0 transfer size register (OTG_DIEPTSIZ0) . . . 3356
67.14.51 OTG device IN endpoint x DMA address register (OTG_DIEPDMAx) . . . 3357
67.14.52 OTG device IN endpoint transmit FIFO status register (OTG_DTXFSTSx) . . . 3357
67.14.53 OTG device IN endpoint x transfer size register (OTG_DIEPTSIZx) . 3358
67.14.54 OTG device control OUT endpoint 0 control register (OTG_DOEPCTL0) . . . 3358
67.14.55 OTG device OUT endpoint x interrupt register (OTG_DOEPINTx) . . 3360
67.14.56 OTG device OUT endpoint 0 transfer size register (OTG_DOEPTSIZ0) . . . 3362
67.14.57 OTG device OUT endpoint x DMA address register (OTG_DOEPDMAx) . . . 3363
67.14.58 OTG device OUT endpoint x control register [alternate] (OTG_DOEPCTLx) . . . 3363
67.14.59 OTG device OUT endpoint x control register [alternate] (OTG_DOEPCTLx) . . . 3365
67.14.60 OTG device OUT endpoint x transfer size register (OTG_DOEPTSIZx) . . . 3367
67.14.61 OTG power and clock gating control register (OTG_PCGCCTL) . . . 3368
67.14.62 OTG power and clock gating control register 1 (OTG_PCGCCTL1) . 3369
67.14.63 OTG_HS register map . . . 3370
67.15 **OTG_HS** programming model . . . 3377
67.15.1 Core initialization . . . 3377
67.15.2 Host initialization . . . 3378
67.15.3 Device initialization . . . 3379
67.15.4 DMA mode . . . 3379
67.15.5 Host programming model . . . 3379
67.15.6 Device programming model . . . 3412
67.15.7 Worst case response time . . . 3432
67.15.8 OTG programming model . . . 3434

68 USB Type-C®/USB Power Delivery interface (UCPD) . . . 3435
68.1 UCPD introduction . . . 3435
68.2 UCPD main features . . . 3435
68.3 UCPD implementation . . . 3436

68.4 UCPD functional description . . . 3436
68.4.1 UCPD block diagram . . . 3437
68.4.2 UCPD reset and clocks . . . 3438
68.4.3 Physical layer protocol . . . 3439
68.4.4 UCPD BMC transmitter . . . 3445
68.4.5 UCPD BMC receiver . . . 3447
68.4.6 UCPD Type-C pull-ups (Rp) and pull-downs (Rd) . . . 3448
68.4.7 UCPD Type-C voltage monitoring and de-bouncing . . . 3449
68.4.8 UCPD fast role swap (FRS) . . . 3449
68.4.9 UCPD DMA Interface . . . 3449
68.4.10 Wake-up from Stop mode . . . 3449
68.5 UCPD programming sequences . . . 3450
68.5.1 Initialization phase . . . 3450
68.5.2 Type-C state machine handling . . . 3450
68.5.3 USB PD transmit . . . 3452
68.5.4 USB PD receive . . . 3453
68.6 UCPD low-power modes . . . 3454
68.7 UCPD interrupts . . . 3455
68.8 UCPD registers . . . 3456
68.8.1 UCPD configuration register 1 (UCPD_CFGR1) . . . 3456
68.8.2 UCPD configuration register 2 (UCPD_CFGR2) . . . 3458
68.8.3 UCPD control register (UCPD_CR) . . . 3459
68.8.4 UCPD interrupt mask register (UCPD_IMR) . . . 3461
68.8.5 UCPD status register (UCPD_SR) . . . 3462
68.8.6 UCPD interrupt clear register (UCPD_ICR) . . . 3465
68.8.7 UCPD Tx ordered set type register (UCPD_TX_ORDSETR) . . . 3466
68.8.8 UCPD Tx payload size register (UCPD_TX_PAYSZR) . . . 3467
68.8.9 UCPD Tx data register (UCPD_TXDR) . . . 3467
68.8.10 UCPD Rx ordered set register (UCPD_RX_ORDSETR) . . . 3468
68.8.11 UCPD Rx payload size register (UCPD_RX_PAYSZR) . . . 3468
68.8.12 UCPD receive data register (UCPD_RXDR) . . . 3469
68.8.13 UCPD Rx ordered set extension register 1 (UCPD_RX_ORDEXTR1) . . . 3469
68.8.14 UCPD Rx ordered set extension register 2 (UCPD_RX_ORDEXTR2) . . . 3470
68.8.15 UCPD register map . . . 3470

69 Ethernet (ETH): media access control (MAC) with DMA controller 3473

69.1 Ethernet introduction 3473

69.2 Ethernet main features 3473

69.2.1 Standard compliance 3473

69.2.2 MAC features 3473

69.2.3 Transaction layer (MTL) features 3475

69.2.4 DMA block features 3476

69.2.5 Bus interface features 3476

69.3 Ethernet pins and internal signals 3477

69.4 Ethernet architecture 3479

69.4.1 DMA controller 3480

69.4.2 MTL 3488

69.4.3 MAC 3488

69.5 Ethernet functional description: MAC 3493

69.5.1 Double VLAN processing 3493

69.5.2 Source address and VLAN insertion, replacement, or deletion 3494

69.5.3 Packet filtering 3496

69.5.4 IEEE 1588 timestamp support 3503

69.5.5 Checksum offload engine 3527

69.5.6 TCP segmentation offload 3533

69.5.7 IPv4 ARP offload 3539

69.5.8 Loopback 3540

69.5.9 Flow control 3541

69.5.10 MAC management counters 3543

69.5.11 Interrupts generated by the MAC 3545

69.5.12 MAC and MMC register descriptions 3545

69.6 Ethernet functional description: PHY interfaces 3546

69.6.1 Station management agent (SMA) 3546

69.6.2 Media independent interface (MII) 3553

69.6.3 Reduced media independent interface (RMII) 3554

69.7 Ethernet low-power modes 3557

69.7.1 Low-power management 3557

69.7.2 Energy-efficient Ethernet (EEE) 3563

69.8 Ethernet interrupts 3569

69.8.1 DMA interrupts 3569

69.8.2 MTL interrupts . . . 3572
69.8.3 MAC interrupts . . . 3572
69.9 Ethernet programming model . . . 3573
69.9.1 DMA initialization . . . 3574
69.9.2 MTL initialization . . . 3575
69.9.3 MAC initialization . . . 3575
69.9.4 Performing normal receive and transmit operation . . . 3576
69.9.5 Stopping and starting transmission . . . 3577
69.9.6 Programming guidelines for switching to new descriptor list in RxDMA . . . 3577
69.9.7 Programming guidelines for switching the AHB clock frequency . . . 3577
69.9.8 Programming guidelines for MII link state transitions . . . 3578
69.9.9 Programming guidelines for IEEE 1588 timestamping . . . 3579
69.9.10 Programming guidelines for PTP offload feature . . . 3580
69.9.11 Programming guidelines for Energy Efficient Ethernet (EEE) . . . 3584
69.9.12 Programming guidelines for flexible pulse-per-second (PPS) output 3586
69.9.13 Programming guidelines for IEEE 1588 auxiliary snapshot . . . 3588
69.9.14 Programming guidelines for TSO . . . 3588
69.9.15 Programming guidelines to perform VLAN filtering on the receiver . . 3589
69.9.16 Programming guidelines for receive idle and receive interrupt watchdog timers . . . 3590
69.10 Descriptors . . . 3591
69.10.1 Descriptor overview . . . 3591
69.10.2 Descriptor structure . . . 3591
69.10.3 Transmit descriptor . . . 3595
69.10.4 Receive descriptor . . . 3607
69.11 Ethernet registers . . . 3620
69.11.1 Ethernet register maps . . . 3620
69.11.2 Ethernet DMA registers . . . 3620
69.11.3 Ethernet MTL registers . . . 3642
69.11.4 Ethernet MAC and MMC registers . . . 3651

70 HDMI-CEC controller (CEC) . . . 3753
70.1 HDMI-CEC introduction . . . 3753
70.2 HDMI-CEC controller main features . . . 3753
70.3 HDMI-CEC functional description . . . 3754
70.3.1 HDMI-CEC pin and internal signals . . . 3754

70.3.2 HDMI-CEC block diagram . . . 3755
70.3.3 Message description . . . 3755
70.3.4 Bit timing . . . 3756
70.4 Arbitration . . . 3756
70.4.1 SFT option bit . . . 3758
70.5 Error handling . . . 3758
70.5.1 Bit error . . . 3758
70.5.2 Message error . . . 3759
70.5.3 Bit rising error (BRE) . . . 3759
70.5.4 Short bit period error (SBPE) . . . 3759
70.5.5 Long bit period error (LBPE) . . . 3759
70.5.6 Transmission error detection (TXERR) . . . 3761
70.6 HDMI-CEC interrupts . . . 3762
70.7 HDMI-CEC registers . . . 3763
70.7.1 CEC control register (CEC_CR) . . . 3763
70.7.2 CEC configuration register (CEC_CFGR) . . . 3764
70.7.3 CEC Tx data register (CEC_TXDR) . . . 3766
70.7.4 CEC Rx data register (CEC_RXDR) . . . 3766
70.7.5 CEC interrupt and status register (CEC_ISR) . . . 3766
70.7.6 CEC interrupt enable register (CEC_IER) . . . 3768
70.7.7 HDMI-CEC register map . . . 3770

71 Debug support (DBG) . . . 3771
71.1 Introduction . . . 3771
71.2 DBG functional description . . . 3772
71.2.1 DBG block diagram . . . 3772
71.2.2 DBG pins and internal signals . . . 3772
71.2.3 DBG reset and clocks . . . 3773
71.2.4 DBG power domains . . . 3773
71.2.5 Debug and low-power modes . . . 3773
71.2.6 Security . . . 3774
71.2.7 Debug authentication . . . 3776
71.3 Serial-wire and JTAG debug port (SWJ-DP) . . . 3779
71.3.1 JTAG debug port . . . 3780
71.3.2 Serial-wire debug port . . . 3782
71.3.3 Debug port registers . . . 3784

71.3.4 Debug port register map and reset values . . . 3790
71.4 Access ports . . . 3791
71.4.1 Access port registers . . . 3791
71.4.2 Access port register map . . . 3798
71.5 ROM tables . . . 3799
71.5.1 System ROM table registers . . . 3802
71.5.2 System ROM table register map . . . 3806
71.5.3 MCU ROM table registers . . . 3807
71.5.4 MCU ROM table register map . . . 3811
71.5.5 Processor ROM table registers . . . 3812
71.5.6 Processor ROM table register map . . . 3816
71.6 Data watchpoint and trace unit (DWT) . . . 3817
71.6.1 DWT registers . . . 3817
71.6.2 DWT register map . . . 3831
71.7 Instrumentation trace macrocell (ITM) . . . 3834
71.7.1 ITM registers . . . 3834
71.7.2 ITM register map . . . 3842
71.8 Breakpoint unit (BPU) . . . 3844
71.8.1 BPU registers . . . 3844
71.8.2 BPU register map . . . 3850
71.9 Embedded Trace Macrocell (ETM) . . . 3851
71.9.1 ETM registers . . . 3851
71.9.2 ETM register map . . . 3876
71.10 Trace port interface unit (TPIU) . . . 3880
71.10.1 TPIU registers . . . 3881
71.10.2 TPIU register map . . . 3890
71.11 Cross-trigger interface (CTI) . . . 3892
71.11.1 CTI registers . . . 3893
71.11.2 CTI register map . . . 3903
71.12 Microcontroller debug unit (DBGMCU) . . . 3905
71.12.1 Device ID . . . 3905
71.12.2 Low-power mode emulation . . . 3905
71.12.3 Peripheral clock freeze . . . 3906
71.12.4 DBGMCU registers . . . 3907
71.12.5 DBGMCU register map . . . 3923
71.13 References . . . 3925

72 Device electronic signature 3926
72.1 Unique device ID register (96 bits) 3926
72.2 Flash size data register 3927
72.3 Package data register 3927

73 Important security notice 3929

74 Revision history 3930

List of tables

Table 1. Securable peripherals by TZSC . . . 134
Table 2. TrustZone-aware peripherals . . . 138
Table 3. Memory map and peripheral register addresses . . . 142
Table 4. Configuring security attributes with IDAU and SAU . . . 160
Table 5. MPCWMx resources . . . 162
Table 6. MPCBBx resources . . . 162
Table 7. DMA channel use (security) . . . 166
Table 8. Secure alternate function between peripherals and allocated I/Os . . . 168
Table 9. Nonsecure peripheral functions that cannot be connected to secure I/Os . . . 169
Table 10. Nonsecure peripheral functions that can be connected to secure I/Os . . . 169
Table 11. TrustZone-aware DBGMCU nonsecure accesses management . . . 170
Table 12. DMA channel use (privilege) . . . 174
Table 13. Internal tampers in TAMP . . . 178
Table 14. Effect of low-power modes on TAMP . . . 179
Table 15. Accelerated cryptographic operations . . . 182
Table 16. Main product life-cycle transitions . . . 185
Table 17. Typical product life-cycle phases . . . 186
Table 18. Software intellectual property protection with PRODUCT_STAT . . . 191
Table 19. STM32H5Ex Boot mode when TrustZone® is disabled (TZEN = 0xC3) . . . 195
Table 20. STM32H5Ex Boot mode when TrustZone® is enabled (TZEN = 0xB4) . . . 195
Table 21. STM32H5Fx Boot mode when TrustZone® is disabled (TZEN = 0xC3) . . . 196
Table 22. STM32H5Fx Boot mode when TrustZone® is enabled (TZEN = 0xB4) . . . 196
Table 23. GTZC features . . . 199
Table 24. GTZC1 sub-block address offset . . . 200
Table 25. MPCWM resource assignment . . . 200
Table 26. MPCWM3 and MPCWM4 (subregions A and B) . . . 200
Table 27. MPCBB resource assignment . . . 201
Table 28. Secure properties of subregions A and B . . . 204
Table 29. Privileged properties of subregions A and B . . . 204
Table 30. GTZC interrupt request . . . 205
Table 31. GTZC1 TZSC register map and reset values . . . 226
Table 32. GTZC1 TZIC register map and reset values . . . 258
Table 33. GTZC1 MPCBBz register map and reset values (z = 1 to 3) . . . 264
Table 34. Features of internal SRAMs . . . 266
Table 35. SRAM2 features . . . 268
Table 36. Effect of low-power modes on RAMCFG . . . 269
Table 37. RAMCFG interrupt requests . . . 269
Table 38. RAMCFG register map and reset values . . . 276
Table 39. Recommended number of wait states and programming delay . . . 283
Table 40. Flash memory OTP organization . . . 292
Table 41. Read-only public data organization . . . 294
Table 42. Memory map and swapping data . . . 296
Table 43. Recommended reactions to FLASH_OPSR contents . . . 298
Table 44. Option byte organization . . . 302
Table 45. Specific OB modifying rules . . . 306
Table 46. OB modifiable in closed product . . . 307
Table 47. Option byte key area . . . 308
Table 48. Default secure watermark . . . 315

Table 49. Flash memory TZ protection summary . . . 315
Table 50. TZ protection and bank or mass erase summary . . . 316
Table 51. Secure watermark-based area . . . 317
Table 52. Secure hide protection . . . 318
Table 53. HDP protections summary . . . 319
Table 54. Secure configuration block-based registers access conditions . . . 319
Table 55. Privilege protection summary . . . 320
Table 56. Privilege and mass or bank erase . . . 320
Table 57. Privilege configuration register access conditions (TZ enabled) . . . 320
Table 58. Privilege configuration register access conditions (TZ disabled) . . . 321
Table 59. Flash register accesses . . . 321
Table 60. Flash interface register protection summary . . . 324
Table 61. High-cycle area protection summary: access to data area address range . . . 325
Table 62. HDP protected definition . . . 325
Table 63. Privileged sectors and data area - Access to data area address range . . . 325
Table 64. Product states, debug states and debug policy . . . 326
Table 65. PRODUCT_STATE transitions . . . 328
Table 66. TZ OBK protection summary . . . 330
Table 67. OBK protection summary with TZ disabled . . . 330
Table 68. Access conditions to secure control register . . . 330
Table 69. Access conditions to nonsecure control register . . . 331
Table 70. OTP/RO access constraints . . . 331
Table 71. Macros for RSS services . . . 332
Table 72. RSS lib interface functions . . . 332
Table 73. NSS lib interface functions . . . 337
Table 74. Effect of low-power modes on the embedded flash memory . . . 338
Table 75. Locating ECC failure . . . 346
Table 76. Flash interrupt request . . . 349
Table 77. Register map and reset value table . . . 396
Table 78. ICACHE features for STM32H5E5/E4/F4/F5 . . . 403
Table 79. TAG memory dimensioning parameters for n-way set associative operating mode (default) . . . 405
Table 80. TAG memory dimensioning parameters for direct-mapped cache mode . . . 406
Table 81. ICACHE cacheability for AHB transaction . . . 408
Table 82. Memory configurations . . . 408
Table 83. ICACHE remap region size, base address, and remap address . . . 409
Table 84. ICACHE interrupts . . . 413
Table 85. ICACHE register map and reset values . . . 417
Table 86. DCACHE features for STM32H5E5/E4/F4/F5 . . . 420
Table 87. TAG memory dimensioning parameters . . . 423
Table 88. DCACHE cacheability for AHB transaction . . . 425
Table 89. DCACHE interrupts . . . 430
Table 90. DCACHE register map and reset values . . . 436
Table 91. PWR input/output pins . . . 438
Table 92. PWR internal input/output signals . . . 439
Table 93. Low-power mode summary . . . 457
Table 94. Functionalities depending on the working mode . . . 457
Table 95. Sleep mode . . . 462
Table 96. Memory shut-off block selection . . . 462
Table 97. Stop mode . . . 464
Table 98. Standby mode . . . 467
Table 99. Power modes output states versus MCU power modes . . . 467

Table 100. PWR security configuration summary . . . 468
Table 101. PWR interrupt requests . . . 470
Table 102. PWR register map and reset values . . . 485
Table 103. RCC input/output signals connected to package pins or balls . . . 488
Table 104. Reset source identification (RCC_RSR) . . . 490
Table 105. STOPWUCK and STOPKERWUCK description . . . 502
Table 106. HSIKERON and CSIKERON behavior . . . 503
Table 107. Kernel clock distribution overview . . . 505
Table 108. RCC security configuration summary . . . 516
Table 109. Interrupt sources and control . . . 519
Table 110. RCC register map and reset values . . . 600
Table 111. CRS features . . . 606
Table 112. CRS internal input/output signals . . . 607
Table 113. CRS interconnection . . . 608
Table 114. Effect of low-power modes on CRS . . . 611
Table 115. Interrupt control bits . . . 611
Table 116. CRS register map and reset values . . . 616
Table 117. Port bit configuration . . . 619
Table 118. GPIO secured bits . . . 627
Table 119. GPIO register map and reset values . . . 636
Table 120. SBS internal input/output signals . . . 640
Table 121. HDPL encoded values . . . 644
Table 122. SBS boot logic . . . 644
Table 123. OBK-HDPL logic . . . 649
Table 124. SBS register map and reset values . . . 663
Table 125. Peripherals interconnect matrix . . . 666
Table 126. GPDMA1/2 channel implementation . . . 683
Table 127. GPDMA1/2 wake-up in low-power modes . . . 683
Table 128. Programmed GPDMA1/2 request . . . 683
Table 129. Programmed GPDMA1/2 request as a block request . . . 688
Table 130. GPDMA1/2 channel with peripheral early termination . . . 688
Table 131. Programmed GPDMA1/2 request with peripheral early termination . . . 688
Table 132. Programmed GPDMA1/2 trigger . . . 689
Table 133. Programmed GPDMA source/destination burst . . . 711
Table 134. Programmed data handling . . . 716
Table 135. Effect of low-power modes on GPDMA . . . 729
Table 136. GPDMA interrupt requests . . . 730
Table 137. GPDMA register map and reset values . . . 758
Table 138. DMA2D input/ouput pins . . . 764
Table 139. DMA2D internal signals . . . 764
Table 140. DMA2D trigger interconnections . . . 764
Table 141. Pixel components order in memory . . . 769
Table 142. ARGB/RGB component reordering . . . 769
Table 143. Supported color mode in input . . . 770
Table 144. Alpha mode configuration . . . 771
Table 145. Supported CLUT color mode . . . 772
Table 146. Layer size definition vs scaler mode . . . 775
Table 147. Layer size definition in DMA2D_NLR vs tile buffer mode . . . 777
Table 148. MCU order in memory . . . 780
Table 149. Supported color mode in output . . . 782
Table 150. Data order in memory . . . 782
Table 151. ARGB/RGB component reordering . . . 783

Table 152. Standard data order in memory . . . 783
Table 153. Output FIFO byte reordering steps . . . 784
Table 154. Linear command list descriptor . . . 794
Table 155. NOP instruction coding . . . 795
Table 156. LD instruction coding . . . 795
Table 157. LDM instruction coding . . . 796
Table 158. END instruction coding . . . 797
Table 159. DMA2D interrupt requests . . . 800
Table 160. DMA2D register map and reset values . . . 837
Table 161. GFXTIM input/output pins . . . 842
Table 162. GFXTIM internal signals . . . 842
Table 163. GFXTIM trigger interconnections . . . 843
Table 164. Graphic timer interrupt requests . . . 853
Table 165. GFXTIM register map and reset values . . . 874
Table 166. Interrupt vector mapping . . . 878
Table 167. EXTI signals . . . 885
Table 168. EVG signals . . . 886
Table 169. EXTI line connections . . . 886
Table 170. Masking functionality . . . 891
Table 171. Register protection overview . . . 892
Table 172. EXTI register map sections . . . 893
Table 173. EXTI register map and reset values . . . 930
Table 174. CRC internal input/output signals . . . 935
Table 175. CRC register map and reset values . . . 940
Table 176. CORDIC functions . . . 942
Table 177. Cosine parameters . . . 942
Table 178. Sine parameters . . . 943
Table 179. Phase parameters . . . 943
Table 180. Modulus parameters . . . 944
Table 181. Arctangent parameters . . . 945
Table 182. Hyperbolic cosine parameters . . . 945
Table 183. Hyperbolic sine parameters . . . 946
Table 184. Hyperbolic arctangent parameters . . . 946
Table 185. Natural logarithm parameters . . . 947
Table 186. Natural log scaling factors and corresponding ranges . . . 947
Table 187. Square root parameters . . . 948
Table 188. Square root scaling factors and corresponding ranges . . . 948
Table 189. Precision vs. number of iterations . . . 951
Table 190. CORDIC register map and reset value . . . 958
Table 191. Valid combinations for read and write methods . . . 972
Table 192. FMAC register map and reset values . . . 985
Table 193. PLAY pins . . . 988
Table 194. PLAY internal signals . . . 988
Table 195. PLAY logic array input n signal selection . . . 989
Table 196. PLAY output connections . . . 990
Table 197. Truth table example 1 . . . 995
Table 198. Truth table example 2 . . . 997
Table 199. Logic element n LUT input selection . . . 999
Table 200. Logic element n register clock selection . . . 1000
Table 201. Output n source selection . . . 1003
Table 202. PLAY register map and reset values . . . 1020
Table 203. NOR/PSRAM bank selection . . . 1028

Table 204. NOR/PSRAM External memory address . . . 1028
Table 205. NAND memory mapping and timing registers. . . . 1028
Table 206. NAND bank selection . . . 1029
Table 207. SDRAM bank selection . . . 1029
Table 208. SDRAM address mapping . . . 1029
Table 209. SDRAM address mapping with 8-bit data bus width. . . . 1030
Table 210. SDRAM address mapping with 16-bit data bus width. . . . 1031
Table 211. SDRAM address mapping with 32-bit data bus width. . . . 1031
Table 212. Programmable NOR/PSRAM access parameters . . . 1033
Table 213. Non-multiplexed I/O NOR flash memory. . . . 1034
Table 214. 16-bit multiplexed I/O NOR flash memory . . . 1034
Table 215. Non-multiplexed I/Os PSRAM/SRAM . . . 1035
Table 216. 16-Bit multiplexed I/O PSRAM . . . 1035
Table 217. NOR flash/PSRAM: example of supported memories and transactions . . . 1036
Table 218. FMC_BCRx bitfields (mode 1) . . . 1039
Table 219. FMC_BTRx bitfields (mode 1) . . . 1039
Table 220. FMC_BCRx bitfields (mode A) . . . 1041
Table 221. FMC_BTRx bitfields (mode A) . . . 1041
Table 222. FMC_BWTRx bitfields (mode A). . . . 1042
Table 223. FMC_BCRx bitfields (mode 2/B). . . . 1044
Table 224. FMC_BTRx bitfields (mode 2/B). . . . 1044
Table 225. FMC_BWTRx bitfields (mode 2/B) . . . 1045
Table 226. FMC_BCRx bitfields (mode C) . . . 1046
Table 227. FMC_BTRx bitfields (mode C) . . . 1047
Table 228. FMC_BWTRx bitfields (mode C). . . . 1047
Table 229. FMC_BCRx bitfields (mode D) . . . 1049
Table 230. FMC_BTRx bitfields (mode D) . . . 1050
Table 231. FMC_BWTRx bitfields (mode D). . . . 1050
Table 232. FMC_BCRx bitfields (Muxed mode) . . . 1052
Table 233. FMC_BTRx bitfields (Muxed mode) . . . 1053
Table 234. FMC_BCRx bitfields (Synchronous multiplexed read mode) . . . 1058
Table 235. FMC_BTRx bitfields (Synchronous multiplexed read mode) . . . 1059
Table 236. FMC_BCRx bitfields (Synchronous multiplexed write mode) . . . 1060
Table 237. FMC_BTRx bitfields (Synchronous multiplexed write mode) . . . 1061
Table 238. Programmable NAND flash access parameters . . . 1070
Table 239. 8-bit NAND flash . . . 1070
Table 240. 16-bit NAND flash . . . 1071
Table 241. Supported memories and transactions . . . 1071
Table 242. ECC result relevant bits . . . 1080
Table 243. SDRAM signals. . . . 1081
Table 244. FMC register map and reset values . . . 1098
Table 245. OCTOSPI implementation . . . 1102
Table 246. OCTOSPI input/output pins . . . 1104
Table 247. OCTOSPI internal signals. . . . 1104
Table 248. Command/address phase description . . . 1113
Table 249. OctaRAM command address bit assignment (based on 64-Mbyte OctaRAM) . . . 1124
Table 250. Address alignment cases . . . 1131
Table 251. OCTOSPI interrupt requests. . . . 1133
Table 252. OCTOSPI register map and reset values . . . 1157
Table 253. OCTOSPIM implementation . . . 1160

Table 254. OCTOSPIM input/output pins . . . 1161
Table 255. Use cases . . . 1162
Table 256. OCTOSPIM register map and reset values . . . 1169
Table 257. SDMMC features . . . 1170
Table 258. SDMMC operation modes SD and SDIO . . . 1173
Table 259. SDMMC operation modes e•MMC . . . 1173
Table 260. SDMMC internal input/output signals . . . 1174
Table 261. SDMMC pins . . . 1175
Table 262. SDMMC Command and data phase selection . . . 1176
Table 263. Command token format . . . 1182
Table 264. Short response with CRC token format . . . 1183
Table 265. Short response without CRC token format . . . 1183
Table 266. Long response with CRC token format . . . 1183
Table 267. Specific Commands overview . . . 1184
Table 268. Command path status flags . . . 1185
Table 269. Command path error handling . . . 1185
Table 270. Data token format . . . 1193
Table 271. Data path status flags and clear bits . . . 1193
Table 272. Data path error handling . . . 1195
Table 273. Data FIFO access . . . 1196
Table 274. Transmit FIFO status flags . . . 1197
Table 275. Receive FIFO status flags . . . 1198
Table 276. AHB and SDMMC_CK clock frequency relation . . . 1203
Table 277. SDIO special operation control . . . 1203
Table 278. 4-bit mode Start, interrupt, and CRC-status Signaling detection . . . 1207
Table 279. CMD12 use cases . . . 1212
Table 280. SDMMC interrupts . . . 1226
Table 281. Response type and SDMMC_RESPxR registers . . . 1233
Table 282. SDMMC register map . . . 1249
Table 283. STM32H5E4/5F4 and STM32H5E5/5F5 features . . . 1252
Table 284. DLYB internal input/output signals . . . 1253
Table 285. Delay block control . . . 1254
Table 286. DLYB register map and reset values . . . 1257
Table 287. ADC features . . . 1260
Table 288. ADC input/output pins . . . 1262
Table 289. ADC internal input/output signals . . . 1262
Table 290. ADC interconnection . . . 1262
Table 291. Configuring the trigger polarity for regular external triggers . . . 1283
Table 292. Configuring the trigger polarity for injected external triggers . . . 1284
Table 293. TSAR timings depending on resolution . . . 1296
Table 294. Offset computation versus data resolution . . . 1299
Table 295. Analog watchdog channel selection . . . 1311
Table 296. Analog watchdog 1 comparison . . . 1312
Table 297. Analog watchdog 2 and 3 comparison . . . 1312
Table 298. Maximum output results versus N and M (gray cells indicate truncation) . . . 1316
Table 299. Oversampler operating modes summary . . . 1321
Table 300. ADC interrupts . . . 1340
Table 301. DELAY bits versus ADC resolution . . . 1375
Table 302. ADC global register map . . . 1377
Table 303. ADC register map and reset values for each ADC (offset = 0x000 for master ADC, 0x100 for slave ADC) . . . 1377
Table 304. ADC register map and reset values (master and slave ADC

common registers) . . . 1379
Table 305. DTS internal input/output signals . . . 1382
Table 306. Sampling time configuration . . . 1385
Table 307. Trigger configuration . . . 1386
Table 308. Temperature sensor behavior in low-power modes . . . 1388
Table 309. Interrupt control bits . . . 1389
Table 310. DTS register map and reset values . . . 1397
Table 311. DAC features . . . 1400
Table 312. DAC input/output pins . . . 1402
Table 313. DAC internal input/output signals . . . 1402
Table 314. DAC interconnection . . . 1403
Table 315. Data format (case of 12-bit data) . . . 1405
Table 316. HFSEL description . . . 1406
Table 317. Sample and refresh timings . . . 1412
Table 318. Channel output modes summary . . . 1413
Table 319. Effect of low-power modes on DAC . . . 1420
Table 320. DAC interrupts . . . 1420
Table 321. DAC register map and reset values . . . 1437
Table 322. VREFBUF typical values . . . 1439
Table 323. VREF buffer modes . . . 1440
Table 324. VREFBUF register map and reset values . . . 1442
Table 325. Possible connections for OPAMP . . . 1444
Table 326. Operating modes and calibration . . . 1452
Table 327. Effect of low-power modes on the OPAMP . . . 1453
Table 328. OPAMP register map and reset values . . . 1456
Table 329. COMP1/2 input/output internal signals . . . 1458
Table 330. COMP1 non-inverting input assignment . . . 1460
Table 331. COMP1 inverting input assignment . . . 1460
Table 332. COMP2 non-inverting input assignment . . . 1460
Table 333. COMP2 inverting input assignment . . . 1460
Table 334. COMP1 blanking source assignment . . . 1461
Table 335. COMP2 blanking source assignment . . . 1461
Table 336. Comparator behavior in low-power modes . . . 1465
Table 337. Interrupt through EXTI control bits . . . 1465
Table 338. Interrupt through NVIC control bits . . . 1466
Table 339. Interrupt through NVIC control bits . . . 1466
Table 340. COMP register map and reset values . . . 1472
Table 341. MDF features . . . 1474
Table 342. MDF external pins . . . 1477
Table 343. MDF internal signals . . . 1477
Table 344. MDF trigger connections . . . 1477
Table 345. MDF break connections . . . 1478
Table 346. MDF ADC data connections . . . 1478
Table 347. Control of the common clock generation . . . 1486
Table 348. Clock constraints with respect to the incoming stream . . . 1487
Table 349. Data size according to CIC order and CIC decimation values . . . 1494
Table 350. Maximum decimation ratio versus order and input data size . . . 1495
Table 351. Possible gain values . . . 1496
Table 352. Recommended maximum gain values versus CIC decimation ratios . . . 1498
Table 353. Most common microphone settings . . . 1498
Table 354. HPF 3 dB cut-off frequencies examples . . . 1500
Table 355. Register protection summary . . . 1520

Table 356. Effect of low-power modes on MDF . . . 1522
Table 357. MDF interrupt requests . . . 1524
Table 358. Examples of MDF settings for microphone capture . . . 1525
Table 359. Programming sequence . . . 1525
Table 360. Output signal levels . . . 1532
Table 361. MDF register map and reset values . . . 1555
Table 362. ADF features . . . 1558
Table 363. ADF external pins . . . 1559
Table 364. ADF internal signals . . . 1559
Table 365. ADF trigger connections . . . 1560
Table 366. ADF ADC data connections . . . 1560
Table 367. Control of the common clock generation . . . 1566
Table 368. Clock constraints with respect to the incoming stream . . . 1567
Table 369. Data size according to CIC order and CIC decimation values . . . 1572
Table 370. Possible gain values . . . 1573
Table 371. Recommended maximum gain values versus CIC decimation ratios . . . 1575
Table 372. Most common microphone settings . . . 1576
Table 373. HPF 3 dB cut-off frequency examples . . . 1578
Table 374. ANSLP values versus FRSIZE and sampling rates . . . 1591
Table 375. Threshold values according SNTHR . . . 1592
Table 376. Register protection summary . . . 1598
Table 377. Effect of low-power modes on ADF . . . 1599
Table 378. ADF interrupt requests . . . 1600
Table 379. Examples of ADF settings for microphone capture . . . 1601
Table 380. Programming sequence (CIC4) . . . 1602
Table 381. Programming sequence (CIC5) . . . 1603
Table 382. Output signal levels . . . 1608
Table 383. ADF register map and reset values . . . 1628
Table 384. DCMI input/output pins . . . 1632
Table 385. DCMI internal input/output signals . . . 1632
Table 386. Positioning of captured data bytes in 32-bit words (8-bit width) . . . 1634
Table 387. Positioning of captured data bytes in 32-bit words (10-bit width) . . . 1634
Table 388. Positioning of captured data bytes in 32-bit words (12-bit width) . . . 1634
Table 389. Positioning of captured data bytes in 32-bit words (14-bit width) . . . 1635
Table 390. Data storage in monochrome progressive video format . . . 1640
Table 391. Data storage in RGB progressive video format . . . 1641
Table 392. Data storage in YCbCr progressive video format . . . 1641
Table 393. Data storage in YCbCr progressive video format - Y extraction mode . . . 1641
Table 394. DCMI interrupts . . . 1642
Table 395. DCMI register map and reset values . . . 1652
Table 396. PSSI input/output pins . . . 1655
Table 397. PSSI internal input/output signals . . . 1655
Table 398. Positioning of captured data bytes in 32-bit words (8-bit width) . . . 1656
Table 399. Positioning of captured data bytes in 32-bit words (16-bit width) . . . 1657
Table 400. PSSI interrupt requests . . . 1660
Table 401. PSSI register map and reset values . . . 1666
Table 402. LTDC external pins . . . 1668
Table 403. LTDC internal signals . . . 1669
Table 404. LTDC trigger interconnection . . . 1669
Table 405. Clock domain for each register . . . 1669
Table 406. Pixel data mapping versus color format . . . 1674

Table 407. LTDC interrupt requests . . . 1678
Table 408. LTDC register map and reset values . . . 1695
Table 409. JPEG internal signals . . . 1699
Table 410. JPEG trigger connections . . . 1700
Table 411. JPEG codec interrupt requests . . . 1705
Table 412. JPEG codec register map and reset values . . . 1718
Table 413. Peripherals connected by CCB interconnect . . . 1721
Table 414. CCB internal input/output signals . . . 1722
Table 415. Blob creation steps for ECDSA signature (CCOP = 0b110000<i>0) . . . 1729
Table 416. Blob use steps for ECDSA signature (CCOP = 0b11000011) . . . 1731
Table 417. Blob use steps for signing public key computation (CCOP = 0b10000001) . . . 1734
Table 418. Blob creation steps for scalar multiplication (CCOP = 0b100000<i>0) . . . 1736
Table 419. Blob use steps for scalar multiplication (CCOP = 0b10000001) . . . 1737
Table 420. Blob creation steps for modular exponentiation (CCOP = 0b01000100) . . . 1738
Table 421. Blob use steps for modular exponentiation (CCOP = 0b01000101) . . . 1739
Table 422. CCB register map and reset values . . . 1745
Table 423. RNG internal input/output signals . . . 1747
Table 424. RNG interrupt requests . . . 1756
Table 425. RNG configurations . . . 1757
Table 426. Additional health test configurations . . . 1757
Table 427. Configuration selection . . . 1757
Table 428. RNG register map and reset map . . . 1765
Table 429. AES versus SAES features . . . 1767
Table 430. AES internal input/output signals . . . 1768
Table 431. AES approved symmetric key functions . . . 1768
Table 432. Counter mode initialization vector definition . . . 1778
Table 433. Initialization of IV registers in GCM mode . . . 1780
Table 434. GCM last block definition . . . 1780
Table 435. Initialization of IV registers in CCM mode . . . 1787
Table 436. AES data swapping example . . . 1790
Table 437. Key endianness in AES_KEYRx registers (128/256-bit keys) . . . 1792
Table 438. IVI bitfield spread over AES_IVRx registers . . . 1793
Table 439. AES interrupt requests . . . 1794
Table 440. Processing latency for ECB, CBC and CTR . . . 1795
Table 441. Processing latency for GCM and CCM (in clock cycles) . . . 1796
Table 442. AES register map and reset values . . . 1808
Table 443. AES versus SAES features . . . 1812
Table 444. SAES internal input/output signals . . . 1813
Table 445. SAES approved symmetric key functions . . . 1814
Table 446. Counter mode initialization vector definition . . . 1824
Table 447. Initialization of IV registers in GCM mode . . . 1827
Table 448. GCM last block definition . . . 1827
Table 449. Initialization of IV registers in CCM mode . . . 1833
Table 450. AES data swapping example . . . 1842
Table 451. Key endianness in SAES_KEYRx registers (128/256-bit keys) . . . 1844
Table 452. IVI bitfield spread over SAES_IVRx registers . . . 1846
Table 453. SAES interrupt requests . . . 1848
Table 454. Processing latency for ECB, CBC and CTR . . . 1849
Table 455. Processing latency for GCM and CCM (in SAES kernel clock cycles) . . . 1849
Table 456. SAES register map and reset values . . . 1864
Table 457. HASH internal input/output signals . . . 1868
Table 458. Information on supported hash algorithms . . . 1868

Table 459. Hash processor outputs . . . 1872
Table 460. Processing time (in clock cycle) . . . 1879
Table 461. HASH interrupt requests . . . 1880
Table 462. HASH1 register map and reset values . . . 1888
Table 463. Internal input/output signals . . . 1891
Table 464. PKA integer arithmetic functions list . . . 1892
Table 465. PKA prime field (Fp) elliptic curve functions list . . . 1893
Table 466. Chaining mode to/from PKA . . . 1898
Table 467. Integrity protected parameters list . . . 1900
Table 468. Confidentiality protected parameter list . . . 1900
Table 469. Example of ‘a’ curve coefficient for ECC Fp scalar . . . 1902
Table 470. Montgomery parameter computation . . . 1903
Table 471. Modular addition . . . 1903
Table 472. Modular subtraction . . . 1904
Table 473. Montgomery multiplication . . . 1905
Table 474. Modular exponentiation (normal mode) . . . 1906
Table 475. Modular exponentiation (fast mode) . . . 1906
Table 476. Modular exponentiation (protected mode) . . . 1907
Table 477. Modular inversion . . . 1907
Table 478. Modular reduction . . . 1908
Table 479. Arithmetic addition . . . 1908
Table 480. Arithmetic subtraction . . . 1908
Table 481. Arithmetic multiplication . . . 1909
Table 482. Arithmetic comparison . . . 1909
Table 483. CRT exponentiation . . . 1910
Table 484. Point on elliptic curve Fp check . . . 1911
Table 485. ECC Fp scalar multiplication . . . 1911
Table 486. ECDSA sign - Inputs . . . 1913
Table 487. ECDSA sign - Outputs . . . 1913
Table 488. Extended ECDSA sign - additional outputs . . . 1914
Table 489. ECDSA verification - inputs . . . 1914
Table 490. ECDSA verification - outputs . . . 1915
Table 491. ECC complete addition . . . 1915
Table 492. ECC double base ladder . . . 1916
Table 493. ECC projective to affine . . . 1917
Table 494. Family of supported curves for ECC operations . . . 1918
Table 495. Modular exponentiation . . . 1919
Table 496. ECC scalar multiplication . . . 1919
Table 497. ECDSA signature average computation time . . . 1920
Table 498. ECDSA verification average computation times . . . 1920
Table 499. ECC double base ladder average computation times . . . 1920
Table 500. ECC projective to affine average computation times . . . 1920
Table 501. ECC complete addition average computation times . . . 1920
Table 502. Point on elliptic curve Fp check average computation times . . . 1920
Table 503. Montgomery parameters average computation times . . . 1921
Table 504. PKA interrupt requests . . . 1921
Table 505. PKA register map and reset values . . . 1928
Table 506. OTFDEC internal input/output signals . . . 1930
Table 507. OTFDEC interrupt requests . . . 1934
Table 508. OTFDEC register map and reset values . . . 1948
Table 509. TIM input/output pins . . . 1954
Table 510. TIM internal input/output signals . . . 1954

Table 511. Interconnect to the tim_ti1 input multiplexer . . . 1956
Table 512. Interconnect to the tim_ti2 input multiplexer . . . 1956
Table 513. Interconnect to the tim_ti3 input multiplexer . . . 1956
Table 514. Interconnect to the tim_ti4 input multiplexer . . . 1956
Table 515. Internal trigger connection . . . 1956
Table 516. Interconnect to the tim_etr input multiplexer . . . 1957
Table 517. Timer break interconnect . . . 1957
Table 518. Timer break2 interconnect . . . 1958
Table 519. System break interconnect . . . 1958
Table 520. Interconnect to the tim_ocref_clr input multiplexer . . . 1958
Table 521. CCR and ARR register change dithering pattern . . . 1992
Table 522. CCR register change dithering pattern in center-aligned PWM mode . . . 1993
Table 523. Behavior of timer outputs versus tim_brk/tim_brk2 inputs . . . 2005
Table 524. Break protection disarming conditions . . . 2007
Table 525. Counting direction versus encoder signals (CC1P = CC2P = 0) . . . 2016
Table 526. Counting direction versus encoder signals and polarity settings . . . 2020
Table 527. DMA request . . . 2041
Table 528. Effect of low-power modes on TIM1/TIM8 . . . 2042
Table 529. Interrupt requests . . . 2042
Table 530. Output control bits for complementary tim_ocx and tim_ocxn channels with break feature . . . 2069
Table 531. TIMx register map and reset values . . . 2092
Table 532. STM32H5E4/5F4 and STM32H5E5/5F5 general purpose timers . . . 2096
Table 533. TIM input/output pins . . . 2098
Table 534. TIM internal input/output signals . . . 2098
Table 535. Interconnect to the tim_ti1 input multiplexer . . . 2099
Table 536. Interconnect to the tim_ti2 input multiplexer . . . 2099
Table 537. Interconnect to the tim_ti3 input multiplexer . . . 2100
Table 538. Interconnect to the tim_ti4 input multiplexer . . . 2100
Table 539. TIMx internal trigger connection . . . 2100
Table 540. Interconnect to the tim_etr input multiplexer . . . 2101
Table 541. Interconnect to the tim_ocref_clr input multiplexer . . . 2101
Table 542. CCR and ARR register change dithering pattern . . . 2132
Table 543. CCR register change dithering pattern in center-aligned PWM mode . . . 2133
Table 544. Counting direction versus encoder signals(CC1P = CC2P = 0) . . . 2142
Table 545. Counting direction versus encoder signals and polarity settings . . . 2147
Table 546. DMA request . . . 2171
Table 547. Effect of low-power modes on TIM2/TIM3/TIM4/TIM5 . . . 2171
Table 548. Interrupt requests . . . 2172
Table 549. Output control bit for standard tim_ocx channels . . . 2193
Table 550. TIM2/TIM3/TIM4/TIM5 register map and reset values . . . 2209
Table 551. TIM internal input/output signals . . . 2213
Table 552. TIMx_ARR register change dithering pattern . . . 2223
Table 553. DMA request . . . 2224
Table 554. Effect of low-power modes on TIM6/TIM7 . . . 2224
Table 555. Interrupt request . . . 2224
Table 556. TIMx register map and reset values . . . 2230
Table 557. TIM input/output pins . . . 2234
Table 558. TIM internal input/output signals . . . 2234
Table 559. Interconnect to the tim_ti1 input multiplexer . . . 2236
Table 560. Interconnect to the tim_ti2 input multiplexer . . . 2236
Table 561. TIMx internal trigger connection . . . 2236

Table 562. CCR and ARR register change dithering pattern . . . 2254
Table 563. Effect of low-power modes on TIM12/TIM13/TIM14 . . . 2263
Table 564. Interrupt requests . . . 2263
Table 565. Output control bit for standard tim_ocx channels . . . 2275
Table 566. TIM12 register map and reset values . . . 2279
Table 567. Output control bit for standard tim_ocx channels . . . 2288
Table 568. TIM13/TIM14 register map and reset values . . . 2291
Table 569. TIM input/output pins . . . 2296
Table 570. TIM internal input/output signals . . . 2297
Table 571. Interconnect to the tim_ti1 input multiplexer . . . 2298
Table 572. Interconnect to the tim_ti2 input multiplexer . . . 2298
Table 573. TIMx internal trigger connection . . . 2298
Table 574. Timer break interconnect . . . 2299
Table 575. System break interconnect . . . 2299
Table 576. Interconnect to the tim_ocref_clr input multiplexer . . . 2299
Table 577. CCR and ARR register change dithering pattern . . . 2320
Table 578. Break protection disarming conditions . . . 2329
Table 579. DMA request . . . 2340
Table 580. Effect of low-power modes on TIM15/TIM16/TIM17 . . . 2341
Table 581. Interrupt requests . . . 2341
Table 582. Output control bits for complementary tim_ocx and tim_ocxn channels with break feature (TIM15) . . . 2357
Table 583. TIM15 register map and reset values . . . 2370
Table 584. Output control bits for complementary tim_oc1 and tim_oc1n channels with break feature (TIM16/TIM17) . . . 2383
Table 585. TIM16/TIM17 register map and reset values . . . 2397
Table 586. STM32H5E4/5F4 and STM32H5E5/5F5 LPTIM features . . . 2401
Table 587. LPTIM1/2/3/5/6 input/output pins . . . 2403
Table 588. LPTIM4 input/output pins . . . 2403
Table 589. LPTIM1/2/3/5/6 internal signals . . . 2404
Table 590. LPTIM4 internal signals . . . 2404
Table 591. LPTIM1/2/3/4/5/6 external trigger connections . . . 2405
Table 592. LPTIM1/2/3/4/5/6 input 1 connections . . . 2405
Table 593. LPTIM1/2/3/5/6 input 2 connections . . . 2405
Table 594. LPTIM1/2/3/5/6 input capture 1 connections . . . 2406
Table 595. LPTIM1 input capture 2 connections . . . 2406
Table 596. LPTIM2 input capture 2 connections . . . 2406
Table 597. LPTIM3/5/6 input capture 2 connections . . . 2406
Table 598. Prescaler division ratios . . . 2408
Table 599. Encoder counting scenarios . . . 2415
Table 600. Input capture Glitch filter latency (in counter step unit) . . . 2419
Table 601. Effect of low-power modes on the LPTIM . . . 2423
Table 602. Interrupt events . . . 2424
Table 603. LPTIM register map and reset values . . . 2448
Table 604. IWDG features . . . 2451
Table 605. IWDG delays versus actions . . . 2452
Table 606. IWDG internal input/output signals . . . 2453
Table 607. Effect of low power modes on IWDG . . . 2458
Table 608. IWDG interrupt request . . . 2460
Table 609. IWDG register map and reset values . . . 2466
Table 610. WWDG features . . . 2467
Table 611. WWDG internal input/output signals . . . 2468

Table 612. WWDG interrupt requests . . . 2471
Table 613. WWDG register map and reset values . . . 2473
Table 614. RTC input/output pins . . . 2477
Table 615. RTC internal input/output signals . . . 2477
Table 616. RTC interconnection . . . 2478
Table 617. RTC pin PC13 configuration . . . 2479
Table 618. PI8 configuration . . . 2481
Table 619. RTC_OUT mapping . . . 2482
Table 620. Effect of low-power modes on RTC . . . 2497
Table 621. RTC pins functionality over modes . . . 2497
Table 622. Nonsecure interrupt requests . . . 2498
Table 623. Secure interrupt requests . . . 2498
Table 624. RTC register map and reset values . . . 2529
Table 625. TAMP input/output pins . . . 2535
Table 626. TAMP internal input/output signals . . . 2535
Table 627. TAMP interconnection . . . 2536
Table 628. Device resource x tamper protection . . . 2542
Table 629. Active tamper output change period . . . 2545
Table 630. Minimum ATPER value . . . 2546
Table 631. Active tamper filtered pulse duration . . . 2547
Table 632. Effect of low-power modes on TAMP . . . 2549
Table 633. TAMP pins functionality over modes . . . 2549
Table 634. Interrupt requests . . . 2549
Table 635. TAMP register map and reset values . . . 2578
Table 636. I2C implementation . . . 2581
Table 637. I2C input/output pins . . . 2582
Table 638. I2C internal input/output signals . . . 2583
Table 639. Comparison of analog and digital filters . . . 2585
Table 640. I²C-bus and SMBus specification data setup and hold times . . . 2587
Table 641. I2C configuration . . . 2591
Table 642. I²C-bus and SMBus specification clock timings . . . 2602
Table 643. Timing settings for f_{I2CCLK} of 8 MHz . . . 2612
Table 644. Timing settings for f_{I2CCLK} of 16 MHz . . . 2612
Table 645. SMBus timeout specifications . . . 2614
Table 646. SMBus with PEC configuration . . . 2616
Table 647. TIMEOUTA[11:0] for maximum $t_{TIMEOUT}$ of 25 ms . . . 2617
Table 648. TIMEOUTB[11:0] for maximum $t_{LOW:SEXT}$ and $t_{LOW:MEXT}$ of 8 ms . . . 2617
Table 649. TIMEOUTA[11:0] for maximum t_{IDLE} of 50 µs . . . 2617
Table 650. Effect of low-power modes to I2C . . . 2627
Table 651. I2C interrupt requests . . . 2627
Table 652. I2C register map and reset values . . . 2643
Table 653. I3C instantiation . . . 2646
Table 654. I3C FIFOs implementation . . . 2646
Table 655. I3C interrupt(s) . . . 2646
Table 656. I3C peripheral controller/target features versus MIPI v1.1 . . . 2647
Table 657. I3C input/output pins . . . 2648
Table 658. I3C internal input/output signals . . . 2648
Table 659. I3C register usage . . . 2661
Table 660. I3C registers/fields usage versus controller state . . . 2662
Table 661. I3C registers/fields usage versus target state . . . 2665
Table 662. List of supported I3C CCCs, as controller/target . . . 2668
Table 663. I3C controller error management . . . 2700

Table 664. I3C target error management . . . 2702
Table 665. Effect of low-power modes . . . 2703
Table 666. I3C register map and reset values . . . 2749
Table 667. Instance implementation on STM32H5E4/5F4 and STM32H5E5/5F5 . . . 2753
Table 668. USART/LPUART features . . . 2754
Table 669. USART/UART input/output pins . . . 2756
Table 670. USART internal input/output signals . . . 2757
Table 671. Noise detection from sampled data . . . 2769
Table 672. Tolerance of the USART receiver when BRR [3:0] = 0000 . . . 2773
Table 673. Tolerance of the USART receiver when BRR[3:0] is different from 0000 . . . 2773
Table 674. USART frame formats . . . 2778
Table 675. Effect of low-power modes on the USART . . . 2801
Table 676. USART interrupt requests . . . 2802
Table 677. USART register map and reset values . . . 2840
Table 678. Instance implementation on STM32H5E4/5F4 and STM32H5E5/5F5 . . . 2843
Table 679. USART/LPUART features . . . 2843
Table 680. LPUART input/output pins . . . 2846
Table 681. LPUART internal input/output signals . . . 2846
Table 682. Error calculation for programmed baud rates at lpuart_ker_ck_pres= 32.768 kHz . . . 2857
Table 683. Tolerance of the LPUART receiver . . . 2858
Table 685. Effect of low-power modes on the LPUART . . . 2870
Table 686. LPUART interrupt requests . . . 2871
Table 687. LPUART register map and reset values . . . 2897
Table 688. SPI features . . . 2900
Table 689. SPI/I2S input/output pins . . . 2903
Table 690. SPI internal input/output signals . . . 2903
Table 691. Effect of low-power modes on the SPI . . . 2930
Table 692. SPI wake-up and interrupt requests . . . 2931
Table 693. Bitfields usable in PCM/I2S mode . . . 2933
Table 694. WS and CK level before SPI/I2S is enabled when AFCNTR = 1 . . . 2942
Table 695. Serial data line swapping . . . 2942
Table 696. CLKGEN programming examples for usual I2S frequencies . . . 2946
Table 697. I2S interrupt requests . . . 2955
Table 698. SPI register map and reset values . . . 2973
Table 699. STM32H5E4/5F4 and STM32H5E5/5F5 SAI features . . . 2976
Table 700. SAI internal input/output signals . . . 2978
Table 701. SAI input/output pins . . . 2978
Table 702. External synchronization selection . . . 2981
Table 703. MCLK_x activation conditions . . . 2986
Table 704. Clock generator programming examples . . . 2989
Table 705. SAI_A configuration for TDM mode . . . 2996
Table 706. TDM frame configuration examples . . . 2998
Table 707. SOPD pattern . . . 3002
Table 708. Parity bit calculation . . . 3002
Table 709. Audio sampling frequency versus symbol rates . . . 3003
Table 710. SAI interrupt sources . . . 3012
Table 711. SAI register map and reset values . . . 3041
Table 712. CAN subsystem I/O signals . . . 3047
Table 713. CAN subsystem I/O pins . . . 3047
Table 714. DLC coding in FDCAN . . . 3051
Table 715. Possible configurations for frame transmission . . . 3065
Table 716. Rx FIFO element . . . 3068

Table 717. Rx FIFO element description . . . 3068
Table 718. Tx buffer and FIFO element . . . 3070
Table 719. Tx buffer element description . . . 3070
Table 720. Tx event FIFO element . . . 3072
Table 721. Tx event FIFO element description . . . 3072
Table 722. Standard message ID filter element . . . 3073
Table 723. Standard message ID filter element field description . . . 3074
Table 724. Extended message ID filter element . . . 3074
Table 725. Extended message ID filter element field description . . . 3075
Table 726. FDCAN register map and reset values . . . 3105
Table 727. OTG_FS speeds supported . . . 3109
Table 728. OTG_FS implementation . . . 3112
Table 729. OTG_FS input/output pins . . . 3113
Table 730. OTG_FS input/output signals . . . 3114
Table 731. Compatibility of STM32 low power modes with the OTG . . . 3124
Table 732. Core global control and status registers (CSRs) . . . 3133
Table 733. Host-mode control and status registers (CSRs) . . . 3134
Table 734. Device-mode control and status registers . . . 3135
Table 735. Data FIFO (DFIFO) access register map . . . 3137
Table 736. Power and clock gating control and status registers . . . 3137
Table 737. TRDT values . . . 3143
Table 738. Minimum duration for soft disconnect . . . 3184
Table 739. OTG_FS register map and reset values . . . 3213
Table 740. OTG_HS speeds supported . . . 3268
Table 741. OTG_HS implementation . . . 3270
Table 742. OTG_HS input/output pins . . . 3271
Table 743. OTG_HS input/output signals . . . 3272
Table 744. Compatibility of STM32 low power modes with the OTG . . . 3282
Table 745. Core global control and status registers (CSRs) . . . 3290
Table 746. Host-mode control and status registers (CSRs) . . . 3291
Table 747. Device-mode control and status registers . . . 3292
Table 748. Data FIFO (DFIFO) access register map . . . 3294
Table 749. Power and clock gating control and status registers . . . 3295
Table 750. TRDT values . . . 3301
Table 751. Minimum duration for soft disconnect . . . 3344
Table 752. OTG_HS register map and reset values . . . 3370
Table 753. UCPD implementation . . . 3436
Table 754. UCPD signals on pins . . . 3437
Table 755. UCPD internal signals . . . 3438
Table 756. 4b5b symbol encoding table . . . 3439
Table 757. Ordered sets . . . 3441
Table 758. Validation of ordered sets . . . 3441
Table 759. Data size . . . 3442
Table 760. Coding for ANAMODE, ANASUBMODE and link with TYPEC_VSTATE_CCx . . . 3450
Table 761. Type-C sequence (source: 3A); cable/sink connected (Rd on CC1; Ra on CC2) . . . 3452
Table 762. Effect of low power modes on the UCPD . . . 3454
Table 763. UCPD interrupt requests . . . 3455
Table 764. UCPD register map and reset values . . . 3470
Table 765. Ethernet peripheral pins . . . 3477
Table 766. Internal Ethernet input/output signals . . . 3478
Table 767. Ethernet trigger connections . . . 3478
Table 768. Priority scheme for Tx DMA and Rx DMA . . . 3487

Table 769. Double VLAN processing features in Tx path . . . 3493
Table 770. Double VLAN processing in Rx path . . . 3494
Table 771. VLAN insertion or replacement based on VLTI bit . . . 3495
Table 772. Destination address filtering . . . 3498
Table 773. Source address filtering . . . 3499
Table 774. VLAN match status . . . 3500
Table 775. Ordinary clock: PTP messages for snapshot . . . 3504
Table 776. End-to-end transparent clock: PTP messages for snapshot . . . 3504
Table 777. Peer-to-peer transparent clock: PTP messages for snapshot . . . 3505
Table 778. Egress and ingress latency for PHY interfaces . . . 3509
Table 779. Minimum PTP clock frequency example . . . 3509
Table 780. Message format defined in IEEE 1588-2008 . . . 3510
Table 781. Message format defined in IEEE 1588-2008 . . . 3511
Table 782. IPv6-UDP PTP packet fields required for control and status . . . 3512
Table 783. Ethernet PTP packet fields required for control and status . . . 3513
Table 784. Timestamp Snapshot Dependency on ETH_MACTSCR bits . . . 3514
Table 785. PTP message generation criteria . . . 3520
Table 786. Common PTP message header fields . . . 3522
Table 787. MAC transmit PTP mode and one-step timestamping operation . . . 3525
Table 788. Transmit checksum offload engine functions for different packet types . . . 3529
Table 789. Receive checksum offload engine functions for different packet types . . . 3532
Table 790. TSO: TCP and IP header fields . . . 3536
Table 791. Pause packet fields . . . 3541
Table 792. Tx MAC flow control . . . 3542
Table 793. Rx MAC flow control . . . 3542
Table 794. Size of the maximum receive packet . . . 3545
Table 795. MCD clock selection . . . 3547
Table 796. MDIO Clause 45 frame structure . . . 3548
Table 797. MDIO Clause 22 frame structure . . . 3549
Table 798. Remote wake-up packet filter register . . . 3560
Table 799. Description of the remote wake-up filter fields . . . 3560
Table 800. Remote wake-up packet and PMT interrupt generation . . . 3562
Table 801. Transfer complete interrupt behavior . . . 3571
Table 802. TDES0 normal descriptor (read format) . . . 3595
Table 803. TDES1 normal descriptor (read format) . . . 3596
Table 804. TDES2 normal descriptor (read format) . . . 3596
Table 805. TDES3 normal descriptor (read format) . . . 3597
Table 806. TDES0 normal descriptor (write-back format) . . . 3600
Table 807. TDES1 normal descriptor (write-back format) . . . 3600
Table 808. TDES2 normal descriptor (write-back format) . . . 3601
Table 809. TDES3 normal descriptor (write-back format) . . . 3601
Table 810. TDES0 context descriptor . . . 3605
Table 811. TDES1 context descriptor . . . 3605
Table 812. TDES2 context descriptor . . . 3605
Table 813. TDES3 context descriptor . . . 3606
Table 814. RDES0 normal descriptor (read format) . . . 3609
Table 815. RDES1 normal descriptor (read format) . . . 3609
Table 816. RDES2 normal descriptor (read format) . . . 3609
Table 817. RDES3 normal descriptor (read format) . . . 3610
Table 818. RDES0 normal descriptor (write-back format) . . . 3611
Table 819. RDES1 normal descriptor (write-back format) . . . 3612
Table 820. RDES2 normal descriptor (write-back format) . . . 3614

Table 821. RDES3 normal descriptor (write-back format) . . . 3615
Table 822. RDES0 context descriptor . . . 3618
Table 823. RDES1 context descriptor . . . 3619
Table 824. RDES2 context descriptor . . . 3619
Table 825. RDES3 context descriptor . . . 3619
Table 826. ETH_DMA common register map and reset values . . . 3640
Table 827. ETH_DMA_CH register map and reset values . . . 3640
Table 828. ETH_MTL register map and reset values . . . 3650
Table 829. Giant Packet Status based on S2KP and JE Bits . . . 3656
Table 830. Packet Length based on the CST and ACS bits . . . 3656
Table 831. Ethernet MAC register map and reset values . . . 3743
Table 832. HDMI pin . . . 3754
Table 833. HDMI-CEC internal input/output signals . . . 3754
Table 834. Error handling timing parameters . . . 3760
Table 835. TXERR timing parameters . . . 3761
Table 836. HDMI-CEC interrupts . . . 3762
Table 837. HDMI-CEC register map and reset values . . . 3770
Table 838. JTAG/Serial-wire debug port pins . . . 3772
Table 839. Trace port pins . . . 3772
Table 840. Single-wire trace port pins . . . 3773
Table 841. Authentication signal states with TrustZone enabled (TZEN = 0xB4) . . . 3775
Table 842. Authentication signal states with TrustZone disabled (TZEN = 0xC3) . . . 3775
Table 843. Life cycle state and debug states . . . 3775
Table 844. Definition of data to provision . . . 3778
Table 845. Permission mask (Endianness: Little Endian) . . . 3778
Table 846. JTAG-DP data registers . . . 3781
Table 847. Packet request . . . 3783
Table 848. ACK response . . . 3783
Table 849. Data transfer . . . 3783
Table 850. Debug port registers . . . 3784
Table 851. Debug port register map and reset values . . . 3790
Table 852. MEM-AP registers . . . 3792
Table 853. Access port register map and reset values . . . 3798
Table 854. System ROM table . . . 3799
Table 855. MCU ROM table . . . 3800
Table 856. Processor ROM table . . . 3800
Table 857. System ROM table register map and reset values . . . 3806
Table 858. MCU ROM table register map and reset values . . . 3811
Table 859. CPU ROM table register map and reset values . . . 3816
Table 860. DWT register map and reset values . . . 3831
Table 861. ITM register map and reset values . . . 3842
Table 862. BPU register map and reset values . . . 3850
Table 863. ETM register map and reset values . . . 3876
Table 864. TPIU register map and reset values . . . 3890
Table 865. CTI inputs . . . 3892
Table 866. CTI outputs . . . 3892
Table 867. CTI register map and reset values . . . 3903
Table 868. Peripheral clock freeze control bits . . . 3906
Table 869. Peripheral behaviour in debug mode . . . 3907
Table 870. DBGMCU register map and reset values . . . 3923
Table 871. Document revision history . . . 3930

List of figures

Figure 1. System architecture . . . 131
Figure 2. Memory map based on IDAU mapping . . . 141
Figure 3. Secure/nonsecure partitioning using TrustZone technology . . . 157
Figure 4. Sharing memory map between CPU in secure and nonsecure state . . . 159
Figure 5. Secure world transition and memory partitioning . . . 159
Figure 6. Global TrustZone framework and TrustZone awareness . . . 161
Figure 7. Flash memory TrustZone protections . . . 165
Figure 8. Flash memory secure HDP area . . . 172
Figure 9. Key management principle . . . 180
Figure 10. Device life-cycle security . . . 184
Figure 11. PRODUCT_STATEs (simplified TrustZone activated view) . . . 187
Figure 12. PRODUCT_STATEs (full TrustZone activated view) . . . 188
Figure 13. Collaborative development principle . . . 190
Figure 14. External flash memory protection using SFI . . . 192
Figure 15. GTZC in Armv8-M subsystem block diagram . . . 199
Figure 16. GTZC block diagram . . . 202
Figure 17. Watermark memory protection controller (region x/subregions A and B) . . . 203
Figure 18. MPCBB block diagram . . . 204
Figure 19. Memory map: SRAM2/3 . . . 267
Figure 20. FLASH block diagram (simplified) . . . 278
Figure 21. Embedded flash memory organization (4-Mbyte devices) . . . 280
Figure 22. Embedded flash memory usage . . . 281
Figure 23. Flash high-cycle data memory map on 4-Mbyte device . . . 295
Figure 24. Flash high-cycle area memory map on a 3-Mbyte device . . . 295
Figure 25. Flash bank swapping sequence . . . 297
Figure 26. OBK protection checks . . . 310
Figure 27. Key writing flow . . . 311
Figure 28. Swap workflow . . . 313
Figure 29. HDP in user flash memory . . . 318
Figure 30. Protection attributes in case of bank swap illustration . . . 323
Figure 31. ICACHE block diagram . . . 404
Figure 32. ICACHE TAG and data memories functional view . . . 406
Figure 33. ICACHE remapping address mechanism . . . 409
Figure 34. DCACHE block diagram . . . 421
Figure 35. DCACHE TAG and data memories functional view . . . 424
Figure 36. Power supply with SMPS . . . 440
Figure 37. Power supply with LDO . . . 441
Figure 38. System supply configurations . . . 443
Figure 39. Power-on (POR) / power-down (PDR) reset waveform . . . 449
Figure 40. BOR thresholds . . . 450
Figure 41. PVD thresholds . . . 451
Figure 42. AVD thresholds . . . 452
Figure 43. VBAT thresholds . . . 453
Figure 44. Temperature thresholds . . . 454
Figure 45. Dynamic voltage scaling in Run mode . . . 455
Figure 46. I/O states in Standby mode . . . 465
Figure 47. Simplified diagram of the reset circuit . . . 489
Figure 48. Clock tree . . . 492

Figure 49. HSE/LSE clock sources . . . 493
Figure 50. CSI calibration flow . . . 496
Figure 51. PLL block diagram . . . 497
Figure 52. PLLs initialization flow . . . 500
Figure 53. Kernel clock distribution for SAIs . . . 506
Figure 54. Clock distribution for CCB subsystem . . . 508
Figure 55. Kernel clock distribution for OTG_FS, OTG_HS and UCPD1 . . . 510
Figure 56. Clock distribution for ETH . . . 511
Figure 57. CRS block diagram . . . 607
Figure 58. CRS counter behavior . . . 609
Figure 59. Structure of 3- or 5-V tolerant GPIO (TT or FT) . . . 619
Figure 60. Input floating/pull-up/pull-down configurations . . . 623
Figure 61. Output configuration . . . 624
Figure 62. Alternate function configuration . . . 625
Figure 63. High-impedance analog configuration . . . 625
Figure 64. SBS block diagram . . . 639
Figure 65. Compensation cell management . . . 641
Figure 66. Compensation cell usage . . . 642
Figure 67. SBS boot control . . . 643
Figure 68. SBS debug control . . . 647
Figure 69. SBS hardware secure storage control . . . 648
Figure 70. GPDMA block diagram . . . 692
Figure 71. GPDMA channel direct programming without linked-list (GPDMA_CxLLR = 0) . . . 693
Figure 72. GPDMA channel suspend and resume sequence . . . 694
Figure 73. GPDMA channel abort and restart sequence . . . 695
Figure 74. Static linked-list data structure (all Uxx = 1) of a linear addressing channel x . . . 696
Figure 75. Static linked-list data structure (all Uxx = 1) of a 2D addressing channel x . . . 697
Figure 76. GPDMA dynamic linked-list data structure of a linear addressing channel x . . . 698
Figure 77. GPDMA dynamic linked-list data structure of a 2D addressing channel x . . . 698
Figure 78. GPDMA channel execution and linked-list programming in run-to-completion mode (GPDMA_CxCR.LSM = 0) . . . 700
Figure 79. Inserting a LLIn with an auxiliary GPDMA channel y . . . 702
Figure 80. GPDMA channel execution and linked-list programming in link step mode (GPDMA_CxCR.LSM = 1) . . . 704
Figure 81. Building LLIn+1: GPDMA dynamic linked-lists in link step mode . . . 705
Figure 82. Replace with a new LLIn' in register file in link step mode . . . 706
Figure 83. Replace with a new LLIn' and LLIn+1' in memory in link step mode (option 1) . . . 707
Figure 84. Replace with a new LLIn' and LLIn+1' in memory in link step mode (option 2) . . . 708
Figure 85. GPDMA channel execution and linked-list programming . . . 710
Figure 86. Programmed 2D addressing . . . 713
Figure 87. GPDMA arbitration policy . . . 720
Figure 88. Trigger hit, memorization, and overrun waveform . . . 723
Figure 89. GPDMA circular buffer programming: update of the memory start address with a linear addressing channel . . . 724
Figure 90. Shared GPDMA channel with circular buffering: update of the memory start address with a linear addressing channel . . . 725
Figure 91. DMA2D block diagram . . . 763
Figure 92. DMA2D pipeline . . . 766

Figure 93. DMA2D image parameters . . . 768
Figure 94. DMA2D input PFC . . . 770
Figure 95. DMA2D image parameters with skipping . . . 774
Figure 96. Tile buffer operations XYSEN = 0 . . . 778
Figure 97. Tile buffer operations XYSEN = 1 . . . 779
Figure 98. Intel 8080 16-bit mode (RGB565) . . . 784
Figure 99. Intel 8080 18/24-bit mode (RGB888) . . . 784
Figure 100. Ring buffer and linear command list . . . 793
Figure 101. GFXTIM block diagram . . . 842
Figure 102. Clock generator . . . 844
Figure 103. Waveforms in standalone . . . 846
Figure 104. Active counters and signals in standalone . . . 846
Figure 105. Waveforms with external HSYNC and VSYNC . . . 846
Figure 106. Waveforms with external HSYNC only . . . 847
Figure 107. Active counters and signals with external HSYNC only . . . 847
Figure 108. Waveforms with external VSYNC only . . . 847
Figure 109. Active counters with external VSYNC only . . . 848
Figure 110. Prescaling when external VSYNC only . . . 848
Figure 111. Waveforms with external CSYNC only . . . 848
Figure 112. Active counters and signals with external CSYNC only . . . 849
Figure 113. Prescaling when external CSYNC only . . . 849
Figure 114. Tearing-effect configurations . . . 851
Figure 115. Watchdog timer . . . 852
Figure 116. EXTI block diagram . . . 885
Figure 117. Configurable event trigger logic CPU wake-up . . . 889
Figure 118. EXTI direct events . . . 890
Figure 119. EXTI multiplexer GPIO selection . . . 890
Figure 120. CRC calculation unit block diagram . . . 935
Figure 121. CORDIC convergence for trigonometric functions . . . 949
Figure 122. CORDIC convergence for hyperbolic functions . . . 950
Figure 123. CORDIC convergence for square root . . . 951
Figure 124. Block diagram . . . 960
Figure 125. Input buffer areas . . . 962
Figure 126. Circular input buffer . . . 963
Figure 127. Circular input buffer operation . . . 964
Figure 128. Circular output buffer . . . 965
Figure 129. Circular output buffer operation . . . 966
Figure 130. FIR filter structure . . . 968
Figure 131. IIR filter structure (direct form 1) . . . 970
Figure 132. X1 buffer initialization . . . 975
Figure 133. Filtering example 1 . . . 976
Figure 134. Filtering example 2 . . . 977
Figure 135. PLAY block diagram . . . 988
Figure 136. Input multiplexing . . . 991
Figure 137. Input filter and edge detection . . . 992
Figure 138. Filter operation example . . . 992
Figure 139. Edge detector operation (rising and falling edge) with filter enabled . . . 993
Figure 140. Edge detector operation (rising and falling edge) with filter bypassed . . . 993
Figure 141. swin_we pulse timing . . . 994
Figure 142. Logic element . . . 995
Figure 143. Example logic expression 1 . . . 995
Figure 144. Example logic expression 2 . . . 996

Figure 145. Input interconnect . . . 998
Figure 146. Logic element cascading . . . 1001
Figure 147. Combining logic elements in parallel . . . 1001
Figure 148. Splitting logic expressions between logic elements . . . 1002
Figure 149. Output interconnect . . . 1003
Figure 150. FMC block diagram . . . 1025
Figure 151. FMC memory banks . . . 1027
Figure 152. Mode 1 read access waveforms . . . 1038
Figure 153. Mode 1 write access waveforms . . . 1038
Figure 154. Mode A read access waveforms . . . 1040
Figure 155. Mode A write access waveforms . . . 1040
Figure 156. Mode 2 and mode B read access waveforms . . . 1042
Figure 157. Mode 2 write access waveforms . . . 1043
Figure 158. Mode B write access waveforms . . . 1043
Figure 159. Mode C read access waveforms . . . 1045
Figure 160. Mode C write access waveforms . . . 1046
Figure 161. Mode D read access waveforms . . . 1048
Figure 162. Mode D write access waveforms . . . 1049
Figure 163. Muxed read access waveforms . . . 1051
Figure 164. Muxed write access waveforms . . . 1052
Figure 165. Asynchronous wait during a read access waveforms . . . 1054
Figure 166. Asynchronous wait during a write access waveforms . . . 1055
Figure 167. Wait configuration waveforms . . . 1057
Figure 168. Synchronous multiplexed read mode waveforms - NOR, PSRAM (CRAM) . . . 1058
Figure 169. Synchronous multiplexed write mode waveforms - PSRAM (CRAM) . . . 1060
Figure 170. NAND flash controller waveforms for common memory access . . . 1072
Figure 171. Access to non ‘CE don’t care’ NAND-flash . . . 1074
Figure 172. Burst write SDRAM access waveforms . . . 1083
Figure 173. Burst read SDRAM access . . . 1084
Figure 174. Logic diagram of Read access with RBURST bit set (CAS=1, RPIPE=0) . . . 1085
Figure 175. Read access crossing row boundary . . . 1087
Figure 176. Write access crossing row boundary . . . 1087
Figure 177. Self-refresh mode . . . 1090
Figure 178. Power-down mode . . . 1091
Figure 179. OCTOSPI block diagram in octal configuration . . . 1103
Figure 180. OCTOSPI block diagram in quad configuration . . . 1103
Figure 181. OCTOSPI block diagram in dual-quad configuration . . . 1104
Figure 182. SDR read command in octal configuration . . . 1105
Figure 183. DTR read in octal-SPI mode with DQS (Macronix mode) example . . . 1108
Figure 184. SDR write command in octo-SPI mode example . . . 1110
Figure 185. DTR write in octal-SPI mode (Macronix mode) example . . . 1111
Figure 186. Example of HyperBus read operation . . . 1113
Figure 187. HyperBus write operation with initial latency . . . 1114
Figure 188. HyperBus read operation with additional latency . . . 1114
Figure 189. HyperBus write operation with additional latency . . . 1115
Figure 190. HyperBus write operation with no latency (register write) . . . 1115
Figure 191. HyperBus read operation page crossing with latency . . . 1116
Figure 192. D0/D1 data ordering in octal-SPI DTR mode (Micron) - Read access . . . 1123
Figure 193. OctaRAM read operation with reverse data ordering D1/D0 . . . 1123
Figure 194. NCS when CKMODE = 0 (T = CLK period) . . . 1129
Figure 195. Example of software control of two external memories . . . 1130
Figure 196. Example of hardware-controller extended memory support . . . 1131

Figure 197. OCTOSPIM block diagram . . . 1161
Figure 198. OCTOSPI direct mode . . . 1163
Figure 199. OCTOSPI swapped mode . . . 1164
Figure 200. OCTOSPI multiplexed mode to Port 1 . . . 1165
Figure 201. OCTOSPI multiplexed mode to Port 2 . . . 1165
Figure 202. OCTOSPI1 and OCTOSPI2 drive a single external memory . . . 1166
Figure 203. Single OCTOSPI driving two external memories . . . 1167
Figure 204. SDMMC “no response” and “no data” operations . . . 1171
Figure 205. SDMMC (multiple) block read operation . . . 1171
Figure 206. SDMMC (multiple) block write operation . . . 1172
Figure 207. SDMMC (sequential) stream read operation . . . 1172
Figure 208. SDMMC (sequential) stream write operation . . . 1172
Figure 209. SDMMC block diagram . . . 1174
Figure 210. SDMMC Command and data phase relation . . . 1176
Figure 211. Control unit . . . 1178
Figure 212. Command/response path . . . 1179
Figure 213. Command path state machine (CPSM) . . . 1180
Figure 214. Data path . . . 1186
Figure 215. DDR mode data packet clocking . . . 1187
Figure 216. DDR mode CRC status / boot acknowledgment clocking . . . 1187
Figure 217. Data path state machine (DPSM) . . . 1188
Figure 218. CLKMUX unit . . . 1199
Figure 219. Linked list structures . . . 1201
Figure 220. Asynchronous interrupt generation . . . 1204
Figure 221. Synchronous interrupt period data read . . . 1205
Figure 222. Synchronous interrupt period data write . . . 1205
Figure 223. Asynchronous interrupt period data read . . . 1206
Figure 224. Asynchronous interrupt period data write . . . 1207
Figure 225. Clock stop with SDMMC_CK for DS, HS, SDR12, SDR25 . . . 1210
Figure 226. Clock stop with SDMMC_CK for DDR50, SDR50, SDR104 . . . 1210
Figure 227. Read Wait with SDMMC_CK < 50 MHz . . . 1211
Figure 228. Read Wait with SDMMC_CK > 50 MHz . . . 1211
Figure 229. CMD12 stream timing . . . 1214
Figure 230. CMD5 Sleep Awake procedure . . . 1216
Figure 231. Normal boot mode operation . . . 1218
Figure 232. Alternative boot mode operation . . . 1219
Figure 233. Command response R1b busy signaling . . . 1220
Figure 234. SDMMC state control . . . 1221
Figure 235. Card cycle power / power up diagram . . . 1222
Figure 236. CMD11 signal voltage switch sequence . . . 1223
Figure 237. Voltage switch transceiver typical application . . . 1225
Figure 238. DLYB block diagram . . . 1253
Figure 239. ADC block diagram . . . 1261
Figure 240. ADC clock scheme . . . 1266
Figure 241. ADC1 connectivity . . . 1267
Figure 242. ADC2 connectivity . . . 1268
Figure 243. ADC3 connectivity . . . 1269
Figure 244. ADC calibration . . . 1272
Figure 245. Updating the ADC calibration factor . . . 1273
Figure 246. Mixing single-ended and differential channels . . . 1274
Figure 247. Enabling / disabling the ADC . . . 1275
Figure 248. Bulb mode timing diagram . . . 1278

Figure 249. Analog-to-digital conversion time . . . 1281
Figure 250. Stopping ongoing regular conversions . . . 1282
Figure 251. Stopping ongoing regular and injected conversions . . . 1283
Figure 252. Triggers shared between ADC master and slave . . . 1284
Figure 253. Injected conversion latency . . . 1286
Figure 254. Example of ADC_JSQR queue of context (sequence change) . . . 1289
Figure 255. Example of ADC_JSQR queue of context (trigger change) . . . 1289
Figure 256. Example of ADC_JSQR queue of context with overflow before conversion . . . 1290
Figure 257. Example of ADC_JSQR queue of context with overflow during conversion . . . 1290
Figure 258. Example of ADC_JSQR queue of context with empty queue (case JQM = 0) . . . 1291
Figure 259. Example of ADC_JSQR queue of context with empty queue (JQM = 1) . . . 1292
Figure 260. Flushing ADC_JSQR queue of context by setting JADSTP = 1 (JQM = 0) - JADSTP occurs during an ongoing conversion . . . 1292
Figure 261. Flushing ADC_JSQR queue of context by setting JADSTP = 1 (JQM = 0) - JADSTP occurs during an ongoing conversion and a new trigger occurs . . . 1293
Figure 262. Flushing ADC_JSQR queue of context by setting JADSTP = 1 (JQM = 0) - JADSTP occurs outside an ongoing conversion . . . 1293
Figure 263. Flushing ADC_JSQR queue of context by setting JADSTP = 1 (JQM = 1) . . . 1294
Figure 264. Flushing ADC_JSQR queue of context by setting ADDIS = 1 (JQM = 0) . . . 1294
Figure 265. Flushing ADC_JSQR queue of context by setting ADDIS = 1 (JQM = 1) . . . 1295
Figure 266. Single conversions of a sequence, software trigger . . . 1297
Figure 267. Continuous conversion of a sequence, software trigger . . . 1297
Figure 268. Single conversions of a sequence, hardware trigger . . . 1298
Figure 269. Continuous conversions of a sequence, hardware trigger . . . 1298
Figure 270. Right alignment (offset disabled, unsigned value) . . . 1300
Figure 271. Right alignment (offset enabled, signed value) . . . 1301
Figure 272. Left alignment (offset disabled, unsigned value) . . . 1301
Figure 273. Left alignment (offset enabled, signed value) . . . 1302
Figure 274. Example of overrun (OVRMOD = 0) . . . 1303
Figure 275. Example of overrun (OVRMOD = 1) . . . 1304
Figure 276. AUTODLY = 1, regular conversion in continuous mode, software trigger . . . 1307
Figure 277. AUTODLY = 1, regular HW conversions interrupted by injected conversions (DISCEN = 0; JDISCEN = 0) . . . 1308
Figure 278. AUTODLY = 1, regular HW conversions interrupted by injected conversions (DISCEN = 1, JDISCEN = 1) . . . 1309
Figure 279. AUTODLY = 1, regular continuous conversions interrupted by injected conversions . . . 1310
Figure 280. AUTODLY = 1 in auto- injected mode (JAUTO = 1) . . . 1310
Figure 281. Analog watchdog guarded area . . . 1311
Figure 282. ADCy_AWDx_OUT signal generation (on all regular channels) . . . 1313
Figure 283. ADCy_AWDx_OUT signal generation (AWDx flag not cleared by software) . . . 1314
Figure 284. ADCy_AWDx_OUT signal generation (on a single regular channel) . . . 1314
Figure 285. ADCy_AWDx_OUT signal generation (on all injected channels) . . . 1314
Figure 286. 20-bit to 16-bit result truncation . . . 1316
Figure 287. Numerical example with 5-bit shift and rounding . . . 1316
Figure 288. Triggered regular oversampling mode (TROVS bit = 1) . . . 1318
Figure 289. Regular oversampling modes (4x ratio) . . . 1319
Figure 290. Regular and injected oversampling modes used simultaneously . . . 1320
Figure 291. Triggered regular oversampling with injection . . . 1320
Figure 292. Oversampling in auto-injected mode . . . 1321
Figure 293. Dual ADC block diagram(1) . . . 1323
Figure 294. Injected simultaneous mode on 4 channels: dual ADC mode . . . 1324

Figure 295. Regular simultaneous mode on 16 channels: dual ADC mode 1326
Figure 296. Interleaved mode on one channel in continuous conversion mode: dual ADC mode. . . 1327
Figure 297. Interleaved mode on 1 channel in single conversion mode: dual ADC mode. 1328
Figure 298. Interleaved conversion with injection 1328
Figure 299. Alternate trigger: injected group of each ADC 1329
Figure 300. Alternate trigger: 4 injected channels (each ADC) in discontinuous mode 1330
Figure 301. Alternate + regular simultaneous 1331
Figure 302. Case of trigger occurring during injected conversion 1331
Figure 303. Interleaved single channel CH0 with injected sequence CH11, CH12 1332
Figure 304. Two Interleaved channels (CH1, CH2) with injected sequence CH11, CH12 - case 1: Master interrupted first 1332
Figure 305. Two Interleaved channels (CH1, CH2) with injected sequence CH11, CH12 - case 2: Slave interrupted first 1332
Figure 306. DMA Requests in regular simultaneous mode when MDMA = 0b00 1333
Figure 307. DMA requests in regular simultaneous mode when MDMA = 0b10 1334
Figure 308. DMA requests in interleaved mode when MDMA = 0b10 1334
Figure 309. Temperature sensor channel block diagram 1336
Figure 310. VBAT channel block diagram 1338
Figure 311. VREFINT channel block diagram 1338
Figure 312. Temperature sensor functional block diagram 1382
Figure 313. Method for low REF_CLK frequencies 1384
Figure 314. Method for high REF_CLK frequencies 1384
Figure 315. Temperature sensor sequence 1387
Figure 316. Dual-channel DAC block diagram 1401
Figure 317. Data registers in single DAC channel mode 1404
Figure 318. Data registers in dual DAC channel mode 1405
Figure 319. Timing diagram for conversion with trigger disabled TEN = 0 1406
Figure 320. DAC LFSR register calculation algorithm 1409
Figure 321. DAC conversion (SW trigger enabled) with LFSR wave generation 1409
Figure 322. DAC triangle wave generation 1410
Figure 323. DAC conversion (SW trigger enabled) with triangle wave generation 1410
Figure 324. DAC sample and hold mode phase diagram 1413
Figure 325. VREFBUF block diagram 1439
Figure 326. Standalone mode: external gain setting mode 1445
Figure 327. Follower configuration 1446
Figure 328. PGA mode, internal gain setting (x2/x4/x8/x16), inverting input not used 1447
Figure 329. PGA mode, internal gain setting (x2/x4/x8/x16), inverting input used for filtering 1448
Figure 330. PGA mode, noninverting gain setting (x2/x4/x8/x16) or inverting gain setting (x-1/x-3/x-7/x-15) 1449
Figure 331. Example configuration 1449
Figure 332. PGA mode, noninverting gain setting (x2/x4/x8/x16) or inverting gain setting (x-1/x-3/x-7/x-15) with filtering 1450
Figure 333. Example configuration 1451
Figure 334. Comparator functional block diagram 1458
Figure 335. Window comparators functional block diagram 1462
Figure 336. Comparator hysteresis 1463
Figure 337. Comparator output blanking 1464
Figure 338. Scaler block diagram 1467
Figure 339. MDF block diagram 1476
Figure 340. SITFx overview 1480
Figure 341. SPI timing example 1481

Figure 342. Manchester timing example (SITFMOD = 11) . . . 1483
Figure 343. CKGEN overview . . . 1486
Figure 344. BSMX overview . . . 1488
Figure 345. SCD functional view . . . 1489
Figure 346. SCD timing example . . . 1489
Figure 347. DFLT overview . . . 1491
Figure 348. Programmable delay . . . 1492
Figure 349. CIC3 and CIC5 frequency response with decimation ratio = 32 . . . 1494
Figure 350. Reshape filter frequency response normalized (FRS / 2 = 1) . . . 1499
Figure 351. Out-of-limit detector thresholds . . . 1502
Figure 352. Trigger logic for DFLT and CKGEN . . . 1504
Figure 353. Asynchronous continuous mode (ACQMOD[2:0] = 0) . . . 1505
Figure 354. Asynchronous single-shot mode (ACQMOD[2:0] = 001) . . . 1506
Figure 355. Synchronous continuous mode (ACQMOD[2:0] = 010) . . . 1507
Figure 356. Synchronous single-shot mode (ACQMOD[2:0] = 011) . . . 1508
Figure 357. Window continuous mode (ACQMOD[2:0] = 100) . . . 1509
Figure 358. Snapshot mode example . . . 1511
Figure 359. Discard function example . . . 1512
Figure 360. Start sequence with DFLTEN, in continuous mode, audio configuration . . . 1513
Figure 361. Start sequence with trigger input, in continuous mode, motor configuration . . . 1514
Figure 362. Break interface simplified view . . . 1515
Figure 363. MDF_DFLTxDR data format . . . 1515
Figure 364. Data resynchronization . . . 1516
Figure 365. Data transfer in interleaved-transfer mode . . . 1517
Figure 366. Data path for interleaved- and independent-transfer modes . . . 1519
Figure 367. Example of overflow and transfer to memory . . . 1520
Figure 368. MDF interrupt interface . . . 1523
Figure 369. Sensor connection examples . . . 1528
Figure 370. Global frequency response . . . 1529
Figure 371. Detailed frequency response . . . 1529
Figure 372. Simplified DFLT view with gain information . . . 1531
Figure 373. ADF block diagram . . . 1559
Figure 374. SITF overview . . . 1561
Figure 375. SPI timing example . . . 1562
Figure 376. Manchester timing example (SITFMOD = 11) . . . 1563
Figure 377. CKGEN overview . . . 1566
Figure 378. BSMX overview . . . 1568
Figure 379. DFLT overview . . . 1569
Figure 380. Programmable delay . . . 1570
Figure 381. CIC4 and CIC5 frequency response with decimation ratio = 32 or 16 . . . 1571
Figure 382. Reshape filter frequency response normalized (FRS / 2 = 1) . . . 1577
Figure 383. Trigger logic for DFLT and CKGEN . . . 1579
Figure 384. Asynchronous continuous mode (ACQMOD[2:0] = 0) . . . 1580
Figure 385. Asynchronous single-shot mode (ACQMOD[2:0] = 001) . . . 1581
Figure 386. Synchronous continuous mode (ACQMOD[2:0] = 010) . . . 1582
Figure 387. Synchronous single-shot mode (ACQMOD[2:0] = 011) . . . 1583
Figure 388. Window continuous mode (ACQMOD[2:0] = 100) . . . 1584
Figure 389. Discard function example . . . 1586
Figure 390. Start sequence with DFLTEN, in continuous mode, audio configuration . . . 1586
Figure 391. SAD block diagram . . . 1587
Figure 392. SAD flow diagram . . . 1589
Figure 393. SAD timing diagram example . . . 1595

Figure 394. ADF_DFLTxDR data format . . . 1595
Figure 395. Data resynchronization . . . 1596
Figure 396. Example of overflow and transfer to memory . . . 1597
Figure 397. ADF interrupt interface . . . 1600
Figure 398. Sensor connection examples . . . 1605
Figure 399. Global frequency response . . . 1605
Figure 400. Detailed frequency response . . . 1606
Figure 401. Simplified DFLT view with gain information . . . 1608
Figure 402. SAD example working with SADMOD = 01 . . . 1611
Figure 403. SAD example working with SADMOD = 1x . . . 1612
Figure 404. DCMI block diagram . . . 1632
Figure 405. DCMI signal waveforms . . . 1633
Figure 406. Timing diagram . . . 1635
Figure 407. Frame capture waveforms in snapshot mode . . . 1637
Figure 408. Frame capture waveforms in continuous grab mode . . . 1638
Figure 409. Coordinates and size of the window after cropping . . . 1638
Figure 410. Data capture waveforms . . . 1639
Figure 411. Pixel raster scan order . . . 1640
Figure 412. PSSI block diagram . . . 1654
Figure 413. Top-level block diagram . . . 1654
Figure 414. Data enable in receive mode waveform diagram (CKPOL=0) . . . 1658
Figure 415. Data enable waveform diagram in transmit mode (CKPOL=1) . . . 1658
Figure 416. Ready in receive mode waveform diagram (CKPOL=0) . . . 1659
Figure 417. Bidirectional PSSI_DE/PSSI_RDY waveform . . . 1660
Figure 418. Bidirectional PSSI_DE/PSSI_RDY connection diagram . . . 1660
Figure 419. LTDC block diagram . . . 1668
Figure 420. LTDC synchronous timings . . . 1671
Figure 421. Layer window programmable parameters . . . 1674
Figure 422. Blending two layers with background . . . 1676
Figure 423. Interrupt events . . . 1678
Figure 424. JPEG codec block diagram . . . 1699
Figure 425. CCB block diagram . . . 1721
Figure 426. CCB operation CPU → PKA + SAES (write) . . . 1723
Figure 427. CCB operation PKA → SAES . . . 1723
Figure 428. CCB operation SAES → PKA . . . 1723
Figure 429. CCB operation SAES → CCB . . . 1724
Figure 430. CCB operation RNG → PKA (write) . . . 1724
Figure 431. CCB operation RNG → SAES (write) . . . 1725
Figure 432. Blob creation scenarios . . . 1726
Figure 433. RNG block diagram . . . 1747
Figure 434. NIST SP800-90B entropy source model . . . 1748
Figure 435. RNG initialization overview . . . 1751
Figure 436. AES block diagram . . . 1767
Figure 437. Encryption/ decryption typical usage . . . 1769
Figure 438. Typical operation with authentication . . . 1771
Figure 439. Example of suspend mode management . . . 1772
Figure 440. ECB encryption . . . 1773
Figure 441. ECB decryption . . . 1773
Figure 442. CBC encryption . . . 1774
Figure 443. CBC decryption . . . 1774
Figure 444. Message construction in CTR mode . . . 1777
Figure 445. CTR encryption . . . 1777

Figure 446. Message construction in GCM . . . 1779
Figure 447. GCM authenticated encryption . . . 1780
Figure 448. Message construction in GMAC mode . . . 1783
Figure 449. GMAC authentication mode . . . 1784
Figure 450. Message construction in CCM mode . . . 1785
Figure 451. CCM mode authenticated encryption . . . 1786
Figure 452. 128-bit block construction according to the data type . . . 1791
Figure 453. SAES block diagram . . . 1813
Figure 454. Encryption/ decryption typical usage . . . 1815
Figure 455. Typical operation with authentication . . . 1817
Figure 456. Example of suspend mode management . . . 1818
Figure 457. ECB encryption . . . 1819
Figure 458. ECB decryption . . . 1819
Figure 459. CBC encryption . . . 1820
Figure 460. CBC decryption . . . 1820
Figure 461. Message construction in CTR mode . . . 1823
Figure 462. CTR encryption . . . 1824
Figure 463. Message construction in GCM . . . 1825
Figure 464. GCM authenticated encryption . . . 1827
Figure 465. Message construction in GMAC mode . . . 1830
Figure 466. GMAC authentication mode . . . 1830
Figure 467. Message construction in CCM mode . . . 1831
Figure 468. CCM mode authenticated encryption . . . 1833
Figure 469. Operation with wrapped keys for SAES in ECB and CBC modes . . . 1836
Figure 470. Operation with wrapped keys for SAES in CTR mode . . . 1839
Figure 471. Usage of Shared-key mode . . . 1840
Figure 472. 128-bit block construction according to the data type . . . 1843
Figure 473. Key protection mechanisms . . . 1845
Figure 474. HASH block diagram . . . 1867
Figure 475. Message data swapping feature . . . 1870
Figure 476. HASH suspend/resume mechanism . . . 1876
Figure 477. PKA block diagram . . . 1891
Figure 478. Chaining of PKA with SAES or RNG . . . 1898
Figure 479. OTFDEC block diagram . . . 1930
Figure 480. Typical OTFDEC use in a SoC . . . 1931
Figure 481. AES CTR decryption flow . . . 1932
Figure 482. OTFDEC flow control overview (dual burst read request) . . . 1933
Figure 483. Advanced-control timer block diagram . . . 1953
Figure 484. Counter timing diagram with prescaler division change from 1 to 2 . . . 1960
Figure 485. Counter timing diagram with prescaler division change from 1 to 4 . . . 1960
Figure 486. Counter timing diagram, internal clock divided by 1 . . . 1962
Figure 487. Counter timing diagram, internal clock divided by 2 . . . 1962
Figure 488. Counter timing diagram, internal clock divided by 4 . . . 1963
Figure 489. Counter timing diagram, internal clock divided by N . . . 1963
Figure 490. Counter timing diagram, update event when ARPE = 0 (TIMx_ARR not preloaded) . . . 1964
Figure 491. Counter timing diagram, update event when ARPE = 1 (TIMx_ARR preloaded) . . . 1965
Figure 492. Counter timing diagram, internal clock divided by 1 . . . 1966
Figure 493. Counter timing diagram, internal clock divided by 2 . . . 1967
Figure 494. Counter timing diagram, internal clock divided by 4 . . . 1967
Figure 495. Counter timing diagram, internal clock divided by N . . . 1968

Figure 496. Counter timing diagram, update event when repetition counter is not used 1968
Figure 497. Counter timing diagram, internal clock divided by 1, TIMx_ARR = 0x6 1970
Figure 498. Counter timing diagram, internal clock divided by 2 1970
Figure 499. Counter timing diagram, internal clock divided by 4, TIMx_ARR = 0x36 1971
Figure 500. Counter timing diagram, internal clock divided by N 1971
Figure 501. Counter timing diagram, update event with ARPE = 1 (counter underflow) 1972
Figure 502. Counter timing diagram, Update event with ARPE = 1 (counter overflow) 1973
Figure 503. Update rate examples depending on mode and TIMx_RCR register settings 1974
Figure 505. Control circuit in normal mode, internal clock divided by 1 1976
Figure 506. tim_ti2 external clock connection example 1976
Figure 507. Control circuit in external clock mode 1 1977
Figure 508. External trigger input block 1978
Figure 509. Control circuit in external clock mode 2 1979
Figure 510. Capture/compare channel (example: channel 1 input stage) 1979
Figure 511. Capture/compare channel 1 main circuit 1980
Figure 512. Output stage of capture/compare channel (channel 1, idem ch. 2, 3 and 4) 1981
Figure 513. Output stage of capture/compare channel (channel 5, idem ch. 6) 1981
Figure 514. PWM input mode timing 1984
Figure 515. Output compare mode, toggle on tim_oc1 1986
Figure 516. Edge-aligned PWM waveforms (ARR = 8) 1987
Figure 517. Center-aligned PWM waveforms (ARR = 8) 1988
Figure 518. Dithering principle 1989
Figure 519. Data format and register coding in dithering mode 1990
Figure 520. PWM resolution vs frequency 1991
Figure 521. PWM dithering pattern 1992
Figure 522. Dithering effect on duty cycle in center-aligned PWM mode 1993
Figure 523. Generation of 2 phase-shifted PWM signals with 50% duty cycle 1995
Figure 524. Combined PWM mode on channel 1 and 3 1996
Figure 525. 3-phase combined PWM signals with multiple trigger pulses per period 1997
Figure 526. Complementary output with symmetrical dead-time insertion 1998
Figure 527. Asymmetrical deadtime 1999
Figure 528. Dead-time waveforms with delay greater than the negative pulse 1999
Figure 529. Dead-time waveforms with delay greater than the positive pulse 1999
Figure 530. Break and Break2 circuitry overview 2002
Figure 531. Various output behavior in response to a break event on tim_brk (OSSI = 1) 2004
Figure 532. PWM output state following tim_brk and tim_brk2 assertion (OSSI = 1) 2005
Figure 533. PWM output state following tim_brk assertion (OSSI = 0) 2006
Figure 534. Output redirection (tim_brk2 request not represented) 2007
Figure 535. tim_ocref_clr input selection multiplexer 2008
Figure 536. Clearing TIMx tim_ocxref 2009
Figure 537. 6-step generation, COM example (OSSR = 1) 2010
Figure 538. Example of one pulse mode. 2011
Figure 539. Retriggerable one-pulse mode 2012
Figure 540. Pulse generator circuitry 2013
Figure 541. Pulse generation on compare event, for edge-aligned and encoder modes 2014
Figure 542. Extended pulsewidth in case of concurrent triggers 2015
Figure 543. Example of counter operation in encoder interface mode. 2017
Figure 544. Example of encoder interface mode with tim_ti1fp1 polarity inverted. 2017
Figure 545. Quadrature encoder counting modes 2018
Figure 546. Direction plus clock encoder mode 2019
Figure 547. Directional clock encoder mode (CC1P = CC2P = 0) 2019
Figure 548. Directional clock encoder mode (CC1P = CC2P = 1) 2020

Figure 549. Index gating options . . . 2021
Figure 550. Jittered Index signals . . . 2021
Figure 551. Index generation for IPOS[1:0] = 11 . . . 2022
Figure 552. Counter reading with index gated on channel A (IPOS[1:0] = 11) . . . 2022
Figure 553. Counter reading with index ungated (IPOS[1:0] = 00) . . . 2023
Figure 554. Counter reading with index gated on channel A and B . . . 2023
Figure 555. Encoder mode behavior in case of narrow index pulse (IPOS[1:0] = 11) . . . 2024
Figure 556. Counter reset Narrow index pulse (closer view, ARR = 0x07) . . . 2025
Figure 557. Index behavior in x1 and x2 mode (IPOS[1:0] = 01) . . . 2026
Figure 558. Directional index sensitivity . . . 2026
Figure 559. Counter reset as function of FIDX bit setting . . . 2027
Figure 560. Index blanking . . . 2027
Figure 561. Index behavior in clock + direction mode, IPOS[0] = 1 . . . 2028
Figure 562. Index behavior in directional clock mode, IPOS[0] = 1 . . . 2028
Figure 563. State diagram for quadrature encoded signals . . . 2029
Figure 564. Up-counting encoder error detection . . . 2030
Figure 565. Down-counting encode error detection . . . 2031
Figure 566. Encoder mode change with preload transferred on update (SMSPS = 0) . . . 2032
Figure 567. Measuring time interval between edges on three signals . . . 2033
Figure 568. Example of Hall sensor interface . . . 2035
Figure 569. Control circuit in reset mode . . . 2036
Figure 570. Control circuit in Gated mode . . . 2037
Figure 571. Control circuit in trigger mode . . . 2038
Figure 572. Control circuit in external clock mode 2 + trigger mode . . . 2039
Figure 573. General-purpose timer block diagram . . . 2097
Figure 574. Counter timing diagram with prescaler division change from 1 to 2 . . . 2103
Figure 575. Counter timing diagram with prescaler division change from 1 to 4 . . . 2103
Figure 576. Counter timing diagram, internal clock divided by 1 . . . 2104
Figure 577. Counter timing diagram, internal clock divided by 2 . . . 2105
Figure 578. Counter timing diagram, internal clock divided by 4 . . . 2105
Figure 579. Counter timing diagram, internal clock divided by N . . . 2106
Figure 580. Counter timing diagram, Update event when ARPE = 0 (TIMx_ARR not preloaded) . . . 2106
Figure 581. Counter timing diagram, Update event when ARPE = 1 (TIMx_ARR preloaded) . . . 2107
Figure 582. Counter timing diagram, internal clock divided by 1 . . . 2108
Figure 583. Counter timing diagram, internal clock divided by 2 . . . 2109
Figure 584. Counter timing diagram, internal clock divided by 4 . . . 2109
Figure 585. Counter timing diagram, internal clock divided by N . . . 2110
Figure 586. Counter timing diagram, Update event . . . 2110
Figure 587. Counter timing diagram, internal clock divided by 1, TIMx_ARR = 0x6 . . . 2112
Figure 588. Counter timing diagram, internal clock divided by 2 . . . 2112
Figure 589. Counter timing diagram, internal clock divided by 4, TIMx_ARR = 0x36 . . . 2113
Figure 590. Counter timing diagram, internal clock divided by N . . . 2113
Figure 591. Counter timing diagram, Update event with ARPE = 1 (counter underflow) . . . 2114
Figure 592. Counter timing diagram, Update event with ARPE = 1 (counter overflow) . . . 2115
Figure 593. Control circuit in normal mode, internal clock divided by 1 . . . 2116
Figure 594. tim_ti2 external clock connection example . . . 2116
Figure 595. Control circuit in external clock mode 1 . . . 2117
Figure 596. External trigger input block . . . 2118
Figure 597. Control circuit in external clock mode 2 . . . 2119
Figure 598. Capture/compare channel (example: channel 1 input stage) . . . 2119
Figure 599. Capture/compare channel 1 main circuit . . . 2120
Figure 600. Output stage of capture/compare channel (channel 1, idem ch.2, 3 and 4) . . . 2120

Figure 601. PWM input mode timing . . . 2123
Figure 602. Output compare mode, toggle on tim_oc1 . . . 2125
Figure 603. Edge-aligned PWM waveforms (ARR = 8) . . . 2126
Figure 604. Center-aligned PWM waveforms (ARR = 8) . . . 2127
Figure 605. Dithering principle . . . 2128
Figure 606. Data format and register coding in dithering mode . . . 2129
Figure 607. PWM resolution vs frequency (16-bit mode) . . . 2130
Figure 608. PWM resolution vs frequency (32-bit mode) . . . 2130
Figure 609. PWM dithering pattern . . . 2131
Figure 610. Dithering effect on duty cycle in center-aligned PWM mode . . . 2132
Figure 611. Generation of two phase-shifted PWM signals with 50% duty cycle . . . 2134
Figure 612. Combined PWM mode on channels 1 and 3 . . . 2135
Figure 613. OCREF_CLR input selection multiplexer . . . 2136
Figure 614. Clearing TIMx tim_ocxref . . . 2136
Figure 615. Example of One-pulse mode . . . 2137
Figure 616. Retriggerable one-pulse mode . . . 2139
Figure 617. Pulse generator circuitry . . . 2140
Figure 618. Pulse generation on compare event, for edge-aligned and encoder modes . . . 2140
Figure 619. Extended pulse width in case of concurrent triggers . . . 2141
Figure 620. Example of counter operation in encoder interface mode . . . 2143
Figure 621. Example of encoder interface mode with tim_ti1fp1 polarity inverted . . . 2143
Figure 622. Quadrature encoder counting modes . . . 2144
Figure 623. Direction plus clock encoder mode . . . 2145
Figure 624. Directional clock encoder mode (CC1P = CC2P = 0) . . . 2146
Figure 625. Directional clock encoder mode (CC1P = CC2P = 1) . . . 2146
Figure 626. Index gating options . . . 2148
Figure 627. Jittered Index signals . . . 2148
Figure 628. Index generation for IPOS[1:0] = 11 . . . 2149
Figure 629. Counter reading with index gated on channel A (IPOS[1:0] = 11) . . . 2149
Figure 630. Counter reading with index ungated (IPOS[1:0] = 00) . . . 2150
Figure 631. Counter reading with index gated on channel A and B . . . 2150
Figure 632. Encoder mode behavior in case of narrow index pulse (IPOS[1:0] = 11) . . . 2151
Figure 633. Counter reset Narrow index pulse (closer view, ARR = 0x07) . . . 2152
Figure 634. Index behavior in x1 and x2 mode (IPOS[1:0] = 01) . . . 2153
Figure 635. Directional index sensitivity . . . 2153
Figure 636. Counter reset as function of FIDX bit setting . . . 2154
Figure 637. Index blanking . . . 2154
Figure 638. Index behavior in clock + direction mode, IPOS[0] = 1 . . . 2155
Figure 639. Index behavior in directional clock mode, IPOS[0] = 1 . . . 2155
Figure 640. State diagram for quadrature encoded signals . . . 2156
Figure 641. Up-counting encoder error detection . . . 2157
Figure 642. Down-counting encode error detection . . . 2158
Figure 643. Encoder mode change with preload transferred on update (SMSPS = 0) . . . 2159
Figure 644. Control circuit in reset mode . . . 2161
Figure 645. Control circuit in gated mode . . . 2162
Figure 646. Control circuit in trigger mode . . . 2162
Figure 647. Control circuit in external clock mode 2 + trigger mode . . . 2164
Figure 648. Master/Slave timer example . . . 2164
Figure 649. Master/slave connection example with 1 channel only timers . . . 2165
Figure 650. Gating TIM_slv with tim_oc1ref of TIM_mstr . . . 2166
Figure 651. Gating TIM_slv with Enable of TIM_mstr . . . 2167
Figure 652. Triggering TIM_slv with update of TIM_mstr . . . 2168

Figure 653. Triggering TIM_slv with Enable of TIM_mstr . . . 2168
Figure 654. Triggering TIM_mstr and TIM_slv with TIM_mstr tim_ti1 input . . . 2169
Figure 655. Basic timer block diagram . . . 2213
Figure 656. Control circuit in normal mode, internal clock divided by 1 . . . 2214
Figure 657. Counter timing diagram with prescaler division change from 1 to 2 . . . 2215
Figure 658. Counter timing diagram with prescaler division change from 1 to 4 . . . 2216
Figure 659. Counter timing diagram, internal clock divided by 1 . . . 2217
Figure 660. Counter timing diagram, internal clock divided by 2 . . . 2217
Figure 661. Counter timing diagram, internal clock divided by 4 . . . 2218
Figure 662. Counter timing diagram, internal clock divided by N . . . 2218
Figure 663. Counter timing diagram, update event when ARPE = 0 (TIMx_ARR not preloaded) . . . 2219
Figure 664. Counter timing diagram, update event when ARPE = 1 (TIMx_ARR preloaded) . . . 2220
Figure 665. Dithering principle . . . 2221
Figure 666. Data format and register coding in dithering mode . . . 2221
Figure 667. FCnt resolution vs frequency . . . 2222
Figure 668. PWM dithering pattern . . . 2222
Figure 669. General-purpose timer block diagram (TIM12) . . . 2233
Figure 670. General-purpose timer block diagram (TIM13/TIM14) . . . 2234
Figure 671. Counter timing diagram with prescaler division change from 1 to 2 . . . 2238
Figure 672. Counter timing diagram with prescaler division change from 1 to 4 . . . 2238
Figure 673. Counter timing diagram, internal clock divided by 1 . . . 2239
Figure 674. Counter timing diagram, internal clock divided by 2 . . . 2240
Figure 675. Counter timing diagram, internal clock divided by 4 . . . 2240
Figure 676. Counter timing diagram, internal clock divided by N . . . 2241
Figure 677. Counter timing diagram, update event when ARPE = 0 (TIMx_ARR not preloaded) . . . 2241
Figure 678. Counter timing diagram, update event when ARPE = 1 (TIMx_ARR preloaded) . . . 2242
Figure 679. Control circuit in normal mode, internal clock divided by 1 . . . 2243
Figure 680. tim_ti2 external clock connection example . . . 2243
Figure 681. Control circuit in external clock mode 1 . . . 2244
Figure 682. Capture/compare channel 1 input stage (TIM13/TIM14) . . . 2245
Figure 683. Capture/compare channel 1 input stage (TIM12) . . . 2245
Figure 684. Capture/compare channel 1 main circuit . . . 2246
Figure 685. Output stage of capture/compare channel 1 . . . 2246
Figure 686. PWM input mode timing . . . 2248
Figure 687. Output compare mode, toggle on tim_oc1 . . . 2250
Figure 688. Edge-aligned PWM waveforms (ARR = 8) . . . 2251
Figure 689. Dithering principle . . . 2252
Figure 690. Data format and register coding in dithering mode . . . 2252
Figure 691. PWM resolution vs frequency . . . 2253
Figure 692. PWM dithering pattern . . . 2254
Figure 693. Combined PWM mode on channel 1 and 2 . . . 2256
Figure 694. Example of one pulse mode . . . 2257
Figure 695. Retriggerable one pulse mode . . . 2258
Figure 696. Measuring time interval between edges on 2 signals . . . 2259
Figure 697. Control circuit in reset mode . . . 2260
Figure 698. Control circuit in gated mode . . . 2261
Figure 699. Control circuit in trigger mode . . . 2261
Figure 700. TIM15 block diagram . . . 2295

Figure 701. TIM16/TIM17 block diagram . . . 2296
Figure 702. Counter timing diagram with prescaler division change from 1 to 2 . . . 2301
Figure 703. Counter timing diagram with prescaler division change from 1 to 4 . . . 2301
Figure 704. Counter timing diagram, internal clock divided by 1 . . . 2303
Figure 705. Counter timing diagram, internal clock divided by 2 . . . 2303
Figure 706. Counter timing diagram, internal clock divided by 4 . . . 2304
Figure 707. Counter timing diagram, internal clock divided by N . . . 2304
Figure 708. Counter timing diagram, update event when ARPE = 0 (TIMx_ARR not preloaded) . . . 2305
Figure 709. Counter timing diagram, update event when ARPE = 1 (TIMx_ARR preloaded) . . . 2306
Figure 710. Update rate examples depending on mode and TIMx_RCR register settings . . . 2307
Figure 711. Control circuit in normal mode, internal clock divided by 1 . . . 2308
Figure 712. tim_ti2 external clock connection example . . . 2308
Figure 713. Control circuit in external clock mode 1 . . . 2309
Figure 714. Capture/compare channel (example: channel 1 input stage) . . . 2310
Figure 715. Capture/compare channel 1 main circuit . . . 2310
Figure 716. Output stage of capture/compare channel (channel 1) . . . 2311
Figure 717. Output stage of capture/compare channel (channel 2 for TIM15) . . . 2311
Figure 718. PWM input mode timing . . . 2314
Figure 719. Output compare mode, toggle on tim_oc1 . . . 2316
Figure 720. Edge-aligned PWM waveforms (ARR = 8) . . . 2317
Figure 721. Dithering principle . . . 2318
Figure 722. Data format and register coding in dithering mode . . . 2318
Figure 723. PWM resolution vs frequency . . . 2319
Figure 724. PWM dithering pattern . . . 2320
Figure 725. Combined PWM mode on channel 1 and 2 . . . 2322
Figure 726. Complementary output with symmetrical dead-time insertion . . . 2323
Figure 727. Asymmetrical deadtime . . . 2324
Figure 728. Dead-time waveforms with delay greater than the negative pulse . . . 2324
Figure 729. Dead-time waveforms with delay greater than the positive pulse . . . 2324
Figure 730. Break circuitry overview . . . 2326
Figure 731. Output behavior in response to a break event on tim_brk . . . 2328
Figure 732. Output redirection . . . 2330
Figure 733. tim_ocref_clr input selection multiplexer . . . 2331
Figure 734. 6-step generation, COM example (OSSR = 1) . . . 2332
Figure 735. Example of one pulse mode . . . 2333
Figure 736. Retriggerable one pulse mode . . . 2335
Figure 737. Measuring time interval between edges on 2 signals . . . 2335
Figure 738. Control circuit in reset mode . . . 2336
Figure 739. Control circuit in gated mode . . . 2337
Figure 740. Control circuit in trigger mode . . . 2338
Figure 741. LPTIM1/2/3/5/6 block diagram(1) . . . 2402
Figure 742. LPTIM4 block diagram(1) . . . 2403
Figure 743. Glitch filter timing diagram . . . 2407
Figure 744. LPTIM output waveform, single-counting mode configuration when repetition register content is different than zero (with PRELOAD = 1) . . . 2409
Figure 745. LPTIM output waveform, single-counting mode configuration and Set-once mode activated (WAVE bit is set) . . . 2410
Figure 746. LPTIM output waveform, Continuous counting mode configuration . . . 2410
Figure 747. Waveform generation . . . 2412
Figure 748. Encoder mode counting sequence . . . 2416

Figure 749. Continuous counting mode when repetition register LPTIM_RCR different from zero (with PRELOAD = 1). . . . 2417
Figure 750. Capture/compare input stage (channel 1) . . . 2418
Figure 751. Capture/compare output stage (channel 1) . . . 2418
Figure 752. Edge-aligned PWM mode (PRELOAD = 1) . . . 2420
Figure 753. Edge-aligned PWM waveforms (ARR=8 and CCxP = 0) . . . 2421
Figure 754. PWM mode with immediate update versus preloaded update . . . 2422
Figure 755. Independent watchdog block diagram . . . 2452
Figure 756. Reset timing due to timeout . . . 2454
Figure 757. Reset timing due to refresh in the not allowed area . . . 2455
Figure 758. Changing PR, RL, and performing a refresh(1) . . . 2456
Figure 759. Window comparator update(1) . . . 2457
Figure 760. Independent watchdog interrupt timing diagram . . . 2459
Figure 761. Early wake-up comparator update(1) . . . 2460
Figure 762. Watchdog block diagram . . . 2468
Figure 763. Window watchdog timing diagram . . . 2470
Figure 764. RTC block diagram . . . 2476
Figure 765. TAMP block diagram . . . 2534
Figure 766. Backup registers protection zones . . . 2539
Figure 767. Tamper sampling with precharge pulse . . . 2544
Figure 768. Low level detection with precharge and filtering . . . 2544
Figure 769. Active tamper filtering . . . 2547
Figure 770. Block diagram . . . 2582
Figure 771. I²C-bus protocol . . . 2584
Figure 772. Setup and hold timings . . . 2586
Figure 773. I2C initialization flow . . . 2588
Figure 774. Data reception . . . 2589
Figure 775. Data transmission . . . 2590
Figure 776. Target initialization flow . . . 2593
Figure 777. Transfer sequence flow for I2C target transmitter, NOSTRETCH = 0 . . . 2595
Figure 778. Transfer sequence flow for I2C target transmitter, NOSTRETCH = 1 . . . 2596
Figure 779. Transfer bus diagrams for I2C target transmitter (mandatory events only) . . . 2597
Figure 780. Transfer sequence flow for I2C target receiver, NOSTRETCH = 0 . . . 2598
Figure 781. Transfer sequence flow for I2C target receiver, NOSTRETCH = 1 . . . 2599
Figure 782. Transfer bus diagrams for I2C target receiver (mandatory events only) . . . 2599
Figure 783. Controller clock generation . . . 2601
Figure 784. Controller initialization flow . . . 2603
Figure 785. 10-bit address read access with HEAD10R = 0 . . . 2603
Figure 786. 10-bit address read access with HEAD10R = 1 . . . 2604
Figure 787. Transfer sequence flow for I2C controller transmitter, N ≤ 255 bytes . . . 2605
Figure 788. Transfer sequence flow for I2C controller transmitter, N > 255 bytes . . . 2606
Figure 789. Transfer bus diagrams for I2C controller transmitter (mandatory events only) . . . 2607
Figure 790. Transfer sequence flow for I2C controller receiver, N ≤ 255 bytes . . . 2609
Figure 791. Transfer sequence flow for I2C controller receiver, N > 255 bytes . . . 2610
Figure 792. Transfer bus diagrams for I2C controller receiver (mandatory events only) . . . 2611
Figure 793. Timeout intervals for $t_{LOW:SEXT}$, $t_{LOW:MEXT}$ . . . 2615
Figure 794. Transfer sequence flow for SMBus target transmitter N bytes + PEC . . . 2618
Figure 795. Transfer bus diagram for SMBus target transmitter (SBC = 1) . . . 2619
Figure 796. Transfer sequence flow for SMBus target receiver N bytes + PEC . . . 2620

Figure 797. Bus transfer diagrams for SMBus target receiver (SBC = 1) 2621
Figure 798. Bus transfer diagrams for SMBus controller transmitter 2622
Figure 799. Bus transfer diagrams for SMBus controller receiver 2624
Figure 800. I3C block diagram 2648
Figure 801. I3C (primary) controller state and programming sequence diagram 2653
Figure 802. I3C target state and programing sequence diagram 2658
Figure 803. I3C CCC messages, as controller 2672
Figure 804. I3C broadcast ENTDAA CCC, as controller 2673
Figure 805. I3C broadcast, direct read and direct write RSTACT CCC, as controller 2674
Figure 806. I3C CCC messages, as target 2676
Figure 807. I3C broadcast ENTDAA CCC, as target 2677
Figure 808. I3C broadcast DEFTGTS CCC, as target 2678
Figure 809. I3C broadcast DEFGRPA CCC, as target 2679
Figure 810. I3C private read/write messages, as controller 2681
Figure 811. I3C private read/write messages, as target 2682
Figure 812. Legacy I2C read/write messages, as controller 2683
Figure 813. IBI transfer, as controller/target 2684
Figure 814. Hot-join request transfer, as controller/target 2686
Figure 815. Controller-role request transfer, as controller/target 2687
Figure 816. C-FIFO management, as controller 2688
Figure 817. TX-FIFO management, as controller 2690
Figure 818. RX-FIFO management, as controller 2692
Figure 819. S-FIFO management, as controller 2695
Figure 820. RX-FIFO management, as target on the I3C bus 2696
Figure 821. TX-FIFO management with I3C_TGTTDR, as target on the I3C bus 2698
Figure 822. TX-FIFO management by software without I3C_TGTTDR if reading less bytes than TX-FIFO size, as target 2700
Figure 823. USART block diagram 2755
Figure 824. Word length programming 2759
Figure 825. Configurable stop bits 2761
Figure 826. TC/TXE behavior when transmitting 2763
Figure 827. Start bit detection when oversampling by 16 or 8 2764
Figure 828. usart_ker_ck clock divider block diagram 2767
Figure 829. Data sampling when oversampling by 16 2768
Figure 830. Data sampling when oversampling by 8 2769
Figure 831. Mute mode using Idle line detection 2776
Figure 832. Mute mode using address mark detection 2777
Figure 833. Break detection in LIN mode (11-bit break length - LBDL bit is set) 2780
Figure 834. Break detection in LIN mode vs. Framing error detection 2781
Figure 835. USART example of synchronous master transmission 2782
Figure 836. USART data clock timing diagram in synchronous master mode (M bits = 00) 2782
Figure 837. USART data clock timing diagram in synchronous master mode (M bits = 01) 2783
Figure 838. USART data clock timing diagram in synchronous slave mode (M bits = 00) 2784
Figure 839. ISO 7816-3 asynchronous protocol 2786
Figure 840. Parity error detection using the 1.5 stop bits 2788
Figure 841. IrDA SIR ENDEC block diagram 2792
Figure 842. IrDA data modulation (3/16) - normal mode 2792
Figure 843. Transmission using DMA 2794
Figure 844. Reception using DMA 2795

Figure 845. Hardware flow control between two USARTs . . . 2795
Figure 846. RS232 RTS flow control . . . 2796
Figure 847. RS232 CTS flow control . . . 2797
Figure 848. Wake-up event verified (wake-up event = address match, FIFO disabled) . . . 2800
Figure 849. Wake-up event not verified (wake-up event = address match, FIFO disabled) . . . 2800
Figure 850. LPUART block diagram . . . 2845
Figure 851. LPUART word length programming . . . 2848
Figure 852. Configurable stop bits . . . 2850
Figure 853. TC/TXE behavior when transmitting . . . 2852
Figure 854. lpuart_ker_ck clock divider block diagram . . . 2856
Figure 855. Mute mode using Idle line detection . . . 2860
Figure 856. Mute mode using address mark detection . . . 2861
Figure 857. Transmission using DMA . . . 2863
Figure 858. Reception using DMA . . . 2864
Figure 859. Hardware flow control between two LPUARTs . . . 2865
Figure 860. RS232 RTS flow control . . . 2865
Figure 861. RS232 CTS flow control . . . 2866
Figure 862. Wake-up event verified (wake-up event = address match, FIFO disabled) . . . 2869
Figure 863. Wake-up event not verified (wake-up event = address match, FIFO disabled) . . . 2869
Figure 864. SPI/I2S block diagram . . . 2901
Figure 865. Full-duplex single master/ single slave application . . . 2904
Figure 866. Half-duplex single master/ single slave application . . . 2905
Figure 867. Simplex single master / single slave application (master in transmit-only / slave in receive-only mode) . . . 2906
Figure 868. Master and three independent slaves connected in star topology . . . 2907
Figure 869. Master and three slaves connected in circular (daisy chain) topology . . . 2909
Figure 870. Multimaster application . . . 2910
Figure 871. Scheme of NSS control logic . . . 2912
Figure 872. Data flow timing control (SSOE = 1, SSOM = 0, SSM = 0) . . . 2912
Figure 873. NSS interleaving pulses between data (SSOE = 1, SSOM = 1, SSM = 0) . . . 2913
Figure 874. Data clock timing diagram . . . 2915
Figure 875. Data alignment when data size is not equal to 8, 16 or 32 bits . . . 2916
Figure 876. TI mode transfer . . . 2925
Figure 877. Optional configurations of the slave behavior when an underrun condition is detected . 2927
Figure 878. Waveform examples . . . 2935
Figure 879. Master I2S Philips protocol waveforms (16/32-bit full accuracy) . . . 2936
Figure 880. I2S Philips standard waveforms . . . 2936
Figure 881. Master MSB-justified 16- or 32-bit full-accuracy length . . . 2937
Figure 882. Master MSB-justified 16- or 24-bit data length . . . 2937
Figure 883. Slave MSB-justified 16-, 24- or 32-bit data length . . . 2938
Figure 884. LSB-justified 16 or 24-bit data length . . . 2938
Figure 885. Master PCM when the frame length is equal the data length . . . 2939
Figure 886. Master PCM standard waveforms (16 or 24-bit data length) . . . 2939
Figure 887. Slave PCM waveforms . . . 2940
Figure 888. Startup sequence, I2S Philips standard, master . . . 2943
Figure 889. Startup sequence, I2S Philips standard, slave . . . 2944
Figure 890. Stop sequence, I2S Philips standard, master . . . 2944
Figure 891. I^2S clock generator architecture . . . 2945
Figure 892. Data Format . . . 2947

Figure 893. Handling of underrun situation . . . 2949
Figure 894. Handling of overrun situation . . . 2950
Figure 895. Frame error detection, with FIXCH = 0 . . . 2951
Figure 896. Frame error detection, with FIXCH = 1 . . . 2951
Figure 897. SAI functional block diagram . . . 2977
Figure 898. Audio frame . . . 2981
Figure 899. FS role is start of frame + channel side identification (FSDEF = TRIS = 1) . . . 2983
Figure 900. FS role is start of frame (FSDEF = 0) . . . 2984
Figure 901. Slot size configuration with FBOFF = 0 in SAI_xSLOTR . . . 2985
Figure 902. First bit offset . . . 2985
Figure 903. Audio block clock generator overview . . . 2987
Figure 904. PDM typical connection and timing . . . 2991
Figure 905. Detailed PDM interface block diagram . . . 2992
Figure 906. Start-up sequence . . . 2993
Figure 907. SAI_ADR format in TDM mode, 32-bit slot width . . . 2994
Figure 908. SAI_ADR format in TDM mode, 16-bit slot width . . . 2995
Figure 909. SAI_ADR format in TDM mode, 8-bit slot width . . . 2996
Figure 910. AC’97 audio frame . . . 2999
Figure 911. Example of typical AC’97 configuration on devices featuring at least two embedded SAIs (three external AC’97 decoders) . . . 3000
Figure 912. SPDIF format . . . 3001
Figure 913. SAI_xDR register ordering . . . 3002
Figure 914. Data companding hardware in an audio block in the SAI . . . 3005
Figure 915. Tristate strategy on SD output line on an inactive slot . . . 3007
Figure 916. Tristate on output data line in a protocol like I2S . . . 3008
Figure 917. Overrun detection error . . . 3009
Figure 918. FIFO underrun event . . . 3009
Figure 919. CAN subsystem . . . 3044
Figure 920. FDCAN block diagram . . . 3046
Figure 921. Bit timing . . . 3048
Figure 922. Transceiver delay measurement . . . 3053
Figure 923. Pin control in bus monitoring mode . . . 3054
Figure 924. Pin control in loop-back mode . . . 3057
Figure 925. CAN error state diagram . . . 3058
Figure 926. Message RAM configuration . . . 3059
Figure 927. Standard message ID filter path . . . 3062
Figure 928. Extended message ID filter path . . . 3063
Figure 929. OTG_FS full-speed block diagram . . . 3113
Figure 930. OTG_FS A-B device connection . . . 3115
Figure 931. OTG_FS peripheral-only connection . . . 3116
Figure 932. OTG_FS host-only connection . . . 3120
Figure 933. SOF connectivity (SOF trigger output to TIM and ITR1 connection) . . . 3123
Figure 934. Updating OTG_HFIR dynamically (RLDCTRL = 1) . . . 3126
Figure 935. Device-mode FIFO address mapping and AHB FIFO access mapping . . . 3127
Figure 936. Host-mode FIFO address mapping and AHB FIFO access mapping . . . 3128
Figure 937. Interrupt hierarchy . . . 3132
Figure 938. Transmit FIFO write task . . . 3224
Figure 939. Receive FIFO read task . . . 3225
Figure 940. Normal bulk/control OUT/SETUP . . . 3226
Figure 941. Bulk/control IN transactions . . . 3230
Figure 942. Normal interrupt OUT . . . 3233
Figure 943. Normal interrupt IN . . . 3238

Figure 944. Isochronous OUT transactions . . . 3240
Figure 945. Isochronous IN transactions . . . 3243
Figure 946. Receive FIFO packet read . . . 3247
Figure 947. Processing a SETUP packet . . . 3249
Figure 948. Bulk OUT transaction . . . 3256
Figure 949. TRDT max timing case . . . 3266
Figure 950. OTG_HS high-speed block diagram . . . 3271
Figure 951. OTG_HS A-B device connection . . . 3273
Figure 952. OTG_HS peripheral-only connection . . . 3274
Figure 953. OTG_HS host-only connection . . . 3278
Figure 954. SOF connectivity (SOF trigger output to TIM and ITR1 connection) . . . 3281
Figure 955. Updating OTG_HFIR dynamically (RLDCTRL = 1) . . . 3283
Figure 956. Device-mode FIFO address mapping and AHB FIFO access mapping . . . 3284
Figure 957. Host-mode FIFO address mapping and AHB FIFO access mapping . . . 3285
Figure 958. Interrupt hierarchy . . . 3289
Figure 959. Transmit FIFO write task . . . 3382
Figure 960. Receive FIFO read task . . . 3383
Figure 961. Normal bulk/control OUT/SETUP . . . 3384
Figure 962. Bulk/control IN transactions . . . 3388
Figure 963. Normal interrupt OUT . . . 3391
Figure 964. Normal interrupt IN . . . 3396
Figure 965. Isochronous OUT transactions . . . 3398
Figure 966. Isochronous IN transactions . . . 3401
Figure 967. Normal bulk/control OUT/SETUP transactions - DMA . . . 3403
Figure 968. Normal bulk/control IN transaction - DMA . . . 3405
Figure 969. Normal interrupt OUT transactions - DMA mode . . . 3406
Figure 970. Normal interrupt IN transactions - DMA mode . . . 3407
Figure 971. Normal isochronous OUT transaction - DMA mode . . . 3408
Figure 972. Normal isochronous IN transactions - DMA mode . . . 3409
Figure 973. Receive FIFO packet read . . . 3415
Figure 974. Processing a SETUP packet . . . 3417
Figure 975. Bulk OUT transaction . . . 3424
Figure 976. TRDT max timing case . . . 3433
Figure 977. UCPD block diagram . . . 3437
Figure 978. Clock division and timing elements . . . 3438
Figure 979. K-code transmission . . . 3441
Figure 980. Transmit order for various sizes of data . . . 3442
Figure 981. Packet format . . . 3443
Figure 982. Line format of Hard Reset . . . 3443
Figure 983. Line format of Cable Reset . . . 3444
Figure 984. BIST test data frame . . . 3445
Figure 985. BIST Carrier Mode 2 frame . . . 3445
Figure 986. UCPD BMC transmitter architecture . . . 3446
Figure 987. UCPD BMC receiver architecture . . . 3447
Figure 988. High-level Ethernet block diagram . . . 3479
Figure 989. DMA transmission flow (standard mode) . . . 3482
Figure 990. DMA transmission flow (OSP mode) . . . 3484
Figure 991. Receive DMA flow . . . 3486
Figure 992. Overview of MAC transmission flow . . . 3490
Figure 993. MAC reception flow . . . 3492
Figure 994. Packet filtering sequence . . . 3496
Figure 995. Networked time synchronization . . . 3505

Figure 996. Propagation delay calculation in clocks supporting peer-to-peer path correction . . . 3506
Figure 997. System time update using fine correction method . . . 3516
Figure 998. TCP segmentation offload overview . . . 3533
Figure 999. TCP segmentation offload flow . . . 3534
Figure 1000. Header and payload fields of segmented packets . . . 3537
Figure 1001. Supported PHY interfaces . . . 3546
Figure 1002. SMA Interface block . . . 3546
Figure 1003. MDIO packet structure (Clause 45) . . . 3547
Figure 1004. MDIO packet structure (Clause 22) . . . 3548
Figure 1005. SMA write operation flow . . . 3550
Figure 1006. Write data packet . . . 3551
Figure 1007. Read data packet . . . 3551
Figure 1008. Media independent interface (MII) signals . . . 3553
Figure 1009. RMII block diagram . . . 3555
Figure 1010. Transmission bit order . . . 3556
Figure 1011. Receive bit order . . . 3557
Figure 1012. LPI transitions (Transmit, 100 Mbds) . . . 3565
Figure 1013. LPI Tx clock gating (when LPITCSE = 1) . . . 3566
Figure 1014. LPI transitions (receive, 100 Mbit/s) . . . 3567
Figure 1015. Descriptor ring structure . . . 3591
Figure 1016. DMA descriptor ring . . . 3593
Figure 1017. Descriptor tail pointer example 1 . . . 3593
Figure 1018. Descriptor tail pointer example 2 . . . 3594
Figure 1019. Transmit descriptor (read format) . . . 3595
Figure 1020. Transmit descriptor write-back format . . . 3600
Figure 1021. Transmit context descriptor format . . . 3604
Figure 1022. Receive normal descriptor (read format) . . . 3608
Figure 1023. Receive normal descriptor (write-back format) . . . 3611
Figure 1024. Receive context descriptor . . . 3618
Figure 1025. Generation of ETH_DMAISR flags . . . 3633
Figure 1026. HDMI-CEC block diagram . . . 3755
Figure 1027. Message structure . . . 3755
Figure 1028. Blocks . . . 3756
Figure 1029. Bit timings . . . 3756
Figure 1030. Signal free time . . . 3757
Figure 1031. Arbitration phase . . . 3757
Figure 1032. SFT of three nominal bit periods . . . 3757
Figure 1033. Error bit timing . . . 3758
Figure 1034. Error handling . . . 3760
Figure 1035. TXERR detection . . . 3761
Figure 1036. Block diagram of debug support infrastructure . . . 3772
Figure 1037. Product life cycle states and debug authentication . . . 3776
Figure 1038. JTAG TAP state machine . . . 3780
Figure 1039. CoreSight topology . . . 3801
Figure 1040. Trace port interface unit (TPIU) . . . 3880
Figure 1041. Embedded cross-trigger . . . 3892

1 Documentation conventions

1.1 General information

The STM32H5E4/5F4 and STM32H5E5/5F5 devices have an Arm®(a) Cortex®-M33 core.

1.2 List of abbreviations for registers

The following abbreviations(b) are used in register descriptions:

read/write (rw)	Software can read and write to this bit.
read-only (r)	Software can only read this bit.
write-only (w)	Software can only write to this bit. Reading this bit returns the reset value.
read/clear write0 (rc_w0)	Software can read as well as clear this bit by writing 0. Writing 1 has no effect on the bit value.
read/clear write1 (rc_w1)	Software can read as well as clear this bit by writing 1. Writing 0 has no effect on the bit value.
read/clear write (rc_w)	Software can read as well as clear this bit by writing to the register. The value written to this bit is not important.
read/clear by read (rc_r)	Software can read this bit. Reading this bit automatically clears it to 0. Writing this bit has no effect on the bit value.
read/set by read (rs_r)	Software can read this bit. Reading this bit automatically sets it to 1. Writing this bit has no effect on the bit value.
read/set (rs)	Software can read as well as set this bit. Writing 0 has no effect on the bit value.
read/write once (rwo)	Software can only write once to this bit and can also read it at any time. Only a reset can return the bit to its reset value.
toggle (t)	The software can toggle this bit by writing 1. Writing 0 has no effect.
read-only write trigger (rt_w1)	Software can read this bit. Writing 1 triggers an event but has no effect on the bit value.
Reserved (Res.)	Reserved bit, must be kept at reset value.

a. Arm is a registered trademark of Arm Limited (or its subsidiaries) in the US and/or elsewhere.

b. This is an exhaustive list of all abbreviations applicable to STMicroelectronics microcontrollers, some of them may not be used in the current document.

1.3 Register reset value

Bits (binary notation) or bits nibbles (hexadecimal notation) of which the reset value is undefined are marked as X.

Bits (binary notation) or bits nibbles (hexadecimal notation) of which the reset value is unmodified are marked as U.

1.4 Glossary

This section gives a brief definition of acronyms and abbreviations used in this document:

- **Word**: data of 32-bit length.
- **Half-word**: data of 16-bit length.
- **Byte**: data of 8-bit length.
- **AHB**: advanced high-performance bus.

2 Memory and bus architecture

2.1 System architecture

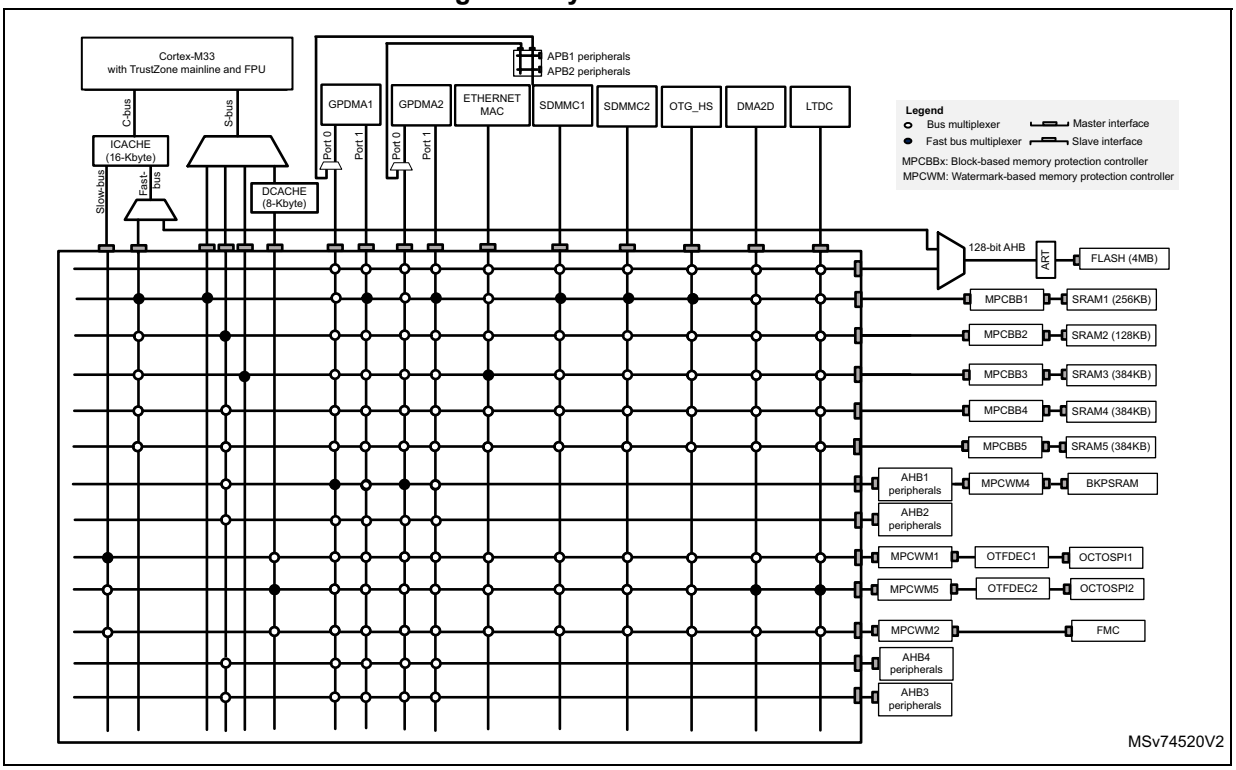
The architecture relies on an Arm Cortex®-M33 core optimized for execution thanks to an instruction cache having a direct access to the embedded flash memory.

This architecture also features a 32-bit multilayer AHB bus matrix that interconnects

- up to 16 masters:
  - Fast C-bus, connecting Cortex®-M33 with TrustZone® mainline and FPU core C-bus to the internal SRAMs through the instruction cache
  - Slow C-bus, connecting Cortex®-M33 with TrustZone® mainline and FPU core C-bus to the external memories through the instruction cache
  - Cortex®-M33 with TrustZone® mainline and FPU core S-bus (three masters connected to three internal SRAMs without latency)
  - Cortex®-M33 with TrustZone® mainline and FPU core S-bus connected to the external memories through the data cache
  - DMA2D
  - Ethernet MAC
  - GPDMA1 (general purpose DMA featuring two master ports)
  - GPDMA2 (general purpose DMA featuring two master ports)
  - LTDC
  - OTG_HS
  - SDMMC1
  - SDMMC2
- up to 13 slaves:
  - Internal flash memory (4 Mbytes)
  - Internal SRAM1 (256 Kbytes)
  - Internal SRAM2 (128 Kbytes)
  - Internal SRAM3, SRAM4, and SRAM5 (384 Kbytes)
  - AHB1 peripherals and 4-Kbyte BKPSRAM, including AHB to APB bridges and APB peripherals (connected to APB1 and APB2)
  - AHB2 peripherals
  - FMC (flexible memory controller)
  - OCTOSPI1, OCTOSPI2
  - AHB3 peripherals, including AHB to APB bridge and APB peripherals (connected to APB3)
  - AHB4 peripherals

The bus matrix provides the access from a master to a slave, enabling concurrent access, and efficient operation even when several high-speed peripherals work simultaneously. This architecture is shown in the following figure.

Figure 1. System architecture



2.1.1 Fast C-bus

This bus connects the C-bus of the Cortex®-M33 core to the internal flash memory and to the bus matrix through the instruction cache. This bus is used for instruction fetch and data access to the internal memories mapped in the code region. This bus targets the internal flash memory and the internal SRAMs (SRAM1/2/3/4/5).

SRAM1/2/3/4/5 are accessible on this bus with a continuous mapping.

2.1.2 Slow C-bus

This bus connects the C-bus of the Cortex®-M33 core to the bus matrix via the instruction cache. This bus is used for instruction fetch and data access to the external memories mapped in the code region. This bus targets the external memories (FMC and OCTOSPIs).

2.1.3 S-bus

This bus connects the system bus of the Cortex®-M33 core to the bus matrix. This bus is used by the core to access data located in a peripheral or SRAM area. This bus targets the internal SRAMs (SRAM1/2/3/4/5 and BKPSRAM), the AHB1 peripherals including the APB1, APB2, AHB2, AHB3, and AHB4 peripherals.

SRAM1/2/3/4/5 are accessible on this bus with a continuous mapping.

Note: The bus matrix has a zero latency when accessing SRAM1/2/3/4/5*.*

2.1.4 DCACHE S-bus

This bus connects the system bus of the Cortex®-M33 core to the bus matrix through the data cache. This bus is used for instruction fetch and data access to the external memories mapped in the data region. This bus targets the external memories (FMC and OCTOSPIs).

Note: Fetching instructions through this bus is less efficient than fetching instructions through the slow C-bus.

2.1.5 GPDMA1 and GPDMA2 buses

These buses connect the four AHB master interfaces of the GPDMA1 and GPDMA2 to the bus matrix. These buses target the internal flash memory, the internal SRAMs (SRAM1/2/3/4/5 and BKPSRAM), the AHB1 peripherals including the APB1 and APB2 peripherals, the AHB2 peripherals, the AHB3 peripherals, the AHB4 peripherals, and the external memories through FMC or OCTOSPIs.

2.1.6 SDMMC1 and SDMMC2 controllers DMA buses

These buses connect the SDMMC1 and SDMMC2 DMA master interfaces to the bus matrix. They are used only by the SDMMC1 and SDMMC2 DMA to load/store data from/to the memory. These buses target the data memories: internal flash memory, internal SRAMs (SRAM1/2/3/4/5), and external memories through FMC or OCTOSPIs.

2.1.7 OTG_HS bus

This bus connects the OTG_HS master interface to the bus matrix. This bus is used only by the OTG_HS to load/store data from/to the memory. This bus targets the data memories: internal flash memory, internal SRAMs (SRAM1/2/3/4/5), and external memories through FMC or OCTOSPIs.

2.1.8 LTDC bus

This bus connects the LTDC master interface to the bus matrix. This bus is used only to load data from the memory. This bus targets the data memories: internal flash memory, internal SRAMs (SRAM1/2/3/4/5), and external memories through FMC or OCTOSPIs

2.1.9 Bus matrix

The bus matrix manages the access arbitration between masters. The arbitration uses a round-robin algorithm. This bus matrix features a fast bus multiplexer used to connect each master to a given slave without latency (see *Figure 1*). For the same master, other slaves undergo a latency of at least one cycle at each new access.

2.1.10 AHB/APB bridges

The three AHB/APB bridges provide full synchronous connections between the AHB and the APB buses, allowing flexible selection of the peripheral frequency.

Refer to*Section 2.3.2: Memory map and register boundary addresses* for the address mapping of the peripherals connected to these bridges.

After each device reset, all peripheral clocks are disabled (except for the internal SRAMs and flash memory interfaces). Before using a peripheral, its clock must be enabled in the RCC_AHBxENR and RCC_APBxENR registers.

Note: When an 8- or 16-bit access is performed on an APB register, the access is transformed into a 32-bit access: the bridge duplicates the 8- or 16-bit data to feed the 32-bit vector.

2.1.11 Ethernet MAC

The Ethernet MAC uses a 32-bit bus, connected to the AHB bus matrix. Through the system bus matrix, it can access the internal flash memory, the internal memories, and the external memories through the OCTOSPIs and the FMC.

2.2 TrustZone® security architecture

The security architecture is based on Arm TrustZone® with the Armv8-M mainline extension. The TrustZone® security is activated by the TZEN option bit in the FLASH_OPTR register.

When the TrustZone® is enabled, the SAU (security-attribution unit) and IDAU (implementation-defined-attribution unit) define the access permissions based on secure and nonsecure states.

- SAU: Up to eight SAU configurable regions are available for security attribution.
- IDAU: provides a first memory partition as nonsecure or nonsecure callable attributes. The IDAU memory map partition is not configurable, it is fixed by hardware implementation (refer to *Figure 2: Memory map based on IDAU mapping*. It is then combined with the results from the SAU security attribution, and the higher security state is selected.

Based on IDAU security attribution, the flash memory, system SRAMs, and peripheral memory spaces are aliased twice for secure and nonsecure states. However, the external memory space is not aliased.

2.2.1 Default TrustZone® security state

When the TrustZone® security is activated by the TZEN option bit in the FLASH_OPTR, the default system security state is detailed below:

- CPU:
  - Cortex®-M33 is in a secure state after reset. The boot address must be at a secure address.
- Memory map:
  - SAU is fully secure after reset. Consequently, all memory maps are fully secure. Up to eight SAU configurable regions are available for security attribution.
- Flash memory:
  - The flash memory security area is defined by watermark user options.
  - Block-based security attributions are nonsecure after reset.
- SRAMs:
  - All SRAMs are secure after reset. MPCBBx (block-based memory protection controller) are secure.

- External memories:
  - FMC and OCTOSPI banks are secure after reset. MPCWMx (watermark-based memory protection controller) are secure.
- Peripherals (see *Table 1 and Table 2 for a list of securable and TrustZone-aware peripherals)*
  - Securable peripherals are nonsecure after reset.
  - TrustZone-aware peripherals are nonsecure after reset. Their secure configuration registers are secure.
- All GPIOs are secure after reset.
- Interrupts:
  - NVIC: All interrupts are secure after reset. NVIC is banked for both secure and nonsecure state.
  - TZIC: All illegal access interrupts are disabled after reset (see *GTZC TrustZone system architecture*).

2.2.2 TrustZone® peripheral classification

When the TrustZone® security is active, a peripheral can be either securable or TrustZone-aware type as follows:

- Securable: peripheral protected by an AHB/APB firewall gate that is controlled from the TZSC controller to define security properties.
- TrustZone-aware: peripheral connected directly to the AHB or APB bus and implementing a specific TrustZone® behavior such as a subset of registers being secure.

Refer to the*GTZC TrustZone system architecture* for more details.

Tables below list the securable and TrustZone-aware peripherals within the system.

Table 1. Securable peripherals by TZSC

Bus	Peripheral
AHB4	FMC
	OCTOSPI1
	OCTOSPI2
	OCTOSPIM
	SDMMC1
	SDMMC2

Table 1. Securable peripherals by TZSC (continued)

Bus	Peripheral
AHB2	ADC1
	ADC2
	ADC3
	ADF1
	AES
	DAC1
	DAC2
	DCMI
	HASH
	OTG_FS
	PKA
	RNG
	SAES
AHB1	CORDIC
	CRC
	DCACHE registers
	DMA2D
	ETHERNET
	FMAC
	ICACHE registers
	JPEG
	RAMCFG
	MDF1
	OTG_HS
	RAMCFG

Table 1. Securable peripherals by TZSC (continued)

Bus	Peripheral
APB3	I2C3
	I2C4
	I3C2
	LPTIM1
	LPTIM3
	LPTIM4
	LPTIM5
	LPTIM6
	LPUART1
	SPI5
	VREFBUF
APB2	GFXTIM
	LTDC
	SAI1
	SAI2
	SPI1
	SPI4
	SPI6
	TIM1
	TIM8
	TIM15
	TIM16
	TIM17
	USART1

Table 1. Securable peripherals by TZSC (continued)

Bus	Peripheral
APB1	CEC
	COMP
	CRS
	DAC1
	DAC2
	DTS
	FDCAN1
	FDCAN2
	FDCAN3
	I2C1
	I2C2
	I3C1
	IWDG
	LPTIM2
	OPAMP
	SPI2S2
	SPI2S3
	TM2
	TM3
	TM4
	TM5
	TM6
	TM7
	TM12

Table 1. Securable peripherals by TZSC (continued)

Bus	Peripheral
APB1 (cont'd)	TM13
	TM14
	UART4
	UART5
	UART7
	UART8
	UART9
	UART12
	UCPD
	USART2
	USART3
	USART6
	USART10
	USART11
	WWDG

Table 2. TrustZone-aware peripherals

Bus	Peripheral
AHB3	EXTI
	PWR
	RCC
AHB4	OTFDEC1
	OTFDEC2
AHB2	GPIOA
	GPIOB
	GPIOC
	GPIOD
	GPIOE
	GPIOF
	GPIOG
	GPIOH
	GPIOI
	GPIOJ
	GPIOK

Table 2. TrustZone-aware peripherals (continued)

Bus	Peripheral
AHB1	DCACHE
	ICACHE
	FLASH
	GPDMA1
	GPDMA2
	GTZC
APB3	PLAY
	RTC
	SBS
	TAMP

2.3 Memory organization

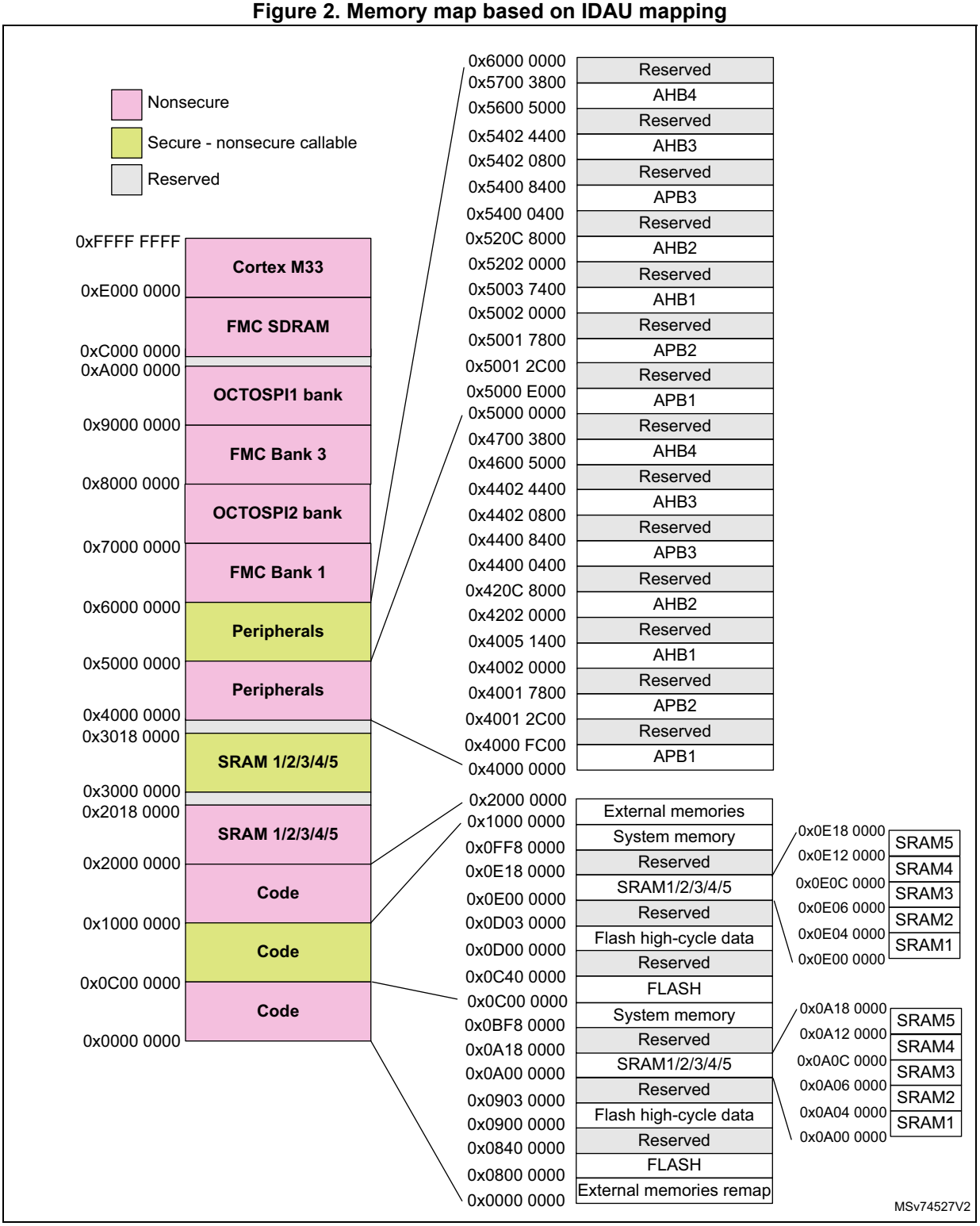
2.3.1 Introduction

Program memory, data memory, registers and I/O ports are organized within the same linear 4-Gbyte address space.

The bytes are coded in memory in Little Endian format. The lowest numbered byte in a word is considered the word's least significant byte and the highest numbered byte the most significant.

2.3.2 Memory map and register boundary addresses

Figure 2. Memory map based on IDAU mapping



All the memory map areas not allocated to on-chip memories and peripherals are reserved. The following table gives the boundary addresses of the available peripherals.

Table 3. Memory map and peripheral register addresses

Bus	Secure boundary address	Nonsecure boundary address	Peripheral	Register map
AHB4	0x5700 3800 - 0x57FF FFFF	0x4700 3800 - 0x47FF FFFF	Reserved	-
	0x5700 3400 - 0x5700 37FF	0x4700 3400 - 0x4700 37FF	OCTOSPIM	*Section 27.6.2: OCTOSPIM register map*
	0x5700 2800 - 0x5700 33FF	0x4700 2800 - 0x4700 33FF	Reserved	-
	0x5700 2400 - 0x5700 27FF	0x4700 2400 - 0x4700 27FF	OCTOSPI2	*Section 26.7.28: OCTOSPI register map*
	0x5700 1800 - 0x57FF 23FF	0x4700 1800 - 0x47FF 23FF	Reserved	-
	0x5700 1400 - 0x5700 17FF	0x4700 1400 - 0x4700 17FF	OCTOSPI1	*Section 26.7.28: OCTOSPI register map*
	0x5700 0800 - 0x5700 13FF	0x4700 0800 - 0x4700 13FF	Reserved	-
	0x5700 0400 - 0x5700 07FF	0x4700 0400 - 0x4700 07FF	FMC	*Section 25.8.6: FMC register map*
	0x5600 F800 - 0x5700 03FF	0x4600 F800 - 0x4700 03FF	Reserved	-
	0x5600 F400 - 0x5600 F7FF	0x4600 F400 - 0x4600 F7FF	DLYBOS2	*Section 29.5.3: DLYB register map*
	0x5600 F000 - 0x5600 F3FF	0x4600 F000 - 0x4600 F3FF	DLYBOS1	
	0x5600 9000 - 0x5600 EFFF	0x4600 9000 - 0x4600 EFFF	Reserved	-
	0x5600 8C00 - 0x5600 8FFF	0x4600 8C00 - 0x4600 8FFF	SDMMC2	*Section 28.10.21: SDMMC register map*
	0x5600 8800 - 0x5600 8BFF	0x4600 8800 - 0x4600 8BFF	DLYBSD2	*Section 29.5.3: DLYB register map*
	0x5600 8400 - 0x5600 87FF	0x4600 8400 - 0x4600 87FF	DLYBSD1	
	0x5600 8000 - 0x5600 83FF	0x4600 8000 - 0x4600 83FF	SDMMC1	*Section 28.10.21: SDMMC register map*
	0x5600 5800 - 0x5600 7FFF	0x4600 5800 - 0x4600 7FFF	Reserved	-
	0x5600 5400 - 0x5600 57FF	0x4600 5400 - 0x6400 57FF	OTFDEC2	*Section 48.6.15: OTFDEC register map*
	0x5600 5000 - 0x5600 53FF	0x4600 5000 - 0x4600 53FF	OTFDEC1	
	0x5600 0000 - 0x5600 4FFF	0x4600 0000 - 0x4600 4FFF	Reserved	-

Table 3. Memory map and peripheral register addresses (continued)

Bus	Secure boundary address	Nonsecure boundary address	Peripheral	Register map
AHB3	0x5402 4400 - 0x54FF FFFF	0x4402 4400 - 0x44FF FFFF	Reserved	-
	0x5402 4000 - 0x5402 43FF	0x4402 4000 - 0x4402 43FF	DEBUG	*Section 71.12.5: DBGMCU register map*
	0x5402 2400 - 0x5402 3FFF	0x4402 2400 - 0x4402 3FFF	Reserved	-
	0x5402 2000 - 0x5402 23FF	0x4402 2000 - 0x4402 23FF	EXTI	*Section 20.6.33: EXTI register map*
	0x5402 1000 - 0x5402 1FFF	0x4402 1000 - 0x4402 1FFF	Reserved	-
	0x5402 0C00 - 0x5402 0FFF	0x4402 0C00 - 0x4402 0FFF	RCC	*Section 11.8.49: RCC register map*
	0x5402 0800 - 0x5402 0BFF	0x4402 0800 - 0x4402 0BFF	PWR	*Section 10.11.19: PWR register map*
	0x5400 8400 - 0x5402 07FF	0x4402 0000 - 0x4402 07FF	Reserved	-

Table 3. Memory map and peripheral register addresses (continued)

Bus	Secure boundary address	Nonsecure boundary address	Peripheral	Register map
APB3	0x5400 8400 - 0x5400 FFFF	0x4400 8400 - 0x4400 FFFF	Reserved	-
	0x5400 8000 - 0x5400 83FF	0x4400 8000 - 0x4400 83FF	PLAY	*Section 24.7: PLAY register map*
	0x5400 7C00 - 0x5400 7FFF	0x4400 7C00 - 0x4400 7FFF	TAMP	*Section 58.6.20: TAMP register map*
	0x5400 7800 - 0x5400 7BFF	0x4400 7800 - 0x4400 7BFF	RTC	*Section 57.6.27: RTC register map*
	0x5400 7400 - 0x5400 77FF	0x4400 7400 - 0x4400 77FF	VREFBUF	*Section 33.5.3: VREFBUF register map*
	0x5400 5800 - 0x5400 73FF	0x4400 5800 - 0x4400 73FF	Reserved	-
	0x5400 5400 - 0x5400 57FF	0x4400 5400 - 0x4400 57FF	LPTIM6	*Section 54.7.19: LPTIM register map*
	0x5400 5000 - 0x5400 53FF	0x4400 5000 - 0x4400 53FF	LPTIM5	
	0x5400 4C00 - 0x5400 4FFF	0x4400 4C00 - 0x4400 4FFF	LPTIM4	
	0x5400 4800 - 0x5400 4BFF	0x4400 4800 - 0x4400 4BFF	LPTIM3	
	0x5400 4400 - 0x5400 47FF	0x4400 4400 - 0x4400 47FF	LPTIM1	
	0x5400 3400 - 0x5400 43FF	0x4400 3400 - 0x4400 43FF	Reserved	-
	0x5400 3000 - 0x5400 33FF	0x4400 3000 - 0x4400 33FF	I3C2	*Section 60.15.30: I3C register map*
	0x5400 2C00 - 0x5400 2FFF	0x4400 2C00 - 0x4400 2FFF	I2C4	*Section 59.9.12: I2C register map*
	0x5400 2800 - 0x5400 2BFF	0x4400 2800 - 0x4400 2BFF	I2C3	
	0x5400 2400 - 0x5400 27FF	0x4400 2400 - 0x4400 27FF	LPUART1	*Section 62.7.14: LPUART register map*
	0x5400 2000 - 0x5400 23FF	0x4400 2000 - 0x4400 23FF	SPI5	*Section 63.11.15: SPI/I2S register map*
	0x5400 0800 - 0x5400 1FFF	0x4400 0800 - 0x4400 1FFF	Reserved	-
	0x5400 0400 - 0x5400 07FF	0x4400 0400 - 0x4400 07FF	SBS	*Section 14.5.20: SBS register map*
	0x5400 0000 - 0x5400 03FF	0x4400 0000 - 0x4400 03FF	Reserved	-

Table 3. Memory map and peripheral register addresses (continued)

Bus	Secure boundary address	Nonsecure boundary address	Peripheral	Register map
AHB2	0x520C 8000 - 0x53FF FFFF	0x420C 8000 - 0x43FF FFFF	Reserved	-
	0x520C 7C00 - 0x520C 7FFF	0x420C 7C00 - 0x420C 7FFF	CCB	*Section 42.7.4: CCB register map*
	0x520C 4000 - 0x53FF 7BFF	0x420C 4000 - 0x43FF 7BFF	Reserved	-
	0x520C 2000 - 0x520C 3FFF	0x420C 2000 - 0x420C 3FFF	PKA +RAM	*Section 47.7.5: PKA register map*
	0x520C 1000 - 0x520C 1FFF	0x420C 1000 - 0x420C 1FFF	Reserved	-
	0x520C 0C00 - 0x520C 0FFF	0x420C 0C00 - 0x420C 0FFF	SAES	*Section 44.8.21: AES register map*
	0x520C 0800 - 0x520C 0BFF	0x420C 0800 - 0x420C 0BFF	RNG	*Section 43.7.9: RNG register map*
	0x520C 0400 - 0x520C 07FF	0x420C 0400 - 0x420C 07FF	HASH	*Section 46.6.8: HASH register map*
	0x520C 0000 - 0x520C 03FF	0x420C 0000 - 0x420C 03FF	AES	*Section 44.8.21: AES register map*
	0x5208 0000 - 0x520B FFFF	0x4208 0000 - 0x420B FFFF	OTG_FS	*Section 66.15.63: OTG_FS register map*
	0x5204 0000 - 0x5207 FFFF	0x4204 0000 - 0x4207 FFFF	OTG_HS	*Section 67.14.63: OTG_HS register map*
	0x5202 DC00 - 0x5203 FFFF	0x4202 DC00 - 0x4203 FFFF	Reserved	-
	0x5202 D800 - 0x5202 DBFF	0x4202 D800 - 0x4202 DBFF	ADC3	*Section 30.8: ADC register map*
	0x5202 C800 - 0x5202 D7FF	0x4202 C800 - 0x4202 D7FF	ADF1	*Section 37.8.16: ADF register map*

Table 3. Memory map and peripheral register addresses (continued)

Bus	Secure boundary address	Nonsecure boundary address	Peripheral	Register map
AHB2(cont'd)	0x5202 C400 - 0x5202 C7FF	0x4202 C400 - 0x4202 C7FF	PSSI	*Section 39.5.8: PSSI register map*
	0x5202 C000 - 0x5202 C3FF	0x4202 C000 - 0x4202 C3FF	DCMI	*Section 38.5.12: DCMI register map*
	0x5202 8800 - 0x5202 BFFF	0x4202 8800 - 0x4202 BFFF	Reserved	-
	0x5202 8400 - 0x5202 87FF	0x4202 8400 - 0x4202 87FF	DAC1 /DAC2	*Section 32.7.21: DAC register map*
	0x5202 8000 - 0x5202 83FF	0x4202 8000 - 0x4202 83FF	ADC1 / ADC2	*Section 30.8: ADC register map*
	0x5202 2C00 - 0x5202 7FFF	0x4202 2C00 - 0x4202 7FFF	Reserved	-
	0x5202 2800 - 0x5202 2BFF	0x4202 2800 - 0x4202 2BFF	GPIOK	*Section 13.4.14: GPIO register map*
	0x5202 2400 - 0x5202 27FF	0x4202 2400 - 0x4202 27FF	GPIOJ	
	0x5202 2000 - 0x5202 23FF	0x4202 2000 - 0x4202 23FF	GPIOI	
	0x5202 1C00 - 0x5202 1FFF	0x4202 1C00 - 0x4202 1FFF	GPIOH	
	0x5202 1800 - 0x5202 1BFF	0x4202 1800 - 0x4202 1BFF	GPIOG	
	0x5202 1400 - 0x5202 17FF	0x4202 1400 - 0x4202 17FF	GPIOF	
	0x5202 1000 - 0x5202 13FF	0x4202 1000 - 0x4202 13FF	GPIOE	
	0x5202 0C00 - 0x5202 0FFF	0x4202 0C00 - 0x4202 0FFF	GPIOD	
	0x5202 0800 - 0x5202 0BFF	0x4202 0800 - 0x4202 0BFF	GPIOC	
	0x5202 0400 - 0x5202 07FF	0x4202 0400 - 0x4202 07FF	GPIOB	
	0x5202 0000 - 0x5202 03FF	0x4202 0000 - 0x4202 03FF	GPIOA	

Table 3. Memory map and peripheral register addresses (continued)

Bus	Secure boundary address	Nonsecure boundary address	Peripheral	Register map
AHB1	0x5003 7400 - 0x51FF FFFF	0x4003 7400 - 0x41FF FFFF	Reserved	-
	0x5003 6400 - 0x5003 73FF	0x4003 6400 - 0x4003 73FF	MPCWM4_BKPRAM	*Section 5.6.12: GTZC1 TZSC register map*
	0x5003 4100 - 0x5003 63FF	0x4003 4100 - 0x4003 63FF	Reserved	-
	0x5003 2400 - 0x5003 40FF	0x4003 2400 - 0x4003 40FF	GTZC1	*Section 5.6.12: GTZC1 TZSC register map*
	0x5003 1800 - 0x5003 23FF	0x4003 1800 - 0x4003 23FF	Reserved	-
	0x5003 1400 - 0x5003 17FF	0x4003 1400 - 0x4003 17FF	DCACHE	*Section 9.7.11: DCACHE register map*
	0x5003 0800 - 0x5003 13FF	0x4003 0800 - 0x4003 13FF	Reserved	-
	0x5003 0400 - 0x5003 07FF	0x4003 0400 - 0x4003 07FF	ICACHE	*Section 8.7.8: ICACHE register map*
	0x5002 C000 - 0x5003 03FF	0x4002 C000 - 0x4003 03FF	Reserved	-
	0x5002 B000 - 0x5002 BFFF	0x4002 B000 - 0x4002 BFFF	JPEG	*Section 41.5.19: JPEG codec register map*
	0x5002 A000 - 0x5002 AFFF	0x4002 A000 - 0x4002 AFFF	DMA2D	*Section 17.5.47: DMA2D register map*
	0x5002 9400 - 0x5002 9FFF	0x4002 9400 - 0x4002 9FFF	Reserved	-
	0x5002 8000 - 0x5002 93FF	0x4002 8000 - 0x4002 93FF	ETHERNET MAC	*Section 69.11.4: Ethernet MAC and MMC registers*
	0x5002 7000 - 0x5002 7FFF	0x4002 7000 - 0x4002 7FFF	Reserved	-
	0x5002 6000 - 0x5002 6FFF	0x4002 6000 - 0x4002 6FFF	RAMCFG	*Section 6.6.13: RAMCFG register map*
	0x5002 5000 - 0x5002 5FFF	0x4002 5000 - 0x4002 5FFF	MDF1	*Section 36.8.21: MDF register map*
	0x5002 4000 - 0x5002 4FFF	0x4002 4000 - 0x4002 4FFF	Reserved	-
	0x5002 3C00 - 0x5002 3FFF	0x4002 3C00 - 0x4002 3FFF	FMAC	*Section 23.4.9: FMAC register map*
	0x5002 3800 - 0x5002 3BFF	0X4002 3800 - 0x4002 3BFF	CORDIC	*Section 22.4.4: CORDIC register map*
	0x5002 3400 - 0x5002 37FF	0x4002 3400 - 0x4002 37FF	Reserved	-
	0x5002 3000 - 0x5002 33FF	0x4002 3000 - 0x4002 33FF	CRC	*Section 21.4.6: CRC register map*
	0x5002 2400 - 0x5002 2FFF	0x4002 2400 - 0x4002 2FFF	Reserved	-
	0x5002 2000 - 0x5002 23FF	0x4002 2000 - 0x4002 23FF	FLASH	*Section 7.12: FLASH register map and reset values*
	0x5002 1000 - 0x5002 1FFF	0X4002 1000 - 0x4002 1FFF	GPDMA2	*Section 16.8.20: GPDMA register map*
	0x5002 0000 - 0x5002 0FFF	0x4002 0000 - 0x4002 0FFF	GPDMA1	

Table 3. Memory map and peripheral register addresses (continued)

Bus	Secure boundary address	Nonsecure boundary address	Peripheral	Register map
APB2	0x5001 7800 - 0x5001 FFFF	0x4001 7800 - 0x4001 FFFF	Reserved	-
	0x5001 7400 - 0x5001 77FF	0x4001 7400 - 0x4001 77FF	GFXTIM	*Section 18.5.27: GFXTIM register map*
	0x5001 7000 - 0x5001 73FF	0x4001 7000 - 0x4001 73FF	Reserved	-
	0x5001 6C00 - 0x5001 6FFF	0x4001 6C00 - 0x4001 6FFF	LTDC	*Section 40.7.26: LTDC register map*
	0x5001 5C00 - 0x5001 6BFF	0x4001 6400 - 0x4001 6BFF	Reserved	-
	0x5001 5800 - 0x5001 5BFF	0x4001 5800 - 0x4001 5BFF	SAI2	*Section 64.6.20: SAI register map*
	0x5001 5400 - 0x5001 57FF	0x4001 5400 - 0x4001 57FF	SAI1	
	0x5001 5000 - 0x5001 53FF	0x4001 5000 - 0x4001 53FF	SPI6	*Section 63.11.15: SPI/I2S register map*
	0x5001 4C00 - 0x5001 4FFF	0x4001 4C00 - 0x4001 4FFF	SPI4	
	0x5001 4800 - 0x5001 4BFF	0x4001 4800 - 0x4001 4BFF	TIM17	*Section 53.8.22: TIM16/TIM17 register map*
	0x5001 4400 - 0x5001 47FF	0x4001 4400 - 0x4001 47FF	TIM16	
	0x5001 4000 - 0x5001 43FF	0x4001 4000 - 0x4001 43FF	TIM15	*Section 53.7.23: TIM15 register map*
	0x5001 3C00 - 0x5001 3FFF	0x4001 3C00 - 0x4001 3FFF	Reserved	-
	0x5001 3800 - 0x5001 3BFF	0x4001 3800 - 0x4001 3BFF	USART1	*Section 61.8.16: USART register map*
	0x5001 3400 - 0x5001 37FF	0x4001 3400 - 0x4001 37FF	TIM8	*Section 49.6.31: TIMx register map*
	0x5001 3000 - 0x5001 33FF	0x4001 3000 - 0x4001 33FF	SPI2S1	*Section 63.11.15: SPI/I2S register map*
	0x5001 2C00 - 0x5001 2FFF	0x4001 2C00 - 0x4001 2FFF	TIM1	*Section 49.6.31: TIMx register map*
	0x5001 0000 - 0x5001 2BFF	0x4001 0000 - 0x4001 2BFF	Reserved	-

Table 3. Memory map and peripheral register addresses (continued)

Bus	Secure boundary address	Nonsecure boundary address	Peripheral	Register map
APB1	0x5000 E000 - 0x5000 FFFF	0x4000 E000 - 0x4000 FFFF	Reserved	-
	0x5000 DC00 - 0x5000 DFFF	0x4000 DC00 - 0x4000 DFFF	UCPD1	*Section 68.8.15: UCPD register map*
	0x5000 B800 - 0x5000 DBFF	0x4000 B800 - 0x4000 DBFF	Reserved	-
	0x5000 AC00 - 0x5000 B7FF	0x4000 AC00 - 0x4000 B7FF	FDCAN SRAM	*Section 65.4.38: FDCAN register map*
	0x5000 A800 - 0x5000 ABFF	0x4000 A800 - 0x4000 ABFF	FDCAN2	
	0x5000 A400 - 0x5000 A7FF	0x4000 A400 - 0x4000 A7FF	FDCAN1	
	0x5000 A000 - 0x5000 A3FF	0x4000 A000 - 0x4000 A3FF	FDCAN3	
	0x5000 9800 - 0x5000 9FFF	0x4000 9800 - 0x4000 9FFF	Reserved	-
	0x5000 9400 - 0x5000 97FF	0x4000 9400 - 0x4000 97FF	LPTIM2	*Section 54.7.19: LPTIM register map*
	0x5000 9000 - 0x5000 93FF	0x4000 9000 - 0x4000 93FF	Reserved	-
	0x5000 8C00 - 0x5000 8FFF	0x4000 8C00 - 0x4000 8FFF	DTS	*Section 31.6.10: DTS register map*
	0x5000 8800 - 0x5000 8BFF	0x4000 8800 - 0x4000 8BFF	Reserved	-
	0x5000 8400 - 0x5000 87FF	0x4000 8400 - 0x4000 87FF	UART12	*Section 61.8.16: USART register map*
	0x5000 8000 - 0x5000 83FF	0x4000 8000 - 0x4000 83FF	UART9	
	0x5000 7C00 - 0x5000 7FFF	0x4000 7C00 - 0x4000 7FFF	UART8	
	0x5000 7800 - 0x5000 7BFF	0x4000 7800 - 0x4000 7BFF	UART7	
	0x5000 7400 - 0x5000 77FF	0x4000 7400 - 0x4000 77FF	Reserved	-
	0x5000 7000 - 0x5000 73FF	0x4000 7000 - 0x4000 73FF	CEC	*Section 70.7.7: HDMI-CEC register map*
	0x5000 6C00 - 0x5000 6FFF	0x4000 6C00 - 0x4000 6FFF	USART11	*Section 61.8.16: USART register map*
	0x5000 6800 - 0x5000 6BFF	0x4000 6800 - 0x4000 6BFF	USART10	
	0x5000 6400 - 0x5000 67FF	0x4000 6400 - 0x4000 67FF	USART6	
	0x5000 6000 - 0x5000 63FF	0x4000 6000 - 0x4000 63FF	CRS	*Section 12.7.5: CRS register map*
	0x5000 5C00 - 0x5000 5FFF	0x4000 5C00 - 0x4000 5FFF	I3C1	*Section 60.15.30: I3C register map*

Table 3. Memory map and peripheral register addresses (continued)

Bus	Secure boundary address	Nonsecure boundary address	Peripheral	Register map
APB1 (cont'd)	0x5000 5800 - 0x5000 5BFF	0x4000 5800 - 0x4000 5BFF	I2C2	*Section 59.9.12: I2C register map*
	0x5000 5400 - 0x5000 57FF	0x4000 5400 - 0x4000 57FF	I2C1	
	0x5000 5000 - 0x5000 53FF	0x4000 5000 - 0x4000 53FF	UART5	*Section 61.8.16: USART register map*
	0x5000 4C00 - 0x5000 4FFF	0x4000 4C00 - 0x4000 4FFF	UART4	
	0x5000 4800 - 0x5000 4BFF	0x4000 4800 - 0x4000 4BFF	USART3	
	0x5000 4400 - 0x5000 47FF	0x4000 4400 - 0x4000 47FF	USART2	
	0x5000 4000 - 0x5000 43FF	0x4000 4000 - 0x4000 43FF	COMP1 / COMP2	*Section 35.7.5: COMP register map*
	0x5000 3C00 - 0x5000 3FFF	0x4000 3C00 - 0x4000 3FFF	SPI2S3	*Section 63.11.15: SPI/I2S register map*
	0x5000 3800 - 0x5000 3BFF	0x4000 3800 - 0x4000 3BFF	SPI2S2	
	0x5000 3400 - 0x5000 37FF	0x4000 3400 - 0x4000 37FF	OPAMP	*Section 34.6.4: OPAMP register map*
	0x5000 3000 - 0x5000 33FF	0x4000 3000 - 0x4000 33FF	IWDG	*Section 55.7.7: IWDG register map*
	0x5000 2C00 - 0x5000 2FFF	0x4000 2C00 - 0x4000 2FFF	WWDG	*Section 56.6.4: WWDG register map*
	0x5000 2400 - 0x5000 2BFF	0x4000 2400 - 0x4000 2BFF	Reserved	-
	0x5000 2000 - 0x5000 23FF	0x4000 2000 - 0x4000 23FF	TIM14	*Section 52.8.13: TIM13/TIM14 register map*
	0x5000 1C00 - 0x5000 1FFF	0x4000 1C00 - 0x4000 1FFF	TIM13	
	0x5000 1800 - 0x5000 1BFF	0x4000 1800 - 0x4000 1BFF	TIM12	*Section 52.7.16: TIM12 register map*
	0x5000 1400 - 0x5000 17FF	0x4000 1400 - 0x4000 17FF	TIM7	*Section 51.4.9: TIMx register map*
	0x5000 1000 - 0x5000 13FF	0x4000 1000 - 0x4000 13FF	TIM6	
	0x5000 0C00 - 0x5000 0FFF	0x4000 0C00 - 0x4000 0FFF	TIM5	*Section 50.5.31: TIMx register map*
	0x5000 0800 - 0x5000 0BFF	0x4000 0800 - 0x4000 0BFF	TIM4	
	0x5000 0400 - 0x5000 07FF	0x4000 0400 - 0x4000 07FF	TIM3	
	0x5000 0000 - 0x5000 03FF	0x4000 0000 - 0x4000 03FF	TIM2	

2.3.3 Embedded SRAMs

The devices feature:

- 256-Kbyte SRAM1
- 128-Kbyte SRAM2
- 384-Kbyte SRAM3
- 384-Kbyte SRAM4
- 384-Kbyte SRAM5
- 4-Kbyte BKPSRAM

The SRAMs can be accessed as bytes, half-words (16 bits), or full words (32 bits).

The memories can be addressed both by CPU and DMAs. The CPU can access the SRAM1/2/3/4/5 through the system bus or through the C-bus, depending on the selected address. The CPU can access the BKPSRAM only through the system bus.

When the TrustZone security is enabled, all SRAMs are secure after reset. The SRAMs can be programmed as nonsecure with a block granularity. For more details, refer to *Section 5: Global TrustZone® controller (GTZC)*.

SRAM features are detailed in*Section 6.3.1: Internal SRAM features*.

2.3.4 Flash memory overview

The flash memory is composed of two distinct physical areas:

- The main memory block, which contains the application program and user data.
- The information block is composed of the following parts:
  - Option bytes for hardware and memory protection user configuration
  - System memory, with the ST proprietary code
  - OTP (one-time programmable) area

The flash interface implements instruction and data access based on the AHB protocol. It also implements the logic necessary to carry out the program/erase operations controlled through the FLASH registers plus security access control features. Refer to *Section 7: Embedded flash memory (FLASH)* for more details.

2.3.5 Boot modes

At startup, the core jumps to the boot address configured through the BOOT0 pin, the BOOT_ADDR option bytes, the TZEN option bit, the debug request, and the product state.

If BOOT_ADDR is not yet configured, dedicated libraries (programmed during ST production), can be used for secure boot. They are located in system flash memory:

- ST libraries in system flash memory assist the application software boot with special features such as secure boot and secure firmware install (SFI-RSS).
- ST iROT (immutable root of trust) secure software in user flash memory is used for secure firmware update and provisioning (SFU).

If a debugger is attached to the product, the entry point is a debug authentication policy, used to unlock the device when attached to the debugger. A digital signature must be provided to perform a regression to the product state, where debug is allowed.

Embedded bootloader

The embedded bootloader is located in the system memory, programmed by ST during production. Refer to the application note *STM32 microcontroller system memory boot mode (*AN2606*)*.

3 System security

The STM32H5 devices are designed with a comprehensive set of security features, some of them based on the standard Arm TrustZone® technology.

These security features simplify the process of evaluating IoT devices against security standards. They also significantly reduce the cost and complexity of software development for OEM and third-party developers, by facilitating the reuse, improving the interoperability, and minimizing the API fragmentation.

This section explains the different security features available on the devices.

3.1 Key security features

- Resource isolation using privilege mode and Armv8-M mainline security extension of Cortex-M33, extended to securable I/Os, memories, and peripherals
- Secure firmware installation (SFI) with device unique cryptographic key pair
  - Leveraging the on-chip immutable bootloader that supports the image download through USART, OTG_FS, OTG_HS, I2C, I3C, and JTAG.
- Boot entry: the platform makes it possible to select between a native immutable root of trust or a proprietary boot entry (in user flash memory).
- Security services (in system flash): the platform comes with native security services, embedded in the system memory to manage the root of trust services. Native root of trust services takes care of: platform security including secure boot, secure updates of the next boot level (uROT: updatable root of trust), and secure debug control (debug reopening, regression control). The services can be personalized for each OEM, using the provisioning tools.
- Temporal isolation: boot levels are isolated thanks to the HDPL (hide protect level) monotonic counter.
- Secure storage, featuring:
  - Five nonvolatile areas dedicated to secure storage, protected with HDPL, and TrustZone
  - Battery-powered volatile secure storage, automatically erased in case of tamper
  - Write-only key registers in the AES engines
  - Device 96-bit unique ID and JTAG 32-bit device-specific ID
  - Secure storage can rely upon the SAES engine to encrypt the stored data, to the benefit of DHUK properties. All data encrypted with the DHUK benefit of temporal and runtime isolation (HDPL and TrustZone), RHUK, EPOCH (version counter) properties.

  a) Data are isolated: all data encrypted/decrypted relying upon the SAES+DHUK benefit of the variation of the DHUK for each different isolated area (HDPL0, HDPL1, HDPL2, HDPL3S, HDPL3NS).

  b) RHUK: hardware secret nonvolatile, unique per device keys (copy protection).

  c) EPOCH: counter incremented each time a regression is done (antirollback).
- General purpose cryptographic acceleration
  - AES 256-bit engine, supporting ECB, CBC, CTR, GCM, and CCM chaining modes

  - Secure AES 256-bit security coprocessor, supporting ECB, CBC, CTR, GCM, and CCM chaining modes with side-channel countermeasures and mitigations
  - HASH processor, supporting SHA-1 checksums and SHA-2 secure hash (SHA2, SHA2-384, SHA2-512), and SHA-3
  - Public key accelerator (PKA) for RSA/DH (up to 4096 bits) and ECC (up to 640 bits), implementing side-channel counter measures, and mitigations when manipulating secrets
  - True random number generator (RNG), NIST SP800-90B precertified
  - Coupling and chaining bridge (CCB) for special coupling and chaining operations (involving PKA, SAES, RNG peripherals) to protect private keys used in PKA protected operations
- Two on-the-fly decryption (OTFDEC1, OTFDEC2) of encrypted image stored on external flash memory connected respectively to OCTOSPI1 and OCTOSPI2
  - Almost-zero latency with standard NOR flash memories
  - Can be used to encrypt the image using the device unique secret keys
  - Automatic key-erase in case of tamper
- New flexible life cycle scheme
  - Allows product maintenance in-the-field (debug reopening or regressions)
  - Allows protected firmware distribution in up to three steps: immutable root of trust, secure and nonsecure application
- Active tamper and protection against temperature, voltage, and frequency attacks
  - Up to eight active inputs, eight active output tamper pins, available in different power modes (refer to TAMP low-power modes)

3.2 Secure install

The secure firmware install (SFI) is an immutable secure service embedded by STMicroelectronics in the devices. The SFI allows secure and counted installation of OEM firmware in an untrusted production environment (such as the OEM contract manufacturer).

The confidentiality of the installed images written in the internal flash memory or encrypted in an external flash memory, is also protected, using the AES.

The SFI native service leverages the following hardware security features:

- Secure boot (see *Section 3.3*)
- Resource isolation using TrustZone (see *Section 3.6*)
- Temporal isolation using hide protection (see *Section 3.7.1*)
- Secure execution (see *Section 3.8*)
- Secure storage, with associated cryptographic engines (see *Section 3.9* and *Section 3.10*) and flash memory dedicated areas

Further information can be found in AN4992 “Introduction to secure firmware install (SFI) for STM32 MCUs”.

3.3 Secure boot

Secure boot is an immutable code that is always executed after a system reset. As a root of trust, this code checks the device static protections and activates available device runtime protections, reducing the risk of invalid or malicious code running on the platform. As root of trust, the secure boot also checks the integrity and authenticity of the next level firmware before executing it.

The device offers two options (using BOOT_UBE) to execute the immutable code after a reset:

- Security services when ST-iROT (code natively present in the system memory) is selected managing the secure boot of the next boot level. ST-iROT takes care of the next level of integrity, authenticity using configuration done by OEMs. The next stage can be an ST updatable service (ST-uROT), or a proprietary one (uROT)
- Proprietary boot entry when the OEM manages the full chain (OEM-iROT), to be installed in user flash memory with proper security activation.

The actual functions of the secure boot depend on the availability of TrustZone features, and on the firmware stored in the device. The secure boot typically initializes the secure storage, and installs on-the-fly decryption keys in the OTFDEC, to be able to use encrypted firmware stored in an external flash memory.

TrustZone application, supported by the STM32 ecosystem, provides a root of trust solution, including secure boot functions.

In the devices, the secure boot benefits of hardware security features:

- Resource isolation using TrustZone (see *Section 3.6*)
- Temporal isolation using hide protection levels (HDPL) (see *Section 3.7.1*)
- Secure execution (see *Section 3.8*)
- Secure install and update (see *Section 3.2* and *Section 3.4*)
- Per domain secure storage, with associated cryptographic engines if available (see *Section 3.9* and *Section 3.10*)

This section describes the features specifically designed for the secure boot.

3.3.1 Unique boot entry

Thanks to the unique boot entry (BOOT_UBE), it is possible to select the boot entry point between security services in the system flash (ST-iROT) and the proprietary boot entry (OEM-iROT). This selection is possible only for products embedding cryptographic acceleration (STM32H5Fxxx), when TrustZone is enabled (TZEN = 0xB4).

When TrustZone is enabled and the SECBOOT_LOCK secure option bit is cleared, the application selects a boot entry point located either in the system flash memory (see the next section), or in the secure user flash memory, at the address defined by the SECBOOTADD option bytes.

When TrustZone is enabled and the SECBOOT_LOCK secure option bit is set, the device unique boot entry is the unmodifiable secure address defined by the SECBOOTADD option bytes. The application cannot modify these option bytes when the SECBOOT_LOCK is set.

When the TrustZone is disabled (TZEN = 0xC3) and the NSBOOT_LOCK option bit is cleared, the application selects a boot entry point located in the nonsecure user flash memory, at the address defined by the NSBOOTADD option bytes.

When the TrustZone is disabled and the NSBOOT_LOCK option bit is set, the device unique boot entry is the unmodifiable nonsecure address defined by the NSBOOTADD option bytes. The application cannot modify these option bytes when NSBOOT_LOCK is set.

Note: SECBOOT_LOCK and NSBOOT_LOCK can be changed only when PRODUCT_STATE = Open, Provisioning, or Regression.

For more information on the boot mechanisms, refer to *Section 4: Boot modes*.

3.3.2 Immutable root of trust in system flash memory

The immutable root-of-trust code stored in the system flash memory is first used to perform SFI, allowing secure and counted installation of OEM firmware in untrusted production environments (such as the OEM contract manufacturer).

The immutable code also includes secure runtime services that can be called at runtime, when a secure application sets the SBS_RSSCMDR register to a non-null value, before triggering a system reset. This runtime feature is deactivated when the BOOT_LOCK secure option bit is set or when the PRODUCT_STATE is different from “Open”.

The STM32H5 products feature ST-DA (debug authentication), to manage the debug authentication control feature, allowing to control the debug reopening and regressions of the product for after sales (field return) of the product.

The products embedding cryptographic acceleration feature ST-iROT (immutable root of trust), to handle the secure provisioning, secure boot, secure updates of the first updatable level of the platform.

3.4 Secure update

The secure firmware update is a secure service that runs after a secure boot. Its actual functions depend on the availability of the TrustZone features, and on the firmware stored in the device.

Cortex-M based application processors are commonly used to run trusted boot and a trusted OS to create a Trusted Execution Environment (TEE). The trusted boot and TEE application, supported by the STM32 ecosystem, allow the update of the microcontroller built-in program with new firmware versions, adding new features and correcting potential issues. The update process is performed in a secure way, to prevent unauthorized updates and access to confidential on-device data.

A firmware update can be done either on a single firmware image including both secure and nonsecure parts, or on the secure (respectively nonsecure) part of the firmware image, independently.

In the devices, the secure update application leverages the same hardware security as the firmware install described in *Section 3.2*.

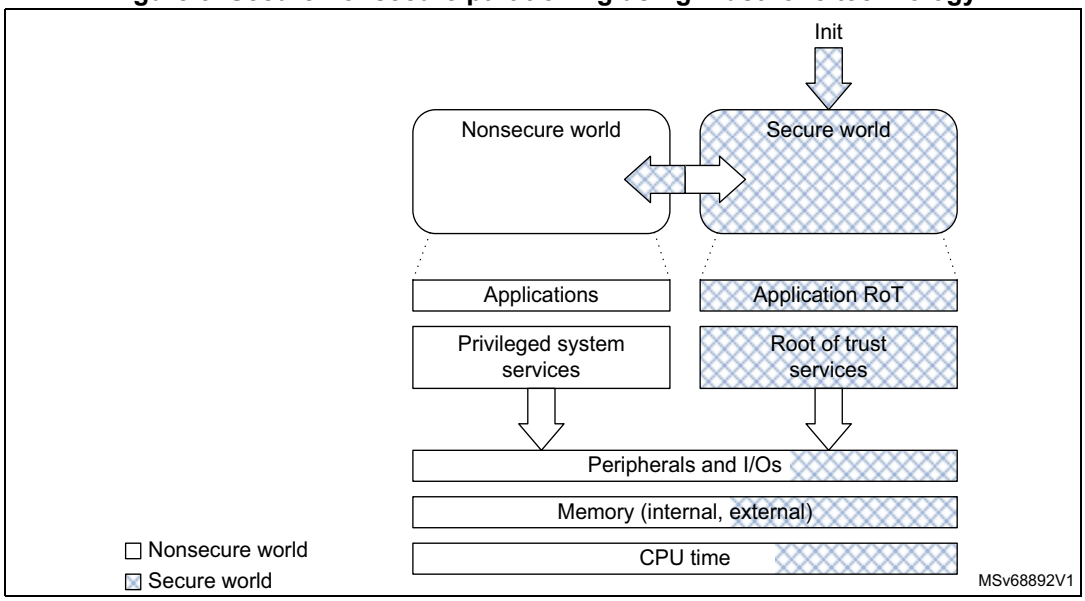
3.5 Resource isolation using hide protection levels

The hardware and software resources used to boot can be isolated. This is called temporal isolation, based on a monotonic counter, taking care of incrementing the levels. When the counter is incremented, the resources (code and data) of the previous levels are hidden.

3.6 Resource isolation using TrustZone

The hardware and software resources can be partitioned so that they exist in the secure or in the nonsecure world, as shown in *Figure 3*.

Figure 3. Secure/nonsecure partitioning using TrustZone technology



Note: The initial partitioning of the platform is under the responsibility of the secure firmware executed after device reset.

Thanks to this resource isolation technology, the secure world can be used to protect critical code against intentional or unintentional tampering from the more exposed code running in the nonsecure world.

Note: The secure code is typically small and rarely modified, while the nonsecure code is more exposed, and prone to firmware updates.

3.6.1 TrustZone security architecture

The Armv8-M TrustZone technology is a comprehensive hardware architecture that proposes to developers a comprehensive, holistic protection across the entire processor and system. The device TrustZone hardware features include:

- The Armv8-M mainline security extension of Cortex-M33, enabling a new processor secure state, with its associated secure interrupts
- The dynamic allocation of memory and peripherals to TrustZone using eight security attribution unit (SAU) regions of Cortex-M33
- A global TrustZone framework (GTZC), extending the TrustZone protection against transactions coming from masters in the system different from the Cortex-M33
- TrustZone-aware embedded flash memory and peripherals

Note: The TZEN option bit in the FLASH_OPTSR2_PRG register activates TrustZone security.

3.6.2 Armv8-M security extension of Cortex-M33

The Arm security extension of the Cortex-M33 is an evolution, not a revolution. It uses the programmer model from earlier Cortex-M subfamilies like Cortex-M4. Indeed, Armv8-M is architecturally similar to Armv7-M, using the same 32-bit architecture, the same memory mapped resources protected with an MPU. Armv8-M also uses the nested vectored interrupt controller (NVIC).

The implementation on STM32H5 devices is composed of the following features:

- A new processor state, with almost no additional code/cycle overhead (as opposed to Armv8-A TrustZone) that uses a dedicated exception routine to trigger a secure/nonsecure world change
- Two memory map views of a shared 4-Gbyte address space
- A low interrupt latency for both secure and nonsecure domains, and a new interrupt configuration for security grouping and priority setting
- Separated exception vector tables for the secure and nonsecure exceptions
- Microcoded context preservation
- Banking of specific registers across secure/nonsecure states, including stack pointers with stack-limit checkers
- Banking of the following *Cortex*®-M33 programmable components (two separate units for secure and nonsecure):
  - SysTick timer
  - MPU configuration registers (12 MPU regions in secure, eight in nonsecure)
  - Some of the system control block (SCB) registers
- New system exception (SecureFault) for handling of security violations
- Configurable debug support, as defined in *Section 3.12*

For more information, refer to the Cortex-M33 programming manual (PM0264).

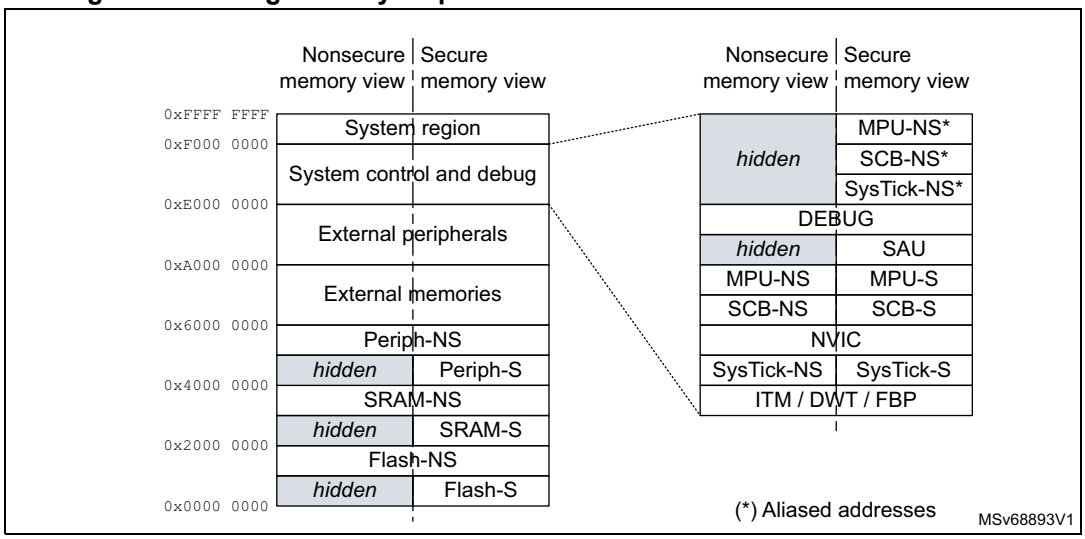
3.6.3 Memory and peripheral allocation using IDAU/SAU

Security attributes

As illustrated in *Figure 4*, the Armv8-M nonsecure memory view is similar to Armv7-M (found in Cortex-M4), with the difference that the secure memory is hidden. The secure memory view shows the flash memory, SRAM, and peripherals that are accessible only while the Cortex processor executes in a secure state.

Note: Figure 4 shows the 32-bit address space after SAU configuration, as viewed by the secure code.

Figure 4. Sharing memory map between CPU in secure and nonsecure state

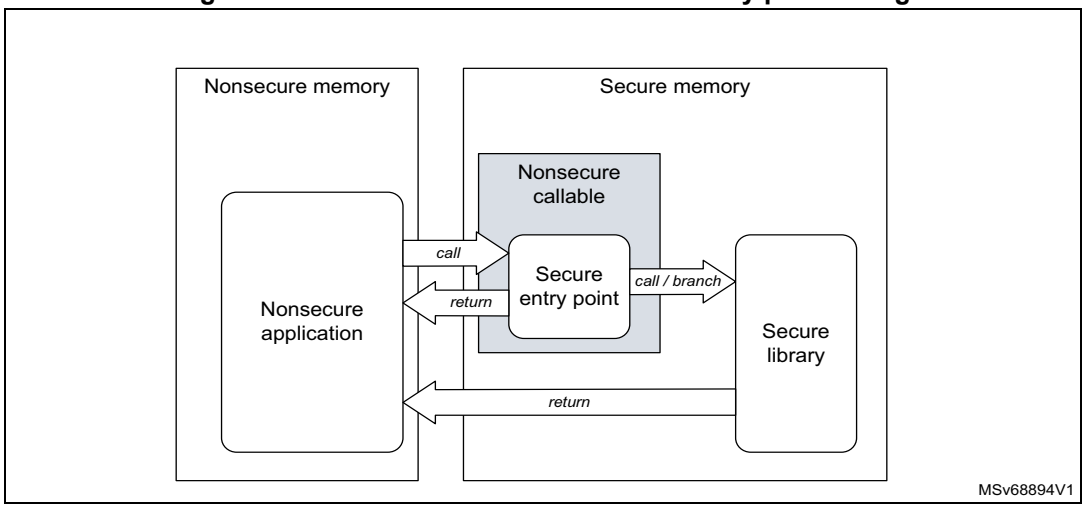


The Cortex processor state (and the associated rights) depends upon the security attribute assigned to the memory region where it is executed:

- A processor in a nonsecure/secure state executes only from nonsecure (NS)/secure (S) program memory.
- When running in a secure state, the processor can access data from both S and NS memories. When running in a nonsecure state, the CPU is limited to nonsecure memories.

To manage transitions to the secure world, developers must create nonsecure callable (NSC) regions containing valid entry points to the secure libraries. The first instruction in these entry points must be the new secure gate (SG) instruction, used by the nonsecure code to call a secure function (see *Figure 5*).

Figure 5. Secure world transition and memory partitioning



Programming security attributes

In *Cortex*®-M33, the static implementation defined attribution unit (IDAU) works with the programmable security attribution unit (SAU) to assign a specific security attribute (S, NS, or NSC) to a specific address, as shown in *Table 4*.

Table 4. Configuring security attributes with IDAU and SAU

IDAU security attribution	SAU security attribution(1)	Final security attribution
Nonsecure	Secure	Secure
	Secure-NSC	Secure-NSC
	Nonsecure	Nonsecure
Secure-NSC	Secure	Secure
	Nonsecure	Secure-NSC

1. Defined regions are aligned to 32-byte boundaries.

The *Cortex*®-M33 can configure the SAU only in the secure-privilege state. When the TrustZone is enabled, the SAU defaults all addresses as secure (S). A secure boot application can then program the SAU to create NSC or NS regions, as shown in *Table 4*.

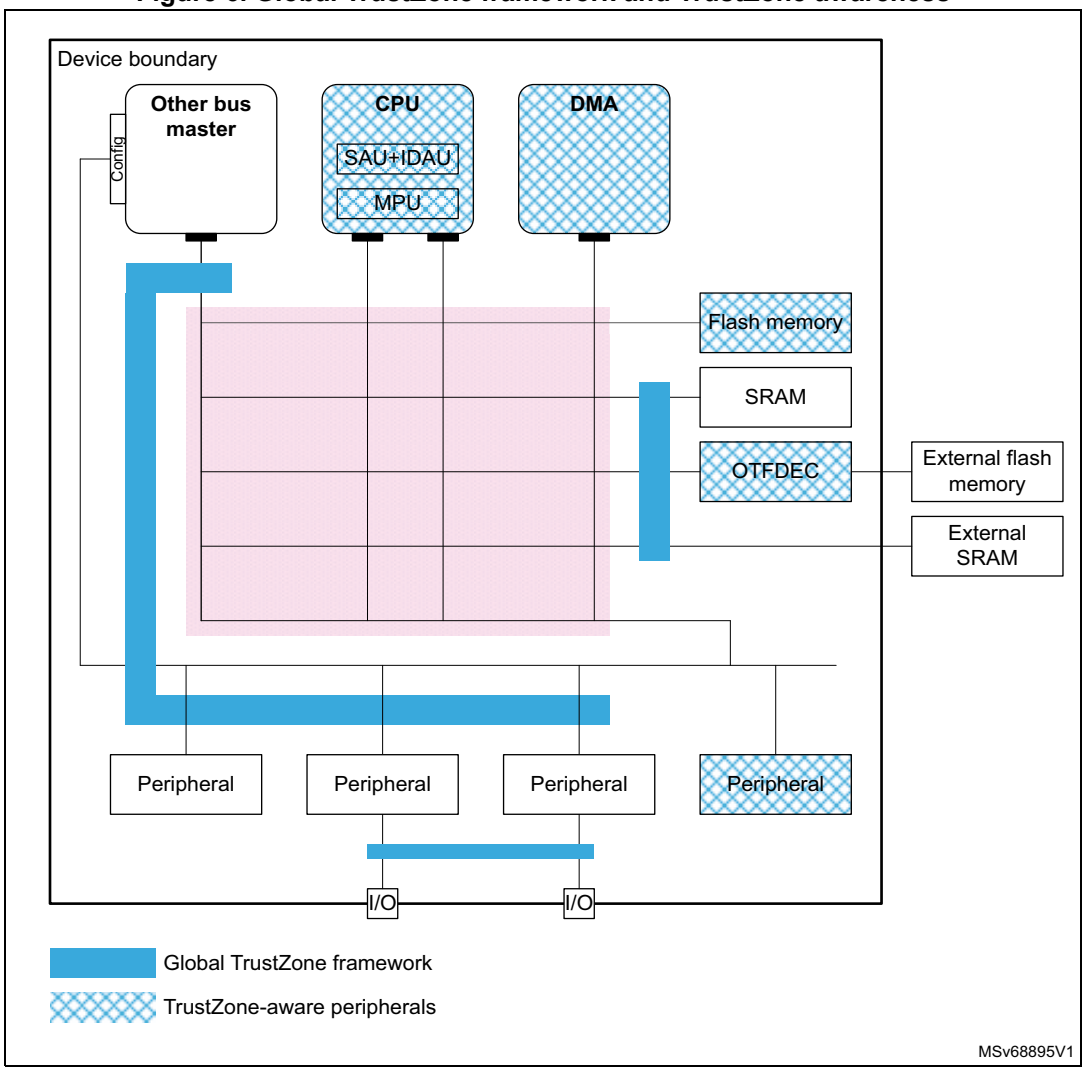
Note: The SAU/IDAU settings are applicable only to the Cortex®-M33. The other masters, like DMA, are not affected by these policies.

3.6.4 Memory and peripheral allocation using GTZC

Global TrustZone framework architecture

On top of the Armv8-M TrustZone security extension in the *Cortex*®-M33, the devices embed complementary security features that reinforce, in a flexible way, the isolation between secure and nonsecure worlds. Unlike the SAU/IDAU, the GTZC can protect legacy memories and peripherals against nonsecure transactions coming from other masters than the *Cortex*®-M33.

Figure 6. Global TrustZone framework and TrustZone awareness



Securing peripherals with TZSC

When the TrustZone security is active, a peripheral is either securable through the GTZC, or is natively TrustZone-aware, as shown in the previous figure:

- A securable peripheral or memory is protected by an AHB/APB firewall gate, controlled by the TrustZone security controller (TZSC).
- A TrustZone-aware peripheral or memory is connected directly to the AHB or APB interconnect, implementing a specific TrustZone behavior, such as a subset of secure registers or a secure memory area.

When a securable peripheral is made secure-only with the GTZC, if this peripheral is master on the interconnect, it automatically issues secure transactions. The SDMMC is an example of a securable master. TrustZone-aware AHB masters like Cortex®-M33 or DMAs, drive a secure signal in the AHB interconnect, according to their security mode, independently of the GTZC.

Note: Like with TrustZone, a peripheral can be made privileged-only with TZSC (see Section 3.7.2). In this case, if this peripheral is master on the interconnect, it automatically issues privileged transactions.

Securing memories with TZSC and MPCBB

The TZSC block in GTZC provides the capability to manage the security and privilege for all securable external memories, programming the MPCWM resources as defined in *Table 5*.

Table 5. MPCWMx resources

Memory	MPC resource	Type of filtering	Number of regions	Default security	On-the-fly decryption(1)
OCTOSPI1	MPCWM1	Nonsecure privileged or unprivileged region (watermarks)	2	Secure privileged(2)	Yes
OCTOSPI2	MPCWM5		2		
FMC_NOR bank	MPCWM2		2		No
FMC_NAND / FMC_SDRAM bank	MPCWM3		1		
Backup SRAM (BKPSRAM)/FMC_SDRAM	MPCWM4		1		

1. Using the OTFDEC.
2. Assuming TrustZone is activated on the device, nonsecure unprivileged otherwise.

The MPCBB resources in GTZC provide the capability to configure the security and privilege of embedded SRAM blocks, as defined in *Table 6*.

Table 6. MPCBBx resources

Memory	MPC resource	Type of filtering	Memory size	Block size	Number of super-blocks	Default security
SRAM1	GTZC1_MPCBB1	Block based, managing security and privilege	256 KB	512(1) bytes	16	Secure privileged(2)
SRAM2	GTZC1_MPCBB2		128 KB		8	
SRAM3	GTZC1_MPCBB3		384 KB		24	
SRAM4	GTZC1_MPCBB4		384 KB		24	
SRAM5	GTZC1_MPCBB5		384 KB		24	

1. Blocks are grouped in superblocks of 32 consecutive blocks, to manage the configuration locking.
2. Assuming TrustZone is activated on the device, nonsecure unprivileged otherwise.

Applying GTZC configurations

The TZSC and MPCBB blocks can be used in one of the following ways:

- Statically programmed during the secure boot, locked and not changed afterwards
- Dynamically reprogrammed using a specific application code or real-time kernel

When the dynamic option is selected and the configuration is not locked:

- MPCBB secure blocks or MPCWM nonsecure region size can be changed by a secure software. This software must be privileged for MPCWM, can be unprivileged if the particular block is not privileged-only.
- The secure (respectively privilege) state of each peripheral can be changed writing to GTZC_TZSC_SECCFRGx (respectively GTZC_TZSC_PRIVCFGRx) registers.

Securing peripherals with TZSC

The TZSC block in GTZC provides the capability to manage the security and the privilege for all securable peripherals. The list of these peripherals can be found in *Section 5: Global TrustZone® controller (GTZC)*.

Note: When the TrustZone is deactivated, the resource isolation hardware GTZC can still be used to isolate peripherals to privileged code only (see Section 3.7.2).

When the TrustZone is activated, peripherals are set as nonsecure and unprivileged after reset.

TrustZone-aware peripherals

The devices include the following TrustZone-aware peripherals:

- GPIOA to GPIOK
- GTZCx_MPCBB, GTZCx_TZIC, and GTZCx_TZSC (GTZC blocks)
- OTFDEC1/OTFDEC2, writable only in secure if TZEN is enabled
- EXTI
- Flash memory
- RCC and PWR
- GPDMA1 and GPDMA2
- SBS registers
- RTC and TAMP
- MCU debug unit DBGMCU
- PLAY1

The way illegal access to those peripherals are monitored through the TZIC registers is described in *Section 5: Global TrustZone® controller (GTZC)*.

For more details, refer to *Section 3.6.5*.

TrustZone illegal access controller (TZIC)

The TZIC block in GTZC gathers all illegal access events originated from sources either protected by GTZC or TrustZone-aware, generating one global secure interrupt towards the NVIC.

TZIC is available only when the system is TrustZone enabled (TZEN = 0xB4). All access to TZIC registers must be secured.

For each illegal event source, a status flag and a clear bit exist. Each illegal event can be masked, not generating an interrupt toward the NVIC.

Note: By default, all events are masked.

3.6.5 Managing security in TrustZone-aware peripherals

This section gives more details on how the security is implemented in the TrustZone-aware peripherals listed in the previous section.

Embedded flash memory

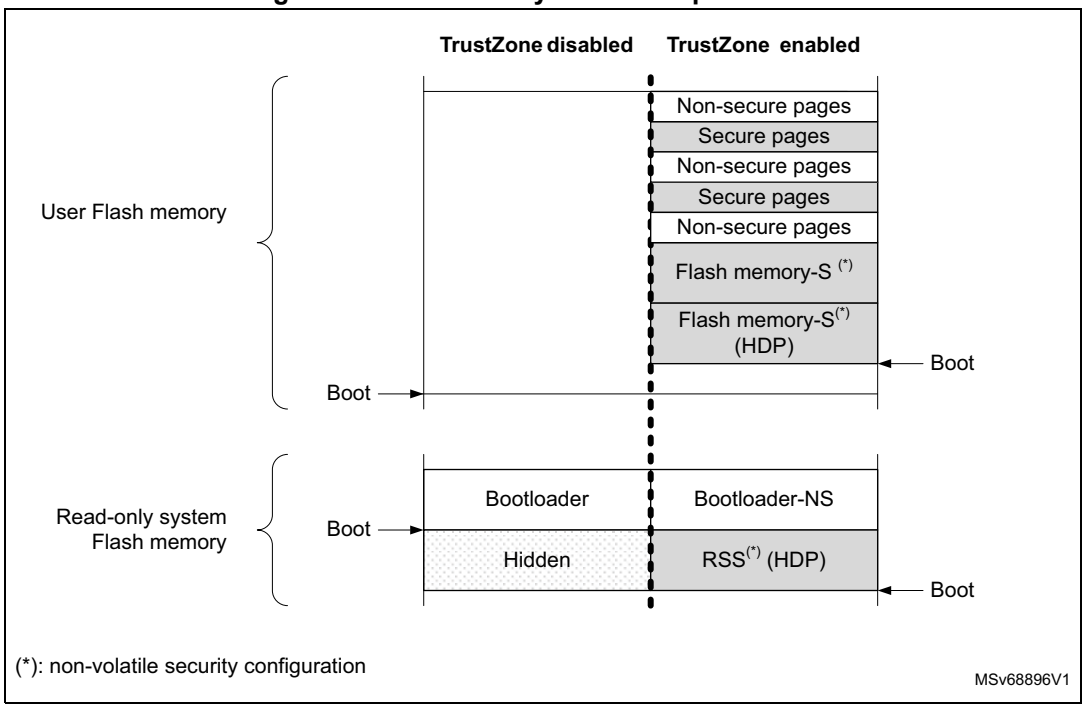
When the TrustZone security is enabled through option bytes (TZEN = 0xB4), the whole memory is secure after reset. The following protections, shown in *Figure 7*, are available to the application:

- Nonvolatile user secure areas, defined with nonvolatile secure user option bytes
  - Watermark-based secure only area (x2)
  - Secure hide protection (HDP) area, stickily hidden after boot (x2)
- Volatile user secure pages, defined with volatile secure registers (lost after reset)
  - Any page set as nonsecure (example: outside the watermark-based secure only area), can be set as secure on-the-fly using the block-based configuration registers.

Note: All areas are aligned on the page granularity of the flash memory, which can be configured as secure while it is tagged as nonsecure in Cortex®-M33 IDAU/SAU. In this case, nonsecure accesses by the CPU to the flash memory are denied.

Erase or program operations can be available to secure/nonsecure code only for secure/ nonsecure pages or memory. A flash memory is considered secure if at least one page is secure.

Figure 7. Flash memory TrustZone protections



As shown above, when TrustZone is enabled (TZEN = 0xB4), the application code can use the HDP area that is part of the flash memory watermark-based secure area. Indeed, when the application sets the HDPx_ACCDIS bit, data read, write, and instruction fetch on this HDP area is denied until the next system reset.

For example, the software code in the secure flash memory HDP area can be executed only once, with any further access to this area denied until the next system reset. Additionally, any flash memory page belonging to an active HDP area cannot be erased anymore.

When the TrustZone is disabled (TZEN = 0xC3), the volatile/non-volatile secure area features are deactivated and all secure registers are RAZ/WI.

See *Section 7: Embedded flash memory (FLASH)* for more details.

On-the-fly encryption/decryption (OTFDEC1, OTFDEC2)

When the TrustZone security is enabled (TZEN = 0xB4), the OTFDEC1 or OTFDEC2 can be initialized only by the secure applications. Each of the four encrypted regions, once the configuration is confirmed, can be write-locked until the next power-on-reset.

Note: Any application (secure or nonsecure) can verify the initialization context of each OTFDEC region (including the CRC of the keys), by reading the peripheral registers.

Key registers in each OTFDEC are write-only.

See *Section 3.10.3* for more details on this cryptographic engine.

Direct memory access controllers (GPDMAx)

When a DMA channel x is defined as secure (SECx = 1 in GPDMA_SECCFGR), the source and destination transfers can be independently set as secure or nonsecure by a secure application using SSEC and DSEC bits in GPDMA_CxTR1. *Table 7* summarizes these security options available in each DMA channel.

Table 7. DMA channel use (security)(1)

Destination type	Secure DMA channel x (SECx = 1)		Nonsecure DMA channel y (SECy = 0)	
	Secure source	Nonsecure source	Secure source	Nonsecure source
Secure destination	OK	OK(2)	Transfer blocked	
Nonsecure destination	OK(3)	OK(4)	Transfer blocked	OK

1. When a transfer is blocked, the transfer completes but the corresponding writes are ignored, and reads return 0s. An illegal access event to TZIC is automatically triggered by the memory/peripheral used as the source or destination.
2. If the source is a memory, the transfer is possible only if SSEC = 0, otherwise the transfer is blocked.
3. If the destination is a memory, the transfer is possible only if DSEC = 0, otherwise the transfer is blocked.
4. If the transfer is memory-to-memory, it is possible only if SSEC = 0 and DSEC = 0, otherwise it is blocked.

When a channel is configured as secure:

- Registers allocated to this channel (excluding GPDMA_SECCFGR, GPDMA_PRIVCFGR and GPDMA_RCFGLOCKR) are read as 0. Writes are ignored for nonsecure access. A secure illegal access event may also be triggered towards the TZIC peripheral.
  - Writes to GPDMA_SECCFGR and GPDMA_RCFGLOCKR must be secure. For each bit in GPDMA_PRIVCFGR, write must be secure if the corresponding bit in GPDMA_SECCFGR is set.
- In linked-list mode, the loading of the next linked-list data structure from memory is performed with secure transfers.
- When switching to a nonsecure state, the secure application must abort the channel or wait until the secure channel is completed before doing the switch.

Note: DMA secure channels are not available when TrustZone is deactivated. When a channel is configured as nonsecure, in linked-list mode, the loading of the next linked-list data structure from memory is performed with nonsecure transfers.

See *Section 16: General purpose direct memory access controller (GPDMA)* for more details.

Power control (PWR)

When the TrustZone security is enabled (TZEN = 0xB4), the selected PWR registers can be secured through PWR_SECCFGR, protecting the following PWR features:

- Low power mode setup
- Wake-up (WKUP) pins definition
- Voltage detection and monitoring
- Backup domain control

Other PWR configuration bits become secure:

- When the system clock selection is secure in the RCC: the voltage scaling (VOS) becomes secure.
- When a GPIO is configured as secure: its corresponding bit for pull-up/pull-down configuration in Standby mode becomes secure.
- When the USB Type-C/USB power delivery interface (UCPD) is configured as secure in TZSC: PWR_UCPDR register becomes secure.

See *Section 10: Power control (PWR)* for details.

Secure clock and reset (RCC)

When the TrustZone security is enabled (TZEN = 0xB4) and security is enabled in the RCC, the bits controlling the peripheral clocks and resets become TrustZone-aware:

- If the peripheral is securable and programmed as secure in the TZSC, the peripheral clock and reset bits become secure.
- If the peripheral is TrustZone-aware, the peripheral clock and reset bits become secure when at least one function is configured as secure inside the peripheral.

Note: Refer to Section 3.6.4 for the list of securable and TrustZone-aware peripherals.

Additionally, the following configurations can be made secure-only using RCC_SECCFGR:

- External clock (such as HSE or LSE), internal oscillator (such as HSI, CSI, or LSI)
- Main PLL and AHB prescaler
- System clock source selection
- MCO clock output
- Reset flag
- Automatic internal oscillator waking up configuration

See *Section 11: Reset and clock control (RCC)* for details.

Real-time clock (RTC)

Like all TrustZone-aware peripherals, a nonsecure read/write access to a secured RTC register is RAZ/WI. It also generates an illegal access event that triggers a secure illegal access interrupt if the RTC illegal access event is enabled in the TZIC.

After a backup domain power-on reset, all RTC registers can be read or written in both secure and nonsecure modes. The secure boot code can then change the security setup, making registers Alarm A, Alarm B, wakeup timer, and timestamp secure or not, using RTC_SECCFGR.

When the SEC bit is set in secure-only RTC_SECCFGR:

- Writing the RTC registers is possible only in secure mode.
- Reading RTC_SECCFGR, RTC_PRIVCFGR, RTC_MISR, RTC_TR, RTC_DR, RTC_SSR, RTC_PRER, and RTC_CALR is always possible in secure and nonsecure modes. All the other RTC registers can be read only in secure mode.

When the SEC is cleared in secure-only RTC_SECCFGR, it is still possible to restrict access in secure mode to some RTC registers by setting dedicated control bits: INITSEC, CALSEC, TSSEC, WUTSEC, ALRASEC, and ALRBSEC.

Note: The RTC security configuration is not affected by a system reset.

See *Section 57: Real-time clock (RTC)* for more details.

Tamper and backup registers (TAMP)

Like all TrustZone-aware peripherals, a nonsecure read/write access to a secured TAMP register is RAZ/WI. It also generates an illegal access event that triggers a secure illegal access interrupt if the TAMP illegal access event is enabled in the TZIC.

After a backup domain power-on reset, all TAMP registers can be read or written in both secure and nonsecure modes. The secure boot code can change this security setup, making some registers secure or not as needed, using the TAMP_SECCFGR register.

When TAMPSEC is set in TAMP_SECCFGR:

- Writing the TAMP registers is possible only in secure mode. Backup registers have their own write protection (see below).
- Reading the TAMP registers (exception TAMP_SECCFGR, TAMP_PRIVCFGR, and TAMP_MISR) returns 0 if the access is nonsecure. Backup registers have their own read protection (see below).

The application can also:

- Make TAMP_COUNTR register read and write secure-only by setting the CNT1SEC bit in TAMP_SECCFGR secure register
- Increase security in backup registers for two of the three protection zones configured using BKPRWSEC[7:0] and BKPWSEC[7:0] bitfields in TAMP_SECCFGR:
  - Protection zone 1 is read nonsecure and write nonsecure
  - Protection zone 2 is read nonsecure and write secure
  - Protection zone 3 is read secure and write secure

Note: The TAMP security configuration is not affected by a system reset.

See *Section 58: Tamper and backup registers (TAMP)* for more details.

General-purpose I/Os (GPIO)

When the TrustZone security is enabled (TZEN = 0xB4), each I/O pin of the GPIO ports can be individually configured as secure through the GPIOx_SECCFGR registers. Only a secure application can write to GPIOx_SECCFGR registers. After boot, each I/O pin is set as secure.

When an I/O pin is configured as secure, its corresponding configuration bits for alternate function (AF), mode selection (MODE), and I/O data are RAZ/WI in case of nonsecure access.

When a digital alternate function is used (input/output mode) to protect data transiting from/to the I/O managed by a secure peripheral, the devices add a secure alternate function gate on the path between the peripheral and its allocated I/Os:

- If the peripheral is secure, the I/O pin must also be secure to allow input/output of data
- If the peripheral is not secure, the connection is allowed regardless of the I/O pin state.

The TrustZone-aware logic around GPIO ports, used as alternate functions, is summarized in *Table 8*.

Table 8. Secure alternate function between peripherals and allocated I/Os

Security configuration		Alternate function logic		Comment
Peripheral	**Allocated I/O pin**	**Input**	**Output**	
Secure	Secure	I/O data	Peripheral data	-
Nonsecure				Out of reset configuration
Secure	Nonsecure	0	0	-
Nonsecure		I/O data	Peripheral data	

When an analog function with an analog switch is used, the connection to the peripherals listed in *Table 9* is blocked by hardware when the peripheral is nonsecure and the I/O is secure.

Table 9. Nonsecure peripheral functions that cannot be connected to secure I/Os

Peripheral	Analog function(1)	Input	Output
ADC12	ADC12_INP/INN	X	-
ADC3	ADC3_INP	X	-
COMP1/2	COMP1/2_INP/INM	X	-
OPAMP1	OPAMP1_VINM/VINP	X	-

1. Used to find the I/O corresponding to the signal/function on the package (refer to the product datasheet).

Finally, regarding GPIO and security, *Table 10* summarizes the list of I/Os without any hardware protection linked to TrustZone. The listed signals (input and/or outputs) are not blocked when the I/O is set as secure, and the associated peripheral is nonsecure.

For example, when a secure application sets PA4 as secure to be used as LPTIM2_CH1, if the DAC is nonsecure, it can be programmed to output data to PA4, potentially causing malfunction to the secure application.

Similarly, when a secure application sets PA0 as secure to be used as UART4_TX, if TAMP is nonsecure, it can be programmed to capture the USART input traffic through the TAMP_IN signal.

It is important that, for each case described in *Table 10*, the secure application decides if a potential effect on data integrity or confidentiality is critical or not. For example, if the USART situation described above is not acceptable (data transiting on secure USART is confidential), then the secure application must configure the TAMP as secure even if not used by the secure application.

Table 10. Nonsecure peripheral functions that can be connected to secure I/Os

Peripheral	Signal(1)	Input	Output	How to set the peripheral or function as secure
DAC1	DAC1_OUTx (x = 1, 2)	-	X	Set DAC1SEC in GTZC1_TZSC_SECCFGR1.
UCPD1	UCPD1_CCx (x = 1, 2)	X	X	Set UCPD1SEC in GTZC1_TZSC_ SECCFGR1.
	UCPD1_DBx (x = 1, 2)	X	-	
TAMP	TAMP_INx (x = 1 to 8)	X	-	Set TAMPSEC in TAMP_SECCFGR
	TAMP_OUTx (x = 1 to 8)	-	X	
RTC	RTC_OUTx (x = 1, 2)	-	X	Set SEC in RTC_SECCFGR.
	RTC_TS	X	-	Set TSSEC in RTC_SECCFGR.
PWR	WKUPx (x = 1 to 8)	X	-	Set WUPxSEC in PWR_SECCFGR.
RCC	LSCO	-	X	Set LSESEC in RCC_SECCFGR.
EXTI	EXTIx (x= 0 to 66)	X	-	Set SECx bit in EXTI_SECCFGR.

1. To find the I/O corresponding to the signal/function on the package, refer to the product datasheet.

Refer to *Section 13: General-purpose I/Os (GPIO)* for more details.

Extended interrupts and event controller (EXTI)

When the TrustZone security is enabled, the EXTI is able to protect event register bits from being modified by nonsecure accesses. The protection can individually be activated per input event via the register bits in EXTI_SECCFGRx. When an input event is configured as secure, only a secure application can change the configuration (including security), change the masking or clear the status of this input event.

The security configuration in EXTI_SECCFGR1 and EXTI_SECCFGR2 can be globally locked after reset in EXTI_LOCKR.

See *Section 20: Extended interrupts and event controller (EXTI)* for more details.

System configuration, boot, and security (SBS)

Like all TrustZone-aware peripherals, when the TrustZone security is enabled, a nonsecure read/write access to a secured SBS register is RAZ/WI. Such access also generates an illegal access event that triggers a secure illegal access interrupt if the SBS illegal access event is not masked in the TZIC.

See *Section 14: System configuration, boot, and security (SBS)* for more details.

Microcontroller debug unit (DBGMCU)

The MCU debug component (DBGMCU) helps the debugger, providing support for:

- Low-power modes behavior during debug
- Peripheral freeze during debug, applicable to I2Cs, I3Cs, IWDG, WWDG, timers, low-power timers, and GPDMA channels

The DBGCMU is a TrustZone-aware peripheral, managing access to its control registers as described in *Table 11*.

Table 11. TrustZone-aware DBGMCU nonsecure accesses management

Debug profile	Peripheral status(1)	DBG_xx_STOP control bits	
		Write access	Read access
Nonsecure invasive (SPIDEN = 0)	NS	Yes (S(2) or NS)	Yes (S or NS)
	S	None (S or NS)	
Secure invasive (SPIDEN =1)	NS	Yes (S or NS)	
	S	Yes (S only)	

1. As reported by the GTZC, the TrustZone-aware peripheral or the DMA channel.
2. Secure access from the debugger is converted to nonsecure access in the device.

Refer to *Section 71.12: Microcontroller debug unit (DBGMCU)* for more details.

3.6.6 Activating TrustZone security

The TrustZone is deactivated by default in all devices. It can be activated by setting the TZEN option bit in FLASH_OPTSR2_PRG when PRODUCT_STATE is Open. Once TZEN has changed from disabled to enabled (0xC3 to 0xB4), the default security state, after reset, is always the following:

- CPU subsystem
  - Cortex-M33 exits reset in the secure state, hence the boot address must point toward a secure memory area.
  - All interrupt sources are secure (in NVIC).
  - The memory mapped viewed by the CPU through IDAU/SAU is fully secure.
- Embedded flash memory
  - Flash memory nonvolatile secure areas (with their HDP zone), are defined with the nonvolatile registers FLASH_SECWMxR (x = 1, 2). The default secure option bytes setup is all user flash secure, without HDP area defined.
  - Volatile block-based security attributions of the flash memory are nonsecure.
- Embedded SRAMs
  - All SRAMs are secure, as defined in GTZC/MPCBB (see *Section 3.6.4*). The secure boot code can change this security setup, making the blocks secure or not.
- External memories
  - All memory devices connected to the FMC and OCTOSPI are secure, as defined in GTZC/MPCWM (see *Section 3.6.4*). The secure boot code can change this security setup, making the components secure or not.
- All GPIOs are secure.
- All GPDMA channels are nonsecure.
- Backup registers are nonsecure.
- Peripherals and GTZC:
  - Securable peripherals are nonsecure and unprivileged.
  - TrustZone-aware peripherals are nonsecure, with their secure configuration registers being secure.
  - All illegal access interrupts in GTZC/TZIC are disabled.

Note: Refer to Section 3.6.4 for the list of securable and TrustZone-aware peripherals.

3.6.7 Deactivating TrustZone security

Once TrustZone is activated, it can only be deactivated during a PRODUCT_STATE regression to open.

Note: Such PRODUCT_STATE regression triggers the erasing of embedded memories (SRAM2, flash), and the reset of all peripherals, including the OTFDEC and all crypto engines.

After the TrustZone deactivation, most of the features mentioned in *Section 3.6* are no longer available:

- The nonvolatile secure area of the embedded flash memory is deactivated, including the HDP area.
- Only the NVIC manages nonsecure interrupts.
- All secure registers in TrustZone-aware peripherals are RAZ/WI.

Note: When the TrustZone is deactivated, the resource isolation using privilege remains available (see Section 3.7.2 for details).

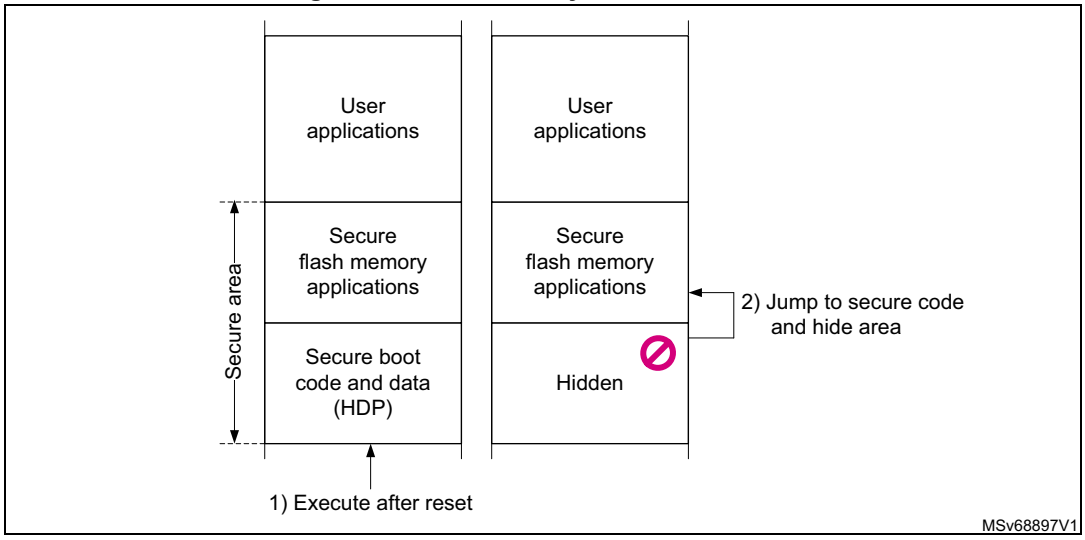
3.7 Other resources isolation

These are hardware mechanisms offering an additional level of isolation on top of the TrustZone technology.

3.7.1 Temporal isolation using secure hide protection (HDP)

The embedded flash memory allows to define an HDP area per watermarked-secure area of each bank (8-Kbyte page granularity). The code executed in this HDP area, with its related data and keys, can be hidden after boot, until the next system reset. The hidden protection principle is shown in *Figure 8*.

Figure 8. Flash memory secure HDP area



Activation of HDP area in user flash memory is related to HDPL1: as soon as HDPL ≥ 2, data read, write, and instruction fetch (on the area defined by HDPx_PSTRT and HDPx_PEND in FLASH_HDPxR_PRG option bytes), are denied until the next device reset.

The END of the HDPx areas can be extended (dynamically by the application) thanks to the FLASH_HDPEXTR flash memory register.

Note: Bank erase aborts when it contains a write-protected area (WRP or HDP area).

3.7.2 Resource isolation using Cortex privileged mode

In parallel to the TrustZone isolation described in *Section 3.6*, the hardware and software resources can be partitioned so that they are restricted to software running in Cortex privileged mode.

Thanks to this hardware isolation technology, available even if TrustZone is disabled, critical code or data can be protected against intentional or unintentional tampering from the more exposed unprivileged code.

Memory and peripheral privileged allocation using MPU

The Cortex-M33 MPU divides the unified memory into eight regions in nonsecure and twelve in TrustZone, each aligned to a multiple of 32 bytes. Each memory region can be programmed to generate faults when accessed inappropriately by unprivileged software.

Memory and peripheral privileged allocation using GTZC

For the Cortex-M33 master, to complement the coarse isolation provided by the MPU, the GTZC reinforces, in a flexible way, the isolation between privileged and unprivileged tasks, for peripherals and selected memories.

For masters other than the Cortex-M33, the GTZC can assign them as unprivileged initiators, automatically protecting resources defined as privileged against this master.

- Securing peripherals with TZSC (privileged-only)

  In the devices, a peripheral is either securable privileged-only through GTZC, or is natively privileged-aware:

  – A securable privileged-only peripheral or memory is protected by an AHB/APB firewall gate controlled by the TZSC.

  – A privileged-aware peripheral or memory is connected directly to the AHB or the APB interconnect, implementing a specific behavior (for example, a subset of registers or a memory area is privilege-only).

  When such a peripheral is made privileged-only with GTZC, if it is master on the interconnect (SDMMC), it automatically issues privileged transactions. Privilege-aware masters like GPDMA1 and GPDMA2, drive the privileged signal in the AHB interconnect according to their internal privileged mode, independently of the GTZC.

  The list of securable peripherals can be found in *Section 5: Global TrustZone® controller (GTZC)*.

- Securing memories with TZSC and MPCBB (privileged-only)

  The TZSC logic in GTZC provides the capability to manage the privilege level for all securable external memories, programming the MPCWM resources defined in *Section 3.6.4*.

  Similarly, the TZSC logic in GTZC provides the capability to configure the privilege level of embedded SRAM blocks, programming the MPCBB resources defined in *Section 3.6.4*.

- Error management (privileged-only)

  – Any unprivileged transaction trying to access a privileged resource is considered as illegal. There is no illegal access event generated for illegal unprivileged read and write accesses.

  – The addressed resource follows a silent-fail behavior, returning all-0 data for read and ignoring any write.

  – When an illegal unprivileged access occurs, no bus error is generated, except when this is an instruction fetch, accessing a privileged memory or a peripheral register.

Managing security in privileged-aware peripherals

TrustZone-aware peripherals also implement privileged-only access mode. The privileged protection is valid even if TrustZone is disabled (TZEN = 0xC3):

- *Embedded flash memory*

  By default, all registers can be read or programmed in both privileged and unprivileged modes.

  When the secure privileged bit SPRIV is set in FLASH_PRIVCFGR, reading and writing the secure registers is possible only in privileged mode. Write access to this bit is ignored if TrustZone is disabled (TZEN = 0xC3).

  When the nonsecure privileged bit NSPRIV is set in FLASH_PRIVCFGR, reading and writing the flash memory nonsecure registers is possible only in privileged mode.

  Regarding privileged protection, the devices offer the following features:

  – The system flash memory can be accessed in both privileged and unprivileged modes.
  – Each watermark-based secure area, including its secure HDP area, is accessible in secure-privileged and secure-unprivileged mode, if applicable.
  – Each 8-Kbyte page of the embedded flash memory can be programmed on-the-fly as privileged only, using the block-based privileged configuration registers FLASH_PRIV1BBRx and FLASH_PRIV2BBRx. An unprivileged page is accessible by privileged or unprivileged access.

Note: Switching a page from privileged to unprivileged does not erase its content.

When applicable, an erase or program operation is always available to privileged code, and is available to unprivileged code only for unprivileged pages or unprivileged memory.

- *On-the-fly encryption/decryption (OTFDEC1, OTFDEC2)*

  When the privileged bit PRIV is set in OTFDEC_PRIVCFGR, only a privileged application can initialize the OTFDEC.

Note: OTFDEC_PRIVCFGR can be read by both privileged and unprivileged code.

- *Direct memory access controllers (GPDMAx)*

  When a DMA channel x is defined as privileged (PRIVx = 1 in GPDMA_PRIVCFGR), special rules (see *Table 12*) apply when accessing the privileged/unprivileged source or destination.

Table 12. DMA channel use (privilege)

Destination	Privileged DMA channel x (PRIVx = 1)		Unprivileged DMA channel y (PRIVy = 0)	
	Privileged source	Unprivileged source	Privileged source	Unprivileged source
Privileged	OK		Transfer blocked(1)	
Unprivileged			Transfer blocked	OK

1. When a transfer is blocked, the transfer completes but the corresponding writes are ignored, and reads return 0s.

- *Power control (PWR)*

  By default, after a power-on or a system reset, all PWR registers except PWR_PRIVCFGR, can be read or written in both privileged and unprivileged modes.

  When secure privileged bit SPRIV is set in PWR_PRIVCFGR, reading and writing the PWR securable registers are possible only in privileged mode. Write access to this bit is ignored if TrustZone is disabled (TZEN = 0xC3).

  When the nonsecure privileged bit NSPRIV is set in PWR_PRIVCFGR, reading and writing the PWR nonsecure registers are possible only in privileged mode.

  See *Section 10: Power control (PWR)* for details.

- *Secure clock and reset (RCC)*

  By default, after a power-on or a system reset, all RCC registers except RCC_PRIVCFGR can be read or written in both privileged and unprivileged modes.

  When the secure privileged bit SPRIV is set in RCC_PRIVCFGR, reading and writing the RCC securable bits are possible only in privileged mode. Write access to this bit is ignored if TrustZone is disabled (TZEN = 0xC3).

  When the nonsecure privileged bit NSPRIV is set in RCC_PRIVCFGR, reading and writing the RCC nonsecure bits are possible only in privileged mode.

  See *Section 11: Reset and clock control (RCC)* for details.

- *Real-time clock (RTC)*

  By default after any backup domain reset, all RTC registers except RTC_PRIVCFGR, can be read or written in both privileged and unprivileged modes.

  When PRIV bit is set in privileged-only RTC_PRIVCFGR:

  – Writing the RTC registers is possible only in privileged mode.

  – Reading the RTC_SECCFGR, RTC_PRIVCFGR, RTC_TR, RTC_DR, RTC_SSR, RTC_PRER and RTC_CALR is always possible in privileged and unprivileged modes.

  All the other RTC registers can be read only in privileged mode.

  When the PRIV bit is cleared in the privileged-only RTC_PRIVCFGR register, it is still possible to restrict access to privileged mode to some RTC registers by setting dedicated control bits: INITPRIV, CALPRIV, TSPRIV, WUTPRIV, ALRAPRV, or ALRBPRIV.

  See *Section 57: Real-time clock (RTC)* for details.

- *Tamper and backup registers (TAMP)*

  By default after any backup domain reset, all TAMP registers except TAMP_PRIVCFGR can be read or written in both privileged and unprivileged modes.

  When PRIV bit is set in privileged-only TAMP_PRIVCFGR:

  – Writing the TAMP registers is possible only in privileged mode, except for the backup registers and the monotonic counters that have their own protection setting.

  – Reading the TAMP_SECCFGR or TAMP_PRIVCFGR is always possible in privilege and unprivilege modes. All the other TAMP registers can be read only in privilege mode, except for the backup registers and the monotonic counters that have their own protection setting.

The application can also:

- Make TAMP_COUNT1R register read and write privileged-only by setting the CNTPRIV bit in TAMP_PRIVCFGR
- Increase security for two of the three protection zones in backup registers, using BKPRWPRIV and BKPWPRIV bits in TAMP_PRIVCFGR:
  - Make protection zone 1 read privileged, write privileged.
  - Make protection zone 2 read privileged or unprivileged, write privileged.
  - Protection zone 3 is always read and write privileged or unprivileged.

- *General-purpose I/Os (GPIO)*

  All GPIO registers can be read and written by privileged and unprivileged accesses, whatever the security state (secure or nonsecure).

- *Extended interrupts and event controller (EXTI)*

  The EXTI peripheral is able to protect event register bits from being modified by unprivileged accesses. The protection is individually activated per input event via the register bits in the privileged-only EXTI_PRIVCFGRx registers. When an input event is configured as privileged, only a privileged application can change the configuration (including security if applicable), change the masking or clear the status of this input event.

  The security configuration in EXTI_PRIVCFGR1 and EXTI_PRIVCFGR2 can be globally locked after reset in EXTI_LOCKR.

  See *Section 20: Extended interrupts and event controller (EXTI)* for more details.

- *System configuration boot and security (SBS)*

  All SBS registers can be read and written in both privileged and unprivileged modes, except:

  - FPUSEC bit in SBS_SECCFGR registers (privileged only)
  - SBS registers for CPU configuration: SBS _CSLOCKR, SBS _FPUIMR, and SBS _CNSLCKR

  See *Section 14: System configuration, boot, and security (SBS)* for more details.

3.8 Secure execution

Through a mix of special software and hardware features, the devices ensure the correct operation of their functions against abnormal situations caused by programmer errors, software attacks through network access or local attempt for tampering code execution.

This section describes the hardware features specifically designed for secure execution.

3.8.1 Memory protection unit (MPU)

The Cortex-M33 includes a memory protection unit (MPU) that can restrict the read and write accesses to each memory region (including those mapped to peripherals), based on one or more of the following parameters

- Cortex-M33 operating mode (privileged, unprivileged)
- data/instruction fetch

The memory map and the programming of the nonsecure and secure MPUs split memory into regions (up to eight for the nonsecure, and up to twelve for the TrustZone). Secure MPU is only available when TrustZone is activated.

3.8.2 Embedded flash memory write protection

The embedded flash memory write protection (WRP) prevents illegal or unwanted write/erase to special sections of the embedded flash memory user area (system area is permanently write protected).

Write protected area is defined through the option bytes, writing the start and end addresses: two write-protected areas can be defined in each bank, with the granularity of a 32-Kbyte page.

WRP areas can be modified through option byte changes unless the corresponding FLASH_WRPSGNxR has its UNLOCK option bit cleared (meaning ROM emulation). UNLOCK can be set only when regressing to PRODUCT_STATE = Open.

Note: Bank erase aborts when it contains a write-protected area (WRP or HDP area).

3.8.3 Tamper detection and response

Principle

The devices include active protection of critical security assets against temperature, voltage and frequency attacks, with the following features:

- Erasure of device secrets upon tamper detection
- Improved guarantee of safe execution for the CPU and its associated security peripherals, including:
  - Out-of-range voltage (example: V_{BAT}, V_{DDA}), temperature and clocking (LSE) detection
  - Security watchdog IWDG clocked by the internal oscillator LSI
  - Possible selection of internal oscillator HSI as system clock
- Power supply protection
  - RTC/TAMP domain powered automatically with V_{DD} or V_{BAT}

See *Section 58: Tamper and backup registers (TAMP)* for more details.

Tamper detection sources

The devices support eight active input/output pins, allowing four independent active-tamper meshes, or up to seven meshes if the same output pin is shared by several input pins (for a total of eight active-tamper I/Os). The active-tamper balls are mapped in the center of packages that can be used in the POS market (such as WLCSP105).

The active pins are clocked by the LSE, and are functional in different system operating modes (Run, Sleep, Stop, or Standby), and in VBAT mode. Refer to TAMP pins functionality over modes for the list of tamper pins and their availability across power modes.

Detection time is programmable, and a digital filtering is available (tamper triggered after two false comparisons in four consecutive comparison samples).

Note: Timestamps are automatically generated when a tamper event occurs.

The internal tamper sources are listed in *Table 13*.

Table 13. Internal tampers in TAMP

Tamper input	NOER bit number in TAMP_CR3	Tamper source
itamp1	0	Backup domain voltage continuous monitoring, functional in VBAT mode
itamp2	1	Temperature monitoring, functional in VBAT mode
itamp3	2	LSE monitoring(1), functional in VBAT mode
itamp4	3	HSE monitoring
itamp5	4	RTC calendar overflow (rtc_calovf)
itamp6	5	JTAG/SWD access
itamp7, 12, 13	6, 11, 12	Voltage monitoring (V_{CORE}, V_{REF+}), through ADC analog watchdog
itamp8	7	Monotonic counter overflow (generated internally)
itamp9	8	Fault generation for cryptographic peripherals (SAES, PKA, AES, RNG)
itamp11	10	IWDG timeout and potential tamper (IWDG reset when at least one enabled tamper flag is set)
itamp15	14	System fault detection

1. LSE missing or over frequency detection (> 2 MHz), glitch filter (> 2 MHz).

Response to tampers

Each source of tamper in the device can be configured to trigger the following events:

- Generate an interrupt, capable of waking up the device from Stop and Standby modes (see TAMPxMSK bits in TAMP_CR2 register).
- Generate a hardware trigger for the low-power timers.
- Erase device secrets if the corresponding TAMPxNOER bit is cleared in TAMP_CR2 (for tamper pins) or TAMP_CR3 (for internal tamper). These erasable secrets are:
  - Symmetric keys stored in backup registers (x32), in SAES, AES, HASH, CCB, and OTFDEC (encrypted flash memory regions are read as 0)
  - Asymmetric keys stored in PKA SRAM, erased when V_{DD} is present
  - Other secrets are stored in SRAM2 and CPU instruction cache memory (SRAM2 erased when V_{DD} is present)
  - Nonvolatile information used to derive the DHUK in SAES is 0-ed until complete SRAM2 erase
  - Backup SRAM (depending on configuration bit), erased when V_{DD} is present

Read/write access by software to all these secrets can be blocked, by setting the BKBLOCK bit in TAMP_CR2. The device secrets access is possible only when BKBLOCK is cleared, and no tamper flag is set for any enabled tamper source.

If V_{DD} is not present, the secrets that are erased when V_{DD} is present are erased only at the next V_{DD} power on.

Note: Device secret erase is also triggered by setting the BKERASE bit in TAMP_CR2, or by performing a PRODUCT_STATE regression as defined in Section 3.11.2.

Device secrets are not reset by a system reset or when the device wakes up from Standby mode.

Software filtering mechanism

Each tamper source can be configured not to launch an immediate erase, by setting the corresponding TAMPxNOER bit in TAMP_CR2 (for external tamper pin) or TAMP_CR3 (for internal tamper).

In such a situation, when the tamper flag is raised, access to below secrets is blocked until all tamper flags are cleared:

- DHUK in SAES: fixed to a dummy value
- Backup registers, backup SRAM, SRAM2: read as 0, write-ignored
- AES, SAES, CCB, and HASH peripherals: automatically reset by RCC
- PKA peripheral: reset, with memory use blocked (meaning PKA not usable)

Once the application, notified by the tamper event, analyzes the situation, there are two possible cases:

- The application launches secrets erase with a software command (confirmed tamper).
- The application clears the flags to release secrets blocking (false tamper).

Note: If the tamper software fails to react to such a tamper flag, an IWDG reset triggers an automatic erasing of secrets.

Tamper detection and low-power modes

The effects of low-power modes on a tamper detection are summarized in *Table 14*.

Table 14. Effect of low-power modes on TAMP

Mode	Description
Sleep	No effect on tamper detection features. TAMP interrupts cause the device to exit the Sleep mode.
Stop	No effect on tamper detection features, except for level detection with filtering and active tamper modes that remain active only when the clock source is LSE or LSI. Tamper events cause the device to exit the Stop mode.
Standby	No effect on tamper detection features, except for level detection with filtering and active tamper modes which remain active only when the clock source is LSE or LSI. Tamper events cause the device to exit the Standby mode.

3.9 Secure storage

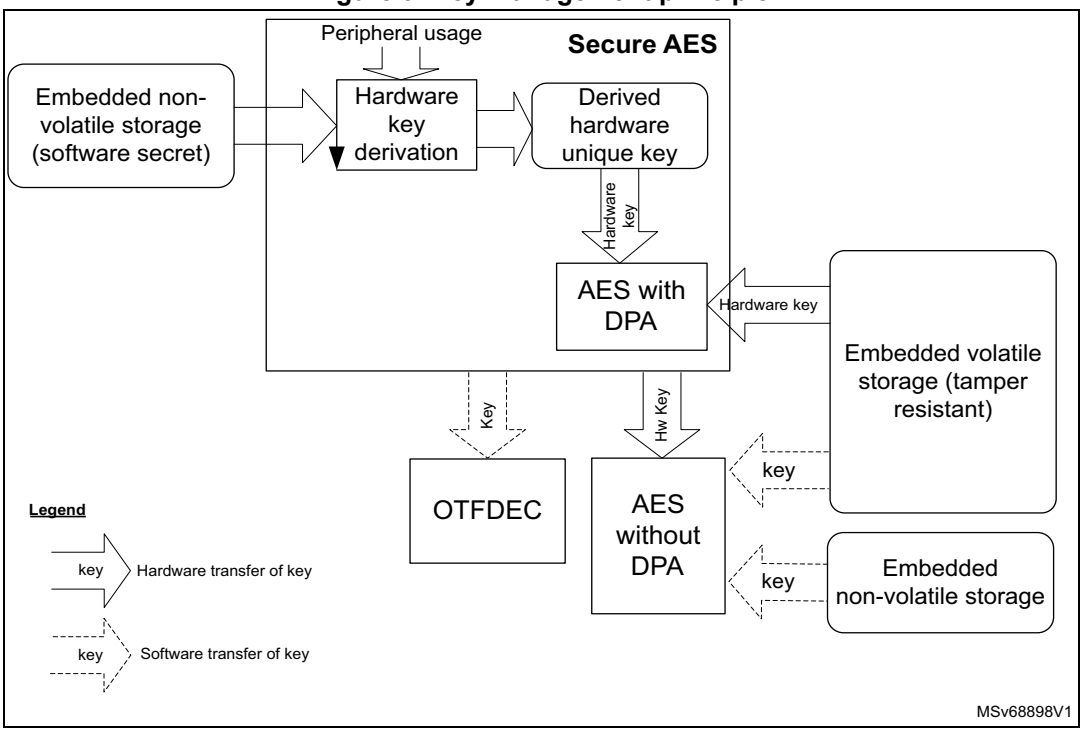
A critical feature of security systems is how long-term keys are stored, protected, and provisioned. Such keys are typically used for loading a boot image, or handling of critical user data.

Figure 9 shows how the key management service application can use the AES engine, for example, to compute external image decryption keys. Nonvolatile keys are stored in the flash memory in a dedicated area including access control (see *Section 3.7.1*), while volatile

key storage consists in the battery-powered, tamper-protected SRAM or registers in TrustZone-aware TAMP.

Figure 9 also shows keys that are manipulated by software (like OTFDEC keys), or keys that are managed only by hardware (like DHUK). More information on those hardware keys can be found in *Section 3.9.1*.

Figure 9. Key management principle



Details on tamper protection can be found in *Section 3.8.3*, while TAMP TrustZone features are briefly described in *Section 3.6.5*.

3.9.1 Hardware secret key management

As shown in the previous figure, the devices propose a better protection for application keys, using hardware secret keys. These AES keys can be made usable to the application, without exposing them in clear-text (unencrypted). Such keys also become immediately unusable in case of tamper.

There are three different sources of hardware secret keys:

- DHUK: derived keys are based on a 256-bit nonvolatile device unique secret in flash memory. The flash memory provides value provisioned during product manufacturing (called RHUK). The generation of DHUK key takes into account the TrustZone state, the OBK-HDPLx (temporal isolation counter), the EPOCH (regression counter allowing anti-replay protection) and the key use state (KMOD).
- BHK: 256-bit application key stored in tamper-resistant volatile storage in TAMP

  This key is written at boot time, then read/write locked to the application until the next reset.
- XORK: result of an XOR of BHK and DHUK

Those keys can be used in the following modes:

- As a normal key, loading in write-only key registers (software key mode)
- As an encryption/decryption key for another key, to be used in the DPA-resistant SAES (wrapped key mode)
- As an encryption/decryption key for another key, to be used in a faster AES engine (shared key mode)

3.9.2 Unique ID

The devices store a 96-bit ID that is unique to each device (see *Section 72.1: Unique device ID register (96 bits)*).

Application services can use this unique identity key to identify the product in the cloud network, or make it difficult for counterfeit devices or clones to inject untrusted data into the network.

Alternatively, the 256-bit device unique key (DHUK) can be used (see *Section 3.9.1*).

3.10 Crypto engines

The devices implement state-of-the-art cryptographic algorithms featuring key sizes and computing protection as recommended by national security agencies such as NIST for the U.S.A, BSI for Germany or ANSSI for France. Those algorithms are used to support privacy, authentication, integrity, entropy, and identity attestation.

The embedded crypto engines reduce weaknesses on the implementation of critical cryptographic functions, preventing, for example, the use of weak cryptographic algorithms and key sizes. They also enable lower processing times and lower power consumption when performing cryptographic operations, offloading those computations from Cortex-M33. This is especially true for asymmetric cryptography.

For product certification purposes, ST can provide certified device information on how these security functions are implemented and validated.

For more information on the crypto engine processing times, refer to their respective sections in the reference manual.

3.10.1 Crypto engines features

Table 15 lists the accelerated cryptographic operations available in the devices. Two AES accelerators are available (both can be reserved to secure application only).

Note: Additional operations can be added using firmware. The PKA can accelerate asymmetric crypto operations (like key pair generation, ECC scalar multiplication, point on curve check). See Section 47: Public key accelerator (PKA) for more details.

Table 15. Accelerated cryptographic operations

Operations	Algorithm	Specification	Length of keys (in bit)	Modes
Get entropy	RNG	NIST SP800-90B(1)	N/A	Software and hardware(2) modes running in parallel
Encryption, decryption	AES	FIPS PUB 197 NIST SP800-38A	128, 256	ECB, CBC, CTR(3)
Authenticated encryption or decryption		NIST SP800-38C NIST SP800-38D	128, 256	GCM, CCM
Cipher-based message authentication code		NIST SP800-38D	128, 256	GMAC
Checksum	SHA-1	FIPS PUB 180-4	N/A	Digest 160-bit
Cryptographic hash	SHA-2		-	SHA-224, SHA-256 SHA2-384, SHA2-512
	SHA-3			SHA3-224, SHA3-256, SHA3-384, SHA3-512
Keyed-hashing for message authentication	HMAC	FIPS PUB 198-1 IETF RFC 2104	Short, long (>64 bytes)	-
Encryption/decryption key-pair generation(4)	RSA	IETF RFC 8017 NIST SP800-56B	Up to 4160	RSAES-OAEP
Signature(4) with hashing	RSA	IETF RFC 8017 FIPS PUB 186-4	Up to 4160	PKCS1-v1_5, PSS
Signature verification	ECDSA	ANSI X9.62 IETF RFC 7027 FIPS PUB 186-4	Up to 640	Refer to table 'Family of supported curves for ECC operations' in PKA section for details
Key agreement	ECDH	ANSI X9.42		

1. Certifiable using STMicroelectronics reviewed documents.
2. Random numbers distribution to SAES and PKA using a dedicated hardware bus.
3. ECB and CBC chaining modes protected against side-channel and timing attacks in SAES (see *Section 3.10.2*).
4. Private key cryptography protected against side-channel and timing attacks.

Note: Binary curves, Edwards curves and Curve25519 are not supported by the PKA.

3.10.2 Secure AES coprocessor (SAES)

The devices provide an additional on-chip hardware AES encryption and decryption engine, implementing countermeasures and mitigations against power and electromagnetic side-channel attacks.

Clocked by the system clock the SAES results in very good performance for a dpa resistant hardware accelerator. The SAES engine supports 128-bit or 256-bit key in the electronic code book (ECB), cipher block chaining (CBC), (CTR), (GCM), (CCM), and (GMAC) modes.

As shown in *Section 3.9*, the SAES can be used for extra-secure on-chip storage for sensitive information. It can also be made secure-only.

For more information, refer to *Section 3.10.2: Secure AES coprocessor (SAES)*.

3.10.3 On-the-fly decryption engine (OTFDEC1, OTFDEC2)

The OTFDEC TrustZone-aware peripheral proposes on-the-fly decryption of encrypted images stored on external flash memory, connected through the OCTOSPI. This decryption process introduces almost no additional cycle overhead when the standard NOR flash memory is used. The OTFDEC can also be used to encrypt flash memory images on the device (for example to encrypt with a device unique secret key).

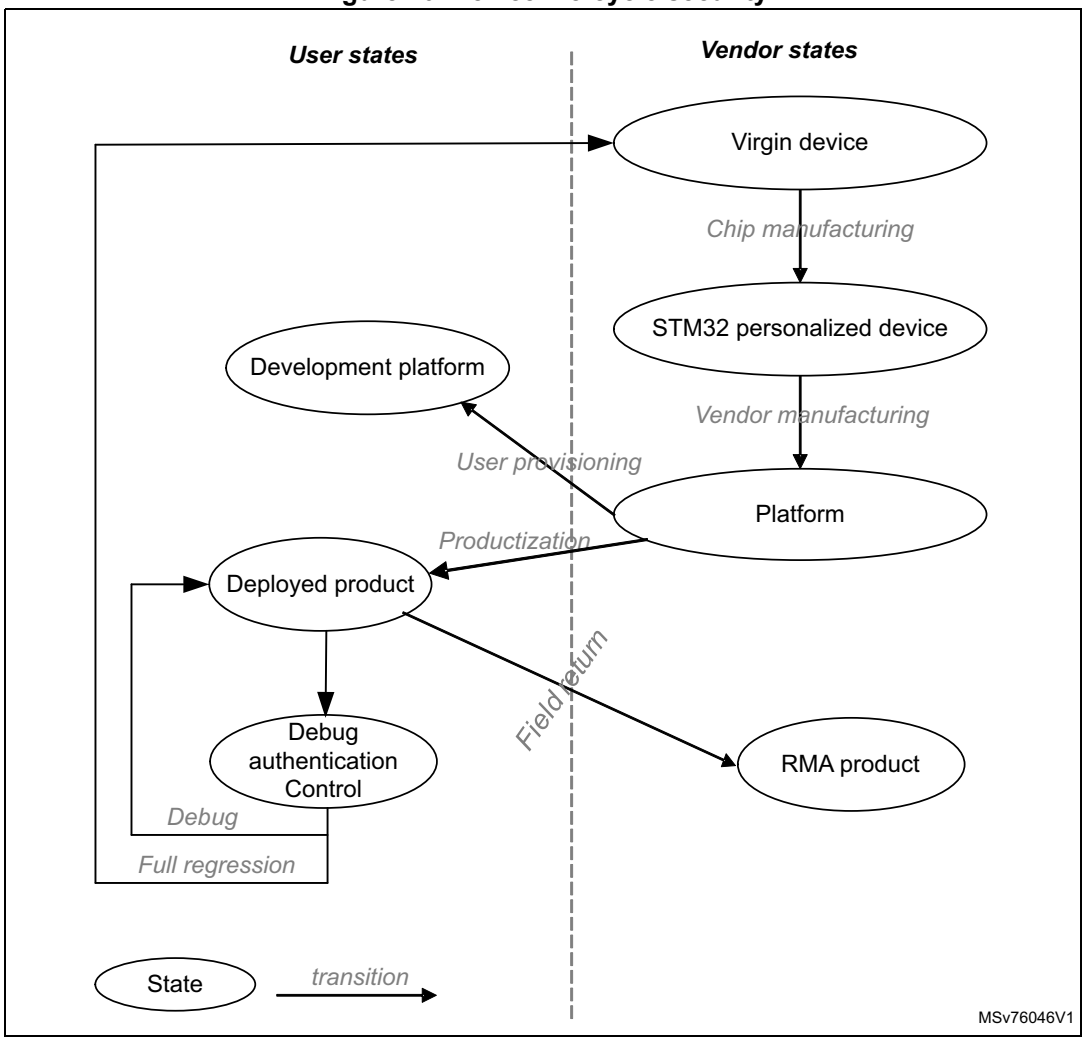
When a tamper event is confirmed in TAMP, all OTFDEC keys are erased and encrypted regions are read as 0 until the OTFDEC is properly initialized again.

An OTFDEC typical use is detailed in *Section 3.12.2*. For more details on the peripheral programming, refer to *Section 48: On-the-fly decryption engine (OTFDEC)*.

3.11 Product life cycle

A typical IoT device life cycle is summarized in *Figure 10*. For each step, the devices propose secure life cycle management mechanisms embedded in the hardware.

Figure 10. Device life-cycle security



Additional details on the various phases and associated transitions, found either at the vendor or end-user premises, are summarized in *Table 16*.

Table 16. Main product life-cycle transitions

Transitions	Description
Device manufacturing	ST creates new STM32 devices, always checking for manufacturing defects. During this process, the device is provisioned with ROM firmware, secure firmware install (SFI) unique key pair, and a public ID.
Vendor manufacturing	One (or more) vendor is responsible for the platform assembly, initialization, and provisioning before delivery to the end user. This end user can use the final product (“productization” transition) or he/she can use the platform for software development (“user provisioning” transition).
Productization	The end user gets a product ready for use. All security functions of the platform are enabled, the debugging/testing features are restricted/disabled, and unique boot entry to immutable code is enforced.
User provisioning	Platform vendor prepares an individual platform for development, not to be connected to a production cloud network.
Full regression	The product is returned for analysis to field return centers. Analysis is possible by opening it partially, or by launching a partial or a full regression. Such accesses require provisioning, including certificates provided by the vendor.
Field return	These are one-way transitions, with devices kept in user premises or returned to the manufacturer. In both cases, all data including user data is destroyed, therefore the devices lose the ability to operate securely (like connecting to a managed IoT network). This Field return is valid including when PRODUCT_STATE is Locked. STMicroelectronics does not perform analysis on defective parts in closed or locked states.

The features described hereafter contribute to secure the device life cycle.

3.11.1 Product configurations and security services

The product is provisioned with ST security services in system flash, but can be configured to let the full control of the boot chain to OEMs. This is done thanks to the unique boot entry (FLASH_OPTSR: BOOT_UBE) option byte, allowing to select between the security services (ST-iROT: ST immutable root of trust), or OEM boot implementation (OEM-iROT: OEM immutable root of trust) to be installed in the user part of the flash memory.

Security services are provisioned by ST in system flash (immutable). They provide the root of trust of the platform managing the verification and the update of the first updatable code (uROT).

3.11.2 Life cycle management

The product life cycle allows to control the access to different assets (code and data) of the product, including during development, manufacturing, and after sales.

It allows to provision the product with different distribution models taking care on the code and data provisioned.

Table 17. Typical product life-cycle phases

PRODUCT_STATE + DebugState		Debug (default configuration)	Comments
Open	Device open	Secure(1) and nonsecure	Allows to develop the product, as it provides the debug of the code. Boot address must target a secure area when TrustZone is enabled. Using the boot pin allows to launch the bootloader. Using boot pin and BOOT_UBE allows to launch user flash code through ST-iROT.
Provisioning	Debug partially opened (only nonsecure)	HDPL3 + Nonsecure only	Allows to manage the provisioning of the product (partial or full). It allows to launch secure firmware Install, or bootloader to provision the product. Boot address must target a secure area when TrustZone is enabled. Boot on SRAM is not permitted.
iROT-Provisioned	Debug partially opened (only nonsecure)	HDPL3 + Nonsecure only	Assumes that immutable root of trust is installed, including its configuration (code, option bytes, secure storage). Boot address must target a secure area when TrustZone is enabled. Boot on SRAM is not permitted.
TZ-Closed	Debug partially opened (only nonsecure)	HDPL3 + Nonsecure only	Assumes that the Secure OS is installed in TrustZone (this state exist only if TZEN = 0xB4). Debug is opened for nonsecure applications
Closed	Debug closed	NoDebug + debug authentication control	Assumes the product configuration as finalized. It allows to support debug authentication for in-the-field repair (read the dedicated application note).
Locked	Debug locked	None	Assumes the product configuration as finalized. The debug authentication is not permitted.The product is definitively in this state, nevertheless the field return procedure allow to launch RMA state.
NS-Regression	Debug closed	NoDebug	This is a temporal (but nonvolatile) state to manage the partial regression to the TZ-Closed, removing all nonsecure code and data including in secure storage.
Regression	Debug closed	NoDebug	This is a temporal state (but nonvolatile) to manage the full regression to Open state, removing all user flash code and data including in secure storage (HDPL1 to HDPL3).
Debug Constrained	Debug opened following debug authentication permissions	Depends upon permissions	This is a temporal state (until power-on-reset) to manage debug based on the permissions acquired by the debug authentication protocol.

1. Debug is not available when executing RSS code.

The supported transitions, summarized in *Figure 11*, can be requested (when available) through the debug interface or via the system bootloader.

Figure 11. PRODUCT_STATEs (simplified TrustZone activated view)

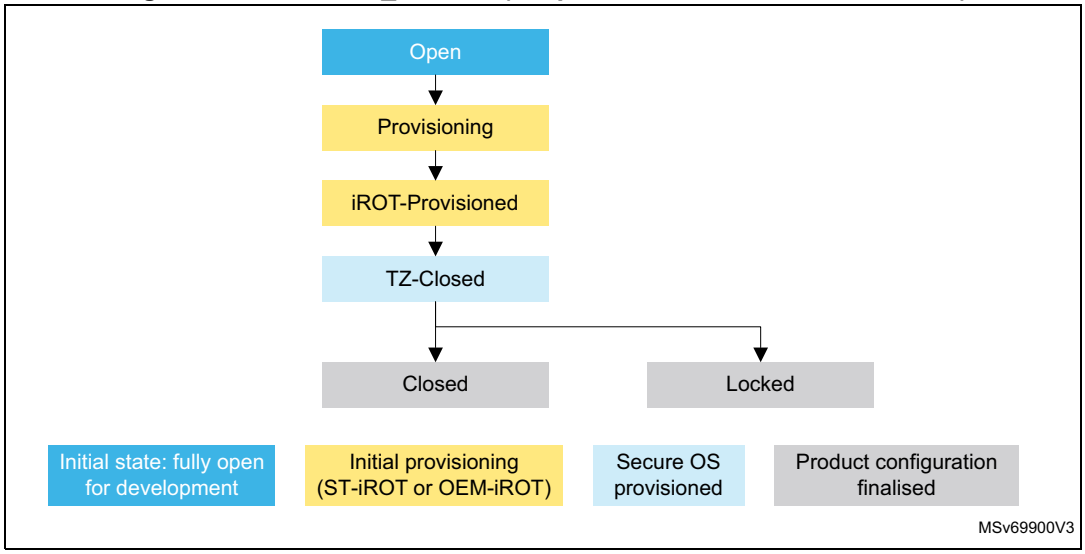
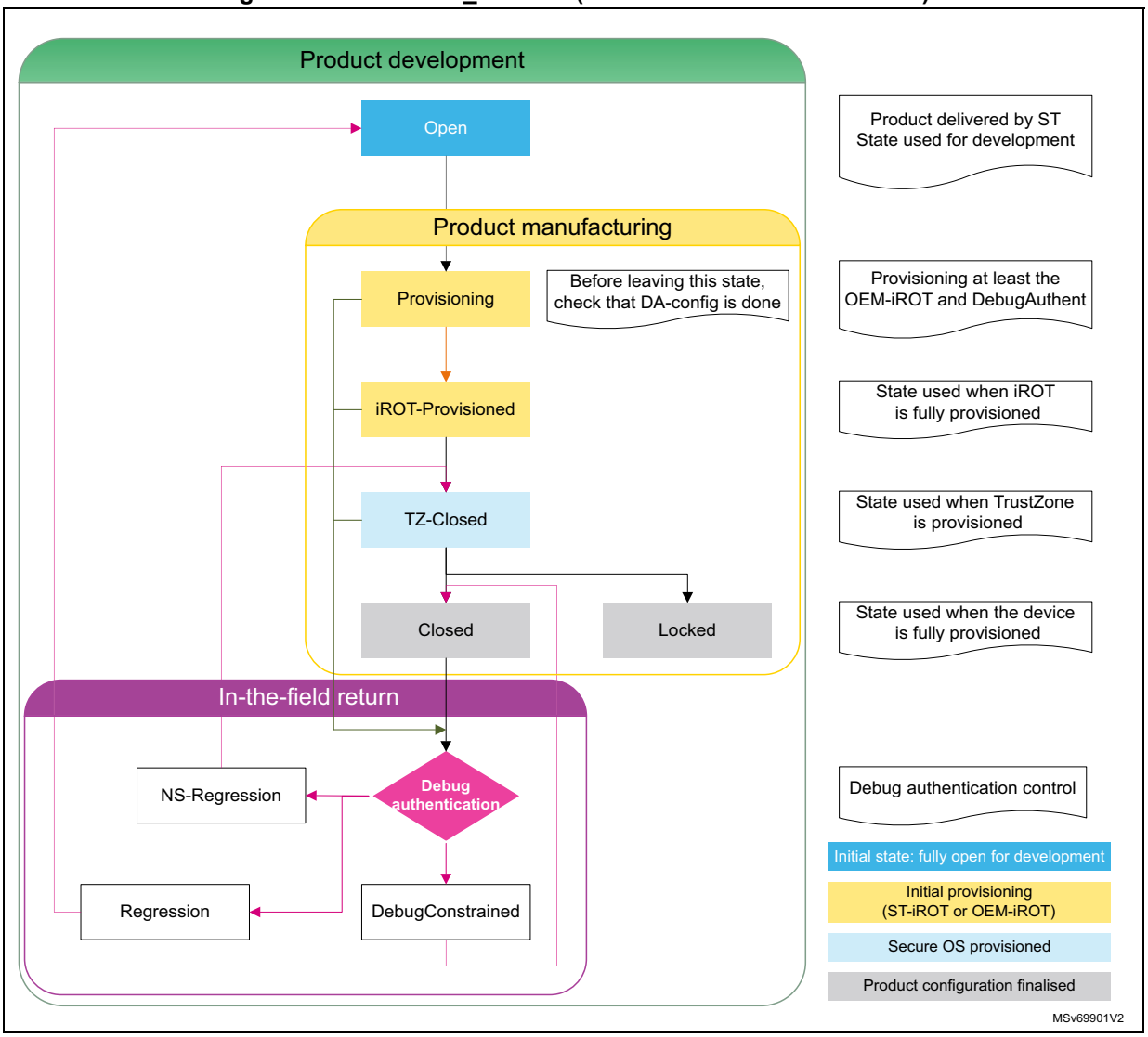


Figure 12. PRODUCT_STATEs (full TrustZone activated view)



The full view of the life cycle includes the debug authentication part, to help product maintenance to manage field returns (in-the-field centers). The debug authentication control is ensured thanks to a protocol based on the Arm PSA ADAC specification. It allows controlling that the host has a trusted certificate with permissions. Permissions definition allows a lot of flexibilities, in our default model we consider: Full or partial regression, or to open the debug for nonsecure.

When TrustZone is disabled, the state TZ-Closed does not exist, and the debug authentication is based on a password authentication method. For details on the debug authentication feature, refer to the corresponding application note.

The protocol includes a “DISCOVER” command allowing to get basic information of the target: manufacturer, product name, device identifier, protocol version supported, and crypto scheme for authentication (this help selecting between certificates and password).

3.11.3 Recommended product settings

To ease the product maintenance (in-the-field), it is recommended to take advantage of the feature called debug authentication control. This enables the maintenance of the product activating the debug and makes it possible to manage regressions while considering the security of the sensible information.

This implies the following actions:

- Set the PRODUCT_STATE in Closed state when the product has been configured
- When debug authentication control is based on certificates (when TrustZone enabled), **provision the OEM-PublicKey and the SOC-Mask**. Setting the SOC-Mask to propose only the nonsecure-debug and partial and full regression guaranty to be compliant with the Arm PSA security model.
- When debug authentication control is based on a password (when TrustZone is disabled), only the HASH of the password must be provisioned.

A dedicated application note is available to help configure the platform, the host tools and to generate certificates.

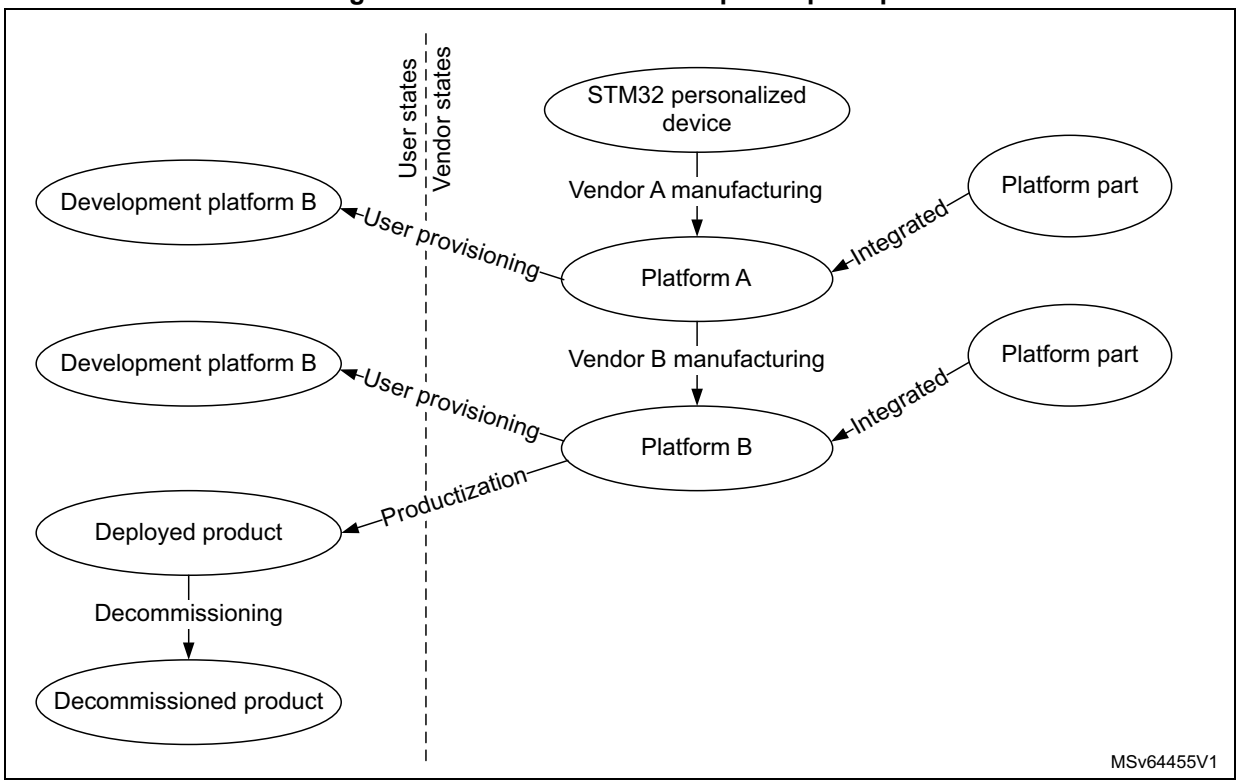
3.12 Software intellectual property protection and collaborative development

Thanks to the software intellectual property protection and collaborative model, the devices allow the design of solutions integrating innovative third-party libraries.

Collaborative development is summarized in *Figure 13*. Starting from a personalized device sold by STMicroelectronics, a vendor A can integrate a portion of hardware and software on a platform A, which can then be used by a vendor B, who does the same before deploying a final product to the end users.

Note: Each platform vendor can provision individual platforms for development not to be connected to a production cloud network (“Development Platform X”).

Figure 13. Collaborative development principle



The features described hereafter contribute to securing the software intellectual property within such a collaborative development.

3.12.1 Software intellectual property protection

As described in *Section 3.11.2,* the hardware PRODUCT_STATE mechanism automatically controls the access to secrets provisioned in the device. The protection of these secrets are defined in *Table 18*.

Table 18. Software intellectual property protection with PRODUCT_STAT

PRODUCT_STATE protection level		Secrets protection
Open	Device open	No special protections.
Provisioning	Debug partially opened (only nonsecure)	All areas protected with HDPL1 cannot be dumped, debugged or traced. The iROT can setup a higher level of protection.
iROT-Provisioned	Debug partially opened (only nonsecure)	All areas protected with HDPL1 cannot be dumped, debugged or traced. The iROT can setup a higher level of protection.
TZ-Closed	Debug partially opened (only nonsecure)	All peripherals and memories mapped as secure during secure boot cannot be dumped, debugged or traced
Closed	No debug	No debug possible except through debug authentication.
Locked	No debug	All data and code stored in the device or encrypted in external flash memory cannot be dumped clear-text, debugged or traced.

3.12.2 Software intellectual property protection with OTFDEC

As described in *Section 3.10.3,* the OTFDEC associated with the OCTOSPI is able to decrypt on the fly, the encrypted images stored in external SPI flash memories.

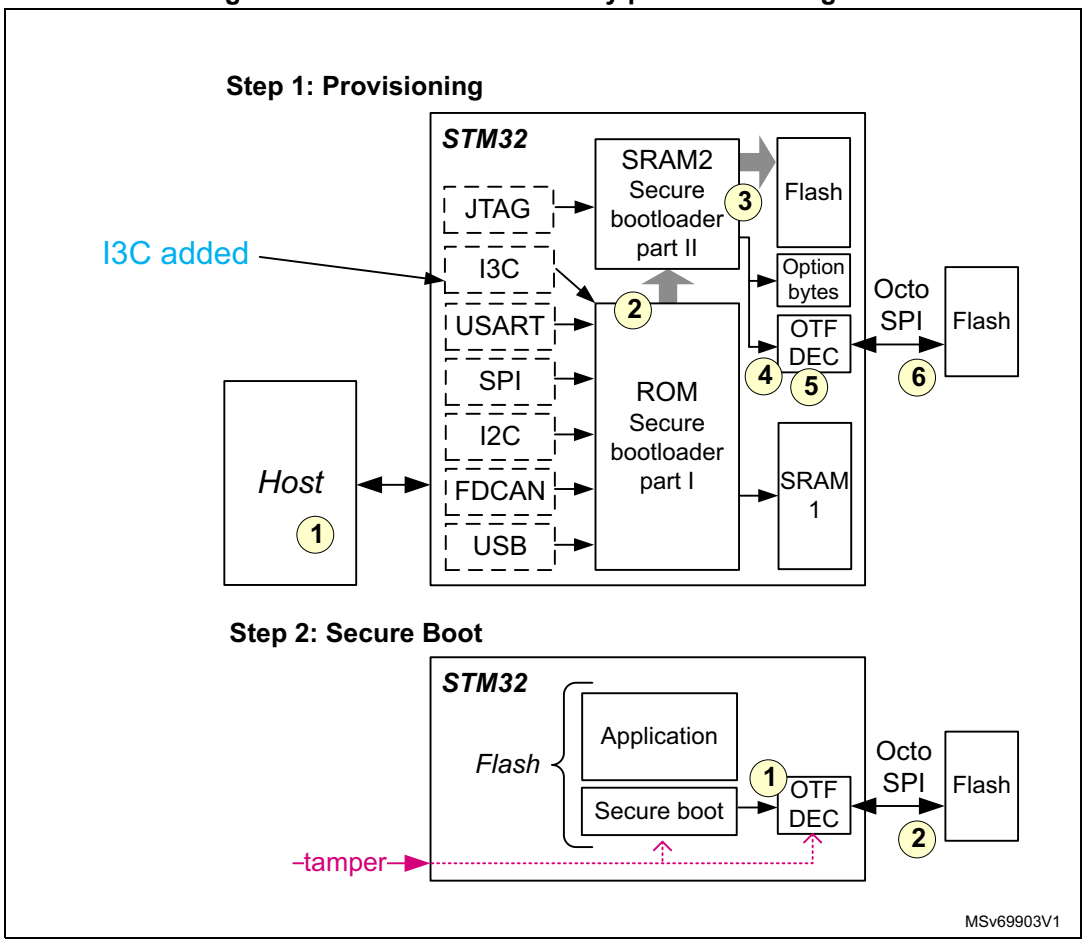
Thanks to this feature, the devices allow the installation of intellectual properties in one of the following ways:

- Over the air, with the image already encrypted with a key provisioned in the device
- Through a provisioning host located in a trusted or a non-trusted environment/facility

Figure 14 illustrates this last case, with the provisioning, in a non-trusted environment, of software intellectual properties both in the embedded flash memory and in an external SPI flash memory (encrypted).

Note: Since the OTFDEC uses the AES in counter mode (CTR) to achieve the lowest possible latency, each time the content of one encrypted region is changed, the corresponding cryptographic context (key or initialization vector) must be changed. This constraint makes OTFDEC suitable to decrypt read-only data or the code stored in external NOR flash memory.

Figure 14. External flash memory protection using SFI



Provisioning

Assuming the device is virgin, the first step is to provision both flash memories, as detailed below:

1. The user creates a SFI image, composed of:
   - Encrypted internal firmware and data (including external flash memory drivers)
   - Encrypted external firmware and data AES key (up to 4)
   - Encrypted external firmware and data image
2. The secure bootloader stored in the system memory, loads the second part of the secure bootloader in SRAM2, through the supported communication ports (USART, SPI, I2C, FDCAN, USB, I3C, and JTAG). This second part runs in the secure SRAM2 and is responsible for executing the SFI process, applying the SFI protocol thanks to the commands received through the above mentioned supported communication ports.
3. The internal flash memory is programmed with decrypted option bytes, internal firmware and data, and external firmware and data AES keys. Alternatively, device unique external firmware AES keys can be used instead of such global keys.
4. The OTFDEC is properly initialized with encrypted region information, including the corresponding external firmware and data AES key.
5. Running the SFI process, chunks of encrypted external firmware and data image are decrypted in the device, then re-encrypted in the OTFDEC.

6. After a chunk OTFDEC re-encryption, the user external flash memory programmer is responsible for programming the last encrypted chunks to the external SPI flash memories through the OCTOSPI.

Secure boot

After provisioning, each time the device initializes on a trusted firmware, the following actions are required:

1. Secure boot firmware executes, programming the external firmware and data AES keys to the OTFDEC write-only key registers, along with the other needed information.
2. The application reads or executes the encrypted external firmware and data through the OCTOSPI in memory-mapped mode, unless a tamper event is detected. In this case, all OTFDEC keys are erased and encrypted regions are read as 0 until the OTFDEC is properly initialized.

For more information on SFI solutions for the devices, refer to the AN4992 "*STM32 MCUs secure firmware install (SFI) overview".*

3.12.3 Other software intellectual property protections

The device additional protections to software intellectual property are:

- Invasive attacks such as physical tampering or perturbation are countered by detection then decommissioning of the device before the detected attack succeeds.
- Noninvasive attacks, such as side channel attacks, are countered by not leaking secret information via side channels (such as timing, power, and EM emissions).

4 Boot modes

At startup, a BOOT0 pin and NSBOOTADD[31:8]/SECBOOTADD[31:8] option bytes are used to select the boot memory address that includes:

- Boot from any address in user flash memory
- Boot from system memory
  - Bootloader
  - ST immutable root of trust (ST-iROT)
  - Root security service (RSS)
  - Debug authentication library (RSS-DA)

Embedded bootloader

The embedded bootloader is located in the system memory, programmed by ST during production. It is used to reprogram the flash memory by using USART, I2C, I3C, OTG_FS, or OTG_HS in device mode through the DFU (device firmware upgrade).

Refer to AN2606 “*STM32 microcontroller system memory boot mode”*.

Embedded root security services (RSS)

The embedded RSS is located in the secure information block, programmed by ST during production.

Refer to AN4992 “Introduction to secure firmware install (SFI) for STM32 MCUs*”*.

Embedded immutable root of trust (ST-iROT)

The embedded ST-iROT in the system memory, programmed by ST during production. ST-iROT is the immutable root of trust managing the secure boot and secure install of the first updatable level to execute in a boot sequence.

Embedded debug authentication (ST-DA)

The embedded ST-DA in the system memory, programmed by ST during production. ST-DA is the library that manages the debug authentication protocol by allowing it to securely reopen the debug or to launch regressions on secured products in the field.

4.1 STM32H5Ex boot modes

Table 19 provides the detail of the boot mode when the TrustZone® is disabled (TZEN = 0xC3), for the STM32H5Ex devices.

Table 19. STM32H5Ex Boot mode when TrustZone® is disabled (TZEN = 0xC3)

PRODUCT_STATE	BOOT0 pin	Boot address option-byte selection	Boot area	ST programmed default value
Open	0	NSBOOTADD[31:8]	Boot address defined by user option byte NSBOOTADD[31:8]	Flash: 0x0800 0000
	1	NA	Bootloader	Bootloader
Provisioning	x	NA	RSS	RSS
Provisioned, Closed, Locked	x	NSBOOTADD[31:8]	Boot address defined by user option byte NSBOOTADD[31:8]	Flash: 0x0800 0000

Note: The BOOT_UBE is only available on STM32H5Fx devices. Refer to Section 4.2.

Table 20 provides the detail of the boot mode when the TrustZone® is enabled (TZEN=0xB4), for the STM32H5Ex devices.

Table 20. STM32H5Ex Boot mode when TrustZone® is enabled (TZEN = 0xB4)

PRODUCT_STATE	BOOT0 pin	Boot address option-byte selection	Boot area	ST programmed default value
Open	0	SECBOOTADD[31:8]	Boot address defined by user option byte SECBOOTADD[31:8]	Flash: 0x0C00 0000
	1	NA	Bootloader	Bootloader
Provisioning	x	NA	RSS	RSS
Provisioned, TZ_Closed, Closed, Locked	x	SECBOOTADD[31:8]	Boot address defined by user option byte SECBOOTADD[31:8]	Flash: 0x0C00 0000

Note: The BOOT_UBE is only available on STM32H5Fx devices. Refer to Section 4.2.

When TrustZone® is enabled (TZEN=0xB4), the boot space must be in a secure area. The SECBOOTADD[24:0] option bytes are used to select the boot secure memory address. A unique boot entry option can be selected by setting the SECBOOT_LOCK option bit.

4.2 STM32H5Fx boot modes

Table 21 provides the detail of the boot mode when the TrustZone® is disabled (TZEN = 0xC3), for the STM32H5Fx products.

Table 21. STM32H5Fx Boot mode when TrustZone® is disabled (TZEN = 0xC3)

PRODUCT_STATE	BOOT0 pin	BOOT_UBE FLASH_OPTSR [29:22]	Boot address option-byte selection	Boot area	ST programmed default value
Open	0	NA	NSBOOTADD[31:8]	Boot address defined by user option byte NSBOOTADD[31:8]	Flash: 0x0800 0000
	1	NA	NA	Bootloader	Bootloader
Provisioning	x	NA	NA	RSS	RSS
Provisioned, Closed, Locked	x	NA	NSBOOTADD[31:8]	Boot address defined by user option byte NSBOOTADD[31:8]	Flash: 0x0800 0000

Table 22 provides the detail of the boot mode when the TrustZone® is enabled (TZEN = 0xB4), for the STM32H5Fx products.

Table 22. STM32H5Fx Boot mode when TrustZone® is enabled (TZEN = 0xB4)

PRODUCT_STATE	BOOT0 pin	BOOT_UBE FLASH_OPTSR [29:22]	Boot address option-byte selection	Boot area	ST programmed default value
Open	0	x	SECBOOTADD [31:8]	Boot address defined by user option byte SECBOOTADD[31:8]	Flash: 0x0C00 0000
	1	0xB4	NA	Bootloader	Bootloader
	1	0xC3	NA	ST-iROT	ST-iROT
Provisioning	x	NA	NA	RSS	RSS
Provisioned, TZ_Closed, Closed, Locked	x	0xC3	ST-iROT	ST-iROT	ST-iROT
		0xB4	SECBOOTADD [31:8]	Boot address defined by user option byte SECBOOTADD[31:8]	Flash: 0x0C00 0000

When TrustZone® is enabled (TZEN=0xB4), the boot space must be in a secure area. The SECBOOTADD[24:0] option bytes are used to select the boot secure memory address. A unique boot entry option can be selected by setting the SECBOOT_LOCK option bit.

5 Global TrustZone® controller (GTZC)

5.1 Introduction

This section describes the global TrustZone controller (GTZC) block that contains the following sub-blocks:

- **TZSC**: TrustZone security controller

  This sub-block defines the secure/privileged state of slave peripherals. It also controls the subregion area size and properties for the watermark memory peripheral controller (MPCWM). The TZSC informs some peripherals (such as RCC or GPIOs) about the secure status of each securable peripheral, by sharing with RCC and I/O logic.
- **MPCBB**: memory protection controller - block based

  This sub-block configures the internal RAM in a TrustZone-system product having segmented SRAM (pages of 512 bytes) with programmable-security and privileged attributes.
- **TZIC**: TrustZone illegal access controller

  This sub-block gathers all illegal access events in the system and generates a secure interrupt towards NVIC.

These sub-blocks are used to configure TrustZone system security in a product having bus agents with programmable-security and privileged attributes such as:

- on-chip RAM with programmable secure and/or privileged blocks (pages)
- AHB and APB peripherals with programmable security and/or privileged access
- off-chip memories with secure and/or privileged areas

5.2 GTZC main features

The GTZC main features are listed below:

- 3 independent 32-bit AHB interface for TZSC, TZIC, and MPCBB
- TZIC accessible only with secure transactions
- Secure and nonsecure access supported for privileged and unprivileged parts of TZSC and MPCBB
- Set of registers to define product security settings:
  - Secure/privileged blocks for internal SRAMs
  - Secure/privileged regions for external memories and internal backup SRAM
  - Secure/privileged access mode for securable peripherals
  - Secure/privileged access mode for securable masters

GTZC TrustZone system architecture

The Armv8-M supports security per TrustZone-M model with isolation between:

- a secure world, where usually security sensitive applications are run and critical resources are located
- a nonsecure or public world (such as the usual nonsecure operating system and user space)

The TrustZone architecture is extended beyond AHB and Armv8-M with:

- AHB/APB bridge used as secure gate to block or propagate secure/nonsecure and privileged/unprivileged transaction towards APB agents
- PPC (peripheral protection controller) used as a secure gate to block or propagate secure/nonsecure and privileged/unprivileged transaction towards AHB agents
- TrustZone block-based MPC firewalls used as secure gate to filter secure/nonsecure, privileged/unprivileged access towards internal SRAMs
- TrustZone watermark MPC firewalls used as secure gate to filter secure/nonsecure, privileged/unprivileged access towards external memories

AHB and APB peripherals can be categorized as:

- **privileged**: peripherals protected by AHB/APB firewall stub that is controlled from TZSC to define privilege properties
- **secure**: peripherals always protected by an AHB/APB firewall stub. These peripherals are always secure (such as TZIC)
- **securable**: peripherals protected by an AHB/APB firewall stub that is controlled from TZSC to define security properties (optional)
- **nonsecure and unprivileged:** peripherals connected directly to AHB/APB interconnect without any secure gate
- **TrustZone-aware**: peripherals connected directly to the AHB or APB bus and implementing a specific TrustZone behavior (such as a subset of registers being secure). TrustZone-aware AHB masters always drive HNONSEC signal according to their security mode (such as Armv8-M core or DMA)

AHB securable masters can be configured in the TZSC to be secure/nonsecure and/or privileged/unprivileged.

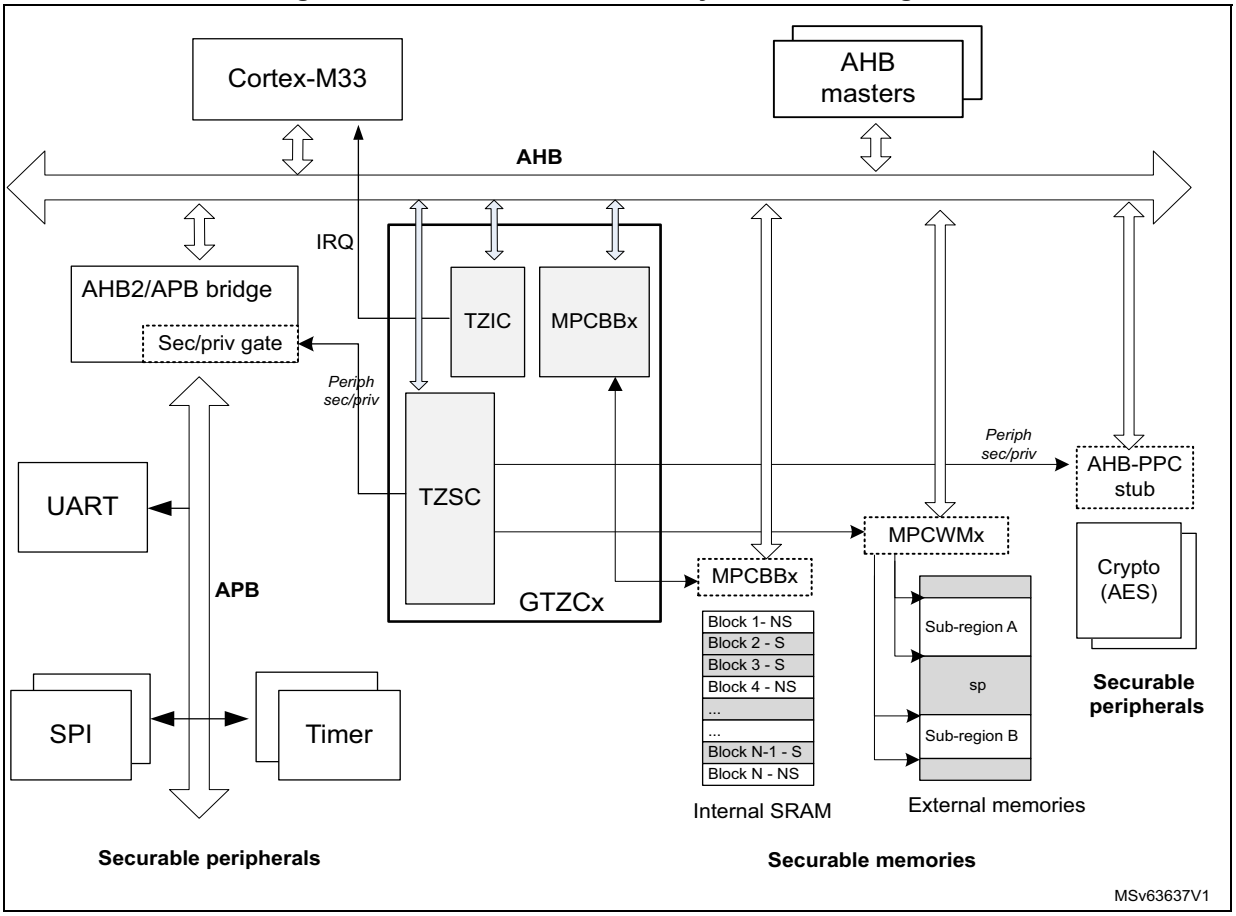
Application information

The TZSC, MPCBB, and TZIC can be used in one of the following ways:

- programmed during secure boot only, locked and not changed afterwards
- dynamically re-programmed when using specific application code or secure kernel (microvisor). When not locked, MPC secure blocks or region size can be changed by secure software executing from the secure FLASH region or secure SRAM. Same remark applies to the GTZC1_TZSC_SECCFGRx/PRIVCFGRx registers that define secure/privileged state of each peripheral.

The Armv8-M security architecture with secure, securable, and TrustZone-aware peripherals is shown in *Figure 15*.

Figure 15. GTZC in Armv8-M subsystem block diagram



5.3 GTZC implementation

The STM32H5E4/5F4 and STM32H5E5/5F5 devices embed one instance of GTZC.

Table 23. GTZC features

GTZC sub-blocks	GTZC1
TZSC	X
TZIC	X
MPCBB sub-block (number of MPCBB)	MPCBB1/2/3/4/5

Table 24 shows the address offset of GTZC sub-blocks versus GTZC base address (refer to *Section 2.3* for GTZC1 base address).

Table 24. GTZC1 sub-block address offset

GTZC1 sub-block	Address offset
GTZC1_TZSC	0x0
GTZC1_TZIC	0x400
GTZC1_MPCBB1	0x800
GTZC1_MPCBB2	0xC00
GTZC1_MPCBB3	0x1000
GTZC1_MPCBB4	0x1400
GTZC1_MPCBB5	0x1800

Table 25 describes the characteristics of the available MPCWM.

Table 25. MPCWM resource assignment

GTZC	MPC	Target memory interface	Number of sec/nonsec and priv/unpriv regions	Watermark granularity (bytes)
GTZC1	MPCWM1	OCTOSPI1	2	128 K
	MPCWM2	FMC_NOR bank	2	128 K
	MPCWM3	FMC_NAND bank	1	128 K
		FMC_SDRAM bank 1	1	128 K
	MPCWM4	BKPSRAM	1	32
		FMC_SDRAM_bank 2	1	128 K
	MPCWM5	OCTOSPI2	2	128 K

Table 26. MPCWM3 and MPCWM4 (subregions A and B)

GTZ	MPC	Target memory interface	Subregion
GTZC1	MPCWM3	FMC_NAND bank	A
		FMC_SDRAM bank 1	B
	MPCWM4	BKPSRAM	A
		FMC_SDRAM bank 2	B

Table 27 describes the characteristics of the available MPCBB.

Table 27. MPCBB resource assignment

GTZC	MPC	Resource	Memory size (Kbytes)	Block size (bytes)	Number of blocks	Number of super-blocks
GTZC1	MPCBB1	SRAM1	256	512	512	16
	MPCBB2	SRAM2	128		256	8
	MPCBB3	SRAM3	384		768	24
	MPCBB4	SRAM4	384		768	24
	MPCBB5	SRAM5	384		768	24

5.4 GTZC functional description

5.4.1 GTZC block diagram

Figure 16 describes the combined feature of TZSC, MPCBB, and TZIC. Each sub-block is controlled by its own AHB configuration port.

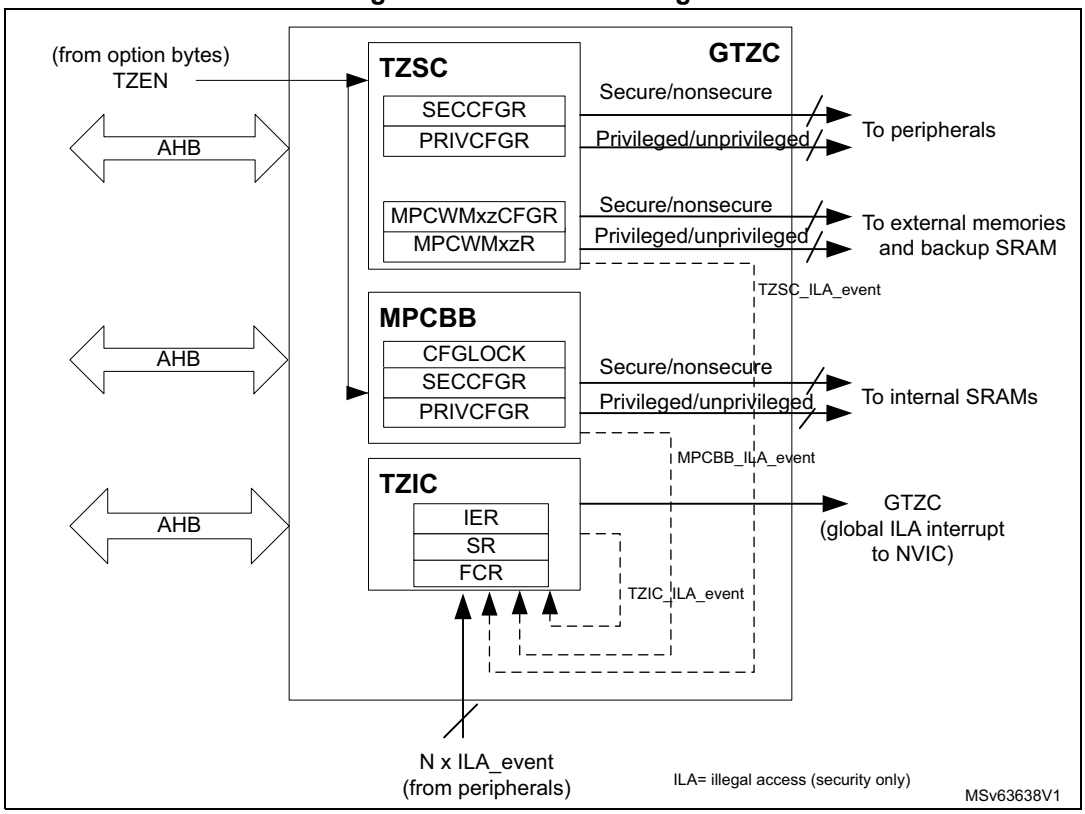
The TZSC defines which peripheral is secure and/or privileged. The privileged configuration bit of a peripheral can be modified by a secure privileged transaction when the peripheral is configured as secure. Otherwise, a privileged transaction (nonsecure) is sufficient.

On the opposite, the secure configuration bit of a peripheral can be modified only with a secure privileged transaction if the peripheral is configured as privileged. Otherwise, a secure transaction (unprivileged) is sufficient.

The secure configuration bit of a given ram block can be modified only with a secure privileged transaction if the same RAM block is configured as privileged. Otherwise, a secure transaction (unprivileged) is sufficient.

The TZIC gathers illegal events generated within the system when an illegal access is detected. TZIC can then generate a secure interrupt towards the CPU if needed.

Figure 16. GTZC block diagram



5.4.2 Illegal access definition

Three different types of illegal access exist:

- Illegal nonsecure access

  Any nonsecure transaction trying to write a secure resource is considered as illegal, hence the addressed resource generates an illegal access interrupt for illegal write access and a bus error for illegal fetch access. There are some exceptions on secure and privileged configuration registers: these latter ones authorize nonsecure read access to secure registers (see GTZC1_TZSC_SECCFGRx and GTZC1_TZSC_PRIVCFGRx).

- Illegal secure access

  Any secure transaction trying to access nonsecure block in internal block-based SRAM or watermarked memory is considered as illegal.

  A correct TZIC setting allows the capture of the associated event and then generates the GTZC_IRQn interrupt to the NVIC. This applies for read, write, and execute access.

  Concerning the MPCBB controller, there is an option to ignore secure data read/write access on nonsecure SRAM blocks, by setting the SRWILADIS bit in the GTZC1_MPCBBz_CR register. Secure read and write data transactions are then

allowed on nonsecure SRAM blocks, while secure execution access remains not allowed.

Any secure execute transaction trying to access a nonsecure peripheral register is considered as illegal and generate a bus error.

- Illegal unprivileged access

  Any unprivileged transaction trying to access a privileged resource is considered as illegal. There is no illegal access event generated for illegal read and write access. The addressed resource follows a silent-fail behavior, returning all zero data for read and ignoring any write. No bus error is generated. A bus error is generated when any unprivileged execute transaction tries to access a privileged memory.

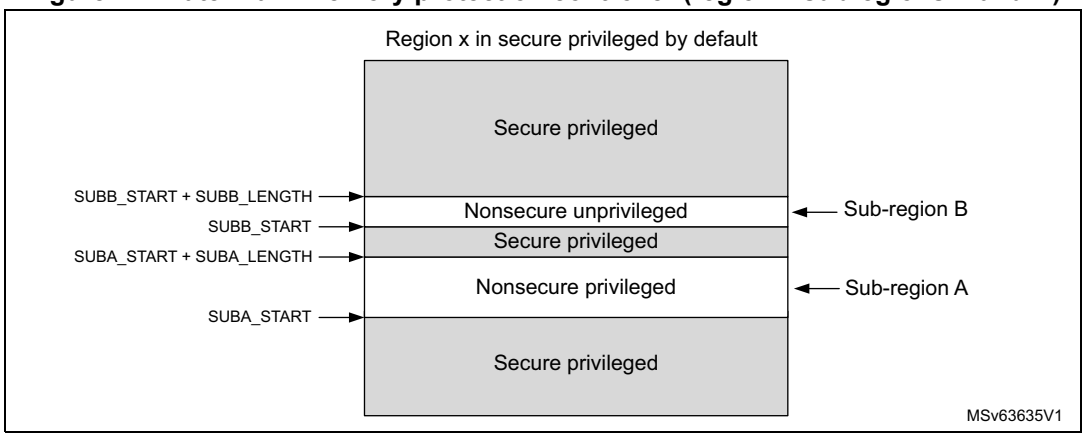
5.4.3 TrustZone security controller (TZSC)

The TZSC is composed of a configurable set of registers, providing the following features:

- Control of secure and privileged state for all peripherals, done through:
  - GTZC1_TZSC_SECCFGRx registers to control AHB/APB firewall stubs for the securable peripherals
  - GTZC1_TZSC_PRIVCFGRx registers to control AHB/APB firewall stubs for the privileged peripherals
- For watermark memory protection controller (external memories and backup SRAM), two independent regions can be defined and the following fields are used to program:
  - the start of the first protected subregion on the external memory/backup SRAM: SUBA_START[10:0]
  - the length of the first protected subregion on the external memory/backup SRAM: SUBA_LENGTH[11:0]
  - the start of the second protected subregion on the external memory/backup SRAM: SUBB_START[10:0]
  - the length of the second protected subregion on the external memory/backup SRAM: SUBB_LENGTH[11:0]

A control register for each subregion can be used to enable/disable the watermark memory protection controller as well as defining the right attributes of each subregion.

Figure 17. Watermark memory protection controller (region x/subregions A and B)



In *Figure 17*, region x represents the external memory or backup SRAM region (such as FMC bank, OCTOSPI1, OCTOSPI2 or BKPSRAM). Secure and privileged attributes of

subregions A and B are independently configurable. When no subregions are defined or enabled on the region x, then the default attribute of the region x is set as secure-privileged.

The following tables describe the secure/privileged properties of the common area of subregion A and B, when an overlap exists.

Table 28. Secure properties of subregions A and B

subregion A	subregion B	Properties of overlapped region A and B
Nonsecure	Nonsecure	Nonsecure
Nonsecure	Secure	Nonsecure
Secure	Nonsecure	Nonsecure
Secure	Secure	Secure

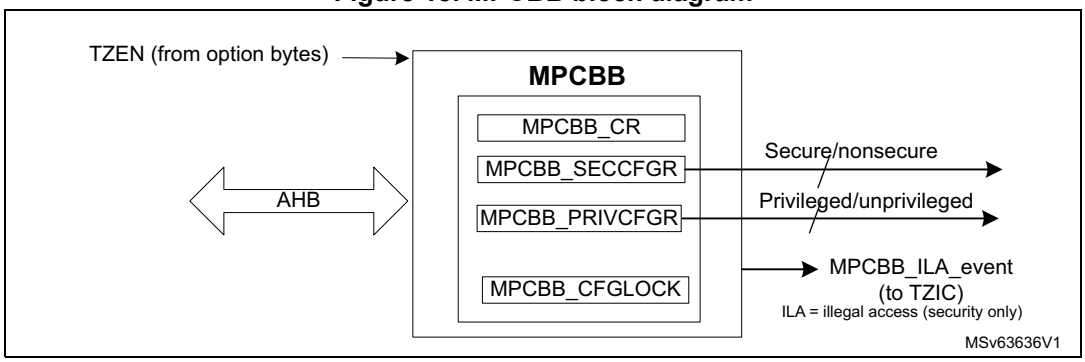
Table 29. Privileged properties of subregions A and B

subregion A	subregion B	Properties of overlapped region A and B
Unprivileged	Unprivileged	Unprivileged
Unprivileged	Privileged	Unprivileged
Privileged	Unprivileged	Unprivileged
Privileged	Privileged	Privileged

5.4.4 Memory protection controller - block based (MPCBB)

The MPCBB is composed of a configurable set of registers allowing to define security and privileged policy for internal SRAM memories. The security and privileged policy can be individually configured per each 512-byte block of SRAM.

Figure 18. MPCBB block diagram



To set up the MPCBB, the following actions are needed (for example at boot time):

- Secure firmware must define which memory blocks are secure by setting the correct bits in GTZC1_MPCBBz_SECCFGRx.
- Privileged firmware must define which memory blocks are privileged by setting the correct bits in GTZC1_MPCBBz_PRIVCFGRx.

A MPCBB super-block is made of 32 consecutive blocks. For each super-block, secure application can lock all related security/privileged bits using the correct bits in GTZC1_MPCBBz_CFGLOCK. This lock remains active until the next system reset.

*Note: The block size is 512 bytes. The super-block size is 512 * 32 = 16 Kbytes.*

5.4.5 TrustZone illegal access controller (TZIC)

The TZIC concentrates all illegal access source events. It is used only when the system is TrustZone enabled (TZEN = 0xB4).

TZIC allows to trace (flag) the event that triggered the secure illegal access interrupt. Register masks (GTZC1_TZIC_IERx) are available to filter unwanted event. On unmasked illegal event, TZIC generates the GTZC_IRQn interrupt to the NVIC.

For each illegal event source, a status flag and a clear bit exist (respectively within GTZC1_TZIC_SRx and GTZC1_TZIC_FCRx). The reset value of mask registers (GTZC1_TZIC_IERx) is such that all events are masked.

5.4.6 Power-on/reset state

The power-on and reset state of the TZSC clear to 0 all bits of GTZC1_TZSC_SECCFGRx and GTZC1_TZSC_PRIVCFGRx, meaning that all securable peripherals are respectively set to nonsecure and unprivileged.nonseFor internal SRAMx (x = 1 to 3), all GTZC1_MPCBBz_SECCFGRx and GTZC1_MPCBBz_PRIVCFGRx are set:

- to 0xFFFF FFFF, making these internal memories block secure and privileged by default when TrustZone security is enabled at system level (TZEN = 0xB4).
- to 0x0000 0000, making these internal memories block nonsecure and unprivileged by default when TrustZone security is disabled at system level (TZEN = 0xC3)

For external memories and backup SRAM, all GTZC1_TZSC_MPCWMxzR registers are set:

- to 0x0000 0000, making these memories secure and privileged by default when TrustZone security is enabled a system level (TZEN = 0xB4).
- to 0x0800 0000, making these memories nonsecure and non-privilege by default when TrustZone security is disabled at system level (TZEN = 0xC3)

Secure boot code can then program the security settings, making components secure or not as needed.

5.5 GTZC interrupts

TZIC is a secure peripheral, thus it systematically generates an illegal access event when accessed by a nonsecure access. The MPCBB and TZSC are TrustZone-aware peripherals, meaning that secure and nonsecure registers coexist within the peripheral.

Table 30. GTZC interrupt request

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit Sleep mode	Exit Stop mode	Exit Standby mode
GTZC	Illegal access	All flags in GTZC1_TZIC_SRx	All bits in GTZC1_TZIC_IERx	Write 1 in the bit GTZC1_TZIC_FCRx	Yes	Yes	No

5.6 GTZC1 TZSC registers

All registers are accessed only by words (32-bit).

5.6.1 GTZC1 TZSC control register (GTZC1_TZSC_CR)

Address offset: 0x000

Reset value: 0x0000 0000

Secure privileged access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LCK
															rs

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **LCK**: lock the configuration of GTZC1_TZSC_SECCFGRx and GTZC1_TZSC_PRIVCFGRx until next reset

This bit is cleared by default and once set, it can not be reset until system reset.

0: configuration of all GTZC1_TZSC_SECCFGRx and GTZC1_TZSC_PRIVCFGRx not locked

1: configuration of all GTZC1_TZSC_SECCFGRx and GTZC1_TZSC_PRIVCFGRx locked

5.6.2 GTZC1 TZSC secure configuration register 1 (GTZC1_TZSC_SECCFGR1)

Address offset: 0x010

Reset value: 0x0000 0000

Write-secure access only.

This register can be written only by secure privileged transaction when the corresponding GTZC1_TZSC_PRIVCFGR signal is set to 1. If a given PRIV bit is not set, the equivalent SEC bit can be written by secure unprivileged transaction.

Read accesses are authorized for any type of transactions, secure or not, privileged or not.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LPTIM2SEC	DTSSEC	UART12SEC	UART9SEC	UART8SEC	UART7SEC	DAC1SEC	HDMICECSEC	USART11SEC	USART10SEC	USART6SEC	CRSSEC	I3C1SEC	I2C2SEC	I2C1SEC	UART5SEC
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
UART4SEC	USART3SEC	USART2SEC	SPI3SEC	SPI2SEC	IWDGSEC	WWDGSEC	TIM14SEC	TIM13SEC	TIM12SEC	TIM7SEC	TIM6SEC	TIM5SEC	TIM4SEC	TIM3SEC	TIM2SEC
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **LPTIM2SEC**: Secure access mode for LPTIM2

0: Nonsecure

1: Secure

Bit 30 **DTSSEC**: Secure access mode for DTS
0: Nonsecure
1: Secure

Bit 29 **UART12SEC**: Secure access mode for UART12
0: Nonsecure
1: Secure

Bit 28 **UART9SEC**: Secure access mode for UART9
0: Nonsecure
1: Secure

Bit 27 **UART8SEC**: Secure access mode for UART8
0: Nonsecure
1: Secure

Bit 26 **UART7SEC**: Secure access mode for UART7
0: Nonsecure
1: Secure

Bit 25 **DAC1SEC**: Secure access mode for DAC1
0: Nonsecure
1: Secure

Bit 24 **HDMICECSEC**: Secure access mode for HDMICEC
0: Nonsecure
1: Secure

Bit 23 **USART11SEC**: Secure access mode for USART11
0: Nonsecure
1: Secure

Bit 22 **USART10SEC**: Secure access mode for USART10
0: Nonsecure
1: Secure

Bit 21 **USART6SEC**: Secure access mode for USART6
0: Nonsecure
1: Secure

Bit 20 **CRSSEC**: Secure access mode for CRS
0: Nonsecure
1: Secure

Bit 19 **I3C1SEC**: Secure access mode for I3C1
0: Nonsecure
1: Secure

Bit 18 **I2C2SEC**: Secure access mode for I2C2
0: Nonsecure
1: Secure

Bit 17 **I2C1SEC**: Secure access mode for I2C1
0: Nonsecure
1: Secure

Bit 16 **UART5SEC**: Secure access mode for UART5
0: Nonsecure
1: Secure

Bit 15 **UART4SEC**: Secure access mode for UART4
0: Nonsecure
1: Secure

Bit 14 **USART3SEC**: Secure access mode for USART3
0: Nonsecure
1: Secure

Bit 13 **USART2SEC**: Secure access mode for USART2
0: Nonsecure
1: Secure

Bit 12 **SPI3SEC**: Secure access mode for SPI3
0: Nonsecure
1: Secure

Bit 11 **SPI2SEC**: Secure access mode for SPI2
0: Nonsecure
1: Secure

Bit 10 **IWDGSEC**: Secure access mode for IWDG
0: Nonsecure
1: Secure

Bit 9 **WWDGSEC**: Secure access mode for WWDG
0: Nonsecure
1: Secure

Bit 8 **TIM14SEC**: Secure access mode for TIM14
0: Nonsecure
1: Secure

Bit 7 **TIM13SEC**: Secure access mode for TIM13
0: Nonsecure
1: Secure

Bit 6 **TIM12SEC**: Secure access mode for TIM12
0: Nonsecure
1: Secure

Bit 5 **TIM7SEC**: Secure access mode for TIM7
0: Nonsecure
1: Secure

Bit 4 **TIM6SEC**: Secure access mode for TIM6
0: Nonsecure
1: Secure

Bit 3 **TIM5SEC**: Secure access mode for TIM5
0: Nonsecure
1: Secure

Bit 2 **TIM4SEC**: Secure access mode for TIM4
0: Nonsecure
1: Secure

Bit 1 **TIM3SEC**: Secure access mode for TIM3
0: Nonsecure
1: Secure

Bit 0 **TIM2SEC**: Secure access mode for TIM2
0: Nonsecure
1: Secure

5.6.3 GTZC1 TZSC secure configuration register 2 (GTZC1_TZSC_SECCFGR2)

Address offset: 0x014

Reset value: 0x0000 0000

Write-secure access only.

This register can be written only by secure privileged transaction when the corresponding GTZC1_TZSC_PRIVCFGR signal is set to 1. If a given PRIV is not set, the equivalent SEC bit can be written by secure unprivileged transaction.

Read accesses are authorized for any type of transactions, secure or not, privileged or not.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LPTIM5SEC	LPTIM4SEC	LPTIM3SEC	LPTIM1SEC	I2C4SEC	I2C3SEC	LPUART1SEC	SPI5SEC	Res.	Res.	GFXTIMSEC	LTDCSEC	Res.	SAI2SEC	SAI1SEC	SPI6SEC
rw	rw	rw	rw	rw	rw	rw	rw			rw	rw		rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI4SEC	TIM17SEC	TIM16SEC	TIM15SEC	USART1SEC	TIM8SEC	SPI1SEC	TIM1SEC	Res.	Res.	FDCAN3SEC	COMPSEC	OPAMPSEC	UCPDSEC	FDCAN2SEC	FDCAN1SEC
rw	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bit 31 **LPTIM5SEC**: Secure access mode for LPTIM5
0: Nonsecure
1: Secure

Bit 30 **LPTIM4SEC**: Secure access mode for LPTIM4
0: Nonsecure
1: Secure

Bit 29 **LPTIM3SEC**: Secure access mode for LPTIM3
0: Nonsecure
1: Secure

Bit 28 **LPTIM1SEC**: Secure access mode for LPTIM1
0: Nonsecure
1: Secure

Bit 27 **I2C4SEC**: Secure access mode for I2C4
0: Nonsecure
1: Secure

Bit 26 **I2C3SEC**: Secure access mode for I2C3
0: Nonsecure
1: Secure

Bit 25 **LPUART1SEC**: Secure access mode for LPUART
0: Nonsecure
1: Secure

Bit 24 **SPI5SEC**: Secure access mode for SPI5
0: Nonsecure
1: Secure

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **GFXTIMSEC**: Secure access mode for GFXTIM
0: Nonsecure
1: Secure

Bit 20 **LTDCSEC**: Secure access mode for LTDC
0: Nonsecure
1: Secure

Bit 19 Reserved, must be kept at reset value.

Bit 18 **SAI2SEC**: Secure access mode for SAI2
0: Nonsecure
1: Secure

Bit 17 **SAI1SEC**: Secure access mode for SAI1
0: Nonsecure
1: Secure

Bit 16 **SPI6SEC**: Secure access mode for SPI6
0: Nonsecure
1: Secure

Bit 15 **SPI4SEC**: Secure access mode for SPI4
0: Nonsecure
1: Secure

Bit 14 **TIM17SEC**: Secure access mode for TIM17
0: Nonsecure
1: Secure

Bit 13 **TIM16SEC**: Secure access mode for TIM16
0: Nonsecure
1: Secure

Bit 12 **TIM15SEC**: Secure access mode for TIM15
0: Nonsecure
1: Secure

Bit 11 **USART1SEC**: Secure access mode for USART1
0: Nonsecure
1: Secure

Bit 10 **TIM8SEC**: Secure access mode for TIM8
0: Nonsecure
1: Secure

Bit 9 **SPI1SEC**: Secure access mode for SPI1
0: Nonsecure
1: Secure

Bit 8 **TIM1SEC**: Secure access mode for TIM1
0: Nonsecure
1: Secure

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **FDCAN3SEC**: Secure access mode for FDCAN3
0: Nonsecure
1: Secure

Bit 4 **COMPSEC**: Secure access mode for COMP
0: Nonsecure
1: Secure

Bit 3 **OPAMPSEC**: Secure access mode for OPAMP
0: Nonsecure
1: Secure

Bit 2 **UCPDSEC**: Secure access mode for UCPD
0: Nonsecure
1: Secure

Bit 1 **FDCAN2SEC**: Secure access mode for FDCAN2
0: Nonsecure
1: Secure

Bit 0 **FDCAN1SEC**: Secure access mode for FDCAN1
0: Nonsecure
1: Secure

5.6.4 GTZC1 TZSC secure configuration register 3 (GTZC1_TZSC_SECCFGR3)

Address offset: 0x018

Reset value: 0x0000 0000

Write-secure access only.

This register can be written only by secure privileged transaction when the corresponding GTZC1_TZSC_PRIVCFGR is set to 1. If a given PRIV is not set, the equivalent SEC bit can be written by secure unprivileged transaction.

Read accesses are authorized for any type of transactions, secure or not, privileged or not.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OTGFSSEC	OTGHSSEC	JPEGSEC	DMA2DSEC	MDF1SEC	RAMCFGSEC	OCTOSPI2SEC	OCTOSPI1SEC	FMCSEC	SDMMC2SEC	SDMMC1SEC	PKASEC	SAESSEC	RNGSEC	HASHSEC	AESSEC
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DCMISEC	ADC12SEC	DCACHESEC	ICACHESEC	ETHSEC	FMACSEC	CORDICSEC	CRCSEC	ADF1SEC	ADC3SEC	OCTOSPIMSEC	CCBSEC	Res.	I3C2SEC	VREFBUFSEC	LPTIM6SEC
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw

Bit 31 **OTGFSSEC**: Secure access mode for OTGFS
0: Nonsecure
1: Secure

Bit 30 **OTGHSSEC**: Secure access mode for OTGHS
0: Nonsecure
1: Secure

Bit 29 **JPEGSEC**: Secure access mode for JPEG
0: Nonsecure
1: Secure

Bit 28 **DMA2DSEC**: Secure access mode for DMA2D
0: Nonsecure
1: Secure

Bit 27 **MDF1SEC**: Secure access mode for MDF1
0: Nonsecure
1: Secure

Bit 26 **RAMCFGSEC**: Secure access mode for RAMSCFG
0: Nonsecure
1: Secure

Bit 25 **OCTOSPI2SEC**: Secure access mode for OCTOSPI2
0: Nonsecure
1: Secure

Bit 24 **OCTOSPI1SEC**: Secure access mode for OCTOSPI1
0: Nonsecure
1: Secure

Bit 23 **FMCSEC**: Secure access mode for FMC
0: Nonsecure
1: Secure

Bit 22 **SDMMC2SEC**: Secure access mode for SDMMC2
0: Nonsecure
1: Secure

Bit 21 **SDMMC1SEC**: Secure access mode for SDMMC1
0: Nonsecure
1: Secure

Bit 20 **PKASEC**: Secure access mode for PKA
0: Nonsecure
1: Secure

Bit 19 **SAESSEC**: Secure access mode for SAES
0: Nonsecure
1: Secure

Bit 18 **RNGSEC**: Secure access mode for RNG
0: Nonsecure
1: Secure

Bit 17 **HASHSEC**: Secure access mode for HASH
0: Nonsecure
1: Secure

Bit 16 **AESSEC**: Secure access mode for AES
0: Nonsecure
1: Secure

Bit 15 **DCMISEC**: Secure access mode for DCMI
0: Nonsecure
1: Secure

Bit 14 **ADC12SEC**: Secure access mode for ADC1 and ADC2
0: Nonsecure
1: Secure

Bit 13 **DCACHESEC**: Secure access mode for DCACHE
0: Nonsecure
1: Secure

Bit 12 **ICACHESEC**: Secure access mode for ICACHE
0: Nonsecure
1: Secure

Bit 11 **ETHSEC**: Secure access mode for register of ETH
0: Nonsecure
1: Secure

Bit 10 **FMACSEC**: Secure access mode for FMAC
0: Nonsecure
1: Secure

Bit 9 **CORDICSEC**: Secure access mode for CORDIC
0: Nonsecure
1: Secure

Bit 8 **CRCSEC**: Secure access mode for CRC
0: Nonsecure
1: Secure

Bit 7 **ADF1SEC**: Secure access mode for ADF1
0: Nonsecure
1: Secure

Bit 6 **ADC3SEC**: Secure access mode for ADC3
0: Nonsecure
1: Secure

Bit 5 **OCTOSPIMSEC**: Secure access mode for OCTOSPIM
0: Nonsecure
1: Secure

Bit 4 **CCBSEC**: Secure access mode for CCB
0: Nonsecure
1: Secure

Bit 3 Reserved, must be kept at reset value.

Bit 2 **I3C2SEC**: Secure access mode for I3C2
0: Nonsecure
1: Secure

Bit 1 **VREFBUFSEC**: Secure access mode for VREFBUF
0: Nonsecure
1: Secure

Bit 0 **LPTIM6SEC**: Secure access mode for LPTIM6
0: Nonsecure
1: Secure

5.6.5 GTZC1 TZSC privilege configuration register 1 (GTZC1_TZSC_PRIVCFGR1)

Address offset: 0x020

Reset value: 0x0000 0000

Write-privileged access only.

This register can be read or written only by secure privileged transaction when the corresponding GTZC1_TZSC_SECCFGR signal is set to1. If a given SEC bit is not set, the equivalent PRIV bit can be read/written by nonsecure privileged transaction.

Read accesses are authorized for any type of transactions, secure or not, privileged or not.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LPTIM2PRIV	DTSPRIV	UART12PRIV	UART9PRIV	UART8PRIV	UART7PRIV	DAC1PRIV	HDMICECPRIV	USART11PRIV	USART10PRIV	USART6PRIV	CRSPRIV	I3C1PRIV	I2C2PRIV	I2C1PRIV	UART5PRIV
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
UART4PRIV	USART3PRIV	USART2PRIV	SPI3PRIV	SPI2PRIV	IWDGPRIV	WWDGPRIV	TIM14PRIV	TIM13PRIV	TIM12PRIV	TIM7PRIV	TIM6PRIV	TIM5PRIV	TIM4PRIV	TIM3PRIV	TIM2PRIV
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **LPTIM2PRIV**: privileged access mode for LPTIM2
0: unprivileged
1: privileged

Bit 30 **DTSPRIV**: privileged access mode for DTS
0: unprivileged
1: privileged

Bit 29 **UART12PRIV**: privileged access mode for UART12
0: unprivileged
1: privileged

Bit 28 **UART9PRIV**: privileged access mode for UART9
0: unprivileged
1: privileged

Bit 27 **UART8PRIV**: privileged access mode for UART8
0: unprivileged
1: privileged

Bit 26 **UART7PRIV**: privileged access mode for UART7
0: unprivileged
1: privileged

Bit 25 **DAC1PRIV**: privileged access mode for DAC1
0: unprivileged
1: privileged

Bit 24 **HDMICECPRIV**: privileged access mode for HDMICEC
0: unprivileged
1: privileged

Bit 23 **USART11PRIV**: privileged access mode for USART11
0: unprivileged
1: privileged

Bit 22 **USART10PRIV**: privileged access mode for USART10
0: unprivileged
1: privileged

Bit 21 **USART6PRIV**: privileged access mode for USART6
0: unprivileged
1: privileged

Bit 20 **CRSPRIV**: privileged access mode for CRS
0: unprivileged
1: privileged

Bit 19 **I3C1PRIV**: privileged access mode for I3C1
0: unprivileged
1: privileged

Bit 18 **I2C2PRIV**: privileged access mode for I2C2
0: unprivileged
1: privileged

Bit 17 **I2C1PRIV**: privileged access mode for I2C1
0: unprivileged
1: privileged

Bit 16 **UART5PRIV**: privileged access mode for UART5
0: unprivileged
1: privileged

Bit 15 **UART4PRIV**: privileged access mode for UART4
0: unprivileged
1: privileged

Bit 14 **USART3PRIV**: privileged access mode for USART3
0: unprivileged
1: privileged

Bit 13 **USART2PRIV**: privileged access mode for USART2
0: unprivileged
1: privileged

Bit 12 **SPI3PRIV**: privileged access mode for SPI3
0: unprivileged
1: privileged

Bit 11 **SPI2PRIV**: privileged access mode for SPI2
0: unprivileged
1: privileged

Bit 10 **IWDGPRIV**: privileged access mode for IWDG
0: unprivileged
1: privileged

Bit 9 **WWDGPRIV**: privileged access mode for WWDG
0: unprivileged
1: privileged

Bit 8 **TIM14PRIV**: privileged access mode for TIM14
0: unprivileged
1: privileged

Bit 7 **TIM13PRIV**: privileged access mode for TIM13
0: unprivileged
1: privileged

Bit 6 **TIM12PRIV**: privileged access mode for TIM12
0: unprivileged
1: privileged

Bit 5 **TIM7PRIV**: privileged access mode for TIM7
0: unprivileged
1: privileged

Bit 4 **TIM6PRIV**: privileged access mode for TIM6
0: unprivileged
1: privileged

Bit 3 **TIM5PRIV**: privileged access mode for TIM5
0: unprivileged
1: privileged

Bit 2 **TIM4PRIV**: privileged access mode for TIM4
0: unprivileged
1: privileged

Bit 1 **TIM3PRIV**: privileged access mode for TIM3
0: unprivileged
1: privileged

Bit 0 **TIM2PRIV**: privileged access mode for TIM2
0: unprivileged
1: privileged

5.6.6 GTZC1 TZSC privilege configuration register 2 (GTZC1_TZSC_PRIVCFGR2)

Address offset: 0x024

Reset value: 0x0000 0000

Write-privileged access only.

This register can be read or written only by secure privileged transaction when the corresponding GTZC1_TZSC_SECCFGR signal is set to1. If a given SEC bit is not set, the equivalent PRIV bit can be read/written by nonsecure privileged transaction.

Read accesses are authorized for any type of transactions, secure or not, privileged or not.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LPTIM5PRIV	LPTIM4PRIV	LPTIM3PRIV	LPTIM1PRIV	I2C4PRIV	I2C3PRIV	LPUART1PRIV	SPI5PRIV	Res.	Res.	GFXTIMPRIV	LTDCPRIV	Res.	SAI2PRIV	SAI1PRIV	SPI6PRIV
rw	rw	rw	rw	rw	rw	rw	rw			rw	rw		rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI4PRIV	TIM17PRIV	TIM16PRIV	TIM15PRIV	USART1PRIV	TIM8PRIV	SPI1PRIV	TIM1PRIV	Res.	Res.	FDCAN3PRIV	COMPPRIV	OPAMPPRIV	UCPDPRIV	FDCAN2PRIV	FDCAN1PRIV
rw	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bit 31 **LPTIM5PRIV**: privileged access mode for LPTIM5
0: unprivileged
1: privileged

Bit 30 **LPTIM4PRIV**: privileged access mode for LPTIM4
0: unprivileged
1: privileged

Bit 29 **LPTIM3PRIV**: privileged access mode for LPTIM3
0: unprivileged
1: privileged

Bit 28 **LPTIM1PRIV**: privileged access mode for LPTIM1
0: unprivileged
1: privileged

Bit 27 **I2C4PRIV**: privileged access mode for I2C4
0: unprivileged
1: privileged

Bit 26 **I2C3PRIV**: privileged access mode for I2C3
0: unprivileged
1: privileged

Bit 25 **LPUART1PRIV**: privileged access mode for LPUART
0: unprivileged
1: privileged

Bit 24 **SPI5PRIV**: privileged access mode for SPI5
0: unprivileged
1: privileged

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **GFXTIMPRIV**: privileged access mode for GFXTIM
0: unprivileged
1: privileged

Bit 20 **LTDCPRIV**: privileged access mode for LTDC
0: unprivileged
1: privileged

Bit 19 Reserved, must be kept at reset value.

Bit 18 **SAI2PRIV**: privileged access mode for SAI2
0: unprivileged
1: privileged

Bit 17 **SAI1PRIV**: privileged access mode for SAI1
0: unprivileged
1: privileged

Bit 16 **SPI6PRIV**: privileged access mode for SPI6
0: unprivileged
1: privileged

Bit 15 **SPI4PRIV**: privileged access mode for SPI4
0: unprivileged
1: privileged

Bit 14 **TIM17PRIV**: privileged access mode for TIM17
0: unprivileged
1: privileged

Bit 13 **TIM16PRIV**: privileged access mode for TIM16
0: unprivileged
1: privileged

Bit 12 **TIM15PRIV**: privileged access mode for TIM15
0: unprivileged
1: privileged

Bit 11 **USART1PRIV**: privileged access mode for USART1
0: unprivileged
1: privileged

Bit 10 **TIM8PRIV**: privileged access mode for TIM8
0: unprivileged
1: privileged

Bit 9 **SPI1PRIV**: privileged access mode for SPI1
0: unprivileged
1: privileged

Bit 8 **TIM1PRIV**: privileged access mode for TIM1
0: unprivileged
1: privileged

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **FDCAN3PRIV**: privileged access mode for FDCAN3
0: unprivileged
1: privileged

Bit 4 **COMPPRIV**: privileged access mode for COMP
0: unprivileged
1: privileged

Bit 3 **OPAMPPRIV**: privileged access mode for OPAMP
0: unprivileged
1: privileged

Bit 2 **UCPDPRIV**: privileged access mode for UCPD
0: unprivileged
1: privileged

Bit 1 **FDCAN2PRIV**: privileged access mode for FDCAN2
0: unprivileged
1: privileged

Bit 0 **FDCAN1PRIV**: privileged access mode for FDCAN1
0: unprivileged
1: privileged

5.6.7 GTZC1 TZSC privilege configuration register 3 (GTZC1_TZSC_PRIVCFGR3)

Address offset: 0x028

Reset value: 0x0000 0000

Write-privileged access only.

This register can be read or written only by secure privileged transaction when the corresponding GTZC1_TZSC_SECCFGR signal is set to1. If a given SEC bit is not set, the equivalent PRIV bit can be read/written by nonsecure privileged transaction.

Read accesses are authorized for any type of transactions, secure or not, privileged or not.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OTGFSPRIV	OTGHSPRIV	JPEGPRIV	DMA2DPRIV	MDF1PRIV	RAMCFGPRIV	OCTOSPI2PRIV	OCTOSPI1PRIV	FMCPRIV	SDMMC2PRIV	SDMMC1PRIV	PKAPRIV	SAESPRIV	RNGPRIV	HASHPRIV	AESPRIV
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DCMIPRIV	ADC12PRIV	DCACHEPRIV	ICACHEPRIV	ETHPRIV	FMACPRIV	CORDICPRIV	CRCPRIV	ADF1PRIV	ADC3PRIV	OCTOSPIMPRIV	CCBPRIV	Res.	I3C2PRIV	VREFBUFPRIV	LPTIM6PRIV
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw

Bit 31 **OTGFSPRIV**: privileged access mode for OTGFS
0: unprivileged
1: privileged

Bit 30 **OTGHSPRIV**: privileged access mode for OTGHS
0: unprivileged
1: privileged

Bit 29 **JPEGPRIV**: privileged access mode for JPEG
0: unprivileged
1: privileged

Bit 28 **DMA2DPRIV**: privileged access mode for DMA2D
0: unprivileged
1: privileged

Bit 27 **MDF1PRIV**: privileged access mode for MDF1
0: unprivileged
1: privileged

Bit 26 **RAMCFGPRIV**: privileged access mode for RAMSCFG
0: unprivileged
1: privileged

Bit 25 **OCTOSPI2PRIV**: privileged access mode for OCTOSPI2
0: unprivileged
1: privileged

Bit 24 **OCTOSPI1PRIV**: privileged access mode for OCTOSPI1
0: unprivileged
1: privileged

Bit 23 **FMCPRIV**: privileged access mode for FMC
0: unprivileged
1: privileged

Bit 22 **SDMMC2PRIV**: privileged access mode for SDMMC2
0: unprivileged
1: privileged

Bit 21 **SDMMC1PRIV**: privileged access mode for SDMMC1
0: unprivileged
1: privileged

Bit 20 **PKAPRIV**: privileged access mode for PKA
0: unprivileged
1: privileged

Bit 19 **SAESPRIV**: privileged access mode for SAES
0: unprivileged
1: privileged

Bit 18 **RNGPRIV**: privileged access mode for RNG
0: unprivileged
1: privileged

Bit 17 **HASHPRIV**: privileged access mode for HASH
0: unprivileged
1: privileged

Bit 16 **AESPRIV**: privileged access mode for AES
0: unprivileged
1: privileged

Bit 15 **DCMIPRIV**: privileged access mode for DCMI
0: unprivileged
1: privileged

Bit 14 **ADC12PRIV**: privileged access mode for ADC1 and ADC2
0: unprivileged
1: privileged

Bit 13 **DCACHEPRIV**: privileged access mode for DCACHE
0: unprivileged
1: privileged

Bit 12 **ICACHEPRIV**: privileged access mode for ICACHE
0: unprivileged
1: privileged

Bit 11 **ETHPRIV**: privileged access mode for register of ETH
0: unprivileged
1: privileged

Bit 10 **FMACPRIV**: privileged access mode for FMAC
0: unprivileged
1: privileged

Bit 9 **CORDICPRIV**: privileged access mode for CORDIC
0: unprivileged
1: privileged

Bit 8 **CRCPRIV**: privileged access mode for CRC
0: unprivileged
1: privileged

Bit 7 **ADF1PRIV**: privileged access mode for ADF1
0: unprivileged
1: privileged

Bit 6 **ADC3PRIV**: privileged access mode for ADC3
0: unprivileged
1: privileged

Bit 5 **OCTOSPIMPRIV**: privileged access mode for OCTOSPIM
0: unprivileged
1: privileged

Bit 4 **CCBPRIV**: privileged access mode for CCB
0: unprivileged
1: privileged

Bit 3 Reserved, must be kept at reset value.

Bit 2 **I3C2PRIV**: privileged access mode for I3C2
0: unprivileged
1: privileged

Bit 1 **VREFBUFPRIV**: privileged access mode for VREFBUF
0: unprivileged
1: privileged

Bit 0 **LPTIM6PRIV**: privileged access mode for LPTIM6
0: unprivileged
1: privileged

5.6.8 GTZC1 TZSC memory x subregion z watermark configuration register (GTZC1_TZSC_MPCWMxACFGR)

Address offset: 0x40 + 0x10 *(x - 1) (x = 1 to 4)

Reset value: 0x0000 0000

Secure privilege access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	PRIV	SEC	Res.	Res.	Res.	Res.	Res.	Res.	SRLOCK	SREN
						rw	rw							rs	rw

Bits 31:10 Reserved, must be kept at reset value.

Bit 9 **PRIV**: Privileged subregion A of base region x

This bit is taken into account only if SREN is set.

0: Privileged and unprivileged accesses are granted in subregion A.

1: Only privileged accesses are granted in subregion A of region x.

Bit 8 **SEC**: Secure subregion A of base region x

This bit is taken into account only if SREN is set.

0: Only nonsecure data accesses are granted to subregion A of region x.

1: Only secure data accesses are granted to subregion A of region x.

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **SRLOCK**: subregion A lock

This bit, once set, can be cleared only by a system reset.

0: GTZC1_TZSC_MPCWMxCFGR and GTZC1_TZSC_MPCWMxAR can be written.

1: Writes to GTZC1_TZSC_MPCWMxCFGR and GTZC1_TZSC_MPCWMxAR are ignored.

Bit 0 **SREN**: Subregion z enable

0: Subregion A is disabled. Access control of base region x applies to any access between this subregion start- and end-addresses.

1: subregion A of region x is enabled. Access control defined in GTZC1_TZSC_MPCWMx_CFGR applies to any access between this subregion start- and end-addresses, both defined in GTZC1_TZSC_MPCWMxAR.

Note: External memories that are watermark controlled start fully nonsecure/unprivileged at reset when TZEN = 0xC3. When TZEN = 0xB4, external memories start fully secure/fully privileged (inverted reset-value).

5.6.9 GTZC1 TZSC memory x subregion z watermark configuration register (GTZC1_TZSC_MPCWMxBCFGR)

Address offset: 0x48 + 0x10 *(x - 1) (x = 1 to 4)

Reset value: 0x0000 0000

Secure privilege access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	PRIV	SEC	Res.	Res.	Res.	Res.	Res.	Res.	SRLOCK	SREN
						rw	rw							rs	rw

Bits 31:10 Reserved, must be kept at reset value.

Bit 9 **PRIV**: Privileged subregion B of base region x

This bit is taken into account only if SREN is set.

0: Privileged and unprivileged accesses are granted in subregion B.

1: Only privileged accesses are granted in subregion B of region x.

Bit 8 **SEC**: Secure subregion B of base region x

This bit is taken into account only if SREN is set.

0: Only nonsecure data accesses are granted to subregion B of region x.

1: Only secure data accesses are granted to subregion B of region x.

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **SRLOCK**: subregion B lock

This bit, once set, can be cleared only by a system reset.

0: GTZC1_TZSC_MPCWMxCFGR and GTZC1_TZSC_MPCWMxBR can be written.

1: Writes to GTZC1_TZSC_MPCWMxCFGR and GTZC1_TZSC_MPCWMxBR are ignored.

Bit 0 **SREN**: subregion B enable

0: Subregion B is disabled. Access control of base region x applies to any access between this subregion start- and end-addresses.

1: Subregion B of region x is enabled. Access control defined in GTZC1_TZSC_MPCWMx_CFGR applies to any access between this subregion start- and end-addresses, both defined in GTZC1_TZSC_MPCWMxBR.

Note: External memories that are watermark controlled start fully nonsecure/unprivileged at reset when TZEN = 0xC3. When TZEN = 0xB4, external memories start fully secure/fully privileged (inverted reset-value).

5.6.10 GTZC1 TZSC memory x subregion A watermark register (GTZC1_TZSC_MPCWMxAR)

Address offset: 0x44 + 0x10 *(x - 1) (x = 1 to 4)

Reset value: 0x0000 0000

The given reset value is valid when TZEN = 0xB4. The reset value is 0x0800 0000 when TZEN = 0xC3.

Secure privilege access only.

When SUBA_START + SUBA_LENGTH is higher than the maximum size allowed for the memory, a saturation of SUBA_LENGTH is applied automatically.

When an overlap of subregion A and B exists, secure/privileged attributes of both subregions apply on the common section (see *Section 5.4.3*)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	SUBA_LENGTH[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	SUBA_START[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **SUBA_LENGTH[11:0]**: Length of subregion A in region x

This field defines the length of the subregion A, to be multiplied by the granularity defined in *Table 25*.

When SUBA_START + SUBA_LENGTH is higher than the maximum size allowed for the memory, a saturation of SUBA_LENGTH is applied automatically.

If SUBA_LENGTH = 0, the subregion A is disabled.(SREN bit in GTZC1_TZSC_MPCMWxACFGR is cleared).

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **SUBA_START[10:0]**: Start of subregion A in region x

This field defines the address offset of the subregion A, to be multiplied by the granularity defined in *Table 25*, versus the start of the region x.

External memories that are watermark controlled, start fully nonsecure at reset when TZEN = 0xC3. When TZEN = 0xB4, external memories start fully secure (inverted reset value).

5.6.11 GTZC1 TZSC memory x subregion B watermark register (GTZC1_TZSC_MPCWMxBR)

Address offset: 0x4C + 0x10 *(x - 1) (x = 1 to 4)

Reset value: 0x0000 0000

The given reset value is valid when TZEN = 0xB4. The reset value is 0x0800 0000 when TZEN = 0xC3.

Secure privilege access only.

When SUBB_START + SUBB_LENGTH is higher than the maximum size allowed for the memory, a saturation of SUBB_LENGTH is applied automatically.

When an overlap of subregion A and B exists, secure/privileged attributes of both subregions apply on the common section (see *Section 5.4.3*)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	SUBB_LENGTH[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	SUBB_START[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **SUBB_LENGTH[11:0]**: Length of subregion B in region x

This field defines the length of the subregion B, to be multiplied by the granularity defined in *Table 25*.

When SUBB_START + SUBB_LENGTH is higher than the maximum size allowed for the memory, a saturation of SUBB_LENGTH is applied automatically.

If SUBB_LENGTH = 0, the subregion B is disabled.(SREN bit in GTZC1_TZSC_MPCMWxBCFGR is cleared).

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **SUBB_START[10:0]**: Start of subregion B in region x

This field defines the address offset of the subregion B, to be multiplied by the granularity defined in *Table 25*, versus the start of the region x.

External memories that are watermark controlled, start fully nonsecure at reset when TZEN = 0xC3. When TZEN = 0xB4, external memories start fully secure (inverted reset value).

5.6.12 GTZC1 TZSC register map

Table 31. GTZC1 TZSC register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	GTZC1_TZSC_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LCK
	Reset value																																0
0x004-0x00C	Reserved	Reserved																															
0x010	GTZC1_TZSC_SECCFGR1	LPTIM2SEC	DTSSEC	UART12SEC	UART9SEC	UART8SEC	UART7SEC	DAC1SEC	HDMICECSEC	USART11SEC	USART10SEC	USART6SEC	CRSSEC	I3C1SEC	I2C2SEC	I2C1SEC	UART5SEC	UART4SEC	USART3SEC	USART2SEC	SPI3SEC	SPI2SEC	IWDGSEC	WWDGSEC	TIM14SEC	TIM13SEC	TIM112SEC	TIM7SEC	TIM6SEC	TIM5SEC	TIM4SEC	TIM3SEC	TIM2SEC
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	GTZC1_TZSC_SECCFGR2	LPTIM5SEC	LPTIM4SEC	LPTIM3SEC	LPTIM1SEC	I2C4SEC	I2C3SEC	LPUART1SEC	SPI5SEC	Res.	Res.	Res.	Res.	Res.	SAI2SEC	SAI1SEC	SPI6SEC	SPI4SEC	TIM17SEC	TIM16SEC	TIM15SEC	USART1SEC	TIM8SEC	SPI1SEC	TIM1SEC	Res.	Res.	Res.	Res.	Res.	UCPDSEC	FDCAN2SEC	FDCAN1SEC
	Reset value	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x018	GTZC1_TZSC_SECCFGR3	Res.	Res.	Res.	Res.	Res.	RAMCFGSEC	Res.	OCTOSPI1SEC	FMCSEC	SDMMC2SEC	SDMMC1SEC	PKASEC	SAESSEC	RNGSEC	HASHSEC	AESSEC	DCMISEC	ADC12SEC	DCACHESEC	ICACHESEC	ETHSEC	FMACSEC	CORDICSEC	CRCSEC	Res.	Res.	Res.	Res.	Res.	Res.	VREFBUFSEC	LPTIM6SEC
	Reset value						0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						0	0
0x01C	Reserved	Reserved																															
0x020	GTZC1_TZSC_PRIVCFGR1	LPTIM2PRIV	DTSPRIV	UART12PRIV	UART9PRIV	UART8PRIV	UART7PRIV	DAC1PRIV	HDMICECPRIV	USART11PRIV	USART10PRIV	USART6PRIV	CRSPRIV	I3C1PRIV	I2C2PRIV	I2C1PRIV	UART5PRIV	UART4PRIV	USART3PRIV	USART2PRIV	SPI3PRIV	SPI2PRIV	IWDGPRIV	WWDGPRIV	TIM14PRIV	TIM13PRIV	TIM112PRIV	TIM7PRIV	TIM6PRIV	TIM5PRIV	TIM4PRIV	TIM3PRIV	TIM2PRIV
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	GTZC1_TZSC_PRIVCFGR2	LPTIM5PRIV	LPTIM4PRIV	LPTIM3PRIV	LPTIM1PRIV	I2C4PRIV	I2C3PRIV	LPUART1PRIV	SPI5PRIV	Res.	Res.	Res.	Res.	USBPRIV	SAI2PRIV	SAI1PRIV	SPI6PRIV	SPI4PRIV	TIM17PRIV	TIM16PRIV	TIM15PRIV	USART1PRIV	TIM8PRIV	SPI1PRIV	TIM1PRIV	Res.	Res.	Res.	Res.	Res.	UCPDPRIV	FDCAN2PRIV	FDCAN1PRIV
	Reset value	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x028	GTZC1_TZSC_PRIVFGR3	Res.	Res.	Res.	Res.	Res.	RAMCFGPRIV	Res.	OCTOSPI1PRIV	FMCPRIV	SDMMC2PRIV	SDMMC1PRIV	PKAPRIV	SAESPRIV	RNGPRIV	HASHPRIV	AESPRIV	DCMIPRIV	ADC12PRIV	DCACHEPRIV	ICACHEPRIV	ETHPRIV	FMACPRIV	CORDICPRIV	CRCPRIV	Res.	Res.	Res.	Res.	Res.	Res.	VREFBUFPRIV	LPTIM6PRIV
	Reset value						0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						0	0
0x02C-0x03C	Reserved	Reserved																															
0x040	GTZC1_TZSC_MPCWM1ACFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV	SEC	Res.	Res.	Res.	Res.	Res.	Res.	SRLOCK	SREN
	Reset value																							0	0							0	0
0x44	GTZC1_TZSC_MPCWM1AR	Res.	Res.	Res.	Res.	SUBA_LENGTH[11:0]												Res.	Res.	Res.	Res.	Res.	SUBA_START[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x048	GTZC1_TZSC_MPCWM1BCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV	SEC	Res.	Res.	Res.	Res.	Res.	Res.	SRLOCK	SREN
	Reset value																							0	0							0	0

Table 31. GTZC1 TZSC register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x04C	GTZC1_TZSC_ MPCWM1BR	Res.	Res.	Res.	Res.	SUBB_LENGTH[11:0]												Res.	Res.	Res.	Res.	Res.	SUBB_START[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x050	GTZC1_TZSC_ MPCWM2ACFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV	SEC	Res.	Res.	Res.	Res.	Res.	Res.	SRLOCK	SREN
	Reset value																							0	0							0	0
0x54	GTZC1_TZSC_ MPCWM2AR	Res.	Res.	Res.	Res.	SUBA_LENGTH[11:0]												Res.	Res.	Res.	Res.	Res.	SUBA_START[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x058	GTZC1_TZSC_ MPCWM2BCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV	SEC	Res.	Res.	Res.	Res.	Res.	Res.	SRLOCK	SREN
	Reset value																							0	0							0	0
0x05C	GTZC1_TZSC_ MPCWM2BR	Res.	Res.	Res.	Res.	SUBB_LENGTH[11:0]												Res.	Res.	Res.	Res.	Res.	SUBB_START[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x060	GTZC1_TZSC_ MPCWM3ACFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV	SEC	Res.	Res.	Res.	Res.	Res.	Res.	SRLOCK	SREN
	Reset value																							0	0							0	0
0x64	GTZC1_TZSC_ MPCWM3AR	Res.	Res.	Res.	Res.	SUBA_LENGTH[11:0]												Res.	Res.	Res.	Res.	Res.	SUBA_START[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x068	GTZC1_TZSC_ MPCWM3BCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV	SEC	Res.	Res.	Res.	Res.	Res.	Res.	SRLOCK	SREN
	Reset value																							0	0							0	0
0x06C	GTZC1_TZSC_ MPCWM3BR	Res.	Res.	Res.	Res.	SUBB_LENGTH[11:0]												Res.	Res.	Res.	Res.	Res.	SUBB_START[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x070	GTZC1_TZSC_ MPCWM4ACFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV	SEC	Res.	Res.	Res.	Res.	Res.	Res.	SRLOCK	SREN
	Reset value																							0	0							0	0
0x74	GTZC1_TZSC_ MPCWM4AR	Res.	Res.	Res.	Res.	SUBA_LENGTH[11:0]												Res.	Res.	Res.	Res.	Res.	SUBA_START[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x078	GTZC1_TZSC_ MPCWM4BCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV	SEC	Res.	Res.	Res.	Res.	Res.	Res.	SRLOCK	SREN
	Reset value																							0	0							0	0
0x07C	GTZC1_TZSC_ MPCWM4BR	Res.	Res.	Res.	Res.	SUBB_LENGTH[11:0]												Res.	Res.	Res.	Res.	Res.	SUBB_START[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0

Refer to *Table 24: GTZC1 sub-block address offset*.

5.7 GTZC1 TZIC registers

All registers are accessed only by words (32-bit).

5.7.1 GTZC1 TZIC interrupt enable register 1 (GTZC1_TZIC_IER1)

Address offset: 0x000

Reset value: 0x0000 0000

Secure privileged access only.

This register is used to enable interrupt of illegal access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LPTIM2IE	DTSIE	UART12IE	UART9IE	UART8IE	UART7IE	DAC1IE	HDMICECIE	USART11IE	USART10IE	USART6IE	CRSIE	I3C1IE	I2C2IE	I2C1IE	UART5IE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
UART4IE	USART3IE	USART2IE	SPI3IE	SPI2IE	IWDGIE	WWDGIE	TIM14IE	TIM13IE	TIM12IE	TIM7IE	TIM6IE	TIM5IE	TIM4IE	TIM3IE	TIM2IE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **LPTIM2IE**: illegal access interrupt enable for LPTIM2
0: interrupt disabled
1: interrupt enabled

Bit 30 **DTSIE**: illegal access interrupt enable for DTS
0: interrupt disabled
1: interrupt enabled

Bit 29 **UART12IE**: illegal access interrupt enable for UART12
0: interrupt disabled
1: interrupt enabled

Bit 28 **UART9IE**: illegal access interrupt enable for UART9
0: interrupt disabled
1: interrupt enabled

Bit 27 **UART8IE**: illegal access interrupt enable for UART8
0: interrupt disabled
1: interrupt enabled

Bit 26 **UART7IE**: illegal access interrupt enable for UART7
0: interrupt disabled
1: interrupt enabled

Bit 25 **DAC1IE**: illegal access interrupt enable for DAC1
0: interrupt disabled
1: interrupt enabled

Bit 24 **HDMICECIE**: illegal access interrupt enable for HDMICEC
0: interrupt disabled
1: interrupt enabled

Bit 23 **USART11IE**: illegal access interrupt enable for USART11
0: interrupt disabled
1: interrupt enabled

Bit 22 **USART10IE**: illegal access interrupt enable for USART10
0: interrupt disabled
1: interrupt enabled

Bit 21 **USART6IE**: illegal access interrupt enable for USART6
0: interrupt disabled
1: interrupt enabled

Bit 20 **CRSIE**: illegal access interrupt enable for CRS
0: interrupt disabled
1: interrupt enabled

Bit 19 **I3C1IE**: illegal access interrupt enable for I3C1
0: interrupt disabled
1: interrupt enabled

Bit 18 **I2C2IE**: illegal access interrupt enable for I2C2
0: interrupt disabled
1: interrupt enabled

Bit 17 **I2C1IE**: illegal access interrupt enable for I2C1
0: interrupt disabled
1: interrupt enabled

Bit 16 **UART5IE**: illegal access interrupt enable for UART5
0: interrupt disabled
1: interrupt enabled

Bit 15 **UART4IE**: illegal access interrupt enable for UART4
0: interrupt disabled
1: interrupt enabled

Bit 14 **USART3IE**: illegal access interrupt enable for USART3
0: interrupt disabled
1: interrupt enabled

Bit 13 **USART2IE**: illegal access interrupt enable for USART2
0: interrupt disabled
1: interrupt enabled

Bit 12 **SPI3IE**: illegal access interrupt enable for SPI3
0: interrupt disabled
1: interrupt enabled

Bit 11 **SPI2IE**: illegal access interrupt enable for SPI2
0: interrupt disabled
1: interrupt enabled

Bit 10 **IWDGIE**: illegal access interrupt enable for IWDG
0: interrupt disabled
1: interrupt enabled

Bit 9 **WWDGIE**: illegal access interrupt enable for WWDG
0: interrupt disabled
1: interrupt enabled

Bit 8 **TIM14IE**: illegal access interrupt enable for TIM14
0: interrupt disabled
1: interrupt enabled

Bit 7 **TIM13IE**: illegal access interrupt enable for TIM13
0: interrupt disabled
1: interrupt enabled

Bit 6 **TIM12IE**: illegal access interrupt enable for TIM12
0: interrupt disabled
1: interrupt enabled

Bit 5 **TIM7IE**: illegal access interrupt enable for TIM7
0: interrupt disabled
1: interrupt enabled

Bit 4 **TIM6IE**: illegal access interrupt enable for TIM6
0: interrupt disabled
1: interrupt enabled

Bit 3 **TIM5IE**: illegal access interrupt enable for TIM5
0: interrupt disabled
1: interrupt enabled

Bit 2 **TIM4IE**: illegal access interrupt enable for TIM4
0: interrupt disabled
1: interrupt enabled

Bit 1 **TIM3IE**: illegal access interrupt enable for TIM3
0: interrupt disabled
1: interrupt enabled

Bit 0 **TIM2IE**: illegal access interrupt enable for TIM2
0: interrupt disabled
1: interrupt enabled

5.7.2 GTZC1 TZIC interrupt enable register 2 (GTZC1_TZIC_IER2)

Address offset: 0x004

Reset value: 0x0000 0000

Secure privileged access only.

This register is used to enable interrupt of illegal access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LPTIM5IE	LPTIM4IE	LPTIM3IE	LPTIM1IE	I2C4IE	I2C3IE	LPUART1IE	SPI5IE	Res.	Res.	GFXTIMIE	LTDCIE	Res.	SAI2IE	SAI1IE	SPI6IE
rw	rw	rw	rw	rw	rw	rw	rw			rw	rw		rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI4IE	TIM17IE	TIM16IE	TIM15IE	USART1IE	TIM8IE	SPI1IE	TIM1IE	Res.	Res.	FDCAN3IE	COMPIE	OPAMPIE	UCPDIE	FDCAN2IE	FDCAN1IE
rw	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bit 31 **LPTIM5IE**: illegal access interrupt enable for LPTIM5
0: interrupt disabled
1: interrupt enabled

Bit 30 **LPTIM4IE**: illegal access interrupt enable for LPTIM4
0: interrupt disabled
1: interrupt enabled

Bit 29 **LPTIM3IE**: illegal access interrupt enable for LPTIM3
0: interrupt disabled
1: interrupt enabled

Bit 28 **LPTIM1IE**: illegal access interrupt enable for LPTIM1
0: interrupt disabled
1: interrupt enabled

Bit 27 **I2C4IE**: illegal access interrupt enable for I2C4
0: interrupt disabled
1: interrupt enabled

Bit 26 **I2C3IE**: illegal access interrupt enable for I2C3
0: interrupt disabled
1: interrupt enabled

Bit 25 **LPUART1IE**: illegal access interrupt enable for LPUART
0: interrupt disabled
1: interrupt enabled

Bit 24 **SPI5IE**: illegal access interrupt enable for SPI5
0: interrupt disabled
1: interrupt enabled

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **GFXTIMIE**: illegal access interrupt enable for GFXTIM
0: interrupt disabled
1: interrupt enabled

Bit 20 **LTDCIE**: illegal access interrupt enable for LTDC
0: interrupt disabled
1: interrupt enabled

Bit 19 Reserved, must be kept at reset value.

Bit 18 **SAI2IE**: illegal access interrupt enable for SAI2
0: interrupt disabled
1: interrupt enabled

Bit 17 **SAI1IE**: illegal access interrupt enable for SAI1
0: interrupt disabled
1: interrupt enabled

Bit 16 **SPI6IE**: illegal access interrupt enable for SPI6
0: interrupt disabled
1: interrupt enabled

Bit 15 **SPI4IE**: illegal access interrupt enable for SPI4
0: interrupt disabled
1: interrupt enabled

Bit 14 **TIM17IE**: illegal access interrupt enable for TIM17
0: interrupt disabled
1: interrupt enabled

Bit 13 **TIM16IE**: illegal access interrupt enable for TIM16
0: interrupt disabled
1: interrupt enabled

Bit 12 **TIM15IE**: illegal access interrupt enable for TIM15
0: interrupt disabled
1: interrupt enabled

Bit 11 **USART1IE**: illegal access interrupt enable for USART1
0: interrupt disabled
1: interrupt enabled

Bit 10 **TIM8IE**: illegal access interrupt enable for TIM8
0: interrupt disabled
1: interrupt enabled

Bit 9 **SPI1IE**: illegal access interrupt enable for SPI1
0: interrupt disabled
1: interrupt enabled

Bit 8 **TIM1IE**: illegal access interrupt enable for TIM1
0: interrupt disabled
1: interrupt enabled

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **FDCAN3IE**: illegal access interrupt enable for FDCAN3
0: interrupt disabled
1: interrupt enabled

Bit 4 **COMPIE**: illegal access interrupt enable for COMP
0: interrupt disabled
1: interrupt enabled

Bit 3 **OPAMPIE**: illegal access interrupt enable for OPAMP
0: interrupt disabled
1: interrupt enabled

Bit 2 **UCPDIE**: illegal access interrupt enable for UCPD
0: interrupt disabled
1: interrupt enabled

Bit 1 **FDCAN2IE**: illegal access interrupt enable for FDCAN2
0: interrupt disabled
1: interrupt enabled

Bit 0 **FDCAN1IE**: illegal access interrupt enable for FDCAN1
0: interrupt disabled
1: interrupt enabled

5.7.3 GTZC1 TZIC interrupt enable register 3 (GTZC1_TZIC_IER3)

Address offset: 0x008

Reset value: 0x0000 0000

Secure privileged access only.

This register is used to enable interrupt of illegal access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OTGFSIE	OTGHSIE	JPEGIE	DMA2DIE	MDF1IE	RAMCFGIE	OCTOSPI2IE	OCTOSPI1IE	FMCIE	SDMMC2IE	SDMMC1IE	PKAIE	SAESIE	RNGIE	HASHIE	AESIE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DCMIIE	ADC12IE	DCACHEIE	ICACHEIE	ETHIE	FMACIE	CORDICIE	CRCIE	ADF1IE	ADC3IE	OCTOSPIMIE	CCBIE	Res.	I3C2IE	VREFBUFIE	LPTIM6IE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw

Bit 31 **OTGFSIE**: illegal access interrupt enable for OTGFS
0: interrupt disabled
1: interrupt enabled

Bit 30 **OTGHSIE**: illegal access interrupt enable for OTGHS
0: interrupt disabled
1: interrupt enabled

Bit 29 **JPEGIE**: illegal access interrupt enable for JPEG
0: interrupt disabled
1: interrupt enabled

Bit 28 **DMA2DIE**: illegal access interrupt enable for DMA2D
0: interrupt disabled
1: interrupt enabled

Bit 27 **MDF1IE**: illegal access interrupt enable for MDF1
0: interrupt disabled
1: interrupt enabled

Bit 26 **RAMCFGIE**: illegal access interrupt enable for RAMSCFG
0: interrupt disabled
1: interrupt enabled

Bit 25 **OCTOSPI2IE**: illegal access interrupt enable for OCTOSPI2
0: interrupt disabled
1: interrupt enabled

Bit 24 **OCTOSPI1IE**: illegal access interrupt enable for OCTOSPI1
0: interrupt disabled
1: interrupt enabled

Bit 23 **FMCIE**: illegal access interrupt enable for FMC
0: interrupt disabled
1: interrupt enabled

Bit 22 **SDMMC2IE**: illegal access interrupt enable for SDMMC2
0: interrupt disabled
1: interrupt enabled

Bit 21 **SDMMC1IE**: illegal access interrupt enable for SDMMC1
0: interrupt disabled
1: interrupt enabled

Bit 20 **PKAIE**: illegal access interrupt enable for PKA
0: interrupt disabled
1: interrupt enabled

Bit 19 **SAESIE**: illegal access interrupt enable for SAES
0: interrupt disabled
1: interrupt enabled

Bit 18 **RNGIE**: illegal access interrupt enable for RNG
0: interrupt disabled
1: interrupt enabled

Bit 17 **HASHIE**: illegal access interrupt enable for HASH
0: interrupt disabled
1: interrupt enabled

Bit 16 **AESIE**: illegal access interrupt enable for AES
0: interrupt disabled
1: interrupt enabled

Bit 15 **DCMIIE**: illegal access interrupt enable for DCMI
0: interrupt disabled
1: interrupt enabled

Bit 14 **ADC12IE**: illegal access interrupt enable for ADC1 and ADC2
0: interrupt disabled
1: interrupt enabled

Bit 13 **DCACHEIE**: illegal access interrupt enable for DCACHE
0: interrupt disabled
1: interrupt enabled

Bit 12 **ICACHEIE**: illegal access interrupt enable for ICACHE
0: interrupt disabled
1: interrupt enabled

Bit 11 **ETHIE**: illegal access interrupt enable for register of ETH
0: interrupt disabled
1: interrupt enabled

Bit 10 **FMACIE**: illegal access interrupt enable for FMAC
0: interrupt disabled
1: interrupt enabled

Bit 9 **CORDICIE**: illegal access interrupt enable for CORDIC
0: interrupt disabled
1: interrupt enabled

Bit 8 **CRCIE**: illegal access interrupt enable for CRC
0: interrupt disabled
1: interrupt enabled

Bit 7 **ADF1IE**: illegal access interrupt enable for ADF1
0: interrupt disabled
1: interrupt enabled

Bit 6 **ADC3IE**: illegal access interrupt enable for ADC3
0: interrupt disabled
1: interrupt enabled

Bit 5 **OCTOSPIMIE**: illegal access interrupt enable for OCTOSPIM
0: interrupt disabled
1: interrupt enabled

Bit 4 **CCBIE**: illegal access interrupt enable for CCB
0: interrupt disabled
1: interrupt enabled

Bit 3 Reserved, must be kept at reset value.

Bit 2 **I3C2IE**: illegal access interrupt enable for I3C2
0: interrupt disabled
1: interrupt enabled

Bit 1 **VREFBUFIE**: illegal access interrupt enable for VREFBUF
0: interrupt disabled
1: interrupt enabled

Bit 0 **LPTIM6IE**: illegal access interrupt enable for LPTIM6
0: interrupt disabled
1: interrupt enabled

5.7.4 GTZC1 TZIC interrupt enable register 4 (GTZC1_TZIC_IER4)

Address offset: 0x00C

Reset value: 0x0000 0000

Secure privileged access only.

This register is used to enable interrupt of illegal access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MPCBB5_REGIE	SRAM5IE	MPCBB3_REGIE	SRAM3IE	MPCBB2_REGIE	SRAM2IE	MPCBB1_REGIE	SRAM1IE	MPCBB4_REGIE	SRAM4IE	OCTOSPI2_MEMIE	BKPSRAMIE	FMC_MEMIE	OCTOSPI1_MEMIE	TZIC1IE	TZSC1IE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	PLAY1IE	EXTIIE	RCCIE	PWRIE	TAMPIE	RTCIE	SBSIE	OTFDEC2IE	OTFDEC1IE	FLASHIE	FLASH_REGIE	GPDMA2IE	GPDMA1IE
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **MPCBB5_REGIE**: illegal access interrupt enable for MPCBB5 registers
0: interrupt disabled
1: interrupt enabled

Bit 30 **SRAM5IE**: illegal access interrupt enable for SRAM5
0: interrupt disabled
1: interrupt enabled

Bit 29 **MPCBB3_REGIE**: illegal access interrupt enable for MPCBB3 registers
0: interrupt disabled
1: interrupt enabled

Bit 28 **SRAM3IE**: illegal access interrupt enable for SRAM3
0: interrupt disabled
1: interrupt enabled

Bit 27 **MPCBB2_REGIE**: illegal access interrupt enable for MPCBB2 registers
0: interrupt disabled
1: interrupt enabled

Bit 26 **SRAM2IE**: illegal access interrupt enable for SRAM2
0: interrupt disabled
1: interrupt enabled

Bit 25 **MPCBB1_REGIE**: illegal access interrupt enable for MPCBB1 registers
0: interrupt disabled
1: interrupt enabled

Bit 24 **SRAM1IE**: illegal access interrupt enable for SRAM1
0: interrupt disabled
1: interrupt enabled

Bit 23 **MPCBB4_REGIE**: illegal access interrupt enable for MPCBB4 registers
0: interrupt disabled
1: interrupt enabled

Bit 22 **SRAM4IE**: illegal access interrupt enable for SRAM4
0: interrupt disabled
1: interrupt enabled

Bit 21 **OCTOSPI2_MEMIE**: illegal access interrupt enable for MPCWM5 (OCTOSPI2) memory bank
0: interrupt disabled
1: interrupt enabled

Bit 20 **BKPSRAMIE**: illegal access interrupt enable for MPCWM4 (BKPSRAM) memory bank
0: interrupt disabled
1: interrupt enabled

Bit 19 **FMC_MEMIE**: illegal access interrupt enable for MPCWM2 (FMC_NOR bank), MPCWM3 (FMC_NAND bank and FMC_SDRAM bank 1), and MPCWM4 (FMC_SDRAM bank 2)
0: interrupt disabled
1: interrupt enabled

Bit 18 **OCTOSPI1_MEMIE**: illegal access interrupt enable for MPCWM1 (OCTOSPI1) memory bank
0: interrupt disabled
1: interrupt enabled

Bit 17 **TZIC1IE**: illegal access interrupt enable for GTZC1 TZIC registers
0: interrupt disabled
1: interrupt enabled

Bit 16 **TZSC1IE**: illegal access interrupt enable for GTZC1 TZSC registers
0: interrupt disabled
1: interrupt enabled

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **PLAY1IE**: illegal access interrupt enable for PLAY1
0: interrupt disabled
1: interrupt enabled

Bit 11 **EXTIIE**: illegal access interrupt enable for EXTI
0: interrupt disabled
1: interrupt enabled

Bit 10 **RCCIE**: illegal access interrupt enable for RCC
0: interrupt disabled
1: interrupt enabled

Bit 9 **PWRIE**: illegal access interrupt enable for PWR
0: interrupt disabled
1: interrupt enabled

Bit 8 **TAMPIE**: illegal access interrupt enable for TAMP
0: interrupt disabled
1: interrupt enabled

Bit 7 **RTCIE**: illegal access interrupt enable for RTC
0: interrupt disabled
1: interrupt enabled

Bit 6 **SBSIE**: illegal access interrupt enable for SBS
0: interrupt disabled
1: interrupt enabled

Bit 5 **OTFDEC2IE**: illegal access interrupt enable for OTFDEC2
0: interrupt disabled
1: interrupt enabled

Bit 4 **OTFDEC1IE**: illegal access interrupt enable for OTFDEC1
0: interrupt disabled
1: interrupt enabled

Bit 3 **FLASHIE**: illegal access interrupt enable for FLASH memory
0: interrupt disabled
1: interrupt enabled

Bit 2 **FLASH_REGIE**: illegal access interrupt enable for FLASH registers
0: interrupt disabled
1: interrupt enabled

Bit 1 **GPDMA2IE**: illegal access interrupt enable for GPDMA2
0: interrupt disabled
1: interrupt enabled

Bit 0 **GPDMA1IE**: illegal access interrupt enable for GPDMA1
0: interrupt disabled
1: interrupt enabled

5.7.5 GTZC1 TZIC status register 1 (GTZC1_TZIC_SR1)

Address offset: 0x010

Reset value: 0x0000 0000

Secure privileged access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LPTIM2F	DTSF	UART12F	UART9F	UART8F	UART7F	DAC1F	HDMICECF	USART11F	USART10F	USART6F	CRSF	I3C1F	I2C2F	I2C1F	UART5F
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
UART4F	USART3F	USART2F	SPI3F	SPI2F	IWDGF	WWDGF	TIM14F	TIM13F	TIM12F	TIM7F	TIM6F	TIM5F	TIM4F	TIM3F	TIM2F
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **LPTIM2F**: illegal access flag for LPTIM2
0: no illegal access event
1: illegal access event

Bit 30 **DTSF**: illegal access flag for DTS
0: no illegal access event
1: illegal access event

Bit 29 **UART12F**: illegal access flag for UART12
0: no illegal access event
1: illegal access event

Bit 28 **UART9F**: illegal access flag for UART9
0: no illegal access event
1: illegal access event

Bit 27 **UART8F**: illegal access flag for UART8
0: no illegal access event
1: illegal access event

Bit 26 **UART7F**: illegal access flag for UART7
0: no illegal access event
1: illegal access event

Bit 25 **DAC1F**: illegal access flag for DAC1
0: no illegal access event
1: illegal access event

Bit 24 **HDMICECF**: illegal access flag for HDMICEC
0: no illegal access event
1: illegal access event

Bit 23 **USART11F**: illegal access flag for USART11
0: no illegal access event
1: illegal access event

Bit 22 **USART10F**: illegal access flag for USART10
0: no illegal access event
1: illegal access event

Bit 21 **USART6F**: illegal access flag for USART6
0: no illegal access event
1: illegal access event

Bit 20 **CRSF**: illegal access flag for CRS
0: no illegal access event
1: illegal access event

Bit 19 **I3C1F**: illegal access flag for I3C1
0: no illegal access event
1: illegal access event

Bit 18 **I2C2F**: illegal access flag for I2C2
0: no illegal access event
1: illegal access event

Bit 17 **I2C1F**: illegal access flag for I2C1
0: no illegal access event
1: illegal access event

Bit 16 **UART5F**: illegal access flag for UART5
0: no illegal access event
1: illegal access event

Bit 15 **UART4F**: illegal access flag for UART4
0: no illegal access event
1: illegal access event

Bit 14 **USART3F**: illegal access flag for USART3
0: no illegal access event
1: illegal access event

Bit 13 **USART2F**: illegal access flag for USART2
0: no illegal access event
1: illegal access event

Bit 12 **SPI3F**: illegal access flag for SPI3
0: no illegal access event
1: illegal access event

Bit 11 **SPI2F**: illegal access flag for SPI2
0: no illegal access event
1: illegal access event

Bit 10 **IWDGF**: illegal access flag for IWDG
0: no illegal access event
1: illegal access event

Bit 9 **WWDGF**: illegal access flag for WWDG
0: no illegal access event
1: illegal access event

Bit 8 **TIM14F**: illegal access flag for TIM14
0: no illegal access event
1: illegal access event

Bit 7 **TIM13F**: illegal access flag for TIM13
0: no illegal access event
1: illegal access event

Bit 6 **TIM12F**: illegal access flag for TIM12
0: no illegal access event
1: illegal access event

Bit 5 **TIM7F**: illegal access flag for TIM7
0: no illegal access event
1: illegal access event

Bit 4 **TIM6F**: illegal access flag for TIM6
0: no illegal access event
1: illegal access event

Bit 3 **TIM5F**: illegal access flag for TIM5
0: no illegal access event
1: illegal access event

Bit 2 **TIM4F**: illegal access flag for TIM4
0: no illegal access event
1: illegal access event

Bit 1 **TIM3F**: illegal access flag for TIM3
0: no illegal access event
1: illegal access event

Bit 0 **TIM2F**: illegal access flag for TIM2
0: no illegal access event
1: illegal access event

5.7.6 GTZC1 TZIC status register 2 (GTZC1_TZIC_SR2)

Address offset: 0x014

Reset value: 0x0000 0000

Secure privileged access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LPTIM5F	LPTIM4F	LPTIM3F	LPTIM1F	I2C4F	I2C3F	LPUART1F	SPI5F	Res.	Res.	GFXTIMF	LTDCF	Res.	SAI2F	SAI1F	SPI6F
r	r	r	r	r	r	r	r			r	r		r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI4F	TIM17F	TIM16F	TIM15F	USART1F	TIM8F	SPI1F	TIM1F	Res.	Res.	FDCAN3F	COMPF	OPAMPF	UCPDF	FDCAN2F	FDCAN1F
r	r	r	r	r	r	r	r			r	r	r	r	r	r

Bit 31 **LPTIM5F**: illegal access flag for LPTIM5
0: no illegal access event
1: illegal access event

Bit 30 **LPTIM4F**: illegal access flag for LPTIM4
0: no illegal access event
1: illegal access event

Bit 29 **LPTIM3F**: illegal access flag for LPTIM3
0: no illegal access event
1: illegal access event

Bit 28 **LPTIM1F**: illegal access flag for LPTIM1
0: no illegal access event
1: illegal access event

Bit 27 **I2C4F**: illegal access flag for I2C4
0: no illegal access event
1: illegal access event

Bit 26 **I2C3F**: illegal access flag for I2C3
0: no illegal access event
1: illegal access event

Bit 25 **LPUART1F**: illegal access flag for LPUART
0: no illegal access event
1: illegal access event

Bit 24 **SPI5F**: illegal access flag for SPI5
0: no illegal access event
1: illegal access event

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **GFXTIMF**: illegal access flag for GFXTIM
0: no illegal access event
1: illegal access event

Bit 20 **LTDCF**: illegal access flag for LTDC
0: no illegal access event
1: illegal access event

Bit 19 Reserved, must be kept at reset value.

Bit 18 **SAI2F**: illegal access flag for SAI2
0: no illegal access event
1: illegal access event

Bit 17 **SAI1F**: illegal access flag for SAI1
0: no illegal access event
1: illegal access event

Bit 16 **SPI6F**: illegal access flag for SPI6
0: no illegal access event
1: illegal access event

Bit 15 **SPI4F**: illegal access flag for SPI4
0: no illegal access event
1: illegal access event

Bit 14 **TIM17F**: illegal access flag for TIM17
0: no illegal access event
1: illegal access event

Bit 13 **TIM16F**: illegal access flag for TIM16
0: no illegal access event
1: illegal access event

Bit 12 **TIM15F**: illegal access flag for TIM15
0: no illegal access event
1: illegal access event

Bit 11 **USART1F**: illegal access flag for USART1
0: no illegal access event
1: illegal access event

Bit 10 **TIM8F**: illegal access flag for TIM8
0: no illegal access event
1: illegal access event

Bit 9 **SPI1F**: illegal access flag for SPI1
0: no illegal access event
1: illegal access event

Bit 8 **TIM1F**: illegal access flag for TIM1
0: no illegal access event
1: illegal access event

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **FDCAN3F**: illegal access flag for FDCAN3
0: no illegal access event
1: illegal access event

Bit 4 **COMPF**: illegal access flag for COMP
0: no illegal access event
1: illegal access event

Bit 3 **OPAMPF**: illegal access flag for OPAMP
0: no illegal access event
1: illegal access event

Bit 2 **UCPDF**: illegal access flag for UCPD
0: no illegal access event
1: illegal access event

Bit 1 **FDCAN2F**: illegal access flag for FDCAN2
0: no illegal access event
1: illegal access event

Bit 0 **FDCAN1F**: illegal access flag for FDCAN1
0: no illegal access event
1: illegal access event

5.7.7 GTZC1 TZIC status register 3 (GTZC1_TZIC_SR3)

Address offset: 0x018

Reset value: 0x0000 0000

Secure privileged access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OTGFSF	OTGHSF	JPEGF	DMA2DF	MDF1F	RAMCFGF	OCTOSPI2F	OCTOSPI1F	FMCF	SDMMC2F	SDMMC1F	PKAF	SAESF	RNGF	HASHF	AESF
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DCMIF	ADC12F	DCACHEF	ICACHEF	ETHF	FMACF	CORDICF	CRCF	ADF1F	ADC3F	OCTOSPIMF	CCBF	Res.	I3C2F	VREFBUFF	LPTIM6F
r	r	r	r	r	r	r	r	r	r	r	r		r	r	r

Bit 31 **OTGFSF**: illegal access flag for OTGFSF
0: no illegal access event
1: illegal access event

Bit 30 **OTGHSF**: illegal access flag for OTGHSF
0: no illegal access event
1: illegal access event

Bit 29 **JPEGF**: illegal access flag for JPEGF
0: no illegal access event
1: illegal access event

Bit 28 **DMA2DF**: illegal access flag for DMA2D
0: no illegal access event
1: illegal access event

Bit 27 **MDF1F**: illegal access flag for MDF1
0: no illegal access event
1: illegal access event

Bit 26 **RAMCFGF**: illegal access flag for RAMSCFG
0: no illegal access event
1: illegal access event

Bit 25 **OCTOSPI2F**: illegal access flag for OCTOSPI2
0: no illegal access event
1: illegal access event

Bit 24 **OCTOSPI1F**: illegal access flag for OCTOSPI1
0: no illegal access event
1: illegal access event

Bit 23 **FMCF**: illegal access flag for FMC
0: no illegal access event
1: illegal access event

Bit 22 **SDMMC2F**: illegal access flag for SDMMC2
0: no illegal access event
1: illegal access event

Bit 21 **SDMMC1F**: illegal access flag for SDMMC1
0: no illegal access event
1: illegal access event

Bit 20 **PKAF**: illegal access flag for PKA
0: no illegal access event
1: illegal access event

Bit 19 **SAESF**: illegal access flag for SAES
0: no illegal access event
1: illegal access event

Bit 18 **RNGF**: illegal access flag for RNG
0: no illegal access event
1: illegal access event

Bit 17 **HASHF**: illegal access flag for HASH
0: no illegal access event
1: illegal access event

Bit 16 **AESF**: illegal access flag for AES
0: no illegal access event
1: illegal access event

Bit 15 **DCMIF**: illegal access flag for DCMI
0: no illegal access event
1: illegal access event

Bit 14 **ADC12F**: illegal access flag for ADC1 and ADC2
0: no illegal access event
1: illegal access event

Bit 13 **DCACHEF**: illegal access flag for DCACHE
0: no illegal access event
1: illegal access event

Bit 12 **ICACHEF**: illegal access flag for ICACHE
0: no illegal access event
1: illegal access event

Bit 11 **ETHF**: illegal access flag for register of ETH
0: no illegal access event
1: illegal access event

Bit 10 **FMACF**: illegal access flag for FMAC
0: no illegal access event
1: illegal access event

Bit 9 **CORDICF**: illegal access flag for CORDIC
0: no illegal access event
1: illegal access event

Bit 8 **CRCF**: illegal access flag for CRC
0: no illegal access event
1: illegal access event

Bit 7 **ADF1F**: illegal access flag for ADF1
0: no illegal access event
1: illegal access event

Bit 6 **ADC3F**: illegal access flag for ADC3
0: no illegal access event
1: illegal access event

Bit 5 **OCTOSPIM**F: illegal access flag for OCTOSPIM
0: no illegal access event
1: illegal access event

Bit 4 **CCBF**: illegal access flag for CCB
0: no illegal access event
1: illegal access event

Bit 3 Reserved, must be kept at reset value.

Bit 2 **I3C2F**: illegal access flag for I3C2
0: no illegal access event
1: illegal access event

Bit 1 **VREFBUFF**: illegal access flag for VREFBUF
0: no illegal access event
1: illegal access event

Bit 0 **LPTIM6F**: illegal access flag for LPTIM6
0: no illegal access event
1: illegal access event

5.7.8 GTZC1 TZIC status register 4 (GTZC1_TZIC_SR4)

Address offset: 0x01C

Reset value: 0x0000 0000

Secure privileged access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MPCBB5_REGF	SRAM5F	MPCBB3_REGF	SRAM3F	MPCBB2_REGF	SRAM2F	MPCBB1_REGF	SRAM1F	MPCBB4_REGF	SRAM4F	OCTOSPI2_MEMF	BKPSRAMF	FMC_MEMF	OCTOSPI1_MEMF	TZIC1F	TZSC1F
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	PLAY1F	EXTIF	RCCF	PWRF	TAMPF	RTCF	SBSF	OTFDEC2F	OTFDEC1F	FLASHF	FLASH_REGF	GPDMA2F	GPDMA1F
			r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **MPCBB5_REGF**: illegal access flag for MPCBB5 registers
0: no illegal access event
1: illegal access event

Bit 30 **SRAM5F**: illegal access flag for SRAM5
0: no illegal access event
1: illegal access event

Bit 29 **MPCBB3_REGF**: illegal access flag for MPCBB3 registers
0: no illegal access event
1: illegal access event

Bit 28 **SRAM3F**: illegal access flag for SRAM3
0: no illegal access event
1: illegal access event

Bit 27 **MPCBB2_REGF**: illegal access flag for MPCBB2 registers
0: no illegal access event
1: illegal access event

Bit 26 **SRAM2F**: illegal access flag for SRAM2
0: no illegal access event
1: illegal access event

Bit 25 **MPCBB1_REGF**: illegal access flag for MPCBB1 registers
0: no illegal access event
1: illegal access event

Bit 24 **SRAM1F**: illegal access flag for SRAM1
0: no illegal access event
1: illegal access event

Bit 23 **MPCBB4_REGF**: illegal access flag for MPCBB4 registers
0: no illegal access event
1: illegal access event

Bit 22 **SRAM4F**: illegal access flag for SRAM4
0: no illegal access event
1: illegal access event

Bit 21 **OCTOSPI2_MEMF**: illegal access flag for MPCWM5 (OCTOSPI2) memory bank
0: no illegal access event
1: illegal access event

Bit 20 **BKPSRAMF**: illegal access flag for MPCWM4 (BKPSRAM) memory bank
0: no illegal access event
1: illegal access event

Bit 19 **FMC_MEMF**: illegal access flag for MPCWM2 (FMC_NOR bank), MPCWM3 (FMC_NAND bank and FMC_SDRAM bank 1), and MPCWM4 (FMC_SDRAM bank 2)
0: no illegal access event
1: illegal access event

Bit 18 **OCTOSPI1_MEMF**: illegal access flag for MPCWM1 (OCTOSPI1) memory bank
0: no illegal access event
1: illegal access event

Bit 17 **TZIC1F**: illegal access flag for GTZC1 TZIC registers
0: no illegal access event
1: illegal access event

Bit 16 **TZSC1F**: illegal access flag for GTZC1 TZSC registers
0: no illegal access event
1: illegal access event

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **PLAY1F**: illegal access flag for PLAY1
0: no illegal access event
1: illegal access event

Bit 11 **EXTIF**: illegal access flag for EXTI
0: no illegal access event
1: illegal access event

Bit 10 **RCCF**: illegal access flag for RCC
0: no illegal access event
1: illegal access event

Bit 9 **PWRF**: illegal access flag for PWR
0: no illegal access event
1: illegal access event

Bit 8 **TAMPF**: illegal access flag for TAMP
0: no illegal access event
1: illegal access event

Bit 7 **RTCF**: illegal access flag for RTC
0: no illegal access event
1: illegal access event

Bit 6 **SBSF**: illegal access flag for SBS
0: no illegal access event
1: illegal access event

Bit 5 **OTFDEC2F**: illegal access flag for OTFDEC2
0: no illegal access event
1: illegal access event

Bit 4 **OTFDEC1F**: illegal access flag for OTFDEC1
0: no illegal access event
1: illegal access event

Bit 3 **FLASHF**: illegal access flag for FLASH memory
0: no illegal access event
1: illegal access event

Bit 2 **FLASH_REGF**: illegal access flag for FLASH registers
0: no illegal access event
1: illegal access event

Bit 1 **GPDMA2F**: illegal access flag for GPDMA2
0: no illegal access event
1: illegal access event

Bit 0 **GPDMA1F**: illegal access flag for GPDMA1
0: no illegal access event
1: illegal access event

5.7.9 GTZC1 TZIC flag clear register 1 (GTZC1_TZIC_FCR1)

Address offset: 0x020

Reset value: 0x0000 0000

Secure privileged access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CLPTIM2F	CDTSF	CUART12F	CUART9F	CUART8F	CUART7F	CDAC1F	CHDMICECF	CUSART11F	CUSART10F	CUSART6F	CCRSF	CI3C1F	CI2C2F	CI2C1F	CUART5F
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CUART4F	CUSART3F	CUSART2F	CSPI3F	CSPI2F	CIWDGF	CWWDGF	CTIM14F	CTIM13F	CTIM12F	CTIM7F	CTIM6F	CTIM5F	CTIM4F	CTIM3F	CTIM2F
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bit 31 **CLPTIM2F**: clear the illegal access flag for LPTIM2
0: no action
1: status flag cleared

Bit 30 **CDTSF**: clear the illegal access flag for DTS
0: no action
1: status flag cleared

Bit 29 **CUART12F**: clear the illegal access flag for UART12
0: no action
1: status flag cleared

Bit 28 **CUART9F**: clear the illegal access flag for UART9
0: no action
1: status flag cleared

Bit 27 **CUART8F**: clear the illegal access flag for UART8
0: no action
1: status flag cleared

Bit 26 **CUART7F**: clear the illegal access flag for UART7
0: no action
1: status flag cleared

Bit 25 **CDAC1F**: clear the illegal access flag for DAC1
0: no action
1: status flag cleared

Bit 24 **CHDMICECF**: clear the illegal access flag for HDMICEC
0: no action
1: status flag cleared

Bit 23 **CUSART11F**: clear the illegal access flag for USART11
0: no action
1: status flag cleared

Bit 22 **CUSART10F**: clear the illegal access flag for USART10
0: no action
1: status flag cleared

Bit 21 **CUSART6F**: clear the illegal access flag for USART6
0: no action
1: status flag cleared

Bit 20 **CCRSF**: clear the illegal access flag for CRS
0: no action
1: status flag cleared

Bit 19 **CI3C1F**: clear the illegal access flag for I3C1
0: no action
1: status flag cleared

Bit 18 **CI2C2F**: clear the illegal access flag for I2C2
0: no action
1: status flag cleared

Bit 17 **CI2C1F**: clear the illegal access flag for I2C1
0: no action
1: status flag cleared

Bit 16 **CUART5F**: clear the illegal access flag for UART5
0: no action
1: status flag cleared

Bit 15 **CUART4F**: clear the illegal access flag for UART4
0: no action
1: status flag cleared

Bit 14 **CUSART3F**: clear the illegal access flag for USART3
0: no action
1: status flag cleared

Bit 13 **CUSART2F**: clear the illegal access flag for USART2
0: no action
1: status flag cleared

Bit 12 **CSPI3F**: clear the illegal access flag for SPI3
0: no action
1: status flag cleared

Bit 11 **CSPI2F**: clear the illegal access flag for SPI2
0: no action
1: status flag cleared

Bit 10 **CIWDGF**: clear the illegal access flag for IWDG
0: no action
1: status flag cleared

Bit 9 **CWWDGF**: clear the illegal access flag for WWDG
0: no action
1: status flag cleared

Bit 8 **CTIM14F**: clear the illegal access flag for TIM14
0: no action
1: status flag cleared

Bit 7 **CTIM13F**: clear the illegal access flag for TIM13
0: no action
1: status flag cleared

Bit 6 **CTIM12F**: clear the illegal access flag for TIM12
0: no action
1: status flag cleared

Bit 5 **CTIM7F**: clear the illegal access flag for TIM7
0: no action
1: status flag cleared

Bit 4 **CTIM6F**: clear the illegal access flag for TIM6
0: no action
1: status flag cleared

Bit 3 **CTIM5F**: clear the illegal access flag for TIM5
0: no action
1: status flag cleared

Bit 2 **CTIM4F**: clear the illegal access flag for TIM4
0: no action
1: status flag cleared

Bit 1 **CTIM3F**: clear the illegal access flag for TIM3
0: no action
1: status flag cleared

Bit 0 **CTIM2F**: clear the illegal access flag for TIM2
0: no action
1: status flag cleared

5.7.10 GTZC1 TZIC flag clear register 2 (GTZC1_TZIC_FCR2)

Address offset: 0x024

Reset value: 0x0000 0000

Secure privileged access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CLPTIM5F	CLPTIM4F	CLPTIM3F	CLPTIM1F	CI2C4F	CI2C3F	CLPUART1F	CSPI5F	Res.	Res.	CGFXTIMF	CLTDCF	Res.	CSAI2F	CSAI1F	CSPI6F
w	w	w	w	w	w	w	w			w	w		w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CSPI4F	CTIM17F	CTIM16F	CTIM15F	CUSART1F	CTIM8F	CSPI1F	CTIM1F	Res.	Res.	CFDCAN3F	CCOMPF	COPAMPF	CUCPDF	CFDCAN2F	CFDCAN1F
w	w	w	w	w	w	w	w			w	w	w	w	w	w

Bit 31 **CLPTIM5F**: clear the illegal access flag for LPTIM5
0: no action
1: status flag cleared

Bit 30 **CLPTIM4F**: clear the illegal access flag for LPTIM4
0: no action
1: status flag cleared

Bit 29 **CLPTIM3F**: clear the illegal access flag for LPTIM3
0: no action
1: status flag cleared

Bit 28 **CLPTIM1F**: clear the illegal access flag for LPTIM1
0: no action
1: status flag cleared

Bit 27 **CI2C4F**: clear the illegal access flag for I2C4
0: no action
1: status flag cleared

Bit 26 **CI2C3F**: clear the illegal access flag for I2C3
0: no action
1: status flag cleared

Bit 25 **CLPUART1F**: clear the illegal access flag for LPUART
0: no action
1: status flag cleared

Bit 24 **CSPI5F**: clear the illegal access flag for SPI5
0: no action
1: status flag cleared

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **CGFXTIMF**: clear the illegal access flag for GFXTIM
0: no action
1: status flag cleared

Bit 20 **CLTDCF**: clear the illegal access flag for LTDC
0: no action
1: status flag cleared

Bit 19 Reserved, must be kept at reset value.

Bit 18 **CSAI2F**: clear the illegal access flag for SAI2
0: no action
1: status flag cleared

Bit 17 **CSAI1F**: clear the illegal access flag for SAI1
0: no action
1: status flag cleared

Bit 16 **CSPI6F**: clear the illegal access flag for SPI6
0: no action
1: status flag cleared

Bit 15 **CSPI4F**: clear the illegal access flag for SPI4
0: no action
1: status flag cleared

Bit 14 **CTIM17F**: clear the illegal access flag for TIM17
0: no action
1: status flag cleared

Bit 13 **CTIM16F**: clear the illegal access flag for TIM16
0: no action
1: status flag cleared

Bit 12 **CTIM15F**: clear the illegal access flag for TIM15
0: no action
1: status flag cleared

Bit 11 **CUSART1F**: clear the illegal access flag for USART1
0: no action
1: status flag cleared

Bit 10 **CTIM8F**: clear the illegal access flag for TIM8
0: no action
1: status flag cleared

Bit 9 **CSPI1F**: clear the illegal access flag for SPI1
0: no action
1: status flag cleared

Bit 8 **CTIM1F**: clear the illegal access flag for TIM1
0: no action
1: status flag cleared

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **CFDCAN3F**: clear the illegal access flag for FDCAN3
0: no action
1: status flag cleared

Bit 4 **CCOMPF**: clear the illegal access flag for COMP
0: no action
1: status flag cleared

Bit 3 **COPAMPF**: clear the illegal access flag for OPAMP
0: no action
1: status flag cleared

Bit 2 **CUCPDF**: clear the illegal access flag for UCPD
0: no action
1: status flag cleared

Bit 1 **CFDCAN2F**: clear the illegal access flag for FDCAN2
0: no action
1: status flag cleared

Bit 0 **CFDCAN1F**: clear the illegal access flag for FDCAN1
0: no action
1: status flag cleared

5.7.11 GTZC1 TZIC flag clear register 3 (GTZC1_TZIC_FCR3)

Address offset: 0x028

Reset value: 0x0000 0000

Secure privilege access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
COTGFSF	COTGHSF	CJPEGF	CDMA2DF	CMDF1F	CRAMCFGF	COCTOSPI2F	COCTOSPI1F	CFMCF	CSDMMC2F	CSDMMC1F	CPKAF	CSAESF	CRNGF	CHASHF	CAESF
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CDCMIF	CADC12F	CDCACHEF	CICACHEF	CETHF	CFMACF	CCORDICF	CCRCF	CADF1F	CADC3F	COCTOSPIMF	CCCBF	Res.	CI3C2F	CVREFBUFF	CLPTIM6F
w	w	w	w	w	w	w	w	w	w	w	w		w	w	w

Bit 31 **COTGFSF**: clear illegal access flag for OTGFS
0: no action
1: status flag cleared

Bit 30 **COTGHSF**: clear illegal access flag for OTGHS
0: no action
1: status flag cleared

Bit 29 **CJPEGF**: clear illegal access flag for JPEG
0: no action
1: status flag cleared

Bit 28 **CDMA2DF**: clear illegal access flag for DMA2D
0: no action
1: status flag cleared

Bit 27 **CMDF1F**: clear illegal access flag for MDF1
0: no action
1: status flag cleared

Bit 26 **CRAMCFGF**: clear illegal access flag for RAMSCFG
0: no action
1: status flag cleared

Bit 25 **COCTOSPI2F**: clear illegal access flag for OCTOSPI2
0: no action
1: status flag cleared

Bit 24 **COCTOSPI1F**: clear illegal access flag for OCTOSPI1
0: no action
1: status flag cleared

Bit 23 **CFMCF**: clear illegal access flag for FMC
0: no action
1: status flag cleared

Bit 22 **CSDMMC2F**: clear illegal access flag for SDMMC2
0: no action
1: status flag cleared

Bit 21 **CSDMMC1F**: clear illegal access flag for SDMMC1
0: no action
1: status flag cleared

Bit 20 **CPKAF**: clear illegal access flag for PKA
0: no action
1: status flag cleared

Bit 19 **CSAESF**: clear illegal access flag for SAES
0: no action
1: status flag cleared

Bit 18 **CRNGF**: clear illegal access flag for RNG
0: no action
1: status flag cleared

Bit 17 **CHASHF**: clear illegal access flag for HASH
0: no action
1: status flag cleared

Bit 16 **CAESF**: clear illegal access flag for AES
0: no action
1: status flag cleared

Bit 15 **CDCMIF**: clear illegal access flag for DCMI
0: no action
1: status flag cleared

Bit 14 **CADC12F**: clear illegal access flag for ADC1 and ADC2
0: no action
1: status flag cleared

Bit 13 **CDCACHEF**: clear illegal access flag for DCACHE
0: no action
1: status flag cleared

Bit 12 **CICACHEF**: clear illegal access flag for ICACHE
0: no action
1: status flag cleared

Bit 11 **CETHF**: clear illegal access flag for register of ETH
0: no action
1: status flag cleared

Bit 10 **CFMACF**: clear illegal access flag for FMAC
0: no action
1: status flag cleared

Bit 9 **CCORDICF**: clear illegal access flag for CORDIC
0: no action
1: status flag cleared

Bit 8 **CCRCF**: clear illegal access flag for CRC
0: no action
1: status flag cleared

Bit 7 **CADF1F**: clear illegal access flag for ADF1
0: no action
1: status flag cleared

Bit 6 **CADC3F**: clear illegal access flag for ADC3
0: no action
1: status flag cleared

Bit 5 **COCTOSPIMF**: clear illegal access flag for OCTOSPIM
0: no action
1: status flag cleared

Bit 4 **CCCBF**: clear illegal access flag for CCB
0: no action
1: status flag cleared

Bit 3 Reserved, must be kept at reset value.

Bit 2 **CI3C2F**: clear illegal access flag for I3C2
0: no action
1: status flag cleared

Bit 1 **CVREFBUFF**: clear illegal access flag for VREFBUF
0: no action
1: status flag cleared

Bit 0 **CLPTIM6F**: clear illegal access flag for LPTIM6
0: no action
1: status flag cleared

5.7.12 GTZC1 TZIC flag clear register 4 (GTZC1_TZIC_FCR4)

Address offset: 0x02C

Reset value: 0x0000 0000

Secure privilege access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CMPCBB5_REGF	CSRAM5F	CMPCBB3_REGF	CSRAM3F	CMPCBB2_REGF	CSRAM2F	CMPCBB1_REGF	CSRAM1F	CMPCBB4_REGF	CSRAM4F	COCTOSPI2_MEMF	CBKPSRAMF	CFMC_MEMF	COCTOSPI1_MEMF	CTZIC1F	CTZSC1F
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	CPLAY1F	CEXTIF	CRCCF	CPWRF	CTAMPF	CRTCF	CSBSF	COTFDEC2F	COTFDEC1F	CFLASHF	CFLASH_REGF	CGPDMA2F	CGPDMA1F
			w	w	w	w	w	w	w	w	w	w	w	w	w

Bit 31 **CMPCBB5_REGF**: clear the illegal access flag for MPCBB5 registers
0: no action
1: status flag cleared

Bit 30 **CSRAM5F**: clear the illegal access flag for SRAM5
0: no action
1: status flag cleared

Bit 29 **CMPCBB3_REGF**: clear the illegal access flag for MPCBB3 registers
0: no action
1: status flag cleared

Bit 28 **CSRAM3F**: clear the illegal access flag for SRAM3
0: no action
1: status flag cleared

Bit 27 **CMPCBB2_REGF**: clear the illegal access flag for MPCBB2 registers
0: no action
1: status flag cleared

Bit 26 **CSRAM2F**: clear the illegal access flag for SRAM2
0: no action
1: status flag cleared

Bit 25 **CMPCBB1_REGF**: clear the illegal access flag for MPCBB1 registers
0: no action
1: status flag cleared

Bit 24 **CSRAM1F**: clear the illegal access flag for SRAM1
0: no action
1: status flag cleared

Bit 23 **CMPCBB4_REGF**: clear the illegal access flag for MPCBB4 registers
0: no action
1: status flag cleared

Bit 22 **CSRAM4F**: clear the illegal access flag for SRAM4
0: no action
1: status flag cleared

Bit 21 **COCTOSPI2_MEMF**: clear the illegal access flag for MPCWM5 (OCTOSPI2) memory bank
0: no action
1: status flag cleared

Bit 20 **CBKPSRAMF**: clear the illegal access flag for MPCWM4 (BKPSRAM) memory bank
0: no action
1: status flag cleared

Bit 19 **CFMC_MEMF**: clear the illegal access flag for MPCWM2 (FMC_NOR bank), MPCWM3 (FMC_NAND bank and FMC_SDRAM bank 1), and MPCWM4 (FMC_SDRAM bank 2)
0: no action
1: status flag cleared

Bit 18 **COCTOSPI1_MEMF**: clear the illegal access flag for MPCWM1 (OCTOSPI1) memory bank
0: no action
1: status flag cleared

Bit 17 **CTZIC1F**: clear the illegal access flag for GTZC1 TZIC registers
0: no action
1: status flag cleared

Bit 16 **CTZSC1F**: clear the illegal access flag for GTZC1 TZSC registers
0: no action
1: status flag cleared

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **CPLAY1F**: clear the illegal access flag for PLAY1
0: no action
1: status flag cleared

Bit 11 **CEXTIF**: clear the illegal access flag for EXTI
0: no action
1: status flag cleared

Bit 10 **CRCCF**: clear the illegal access flag for RCC
0: no action
1: status flag cleared

Bit 9 **CPWRF**: clear the illegal access flag for PWR
0: no action
1: status flag cleared

Bit 8 **CTAMPF**: clear the illegal access flag for TAMP
0: no action
1: status flag cleared

Bit 7 **CRTCF**: clear the illegal access flag for RTC
0: no action
1: status flag cleared

Bit 6 **CSBSF**: clear the illegal access flag for SBS
0: no action
1: status flag cleared

Bit 5 **COTFDEC2F**: clear the illegal access flag for OTFDEC2
0: no action
1: status flag cleared

Bit 4 **COTFDEC1F**: clear the illegal access flag for OTFDEC1
0: no action
1: status flag cleared

Bit 3 **CFLASHF**: clear the illegal access flag for FLASH memory
0: no action
1: status flag cleared

Bit 2 **CFLASH_REGF**: clear the illegal access flag for FLASH registers
0: no action
1: status flag cleared

Bit 1 **CGPDMA2F**: clear the illegal access flag for GPDMA2
0: no action
1: status flag cleared

Bit 0 **CGPDMA1F**: clear the illegal access flag for GPDMA1
0: no action
1: status flag cleared

5.7.13 GTZC1 TZIC register map

Table 32. GTZC1 TZIC register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	GTZC1_TZIC_IER1	LPTIM2IE	DTSIE	UART12IE	UART9IE	UART8IE	UART7IE	DAC1IE	HDMICECIE	USART11IE	USART10IE	USART6IE	CRSIE	I3C1IE	I2C2IE	I2C1IE	UART5IE	UART4IE	USART3IE	USART2IE	SPI3IE	SPI2IE	IWDGIE	WWDGIE	TIM14IE	TIM13IE	TIM112IE	TIM7IE	TIM6IE	TIM5IE	TIM4IE	TIM3IE	TIM2IE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x004	GTZC1_TZIC_IER2	LPTIM5IE	LPTIM4IE	LPTIM3IE	LPTIM1IE	I2C4IE	I2C3IE	LPUART1IE	SPI5IE	Res.	Res.	Res.	Res.	Res.	SAI2IE	SAI1IE	SPI6IE	SPI4IE	TIM17IE	TIM16IE	TIM15IE	USART1IE	TIM8IE	SPI1IE	TIM1IE	Res.	Res.	Res.	Res.	Res.	Res.	UCPDIE	FDCAN2IE	FDCAN1IE
	Reset value	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x008	GTZC1_TZIC_IER3	Res.	Res.	Res.	Res.	Res.	RAMCFGIE	Res.	OCTOSPI1IE	FMCIE	SDMMC2IE	SDMMC1IE	PKAIE	SAESIE	RNGIE	HASHIE	AESIE	DCMIIE	ADC12IE	DCACHEIE	ICACHEIE	ETHIE	FMACIE	CORDICIE	CRCIE	Res.	Res.	Res.	Res.	Res.	Res.	VREFBUFIE	LPTIM6IE
	Reset value						0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						0	0
0x00C	GTZC1_TZIC_IER4	Res.	Res.	MPCBB3_REGIE	SRAM3IE	MPCBB2_REGIE	SRAM2IE	MPCBB1_REGIE	SRAM1IE	Res.	Res.	Res.	BKPSRAMIE	FMC_MEMIE	OCTOSPI1_MEMIE	TZIC1IE	TZSC1IE	Res.	Res.	Res.	Res.	EXTIIE	RCCIE	PWRIE	TAMPIE	RTCIE	SBSIE	Res.	OTFDEC1IE	FLASHIE	FLASH_REGIE	GPDMA2IE	GPDMA1IE
	Reset value			0	0	0	0	0	0				0	0	0	0	0					0	0	0	0	0	0		0	0	0	0	0
0x010	GTZC1_TZIC_SR1	LPTIM2F	DTSF	UART12F	UART9F	UART8F	UART7F	DAC1F	HDMICECF	USART11F	USART10F	USART6F	CRSF	I3C1F	I2C2F	I2C1F	UART5F	UART4F	USART3F	USART2F	SPI3F	SPI2F	IWDGF	WWDGF	TIM14F	TIM13F	TIM112F	TIM7F	TIM6F	TIM5F	TIM4F	TIM3F	TIM2F
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	GTZC1_TZIC_SR2	LPTIM5F	LPTIM4F	LPTIM3F	LPTIM1F	I2C4F	I2C3F	LPUART1F	SPI5F	Res.	Res.	Res.	Res.	Res.	SAI2F	SAI1F	SPI6F	SPI4F	TIM17F	TIM16F	TIM15F	USART1F	TIM8F	SPI1F	TIM1F	Res.	Res.	Res.	Res.	Res.	Res.	UCPDF	FDCAN2F	FDCAN1F
	Reset value	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x018	GTZC1_TZIC_SR3	Res.	Res.	Res.	Res.	Res.	RAMCFGF	Res.	OCTOSPI1F	FMCF	SDMMC2F	SDMMC1F	PKAF	SAESF	RNGF	HASHF	AESF	DCMIF	ADC12F	DCACHEF	ICACHEF	ETHF	FMACF	CORDICF	CRCF	Res.	Res.	Res.	Res.	Res.	Res.	VREFBUFF	LPTIM6F
	Reset value						0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x01C	GTZC1_TZIC_SR4	Res.	Res.	MPCBB3_REGF	SRAM3F	MPCBB2_REGF	SRAM2F	MPCBB1_REGF	SRAM1F	Res.	Res.	Res.	BKPSRAMF	FMC_MEMF	OCTOSPI1_MEMF	TZIC1F	TZSC1F	Res.	Res.	Res.	Res.	EXTIF	RCCF	PWRF	TAMPF	RTCF	SBSF	Res.	OTFDEC1F	FLASHF	FLASH_REGF	GPDMA2F	GPDMA1F
	Reset value			0	0	0	0	0	0				0	0	0	0	0					0	0	0	0	0	0		0	0	0	0	0
0x020	GTZC1_TZIC_FCR1	CLPTIM2F	CDTSF	CUART12F	CUART9F	CUART8F	CUART7F	CDAC1F	CHDMICECF	CUSART11F	CUSART10F	CUSART6F	CCRSF	CI3C1F	CI2C2F	CI2C1F	CUART5F	CUART4F	CUSART3F	CUSART2F	CSPI3F	CSPI2F	CIWDGF	CWWDGF	CTIM14F	CTIM13F	CTIM112F	CTIM7F	CTIM6F	CTIM5F	CTIM4F	CTIM3F	CTIM2F
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 32. GTZC1 TZIC register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x024	GTZC1_TZIC_FCR2	CLPTIM5F	CLPTIM4F	CLPTIM3F	CLPTIM1F	CI2C4F	CI2C3F	CLPUART1F	CSPI5F	Res.	Res.	Res.	Res.	Res.	CSAI2F	CSAI1F	CSPI6F	CSPI4F	CTIM17F	CTIM16F	CTIM15F	CUSART1F	CTIM8F	CSPI1F	CTIM1F	Res.	Res.	Res.	Res.	Res.	CUCPDF	CFDCAN2F	CFDCAN1F
	Reset value	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x028	GTZC1_TZIC_FCR3	Res.	Res.	Res.	Res.	Res.	CRAMCFGF	Res.	COCTOSPI1F	CFMCF	CSDMMC2F	CSDMMC1F	CPKAF	CSAESF	CRNGF	CHASHF	CAESF	CDCMIF	CADC12F	CDCACHEF	CICACHEF	CETHF	CFMACF	CCORDICF	CCRCF	Res.	Res.	Res.	Res.	Res.	Res.	CVREFBUFF	CLPTIM6F
	Reset value						0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0							0	0
0x02C	GTZC1_TZIC_FCR4	Res.	Res.	CMPCBB3_REGF	CSRAM3F	CMPCBB2_REGF	CSRAM2F	CMPCBB1_REGF	CSRAM1F	Res.	Res.	Res.	CBKPSRAMF	CFMC_MEMF	COCTOSPI1_MEMF	CTZIC1F	CTZSC1F	Res.	Res.	Res.	Res.	CEXTIF	CRCCF	CPWRF	CTAMPF	CRTCF	CSBSF	Res.	COTFDEC1F	CFLASHF	CFLASH_REGF	CGPDMA2F	CGPDMA1F
	Reset value			0	0	0	0	0	0				0	0	0	0	0					0	0	0	0	0	0		0	0	0	0	0

Refer to *Table 24: GTZC1 sub-block address offset*.

5.8 GTZC1 MPCBBz registers (z = 1 to 3)

All registers are accessed only by words (32-bit).

5.8.1 GTZC1 SRAMz MPCBB control register (GTZC1_MPCBBz_CR) (z = 1 to 3)

Address offset: 0x000

Reset value: 0x0000 0000

Secure privileged access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SRWILADIS	INVSECSTATE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw														
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GLOCK
															rs

Bit 31 **SRWILADIS**: Secure read/write illegal access disable

This bit disables the detection of an illegal access when a secure read/write transaction access a nonsecure blocks of the block-based SRAM (secure fetch on nonsecure block is always considered illegal).

0: Enabled, secure read/write access not allowed on nonsecure SRAM block

1: Disabled, secure read/write access allowed on nonsecure SRAM block

Bit 30 **INVSECSTATE**: SRAMx clocks security state

This bit is used to define the internal SRAMs clocks control in RCC as secure or not.

0: SRAMs clocks are secure if a secure area exists in the MPCBB. It is nonsecure if there is no secure area.

1: SRAMs clocks are nonsecure even if a secure area exists in the MPCBB, and secure even if no secure block is set in the MPCBB.

Bits 29:1 Reserved, must be kept at reset value.

Bit 0 **GLOCK**: lock the control register of the MPCBB until next reset

This bit is cleared by default and once set, it can not be reset until system reset.

0: Control register not locked

1: Control register locked

5.8.2 GTZC1 SRAMz MPCBB configuration lock register 1 (GTZC1_MPCBBz_CFGLOCK1) (z = 1 to 3)

Address offset: 0x010

Reset value: 0x0000 0000

Secure privileged access only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SPLCK 31	SPLCK 30	SPLCK 29	SPLCK 28	SPLCK 27	SPLCK 26	SPLCK 25	SPLCK 24	SPLCK 23	SPLCK 22	SPLCK 21	SPLCK 20	SPLCK 19	SPLCK 18	SPLCK 17	SPLCK 16
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPLCK 15	SPLCK 14	SPLCK 13	SPLCK 12	SPLCK 11	SPLCK 10	SPLCK 9	SPLCK 8	SPLCK 7	SPLCK 6	SPLCK 5	SPLCK 4	SPLCK 3	SPLCK 2	SPLCK 1	SPLCK 0
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs

Bits 31:0 **SPLCKy**: Security/privilege configuration lock for super-block (y = 31 to 0)
This bit is set by software and can be cleared only by system reset.
0: GTZC1_MPCBBz_SECCFGRy and GTZC1_MPCBBz_PRIVCFGRy can be written.
1: Writes to GTZC1_MPCBBz_SECCFGRy and GTZC1_MPCBBz_PRIVCFGRy are ignored

5.8.3 GTZC1 SRAM1 MPCBB security configuration for super-block x register (GTZC1_MPCBB1_SECCFGRx)

Address offset: 0x100 + 0x4 * x, (x = 0 to 31)

Reset value: 0xFFFF FFFF

The given reset value is valid when TZEN = 0xB4. The reset value is 0x0000 0000 when TZEN = 0xC3.

Write access to this register is secure only. Any read is allowed.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SEC31	SEC30	SEC29	SEC28	SEC27	SEC26	SEC25	SEC24	SEC23	SEC22	SEC21	SEC20	SEC19	SEC18	SEC17	SEC16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEC15	SEC14	SEC13	SEC12	SEC11	SEC10	SEC9	SEC8	SEC7	SEC6	SEC5	SEC4	SEC3	SEC2	SEC1	SEC0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SECy**: Security configuration for block y (y = 31 to 0)
0: Nonsecure access only to block y, belonging to super-block x. Secure access is also allowed if the SRWILADIS bit is set in GTZC1_MPCBB1_CR.
1: Secure access only to block y, belonging to super-block x.
Unprivileged write to this bit is ignored if PRIVy bit is set in GTZC1_MPCBB1_PRIVCFGRx.
Writes are ignored if SPLCKx bit is set in GTZC1_MPCBB1_CFGLOCK.

5.8.4 GTZC1 SRAM2 MPCBB security configuration for super-block x register (GTZC1_MPCBB2_SECCFGRx)

Address offset: 0x100 + 0x4 * x, (x = 0 to 31)

Reset value: 0xFFFF FFFF

The given reset value is valid when TZEN = 0xB4. The reset value is 0x0000 0000 when TZEN = 0xC3.

Write access to this register is secure only. Any read is allowed.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SEC31	SEC30	SEC29	SEC28	SEC27	SEC26	SEC25	SEC24	SEC23	SEC22	SEC21	SEC20	SEC19	SEC18	SEC17	SEC16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEC15	SEC14	SEC13	SEC12	SEC11	SEC10	SEC9	SEC8	SEC7	SEC6	SEC5	SEC4	SEC3	SEC2	SEC1	SEC0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SECy**: Security configuration for block y (y = 31 to 0)

0: Nonsecure access only to block y, belonging to super-block x. Secure access is also allowed if the SRWILADIS bit is set in GTZC1_MPCBB2_CR.

1: Secure access only to block y, belonging to super-block x.

Unprivileged write to this bit is ignored if PRIVy bit is set in GTZC1_MPCBB2_PRIVCFGRx.

Writes are ignored if SPLCKx bit is set in GTZC1_MPCBB2_CFGLOCK.

5.8.5 GTZC1 SRAM3 MPCBB security configuration for super-block x register (GTZC1_MPCBB3_SECCFGRx)

Address offset: 0x100 + 0x4 * x, (x = 0 to 31)

Reset value: 0xFFFF FFFF

The given reset value is valid when TZEN = 0xB4. The reset value is 0x0000 0000 when TZEN = 0xC3.

Write access to this register is secure only. Any read is allowed.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SEC31	SEC30	SEC29	SEC28	SEC27	SEC26	SEC25	SEC24	SEC23	SEC22	SEC21	SEC20	SEC19	SEC18	SEC17	SEC16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEC15	SEC14	SEC13	SEC12	SEC11	SEC10	SEC9	SEC8	SEC7	SEC6	SEC5	SEC4	SEC3	SEC2	SEC1	SEC0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SECy**: Security configuration for block y (y = 31 to 0)

0: Nonsecure access only to block y, belonging to super-block x. Secure access is also allowed if the SRWILADIS bit is set in GTZC1_MPCBB3_CR.

1: Secure access only to block y, belonging to super-block x.

Unprivileged write to this bit is ignored if PRIVy bit is set in GTZC1_MPCBB3_PRIVCFGRx.

Writes are ignored if SPLCKx bit is set in GTZC1_MPCBB3_CFGLOCK.

5.8.6 GTZC1 SRAM1 MPCBB privileged configuration for super-block x register (GTZC1_MPCBB1_PRIVCFGRx)

Address offset: 0x200 + 0x4 * x, (x = 0 to 31)

Reset value: 0xFFFF FFFF

The given reset value is valid when TZEN = 0xB4. The reset value is 0x0000 0000 when TZEN = 0xC3. Write access to this register is privileged only. Any read is allowed.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRIV31	PRIV30	PRIV29	PRIV28	PRIV27	PRIV26	PRIV25	PRIV24	PRIV23	PRIV22	PRIV21	PRIV20	PRIV19	PRIV18	PRIV17	PRIV16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRIV15	PRIV14	PRIV13	PRIV12	PRIV11	PRIV10	PRIV9	PRIV8	PRIV7	PRIV6	PRIV5	PRIV4	PRIV3	PRIV2	PRIV1	PRIV0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PRIVy**: Privileged configuration for block y, belonging to super-block x (y = 31 to 0).
0: Privileged and unprivileged access to block y, belonging to super-block x
1: Only privileged access to block y, belonging to super-block x
Nonsecure write to this bit is ignored if SECy bit is set in GTZC1_MPCBB1_SECCFGRx.
Writes are ignored if SPLCKx bit is set in GTZC1_MPCBB1_CFGLOCK.

5.8.7 GTZC1 SRAM2 MPCBB privileged configuration for super-block x register (GTZC1_MPCBB2_PRIVCFGRx)

Address offset: 0x200 + 0x4 * x, (x = 0 to 31)

Reset value: 0xFFFF FFFF

The given reset value is valid when TZEN = 0xB4. The reset value is 0x0000 0000 when TZEN = 0xC3. Write access to this register is privileged only. Any read is allowed.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRIV31	PRIV30	PRIV29	PRIV28	PRIV27	PRIV26	PRIV25	PRIV24	PRIV23	PRIV22	PRIV21	PRIV20	PRIV19	PRIV18	PRIV17	PRIV16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRIV15	PRIV14	PRIV13	PRIV12	PRIV11	PRIV10	PRIV9	PRIV8	PRIV7	PRIV6	PRIV5	PRIV4	PRIV3	PRIV2	PRIV1	PRIV0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PRIVy**: Privileged configuration for block y, belonging to super-block x (y = 31 to 0).
0: Privileged and unprivileged access to block y, belonging to super-block x
1: Only privileged access to block y, belonging to super-block x
Nonsecure write to this bit is ignored if SECy bit is set in GTZC1_MPCBB2_SECCFGRx.
Writes are ignored if SPLCKx bit is set in GTZC1_MPCBB2_CFGLOCK.

5.8.8 GTZC1 SRAM3 MPCBB privileged configuration for super-block x register (GTZC1_MPCBB3_PRIVCFGRx)

Address offset: 0x200 + 0x4 * x, (x = 0 to 31)

Reset value: 0xFFFF FFFF

The given reset value is valid when TZEN = 0xB4. The reset value is 0x0000 0000 when TZEN = 0xC3. Write access to this register is privileged only. Any read is allowed.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRIV31	PRIV30	PRIV29	PRIV28	PRIV27	PRIV26	PRIV25	PRIV24	PRIV23	PRIV22	PRIV21	PRIV20	PRIV19	PRIV18	PRIV17	PRIV16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRIV15	PRIV14	PRIV13	PRIV12	PRIV11	PRIV10	PRIV9	PRIV8	PRIV7	PRIV6	PRIV5	PRIV4	PRIV3	PRIV2	PRIV1	PRIV0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PRIVy**: Privileged configuration for block y, belonging to super-block x (y = 31 to 0).
0: Privileged and unprivileged access to block y, belonging to super-block x
1: Only privileged access to block y, belonging to super-block x
Nonsecure write to this bit is ignored if SECy bit is set in GTZC1_MPCBB3_SECCFGRx.
Writes are ignored if SPLCKx bit is set in GTZC1_MPCBB3_CFGLOCK.

5.8.9 GTZC1 MPCBBz register map (z = 1 to 3)

Table 33. GTZC1 MPCBBz register map and reset values (z = 1 to 3)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	GTZC1_ MPCBBz_CR	SRWILADIS	INVSECSTATE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GLOCK
	Reset value	0	0																														0
0x004-0x00C	Reserved	Reserved																															
0x010	GTZC1_MPCBBz_ CFGLOCK1	SPLCK31	SPLCK30	SPLCK29	SPLCK28	SPLCK27	SPLCK26	SPLCK25	SPLCK24	SPLCK23	SPLCK22	SPLCK21	SPLCK20	SPLCK19	SPLCK18	SPLCK17	SPLCK16	SPLCK15	SPLCK14	SPLCK13	SPLCK12	SPLCK11	SPLCK10	SPLCK9	SPLCK8	SPLCK7	SPLCK6	SPLCK5	SPLCK4	SPLCK3	SPLCK2	SPLCK1	SPLCK0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014-0x0FC	Reserved	Reserved																															
0x100 + 0x04 *x (x = 0 to 31)	GTZC1_MPCBBz_ SECCFGRx	SEC31	SEC30	SEC29	SEC28	SEC27	SEC26	SEC25	SEC24	SEC23	SEC22	SEC21	SEC20	SEC19	SEC18	SEC17	SEC16	SEC15	SEC14	SEC13	SEC12	SEC11	SEC10	SEC9	SEC8	SEC7	SEC6	SEC5	SEC4	SEC3	SEC2	SEC1	SEC0
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x180-0x1FC	Reserved	Reserved																															
0x200 + 0x04 *x (x = 0 to 31)	GTZC1_MPCBBz_ PRIVCFGRx	PRIV31	PRIV30	PRIV29	PRIV28	PRIV27	PRIV26	PRIV25	PRIV24	PRIV23	PRIV22	PRIV21	PRIV20	PRIV19	PRIV18	PRIV17	PRIV16	PRIV15	PRIV14	PRIV13	PRIV12	PRIV11	PRIV10	PRIV9	PRIV8	PRIV7	PRIV6	PRIV5	PRIV4	PRIV3	PRIV2	PRIV1	PRIV0
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Refer to *Table 24: GTZC1 sub-block address offset*.

6 RAMs configuration controller (RAMCFG)

6.1 RAMCFG introduction

The RAMCFG configures the features of the internal SRAMs (SRAM1, SRAM2, SRAM3, SRAM4, SRAM5, and BKPSRAM).

6.2 RAMCFG main features

The internal SRAMs support some of the features listed hereafter, configured in RAMCFG:

- Error code correction (ECC):
  - Single error detection and correction with interrupt generation
  - Double error detection with interrupt or NMI generation
  - Status with failing address
- Write protection (1-Kbyte granularity)
- SRAM software erase

6.3 RAMCFG functional description

6.3.1 Internal SRAM features

Six SRAMs are embedded in the devices, each with specific features (see *Table 34*):

- SRAM1/2/3/4/5 are the main SRAMs, made of several blocks that can be powered down in Stop mode to reduce consumption:
  - SRAM1: four 64-Kbyte blocks (total 256 Kbytes)
  - SRAM2: 16-Kbyte + 48-Kbyte + 16-Kbyte + 48-Kbyte blocks (total 128 Kbytes)
  - SRAM3: six 64-Kbyte blocks (total 384 Kbytes)
  - SRAM4: six 64-Kbyte blocks (total 384 Kbytes)
  - SRAM5: six 64-Kbyte blocks (total 384 Kbytes)

  The backup SRAM (BKPSRAM) can be retained in all low-power modes and when V_{DD} is off in VBAT mode. Refer to *Section 10: Power control (PWR)* for more details.
- SRAM2 is erased when a system reset occurs, if the SRAM2_RST option bit is selected in the flash memory user option bytes. SRAM1, SRAM3, and SRAM4/5 are erased when a system reset occurs if the SRAM1345_RST option bit is selected in the flash memory user option bytes. Refer to *Section 7: Embedded flash memory (FLASH)* for more details.
- SRAM2 and optionally BKPSRAM are protected by the tamper detection circuit, and are erased by hardware in case of tamper detection. Refer to *Section 58: Tamper and backup registers (TAMP)* for more details.
- The RAMCFG embeds the registers related to the internal SRAMs ECC, write protection, and software erase.

Table 34. Features of internal SRAMs

Feature	SRAM1	SRAM2	SRAM3	SRAM4	SRAM5	BKPSRAM
Total size (Kbytes)	256 (4 x 64)	128 (16 + 48 + 16 + 48)	384 (6 x 64)			4
Optional retention in Standby mode	-	-	-	-	-	X
Optional retention in Stop mode	X	X	X	X	X	X
Optional retention in VBAT mode	-	-	-	-	-	X
Erased with tamper detection	-	X	-	-	-	X
Erased with backup domain reset	-	-	-	-	-	X
Erased with product state regression	X	X	X	X	X	X
Optionally erased with system reset	X	X	X	X	X	-
Software erase	X	X	X	X	X	X
ECC	-	X	X	-	-	X
Write protection	-	X	-	-	-	X(1)

1. BKPSRAM write protection can be enabled/disabled by using disable backup domain write protection (DBP) bit in the Backup domain.

6.3.2 Error code correction (SRAM2, SRAM3, BKPSRAM)

The ECC is supported by SRAM2, SRAM3, and BKPSRAM when enabled with the SRAM2_ECC, SRAM3_ECC, and BKPRAM_ECC user option bits. Refer to *Section 7: Embedded flash memory (FLASH)* for more details.

Seven ECC bits are added per 32 bits of SRAM, allowing two bits error detection and one bit error correction on memory read access.

The ECC is calculated and checked for a 32-bit word. Byte and half-word write accesses are managed by the SRAM interface by first reading the whole word, then writing it again with the new byte/half-word value. ECC double errors are also detected during these accesses (read/modify/write done by interface). The byte or half-word write access latency is two AHB clock cycles.

Caution: In case of a byte or half-word write on SRAM with ECC, the read/modify/write operation is done in a buffer. The buffer content is written into the SRAM, two AHB clock cycles after the SRAM AHB is released (when SRAM is no more accessed).

Single and double ECC errors

When a single error is detected, it is automatically corrected. SEDC and CSEDC bits are set, respectively, in the *RAMCFG memory interrupt status register (RAMCFG_MxISR)* and *RAMCFG memory x interrupt clear register x (RAMCFG_MxICR)*. The associated ECC single error address is updated only if the single error interrupt is enabled (SEIE bit of *RAMCFG memory x interrupt enable register (RAMCFG_MxIER)* is set). An interrupt is generated if enabled by the SEIE bit. The failing address is stored in the *RAMCFG memory x ECC single error address register (RAMCFG_MxSEAR)* if the ALE bit is set in the *RAMCFG memory x control register (RAMCFG_MxCR)*.

Caution: Single errors cannot be detected when the SEDC bit is set.

When a double error is detected, the DED and CDED bits are set in the *RAMCFG memory interrupt status register (RAMCFG_MxISR)* and *RAMCFG memory x interrupt clear register x (RAMCFG_MxICR)*, respectively. The associated ECC double error address is updated only if double error interrupt or NMI is enabled (DEIE bit or ECCNMI bit of RAMCFG_MxIER is set). An interrupt or NMI is generated if enabled by the DEIE or ECCNMI bit in the *RAMCFG memory x interrupt enable register (RAMCFG_MxIER)*. The failing address is stored in the *RAMCFG memory x ECC double error address register (RAMCFG_MxDEAR)* if the ALE bit is set in the *RAMCFG memory x control register (RAMCFG_MxCR)*.

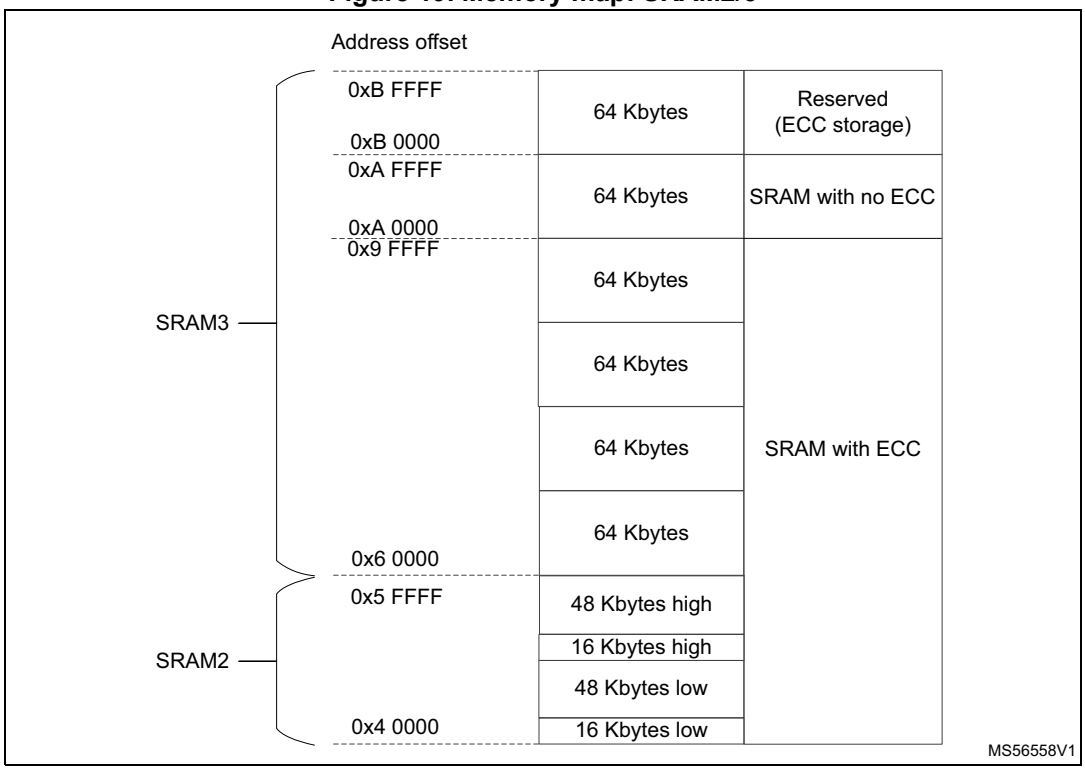
Caution: Double errors cannot be detected when the DED bit is set.

SRAM3 ECC specific management

When the ECC is enabled for SRAM3, only the first 256 Kbytes of SRAM3 are with ECC. The next 64 Kbytes are without ECC, and the last block is used to store the ECC, hence it cannot be used by the application.

Figure 19 shows the SRAM areas, when SRAM2 and SRAM3 ECC are enabled.

Figure 19. Memory map: SRAM2/3



When ECC is enabled by user option bits, the ECCE bit is automatically set after a system reset in the related *RAMCFG memory x control register (RAMCFG_MxCR)*.

The ECC can be deactivated by executing the following software sequence:

1. Write 0xAE in the *RAMCFG memory x ECC key register (RAMCFG_MxECCKEYR)*.
2. Write 0x75 in the *RAMCFG memory x ECC key register (RAMCFG_MxECCKEYR)*.
3. Write 0 in the ECCE bit of the *RAMCFG memory x control register (RAMCFG_MxCR)*.

When ECC is deactivated (ECCE = 0), the SRAM3 ECC storage area can be read and written for ECC user test purpose. When the ECC is activated (ECCE = 1), this area is reserved for ECC storage purpose, and cannot be neither read, nor written.

The procedure to check ECC on SRAM3 is the following:

1. On an erased memory, write data with ECC on.
2. Disable ECC.
3. Write the same data with 1- or 2-bit modification, respectively, for single or double error test.
4. Enable ECC.
5. Wait until ECCE bit of RAMCFG_M3CR is read at 1.
6. Read data. Enabled interrupt is generated because of single or double error.
7. Instructions for steps *3* and *4* must not be located in SRAM3 with ECC area. Any access to SRAM3 with ECC area by the other masters is forbidden during the execution of steps *4* and *5*, until they are completed.

Warning: The ECC fault injection test triggers a system break event in TIM1/8/15/16/17 if the SEL bit is set in SBS_CFGR2. As a consequence, the test must be performed while the PWM outputs of the timers are in idle state.

6.3.3 Write protection (SRAM2)

The SRAM2 is made of 1-Kbyte pages, each of them can be write-protected by setting its corresponding PxWP bit in *RAMCFG memory 2 write protection register 1 (RAMCFG_M2WPR1)*, *RAMCFG memory 2 write protection register 2 (RAMCFG_M2WPR2)*, *RAMCFG memory 2 write protection register 3 (RAMCFG_M2WPR3)*, and *RAMCFG memory 2 write protection register 4 (RAMCFG_M2WPR4)*.

Table 35. SRAM2 features

Page size	Number of pages	PxWP bits
1 Kbytes	128	0 to 127

6.3.4 Software erase

SRAM erase can be requested by executing this software sequence:

1. Write 0xCA in the *RAMCFG memory x erase key register (RAMCFG_MxERKEYR)*.
2. Write 0x53 in the *RAMCFG memory x erase key register (RAMCFG_MxERKEYR)*.
3. Write 1 in the SRAMER bit of the *RAMCFG memory x control register (RAMCFG_MxCR)*.

SRAMBUSY flag is set in the related SRAM interrupt status register as long as the erase is ongoing. The total duration of each SRAM erase is N AHB clock cycles, where N is the size of the SRAM in 32-bit words. If the SRAM is read or written while an erase is ongoing, wait states are inserted on the AHB bus until the end of the operation.

6.4 RAMCFG low-power modes

Table 36. Effect of low-power modes on RAMCFG

Mode	Description
Sleep	No effect. RAMCFG interrupts cause the device to exit Sleep mode.
Stop	The content of RAMCFG registers is kept.
Standby	The RAMCFG is powered down, and must be reinitialized after exiting Standby mode.

6.5 RAMCFG interrupts

Table 37. RAMCFG interrupt requests

Interrupt acronym	Interrupt event	Event flag	Enable control bit(s)	Interrupt clear method	Exit Sleep mode	Exit Stop mode	Exit Standby mode
RAMCFG	ECC single error detection and correction	SEDC	SEIE	Write 1 in CSEDC	Yes	No	No
	ECC double error detection	DED	DEIE = 1 and ECCNMI = 0	Write 1 in CDED	Yes	No	No
NMI	ECC double error detection	DED	ECCNMI	Write 1 in CDED	Yes	No	No

6.6 RAMCFG registers

In the registers description, x refers to:

- SRAM1/2/3 when x = 1/2/3, respectively
- BKPSRAM when x = 5
- SRAM4 when x = 6
- SRAM5 when x = 7

6.6.1 RAMCFG memory x control register (RAMCFG_MxCR)

Address offset: 0x000 + 0x040 * (x - 1), (x = 1, 2, 3, 5, 6, 7)

Reset value: 0x0000 000X

ECCE reset value depends on ECC enable user option bit.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	SRAMER	Res.	Res.	Res.	ALE	Res.	Res.	Res.	ECCE
							rs				rw				rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **SRAMER**: SRAM erase

This bit can be set by software only after writing the unlock sequence in the ERASEKEY field of the RAMCFG_MxERKEYR register. Setting this bit starts the SRAM erase. This bit is automatically cleared by hardware at the end of the erase operation.

0: No erase operation ongoing

1: Erase operation ongoing

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **ALE**: Address latch enable

0: Failing address not stored in the SRAMx ECC single/double error address registers

1: Failing address stored in the SRAMx ECC single/double error address registers

Note: For SRAM1/4/5, this bit is reserved and must be kept at reset value.

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **ECCE**: ECC enable.

This bit reset value is defined by the user option bit configuration. When set, it can be cleared by software only after writing the unlock sequence in the RAMCFG_MxECCKEYR register.

0: ECC disabled

1: ECC enabled

Note: For SRAM1/4/5, this bit is reserved and must be kept at reset value.

6.6.2 RAMCFG memory x interrupt enable register (RAMCFG_MxIER)

Address offset: 0x004 + 0x040 * (x - 1), (x = 2, 3, 5)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCNMI	Res.	DEIE	SEIE
												rs		rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **ECCNMI**: Double error NMI

This bit is set by software and cleared only by a global RAMCFG reset.

0: NMI not generated in case of ECC double error

1: NMI generated in case of ECC double error

Note: if ECCNMI is set, the RAMCFG maskable interrupt is not generated, whatever DEIE bit value.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **DEIE**: ECC double error interrupt enable

0: Double error interrupt disabled

1: Double error interrupt enabled

Bit 0 **SEIE**: ECC single error interrupt enable

0: Single error interrupt disabled

1: Single error interrupt enabled

6.6.3 RAMCFG memory interrupt status register (RAMCFG_MxISR)

Address offset: 0x008 + 0x040 * (x - 1), (x = 1, 2, 3, 5, 6, 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	SRAM BUSY	Res.	Res.	Res.	Res.	Res.	Res.	DED	SEDC
							r							r	r

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **SRAMBUSY**: SRAM busy with erase operation

0: No erase operation ongoing

1: Erase operation ongoing

Note: Depending on the SRAM, the erase operation can be started by a software request, by a system reset if the option bit is enabled, by tamper detection, or by readout protection regression. Refer to Table 34.

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **DED**: ECC double error detected

0: No double error

1: Double error detected

Note: For SRAM1/4/5, this bit is reserved and must be kept at reset value.

Bit 0 **SEDC**: ECC single error detected and corrected

0: No single error

1: Single error detected and corrected

Note: For SRAM1/4/5, this bit is reserved and must be kept at reset value.

6.6.4 RAMCFG memory x ECC single error address register (RAMCFG_MxSEAR)

Address offset: 0x00C + 0x040 * (x - 1), (x = 2, 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ESEA[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ESEA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **ESEA[31:0]**: ECC single error address

When the ALE bit is set in the RAMCFG_MxCR register, this bitfield is updated with the address corresponding to the ECC single error.

6.6.5 RAMCFG memory x ECC double error address register (RAMCFG_MxDEAR)

Address offset: 0x010 + 0x040 * (x - 1), (x = 2, 3, 5)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EDEA[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EDEA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **EDEA[31:0]**: ECC double error address

When the ALE bit is set in the RAMCFG_MxCR register, this bitfield is updated with the address corresponding to the ECC double error.

6.6.6 RAMCFG memory x interrupt clear register x (RAMCFG_MxICR)

Address offset: 0x014 + 0x040 * (x - 1), (x = 2, 3, 5)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CDED	CSEDC
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **CDED**: Clear ECC double error detected

Writing 1 to this flag clears the DED bit in the RAMCFG_MxISR register. Reading this flag returns the DED value.

Bit 0 **CSEDC**: Clear ECC single error detected and corrected

Writing 1 to this flag clears the SEDC bit in the RAMCFG_MxISR register. Reading this flag returns the SEDC value.

6.6.7 RAMCFG memory 2 write protection register 1 (RAMCFG_M2WPR1)

Address offset: 0x058

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
P31WP	P30WP	P29WP	P28WP	P27WP	P26WP	P25WP	P24WP	P23WP	P22WP	P21WP	P20WP	P19WP	P18WP	P17WP	P16WP
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
P15WP	P14WP	P13WP	P12WP	P11WP	P10WP	P9WP	P8WP	P7WP	P6WP	P5WP	P4WP	P3WP	P2WP	P1WP	P0WP
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs

Bits 31:0 **PyWP**: SRAM2 1-Kbyte page y write protection (y = 31 to 0)
These bits are set by software and cleared only by a global RAMCFG reset.
0: Write protection of SRAM2 1-Kbyte page y is disabled.
1: Write protection of SRAM2 1-Kbyte page y is enabled.

6.6.8 RAMCFG memory 2 write protection register 2 (RAMCFG_M2WPR2)

Address offset: 0x05C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
P63WP	P62WP	P61WP	P60WP	P59WP	P58WP	P57WP	P56WP	P55WP	P54WP	P53WP	P52WP	P51WP	P50WP	P49WP	P48WP
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
P47WP	P46WP	P45WP	P44WP	P43WP	P42WP	P41WP	P40WP	P39WP	P38WP	P37WP	P36WP	P35WP	P34WP	P33WP	P32WP
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs

Bits 31:0 **PyWP**: SRAM2 1-Kbyte page y write protection (y = 63 to 32)
These bits are set by software and cleared only by a global RAMCFG reset.
0: Write protection of SRAM2 1-Kbyte page y is disabled.
1: Write protection of SRAM2 1-Kbyte page y is enabled.

6.6.9 RAMCFG memory x ECC key register (RAMCFG_MxECCKEYR)

Address offset: 0x024 + 0x040 * (x - 1), (x = 2, 3, 5)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCKEY[7:0]							
								w	w	w	w	w	w	w	w

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **ECCKEY[7:0]**: ECC write protection key

The following steps are required to unlock the write protection of the ECCE bit in the RAMCFG_MxCR register.

1) Write 0xAE into ECCKEY[7:0].

2) Write 0x75 into ECCKEY[7:0].

Note: Writing a wrong key reactivates the write protection.

6.6.10 RAMCFG memory x erase key register (RAMCFG_MxERKEYR)

Address offset: 0x028 + 0x040 * (x - 1), (x = 1, 2, 3, 5, 6, 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ERASEKEY[7:0]							
								w	w	w	w	w	w	w	w

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **ERASEKEY[7:0]**: Erase write protection key

The following steps are required to unlock the write protection of the SRAMER bit in the RAMCFG_MxCR register.

1) Write 0xCA into ERASEKEY[7:0].

2) Write 0x53 into ERASEKEY[7:0].

Note: Writing a wrong key reactivates the write protection.

6.6.11 RAMCFG memory 2 write protection register 3 (RAMCFG_M2WPR3)

Address offset: 0x070

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
P95WP	P94WP	P93WP	P92WP	P91WP	P90WP	P89WP	P88WP	P87WP	P86WP	P85WP	P84WP	P83WP	P82WP	P81WP	P80WP
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
P79WP	P78WP	P77WP	P76WP	P75WP	P74WP	P73WP	P72WP	P71WP	P70WP	P69WP	P68WP	P67WP	P66WP	P65WP	P64WP
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs

Bits 31:0 **PyWP**: SRAM2 1-Kbyte page y write protection (y = 95 to 64)

These bits are set by software and cleared only by a global RAMCFG reset.

0: Write protection of SRAM2 1-Kbyte page y is disabled.

1: Write protection of SRAM2 1-Kbyte page y is enabled.

6.6.12 RAMCFG memory 2 write protection register 4 (RAMCFG_M2WPR4)

Address offset: 0x074

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
P127 WP	P126 WP	P125 WP	P124 WP	P123 WP	P122 WP	P121 WP	P120 WP	P119 WP	P118 WP	P117 WP	P116 WP	P115 WP	P114 WP	P113 WP	P112 WP
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
P111 WP	P110 WP	P109 WP	P108 WP	P107 WP	P106 WP	P105 WP	P104 WP	P103 WP	P102 WP	P101 WP	P100 WP	P99 WP	P98 WP	P97 WP	P96 WP
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs

Bits 31:0 **PyWP**: SRAM2 1-Kbyte page y write protection (y = 127 to 96)
These bits are set by software and cleared only by a global RAMCFG reset.
0: Write protection of SRAM2 1-Kbyte page y is disabled.
1: Write protection of SRAM2 1-Kbyte page y is enabled.

6.6.13 RAMCFG register map

Table 38. RAMCFG register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000 + 0x040 * (x-1) (x=1,2,3,5,6,7)	RAMCFG_MxCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SRAMER	Res.	Res.	Res.	ALE	Res.	Res.	Res.	ECCE
	Reset value																								0				0				x
0x004 + 0x040 * (x-1) (x=2,3,5)	RAMCFG_MxIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCNMI	Res.	DEIE	SEIE
	Reset value																													0		0	0
0x008 + 0x040 * (x-1) (x=1,2,3,5,6,7)	RAMCFG_MxISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SRAMBUSY	Res.	Res.	Res.	Res.	Res.	Res.	DED	SEDC
	Reset value																								0							0	0
0x00C + 0x040 * (x-1) (x=2,3)	RAMCFG_MxSEAR	ESEA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x010 + 0x040 * (x-1) (x=2,3,5)	RAMCFG_MxDEAR	EDEA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014 + 0x040 * (x-1) (x=2,3,5)	RAMCFG_MxICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CDED	CSEDC
	Reset value																															0	0
0x058	RAMCFG_M2WPR1	P31WP	P30WP	P29WP	P28WP	P27WP	P26WP	P25WP	P24WP	P23WP	P22WP	P21WP	P20WP	P19WP	P18WP	P17WP	P16WP	P15WP	P14WP	P13WP	P12WP	P11WP	P10WP	P9WP	P8WP	P7WP	P6WP	P5WP	P4WP	P3WP	P2WP	P1WP	P0WP
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x05C	RAMCFG_M2WPR2	P63WP	P62WP	P61WP	P60WP	P59WP	P58WP	P57WP	P56WP	P55WP	P54WP	P53WP	P52WP	P51WP	P50WP	P49WP	P48WP	P47WP	P46WP	P45WP	P44WP	P43WP	P42WP	P41WP	P40WP	P39WP	P38WP	P37WP	P36WP	P35WP	P34WP	P33WP	P32WP
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024 + 0x040 * (x-1) (x=2,3,5)	RAMCFG _MxECCKEYR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCKEY[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x028 + 0x040 * (x-1) (x=1,2,3,5,6,7)	RAMCFG _MxERKEYR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ERASEKEY[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x070	RAMCFG_M2WPR3	P95WP	P94WP	P93WP	P92WP	P91WP	P90WP	P89WP	P88WP	P87WP	P86WP	P85WP	P84WP	P83WP	P82WP	P81WP	P80WP	P79WP	P78WP	P77WP	P76WP	P75WP	P74WP	P73WP	P72WP	P71WP	P70WP	P69WP	P68WP	P67WP	P66WP	P65WP	P64WP
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x074	RAMCFG_M2WPR4	P127WP	P126WP	P125WP	P124WP	P123WP	P122WP	P121WP	P120WP	P119WP	P118WP	P117WP	P116WP	P115WP	P114WP	P113WP	P112WP	P111WP	P110WP	P109WP	P108WP	P107WP	P106WP	P105WP	P104WP	P103WP	P102WP	P101WP	P100WP	P99WP	P98WP	P97WP	P96WP
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3* for the register boundary addresses.

7 Embedded flash memory (FLASH)

7.1 FLASH introduction

The embedded flash memory (FLASH) manages the accesses of any master to the 4 Mbytes of embedded nonvolatile memory. It implements the read, program and erase operations, error corrections, as well as various integrity and confidentiality protection mechanisms.

FLASH manages the automatic loading of nonvolatile user option bytes at power-on reset, and implements the dynamic update of these options. It also features a high-cycle data area, a one-time-programmable (OTP) area, a secure key storage area (OBKeys), and a read-only area configured by STMicroelectronics during manufacturing.

7.2 FLASH main features

- Up to 4 Mbytes of nonvolatile memory, divided into two 2-Mbyte banks
- Flash memory read operations supporting multiple lengths: 128 bits, 64 bits, 32 bits, 16 bits, or one byte
- Flash memory programming by 128 (user area, OBKeys) and by 16 bits (OTP and flash high-cycle data area)
- 8-Kbyte sector erase, bank erase and dual-bank mass erase
- Dual-bank organization supporting:
  - Simultaneous operations: read-while-write (program and erase) is supported, including flash high-cycle data area. The two banks share the same interface, hence write and erase cannot be performed in parallel (write-while-write is not supported).
  - Bank swapping: the address mapping of the user memory of each bank can be swapped, along with the corresponding registers. Security flags remain valid for the physical bank, so the data are not reveled by swapping to a bank with lower security configuration.
- Error code correction (ECC): one error detection/correction, or two errors detection per 128-bit flash word using nine ECC bits, on 16-bit words with six bits within configurable flash high-cycle data area.
- User configurable nonvolatile option bytes
- Flash memory enhanced protections, activated by option bytes
  - different product states for protecting memory content from debug access
  - sector group write-protection (WRPSG), protecting up to 64 groups of four sectors (32 Kbytes) per bank
  - two secure-only areas (one per user flash bank): when enabled, these areas are accessible only if the microcontroller operates in Secure access mode
  - HDP protection, providing temporal isolation for startup code
- 2-Kbyte one-time programmable (OTP) area
- Read-only area configured by STMicroelectronics
- Prefetch reads the next sequential instruction from flash memory

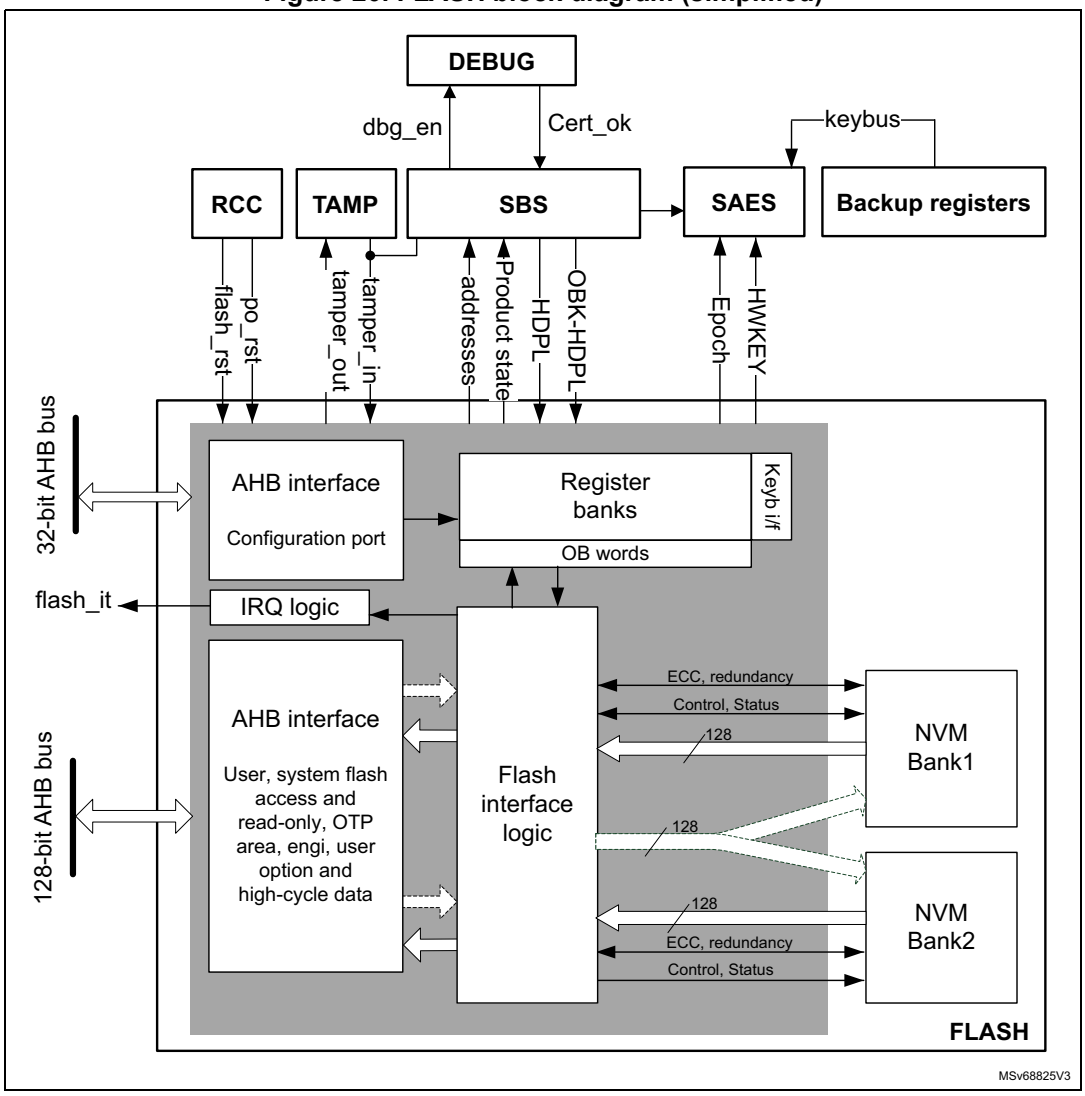
- Up to 96 Kbytes per bank supporting high-cycling capability (100 kcycles), to be used for data (EEPROM emulation)

7.3 FLASH functional description

7.3.1 FLASH block diagram

Figure 20 shows the embedded flash memory block diagram.

Figure 20. FLASH block diagram (simplified)



7.3.2 FLASH signals

The flash memory has two AHB connections, namely the flash AHB register interface and the main AHB interface.

Flash AHB register interface

- Data size is 32 bits
- Except for some registers (FLASH_NS/SECKEYR, FLASH_NS/SECOBKKEYR and FLASH_OPTKEYR, used to insert unlock sequences for control, and option registers that can be written by 32 bits), it is possible to read and write all registers by 8, 16 and 32 bits.
- When the unlock sequence for control and option registers is wrong, a bus error is raised, otherwise no read or write errors are generated on the bus.

Main AHB interface

The AHB data bus size is 128 bits. This interface is used to handle three different targets:

- Code placed in user and system memory, protected by 9 bits of ECC.
- Secure keys placed in OBKey sectors, protected by 9 bits of ECC.
- OTP, read-only and flash memory high-cycle data area. protected by 6 bits of ECC.

The main AHB interface is implemented as follows:

- User and system memory, OBKeys storage:
  - Supports multiple lengths: 128-, 64-, 32-, 16-, and 8-bit data width.
  - There is a read buffer of 128 bits for each bank where the last data read is stored. If data are available in the read buffer, no read access is given to the flash memory. Buffer is flushed when write access, OTP access, OBK swap, OBK alternate sector erase, high-cycle data area access, user option change request or erase operation occur.
  - There is a prefetch of the same size as the read buffer.
  - A 9-bit ECC is associated to each 128-bit data flash memory word.
- OTP, read-only and flash high-cycle data
  - Two dedicated data buffer of 137 bits are used to manage 16-bit data with 6-bit ECC
  - Reading two times the same address triggers two flash read accesses.
  - During a read access, two wait states are added in addition to the memory wait states. These wait states are necessary to parse the data buffer.
  - Each write access triggers a write in the flash memory.
  - 6-bit ECC is associated to each 16-bit data.

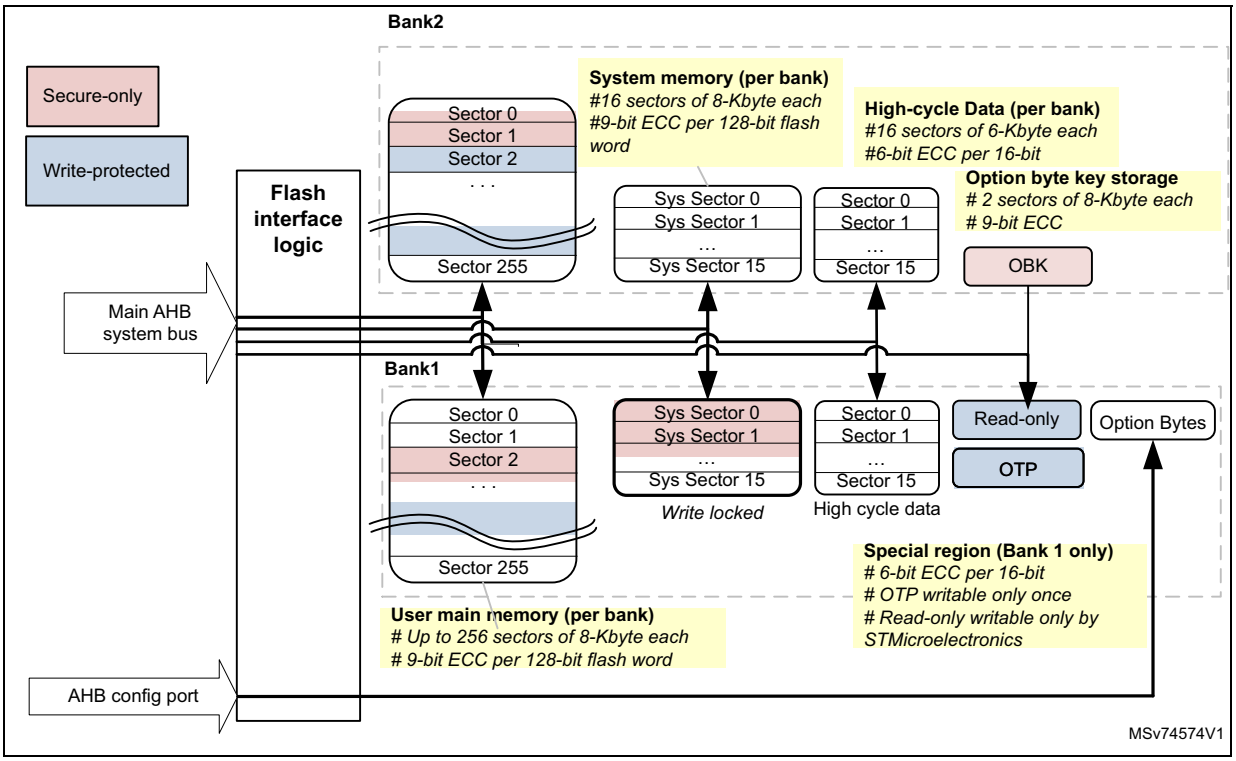
By default, all the AHB memory range is cacheable. For regions where caching is not practical (OTP, RO, data area), MPU must be used to disable local cacheability.

7.3.3 Flash memory architecture and usage

Flash memory architecture

Figure 21 shows the organization supported by the embedded flash memory.

Figure 21. Embedded flash memory organization (4-Mbyte devices)



The embedded flash nonvolatile memory is composed of:

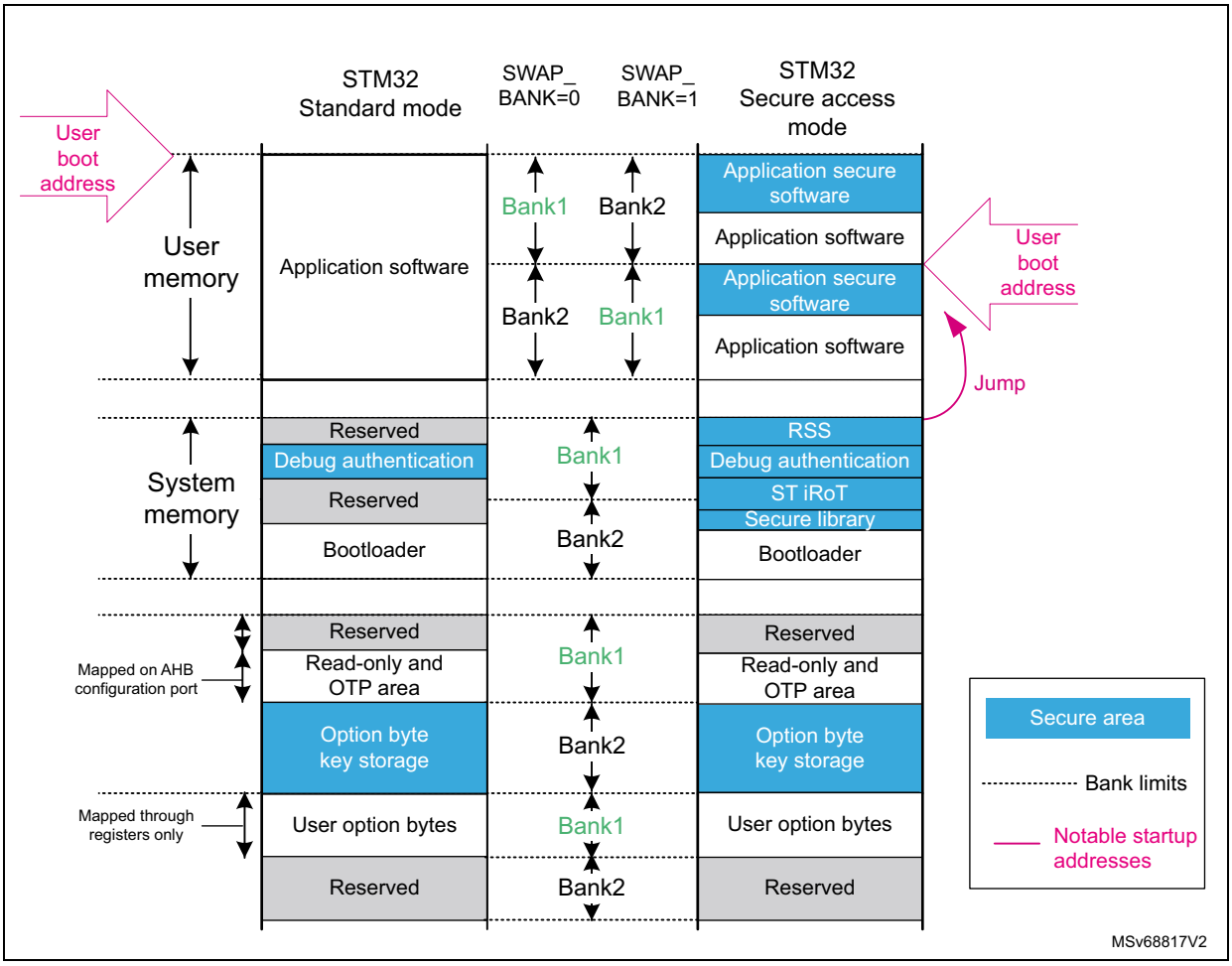
- A 4-Mbyte main memory block, organized in two banks. Each bank is divided in 256 sectors of 8 Kbytes each, and features flash-word rows of 128 bits + 9 bits of ECC per word.
- A system memory block of 256 Kbytes, divided into two 128-Kbyte banks. Each bank is divided in sixteen 8-Kbyte sectors. The system flash memory is ECC protected (9-bit ECC per 128-bit word).
- A set of nonvolatile option bytes loaded at reset by the embedded flash memory and accessible by the application software only through the AHB configuration register interface.
- A 2-Kbyte one-time-programmable (OTP) area that can be written only once by the application software.
- A 2-Kbyte read-only area. It contains a unique device ID and product information.
- Two memory sectors (2 x 8 Kbytes) of secure key storage, OBKeys.
- Up to 32 sectors of user flash memory with high cycling capability (100 K cycles) for data, 16 sectors per bank.

The overall flash memory architecture and its corresponding access interface is summarized in *Table 49*.

Partition usage

Figure 22 shows how the embedded flash memory is used by STMicroelectronics and by the application software.

Figure 22. Embedded flash memory usage



User and system memories are used differently, according to product state and other option bytes settings:

- The user memory contains the application code and data, while the system memory is used with root secure services (RSS), the debug authentication code, and the STM32 bootloader. When a reset occurs, the core jumps to the boot address configured through the BOOT pin, the (SEC/NS)BOOTADD option bytes, and the product state.
- The unique boot entry (BOOT_UBE) is set to either ST iRoT located in the system flash memory, or iRoT in the user flash memory. This feature is available only on cryptography enabled devices.
- Secure service library in system flash memory is available in secure mode.
- If the debugger is attached to the product, the entry point is the debug authentication policy, used to unlock the device via the SBS when attached to debugger. A digital signature must be provided to perform a regression to product state, where debug is allowed.

- If (SEC/NS)BOOTADD is not yet configured, dedicated libraries can be used for secure boot. They are located in the system flash memory:
  - ST libraries in system flash memory assist the application software boot with special features, such as secure boot and secure firmware install (SFI-RSS)
  - ST iROT (immutable root of trust) secure software in user flash memory is used for secure firmware update and provisioning (SFU)

Note: For more information on option byte setup for boot, refer to Section 7.4.6.

7.3.4 FLASH read operations

Read operation overview

Read access to main and system flash memory operates as follows:

- There is a 128-bit read data buffer associated to each bank, which stores the last data read. If several consecutive read accesses request data belonging to the same flash data word (128 bits), data are read directly from the current data read buffer, without triggering additional flash read operations. This mechanism occurs each time a read access is granted. When a read access is rejected for security reasons, the corresponding read error response is issued by the embedded flash memory and no read operation to flash memory is triggered.
- The read data buffer is disabled when write access or OTP access, user option change request, OBK swap, OBK erase or other erase operation occur.

Read access to OTP, RO and flash high-cycle data operates as follows:

1. Flash data word of 137 bits is read and stored in a temporary buffer.
2. The interface parses the 137-bit data word, and selects the 16- or 32-bit data requested.
3. While parsing the 137-bit data word, (two) wait states are added, and the AHB bus is stalled.
4. If the application reads an OTP data or flash high-cycle data not previously written, **a double ECC error** is reported and **only a word full of set bits is returned** (see *Section 7.3.9* for details). The read data (in 16 bits) is stored in FLASH_ECCDR register, so that the user can identify if the double ECC error is due to a virgin data or a real ECC error.
5. Reading two times the same address triggers two reads in the flash memory.
6. For 8-bit accesses, an AHB bus error is generated.

Note: The embedded flash memory can perform single-error correction and double-error detection while read operations are being executed (see Section 7.3.8).

Instruction prefetch

The Cortex-M33 fetches instructions and literal pools (constants/data) over the C-Bus and through the instruction cache, if it is enabled. The prefetch block aims at increasing the efficiency of C-Bus accesses when the instruction cache is enabled, by reducing the cache refill latency.

Prefetch is efficient in case of sequential code; prefetch in the flash memory allows the next sequential instruction line to be read from the memory, while the current instruction line is being filled in instruction cache and executed by the CPU.

Prefetch is enabled by setting the PRFTEN bit in the FLASH access control register (FLASH_ACR). PRFTEN must be set only if at least one wait state is needed to access the flash memory.

Adjusting read timing constraints

The embedded clock must be enabled and running before reading data from a nonvolatile memory.

To correctly read data from the memory, the number of wait states (LATENCY) must be correctly programmed in the access control register (FLASH_ACR), according to the main AHB interface clock frequency, and the internal voltage range of the device (V_{core}).

Table 39 shows the correspondence between the number of wait states (LATENCY), the programming delay parameter (WRHIGHFREQ), the embedded flash memory clock frequency, and the supply voltage range.

Table 39. Recommended number of wait states and programming delay

Number of wait states (LATENCY)	Programming delay (WRHIGHFREQ)	Interface clock frequency vs. V_{CORE} range(1)			
		VOS3 range 0.95 to 1.05 V	VOS2 range 1.05 to 1.15 V	VOS1 range 1.15 to 1.26 V	VOS0 range 1.30 to 1.40 V
0 WS (1 FLASH clock cycle)	00	0 to 20 MHz	0 to 30 MHz	0 to 34 MHz	0 to 42 MHz
1 WS (2 FLASH clock cycles)		20 to 40 MHz	30 to 60 MHz	34 to 68 MHz	42 to 84 MHz
2 WS (3 FLASH clock cycles)	01	40 to 60 MHz	60 to 90 MHz	68 to 102 MHz	84 to 126 MHz
3 WS (4 FLASH clock cycles)		60 to 80 MHz	90 to 120 MHz	102 to 136 MHz	126 to 168 MHz
4 WS (5 FLASH clock cycles)	10	80 to 100 MHz	120 to 150 MHz	136 to 170 MHz	168 to 210 MHz
5 WS (6 FLASH clock cycles)		N/A	N/A	170 to 200 MHz	210 to 250 MHz

1. Voltage range from 1.26 to 1.30 V is not supported.

Adjusting system frequency

After power-on, the embedded flash memory is clocked by the 64 MHz high-speed internal oscillator (HSI), with a voltage range set at a scaled value of VOS3: a conservative 3 wait-state latency is specified in FLASH_ACR register (see *Table 39*).

When changing the bus frequency, the application software must follow the sequence described below, to tune the number of wait states required to access the memory.

To increase the CPU frequency:

1. If necessary, program the LATENCY and WRHIGHFREQ bits to the right value in the FLASH_ACR register, as described in *Table 39.*
2. Check that the new number of wait states is taken into account by reading back the FLASH_ACR register.
3. Modify the embedded flash memory clock source and/or the clock prescaler in the RCC_CFGR register of the reset and clock controller (RCC).
4. Check that the new embedded flash memory clock source and/or the new AHB clock prescaler value are taken in account by reading back the embedded flash memory clock source status and/or the prescaler value in the RCC_CFGR register of the reset and clock controller (RCC).

To decrease the CPU frequency:

1. Modify the embedded flash memory clock source and/or the clock prescaler in the RCC_CFGR register of reset and clock controller (RCC).
2. Check that the embedded flash memory new clock source and/or the new clock prescaler value are taken into account by reading back the embedded flash memory clock source status and/or the AHB interface prescaler value in the RCC_CFGR register of reset and clock controller (RCC).
3. If necessary, program the LATENCY and WRHIGHFREQ bits to the right value in FLASH_ACR register, as described in *Table 39.*
4. Check that the new number of wait states has been taken into account by reading back the FLASH_ACR register.

Error code correction (ECC)

The memory embeds an error correction mechanism. Single-error correction and double-error detection are performed for each read operation. For more details, refer to *Section 7.3.8*.

Read errors

When the ECC mechanism is unable to correct the read operation, the memory reports read errors, as described in *Section 7.9.10*.

Read interrupts

See *Section 7.10* for details.

7.3.5 FLASH program operations

Program operation overview

Program operation consists in issuing write commands. The memory supports the execution of only one write-command at a time. Write-while-write is not supported. Nothing prevents overwriting a non-virgin flash word, but this is not recommended. The result may lead to invalid data and inconsistent ECC code.

User flash, OBK storage and system flash memories sectors

For the user and system flash memories, 9-bit ECC is associated to each 128-bit data flash word. In this case, the embedded flash memory must always perform write operations to nonvolatile memory with a 128-bit word granularity. Once the write buffer is full (128 bits), the Busy flag is set, and a programming operation is triggered.

There is a write buffer common to bank1 and bank2, which supports multiple write-access types (128, 64, 32, 16 or 8 bits). The application can decide to write from 8 bits to 128 words. In this case, a force-write mechanism to the 128 bits + ECC is used (see FW bit of FLASH_NS/SECCR register).

When the write request is issued to the memory, any new write request stalls the main AHB bus. Moreover, while a write operation is ongoing, any new read request to the same bank stalls the main AHB bus.

OTP, RO, flash high-cycle data

When the target memory is OTP, RO and flash high-cycle data sectors, 6-bits ECC code is associated to each 16-bit data flash word. The embedded flash memory supports 16- or 32-bit write operations (8-bit write operations are not supported).For 8-bit accesses, write accesses are ignored. There is no write data buffer. Each write access triggers a write in the flash memory.

Note: The OTP area is typically write-protected on the final product, as described in Section 7.3.9.

The write protection check is performed at the reception of the write request (during address phase).Write protection is not checked anymore at the output of the write buffer. If a write protection violation is detected, the write operation is canceled, and write protection error (WRPERR) is raised in FLASH_NS/SECSR register.

Note: For write protections of main flash, ICP, and OTP see Section 7.6.

Monitoring ongoing write operations

The application software can use a status flag located in FLASH_NS/SECSR to monitor ongoing write operations. Since only one operation is possible at a time, this flag indicates if any operation (write, erase, option change) is ongoing, whatever the bank.

- **BSY**: indicates that an effective write, erase, option byte change, OBK swap, OBK alt sector erase is ongoing in the nonvolatile memory. This flag is not dedicated to a specific bank. It is set when an operation is starting on the memory, whatever the bank. An operation is triggered by:
  - An erase (FLASH_NS/SECCR.STRT)
  - A write (FLASH_NS/SECCR.PG + AHB write)
  - An option modification (FLASH_OPTCR.OPTSTRT)
  - OBKeys sector swap and OBKeys sector erase (FLASH_NS/SECOBKCFGR.SWAP_SECT_REQ and FLASH_NS/SECOBKCFGR.ALT_SECT_ERASE)

They are cleared when the current operation ends, or in case of error.

- **WBNE**: this bit indicates that the embedded flash memory is waiting for new data to complete the 128-bit write buffer. In this state the write buffer is not empty. It is reset as soon as the application software fills the write buffer, or forces the writes by using FW bit in FLASH_NS/SECCR, or an error is detected. When WBNE is high, it is not

possible to launch an erase, an option modification, an OBK swap or OBK alternate sector erase operation on flash memory.

- **DBNE**: this bit indicates that the data buffer for parsing 16-bits data is not empty:
  - 16-bit data write access is received, and the data buffer is being filled. It is set at the receipt of a valid write access, and reset as soon as the write request preparation has been processed.

Note: If the memory is busy at the receipt of the AHB write request, the CPU execution is stalled.

Enabling write operations

Before programming the user flash memory in bank1 or in bank2, the application software must ensure that the PG bit is set to 1 in FLASH_NS/SECCR. If not, an unlock sequence must be used (see *Section 7.6.7*), and the PG bit must be set.

When an option byte or an option byte key must be modified, or a mass erase must be started, the application software must ensure that FLASH_OPTCR is unlocked. If this is not the case, an unlock sequence must be used (see *Section 7.6.7*).

A separate mechanism with similar use exists for FLASH_NS/SECOBKCFGR. The control register must be unlocked prior to the start of any OBKeys storage modification. Writing the correct sequence to the FLASH_NSOBKKEYR unlocks FLASH_NSOBKCFGR. FLASH_SECOBKKEYR is linked to FLASH_SECOBKCFGR, as described in *Section 7.6.7*.

Note: The application software must not unlock an already unlocked register, otherwise this register remains locked until the next system reset.

If needed, the application software can update the programming delay, as described in *Adjusting programming timing constraints*.

Writing to the FLASH control register FLASH_NS/SECCR and FLASH_OPTCR

The FLASH_NS/SECCR, FLASH_OPTCR and FLASH_NS/SECOBKCFGR registers are not accessible in write mode when the BSY bit is set. Any attempt to write these registers while the BSY bits is set causes the AHB bus to stall until SEC/NSBSY bit is cleared.

Single-write sequence

The recommended single-write sequence is the following:

1. Make sure protection mechanism does not prevent programming
2. Check that no memory operations are ongoing by checking the BSY bit in the FLASH_NS/SECSR register and CDBNE bits in the FLASH_NS/SECSR register. Check that the write buffer is empty by checking the WBNE bit in the FLASH_NS/SECSR register
3. Check and clear all the error flags due to previous programming/erase operation
4. Unlock the FLASH_NS/SECCR register, as described in *Section 7.6.7* (only if this register is not already unlocked)
5. Enable write operations by setting PG bit in the FLASH_NS/SECCR register
6. Write one flash-word at aligned address

Note: NS/SECWBNE flag indicates if the 128-bit write buffer is waiting for new data.

Note: No erase request, options change request, OBK operation is allowed between the first write and the completion of the write operation.

7. Wait for the BSY bit to be cleared in the corresponding FLASH_NS/SECSR register
8. Clear PG bit in FLASH_NS/SECCR register if there are not any more programming requests

If step *6* is executed incrementally (for example byte per byte), the write buffer can become partially filled. In this case the application software can decide to force-write what is stored in the write buffer by using FW bit in FLASH_NS/SECCR register. In this particular case, the unwritten bits are automatically set to 1. If no bit in the write buffer is cleared to 0, the FW bit has no effect.

Note: The usage of a force-write operation prevents the application from updating, in a later stage, the missing bits with a value different from 1. This can lead to unexpected or inconsistent data, or ECC.

Adjusting programming timing constraints

Program operation timing constraints depend of the memory clock frequency, which directly impacts the performance. If timing constraints are too tight, the nonvolatile memory does not operate correctly, if they are too lax, the programming speed is not optimal.

The user must therefore trim the optimal programming delay through the WRHIGHFREQ parameter in the FLASH_ACR register. Refer to *Table 39* for the recommended programming delay, depending upon the memory clock frequency.

FLASH_ACR configuration register is common to both banks.

The application software must check that no program/erase operation is ongoing before modifying WRHIGHFREQ.

Caution: Modifying WRHIGHFREQ while programming/erasing the memory can corrupt its content.

Programming errors

When a program operation fails, an error is reported, as described in *Section 7.9*.

Programming interrupts

See *Section 7.10: FLASH interrupts* for details.

7.3.6 FLASH erase operations

Erase operation overview

The memory can perform erase operations on 8-Kbyte user sectors, on one user flash memory bank, or on two user flash memory banks (for example mass erase). For more details in user flash memory, ICP, user options and OTP erase protection, see *Section 7.6*.

Erase commands are issued through the AHB configuration interface. The memory supports one operation at a time, if it receives simultaneously a write and an erase request an error flag is raised, and both operations are canceled. See *Section 7.9* for details.

Erase and WRP

If the application software attempts to erase a write-protected user sector, the sector erase operation is aborted, and the WRPERR flag is raised in the FLASH_NS/SECSR register, as described in *Section 7.9.2*.

Flash busy

Busy signals is described in *Monitoring ongoing write operations*.

Writing to the FLASH control register FLASH_NS/SECCR and FLASH_OPTCR

Refer to *Writing to the FLASH control register FLASH_NS/SECCR and FLASH_OPTCR*.

Enabling erase operations

Before erasing a sector, the application software must make sure that FLASH_NS/SECCR is unlocked. If this is not the case, an unlock sequence must be used (see *Section 7.6.7*).

Note: The application software must not unlock a register that is already unlocked, otherwise this register remains locked until next system reset. This can be used to deliberately lock-out a register from further accesses.

Similar constraints apply to bank erase requests.

Standard flash sector erase sequence

To erase an 8- or 6-Kbyte data user sector without security protections, proceed as follows:

1. Make sure protection mechanism does not prevent sector erase (WRP, secure flag, HDP).
2. Check that no memory operations are ongoing by checking the BSY and DBNE bits in the FLASH_NSSR register, and that the write buffer is empty by checking the WBNE bit in the FLASH_NSSR register.
3. Check and clear all the nonsecure error flags due to previous programming/erase operation. Refer to *Section 7.9* for details.
4. Unlock the FLASH_NSCR register, as described in *Section 7.6.7* (only if this register is not already unlocked).
5. Set the BKSEL bit, the SER bit and SNB bitfield in the FLASH_NSCR register. BKSEL indicates in which physical bank sector must be erased, then SER indicates a sector erase operation, while SNB contains the target sector number. In case of data sector, use the number of the corresponding regular sector.
6. Set the STRT bit in the FLASH_NSCR register.
7. Wait for the BSY bit to be cleared in the FLASH_NSSR register.
8. STRT bit is automatically cleared at the end of the sector erase, or in case of error.
9. Clear SER in FLASH_NSCR register if there are not anymore sector erase request to be issued.

Note: If another erase flag is requested simultaneously to the sector erase, a PGSERR error is generated.

Secure flash memory sector erase sequence

To erase an 8- or 6-Kbyte data secure configured user sector, proceed as follows:

1. Make sure write protection or HDP mechanism does not prevent sector erase.
2. Ensure that no memory operations are ongoing (by checking the BSY and DBNE bits in the FLASH_SECSR register), and that the write buffer is empty (by checking the WBNE bit in the FLASH_SECSR register).
3. Check and clear all the secure error flags due to previous programming/erase operations. Refer to *Section 7.9* for details.
4. Unlock the FLASH_SECCR register, as described in *Section 7.6.7* (only if this register is not already unlocked).
5. Set the BKSEL bit, the SER bit and SNB bitfield in the FLASH_SECCR register. BKSEL indicates in which physical bank sector must be erased, then SER indicates a sector erase operation, while SNB contains the target secure sector number. In case of data sector, use the number of the corresponding regular sector.
6. Set the STRT bit in the FLASH_SECCR register.
7. Wait for the BSY bit to be cleared in the FLASH_SECSR register.
8. STRT bit is automatically cleared at the end of the sector erase or in case of error.
9. Clear SER in FLASH_SECCR register if there are not any secure sector erase request to be issued.

Note: If another erase flag is requested simultaneously to the sector erase, a PGSERR error is generated.

Standard flash memory bank erase sequence

To erase bank where no sector is configured as secure:

1. Make sure protection mechanism does not prevent sector erase.
2. Check that no memory operations are ongoing by checking the BSY and DBNE bits in the FLASH_NSSR register and that the write buffer is empty by checking the WBNE bit in the same register.
3. Check and clear all the nonsecure error flags due to previous programming/erase operation. Refer to *Section 7.9* for details.
4. Unlock the FLASH_NSCR register, as described in *Section 7.6.7* (only if this register is not already unlocked).
5. Set the BKSEL bit and the BER bit in the FLASH_NSCR register to the targeted physical bank (swap setting is ignored).
6. Set the STRT bit in the FLASH_NSCR register to start the bank erase operation. Then wait until the BSY bit is cleared in the FLASH_NSSR register.
7. STRT bit is automatically cleared at the end of erase sequence or in case of error.
8. Clear BER in FLASH_NSCR register if there is not other bank erase request to be issued.

Secure flash memory bank erase sequence

To erase bank where all sectors are configured with secure flag:

1. Make sure protection mechanism does not prevent sector erase (for mass erase the HDP is also considered, it cannot be fully executed from HDPL= 2, 3 if HDP is defined).
2. Check that no memory operations are ongoing by checking the BSY and DBNE bits in the FLASH_SECSR register and that the write buffer is empty by checking the WBNE bit in the same register.
3. Check and clear all the secure error flags due to previous programming/erase operation. Refer to *Section 7.9* for details.
4. Unlock the FLASH_SECCR register, as described in *Section 7.6.7* (only if this register is not already unlocked).
5. Set the BKSEL bit and the BER bit in the FLASH_SECCR register to the targeted physical bank (swap setting is ignored).
6. Set the STRT bit in the FLASH_SECCR register to start the bank erase operation. Then wait until the BSY bit is cleared in the FLASH_SECSR register.
7. STRT bit is automatically cleared at the end of erase sequence or in case of error.
8. Clear BER in FLASH_SECCR register if there is not other bank erase request to be issued.

Flash mass erase sequence

To erase all sectors of both banks, using nonsecure access, all sectors must be configured as nonsecure. The application software can set the MER bit to 1 in FLASH_NSCR register, as described below:

1. Make sure protection mechanisms do not prevent mass erase (*Section 7.6*).
2. Check that no memory operations are ongoing by checking the BSY and DBNE bits in the FLASH_NSSR register and that the write buffer is empty by checking the WBNE bit in the FLASH_NSSR register.
3. Check and clear all the nonsecure error flags due to previous programming/erase operation. Refer to *Section 7.9* for details.
4. Unlock the FLASH_NSCR register as described in *Section 7.6.7* (only if the registers are not already unlocked).
5. Set the MER bit to 1 in FLASH_NSCR register.
6. Set the STRT bit in the FLASH_NSCR register. Then wait until BSY bit is cleared in the FLASH_NSSR register.
7. STRT bit is cleared automatically at the end of the erase sequence, or in case of error.
8. Clear MER in FLASH_NSCR register.

Secure flash memory mass erase sequence

To erase all sectors of both banks simultaneously, using secure access, all sectors must be configured as secure. The application software can set the MER bit to 1 in FLASH_SECCR register, as described below:

1. Make sure protection mechanisms do not prevent mass erase (*Section 7.6*).
2. Check that no memory operations are ongoing by checking the BSY and DBNE bits in the FLASH_SECSR register and that the write buffer is empty by checking the WBNE bit in the FLASH_SECSR register.
3. Check and clear all the secure error flags due to previous programming/erase operation. Refer to *Section 7.9* for details.
4. Unlock the FLASH_SECCR register as described in *Section 7.6.7* (only if the registers are not already unlocked).
5. Set the MER bit to 1 in FLASH_SECCR register.
6. Set the STRT bit in the FLASH_SECCR register. Then wait until BSY bit is cleared in the FLASH_SECSR register.
7. STRT bit is cleared automatically at the end of the erase sequence, or in case of error.
8. Clear MER in FLASH_SECCR register.

Note: Mass and bank erase also erase high-cycle data sectors aliased from the erased bank.

7.3.7 FLASH parallel operations

As the memory is divided into two independent banks, the embedded flash memory interface supports a read in one bank while a write (RWW. read while write) or an erase is executed in the other bank. It does not support write-while-write, nor read-while-read. Same is valid for the high-cycle data area, system flash libraries, or the OBK (located on bank2).

In all cases, the sequences described in *Section 7.3.4*, *Section 7.3.5* and *Section 7.3.6* apply.

7.3.8 FLASH error protections

Error correction codes (ECC)

The embedded flash memory supports an error correction code (ECC) mechanism, based on the SECDED algorithm, to correct single errors and detect double errors.

This mechanism uses nine ECC bits per 128-bit flash word, and applies to user and system memory.For read-only, OTP, flash high-cycle data, a stronger six ECC bits per 16-bit word is used. A double ECC error is generated for an OTP or flash high-cycle data virgin word (for example a word with 22 bits at 1). When this OTP or flash high-cycle data word is no more virgin, the ECC error disappears.

More specifically, during each read operation from a 128-bit flash word, the embedded flash memory retrieves the 9-bit ECC information, computes the ECC of the flash word, and compares the result with the reference value. If they do not match, the corresponding ECC error is raised, as described in *Section 7.9.10*.

During each program operation, a 9-bit ECC code is associated to each 128-bit data flash word, and the resulting 137-bit flash word information is written in nonvolatile memory.

A similar mechanism applies to read-only and OTP areas, but with 6-bit ECC for 16-bit data.

7.3.9 OTP and RO memory access

OTP and RO memory are accessed through main AHB interface. The OTP is accessible at addresses 0x08FF_F000 to 0x08FF F7FF, and the read-only section is accessible from 0x08FF F800 to 0x08FF_FFFF.

FLASH one-time programmable area

The embedded flash memory offers a 2048-byte memory area dedicated to application non-confidential, one-time programmable data (OTP). This area is composed by 1024 words of 16 bits (plus 6 bits of ECC). It cannot be erased, and can be written only once. The OTP area can be accessed through the main AHB interface from address 0x08FF F000 to 0x08FF F7FE.

OTP data can be programmed by the application software by 16-bit chunks. Overwriting an already programmed16-bit half-word can lead to data and ECC errors, and is therefore not supported.

Note: The OTP area is virgin when the device is delivered by STMicroelectronics.

When reading OTP data with a single error corrected or a double error detected, the embedded flash memory reports read errors, as described in *Section 7.9.10*.

When reading OTP data not written by the application software (such as virgin OTP), the ECC correction reports a double-error detection (ECCD), and the data are to be found in the FLASH_ECCDR register. ECCD implies an NMI raised.

OTP write protection

OTP data are organized as 32 blocks of 32 OTP words, as shown in *Table 40*. An entire OTP block can be protected (locked) from write accesses by setting the LOCKBLi bit (i = 0 to 31) corresponding to each OTP block in the FLASH_OTPBLR register. A block can be write-protected, if it has been programmed (even partially) or not.

The OTP block locking operation is irreversible, and independent from the product life state.

Note: The OTP area can be accessed only in read mode.

Table 40. Flash memory OTP organization

OTP block	AHB address	AHB word		Lock bit
		[31:16]	[15:0]	
Block 0	0x08FF F000	OTP001	OTP000	LOCKBL0
	0x08FF F004	OTP003	OTP002	
	...			
	0x08FF F03C	OTP031	OTP030	
Block 1	0x08FF F040	OTP033	OTP032	LOCKBL1
	0x08FF F044	OTP035	OTP034	
	...			
	0x08FF F07C	OTP063	OTP062	

Table 40. Flash memory OTP organization (continued)

OTP block	AHB address	AHB word		Lock bit
		[31:16]	[15:0]	
Block 2	0x08FF F080	OTP065	OTP064	LOCKBL2
	0x08FF F084	OTP067	OTP066	
	...			
	0x08FF F0BC	OTP95	OTP94	
...				
Block 31	0x08FF F7C0	OTP993	OTP992	LOCKBL31
	0x08FF F7C4	OTP995	OTP994	
	...			
	0x08FF F7FC	OTP1023	OTP1022	

OTP write sequence

Follow the sequence below to write an OTP word:

1. Check that no memory operations are ongoing by checking the BSY bit in the FLASH_NSSR register and that the data buffer is empty by checking the DBNE bit in the FLASH_NSSR register.
2. Check and clear all the error flags due to previous programming/erase operation.
3. Set PG bit in the FLASH_NSCR register.
4. Check the protection status of the target OTP word (see *Table 40*). The corresponding LOCKBLi bit must not be set to 1.
5. Write two OTP words (32 bits) corresponding to the 4-byte aligned address shown in *Table 40*. Alternatively, the application software can program separately the 16-bit MSB or 16-bit LSB. In this case the first 16-bit write operation starts immediately, without waiting for the second one.
6. Wait for the BSY bit to be cleared in the FLASH_NSSR register.
7. Clear PG bit in FLASH_NSCR register if there is not any programming request anymore in the bank.
8. Optionally, lock the OTP block using LOCKBLi to prevent further data changes.

Note: Do not write twice an OTP 16-bit word, otherwise an ECC error is generated.

Writing OTP data at byte level is not supported, and generates a bus error.

To avoid data corruption, it is important to complete the OTP write process (for example by reading back the OTP value), before starting an option change.

Flash read-only area

The embedded flash memory offers a 2-Kbyte area to store read-only data. This area can be accessed through the AHB main port, and is protected by a robust ECC scheme, as detailed in *Section 7.3.8*.

The read-only information (programmed by STMicroelectronics) that can be used by the application software is detailed in *Table 41*.

Table 41. Read-only public data organization

Read-only data name	Address	Comment
Unique device ID	0x08FF F800	U_ID[31:0]
	0x08FF F804	U_ID[63:32]
	0x08FF F808	U_ID[96:64]
Flash memory size/ package	0x08FF F80C	Flash memory size[15:0] / Package code[15:0]
Reserved	0x08FF F810 to 0x08FF FFFF	Reserved information

7.3.10 Flash high-cycle data

The embedded flash memory offers up to 192 Kbytes (maximum) memory area with high-cycling capability (100 kcycles) to store data and emulate EEPROM. It can be accessed through the AHB system port from address 0x0900_0000 to 0x0902_7FFF (see *Figure 23*). It is mapped in the 16 last sectors of bank1 and bank2. This area is protected by a robust 6-bit ECC, which allows a read and write granularity of 16 bits at the expense of having sector size shrunk to 6 Kbytes.

A threshold per bank (EDATA(1/2)_STRT) is programmable to determine the beginning of the data flash area. By default, the whole memory is used for code.

For example, if 96Kbytes of data are needed in bank1, set EDATA1_EN to 1, and EDATA1_STRT to 15. If no data are needed in bank2, set EDATA2_EN to 0. In this case the data are accessible from address 0x0900_0000 to 0x0901_7FFF for bank1.

For greater efficiency, it is always recommended to use sector on the other bank for flash high-cycle data, so that the application benefits from RWW capability of the dual-bank arrangement.

When SWAP_BANK feature is enabled, the banks are swapped: the flash high-cycle data in Bank 2 are accessible on the bank1 address range, and vice versa.

A bus error is generated on:

- Attempt to access an address between 0x0900_0000 to 0x0902_FFFF and this address is not valid (EDATA(1/2)_EN not enabled or EDATA(1/2)_STRT not correct).
- Attempt to fetch instructions from flash high-cycle data area.

Erasing the data area sector is possible by normal erase request for the corresponding user flash sector (255-240 for largest device).

Protections and security of high-cycle area are detailed in *Section 7.6.9*.

Figure 23. Flash high-cycle data memory map on 4-Mbyte device

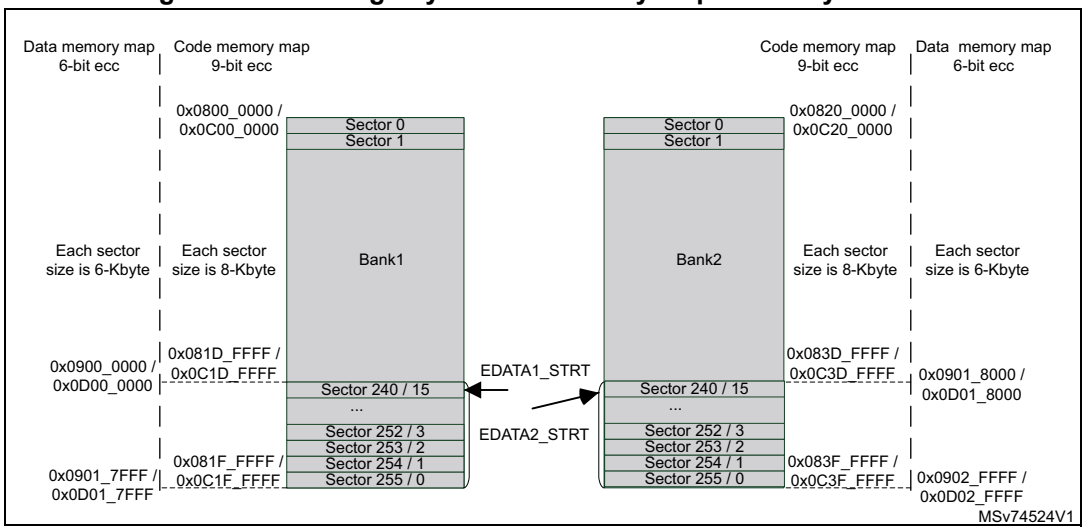
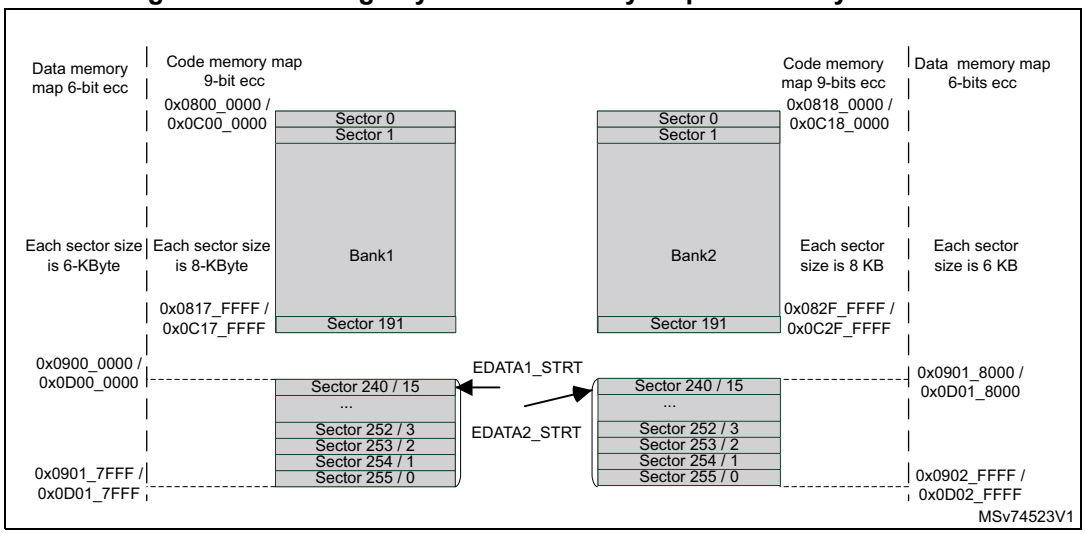


Figure 24. Flash high-cycle area memory map on a 3-Mbyte device



Note: When the flash high-cycle data area on bank1 is enabled, the code memory map is not continuous from bank1 to bank2 on 4M devices.

7.3.11 Flash bank swapping

Bank1 and bank2 can be swapped for the user flash. This feature can be used after a firmware upgrade to restart the device on the new firmware. Bank swapping is an user option byte flag controlled by the SWAP_BANK bit of the FLASH_OPTCR register.

Bank specific settings for data area and security attributes follow the original bank and its contents. Control bit BKSEL always refers to physical bank, not the SWAP_BANK setting.

Table 42 shows the accessible memory, depending upon the SWAP_BANK bit value.

Table 42. Memory map and swapping data

Area	Corresponding bank		Start address	End address	Size (bytes)	Region name
	SWAP_BANK = 0	SWAP_BANK = 1				
User main memory	Bank1	Bank2	0x0800 0000	0x0800 1FFF	8 K	Sector 0
			0x0800 2000	0x0800 3FFF	8 K	Sector 1
			...	...	...	...
			0x081F E000	0x081F FFFF	8 K	Sector 255
	Bank2	Bank1	0x0820 0000	0x0820 1FFF	8 K	Sector 0
			0x0820 2000	0x0820 3FFF	8 K	Sector 1
			...	...	...	...
			0x083F E000	0x083F FFFF	8 K	Sector 255
System memory	Bank1		0x0BF8 0000	0x0BF8 1FFF	8 K	System 1 Sector 0
			0x0BF8 2000	0x0BF8 3FFF	8 K	System 1 Sector 1
			...	...	...	...
			0x0BF9 E000	0x0BF9 FFFF	8 K	System 1 Sector 15
	Bank2		0x0BFA 0000	0x0BFA 1FFF	8 K	System 2 Sector 0
			0x0BFA 0000	0x0BFA 3FFF	8 K	System 2 Sector 1
			...	...	...	...
			0x0BFB E000	0x0BFB FFFF	8 K	System 2 Sector 15

The SWAP_BANK bit in FLASH_OPTCR register is loaded from the SWAP_BANK option bit only after system reset or POR.

To change the SWAP_BANK bit (for example to apply a new firmware update), follow the sequence below:

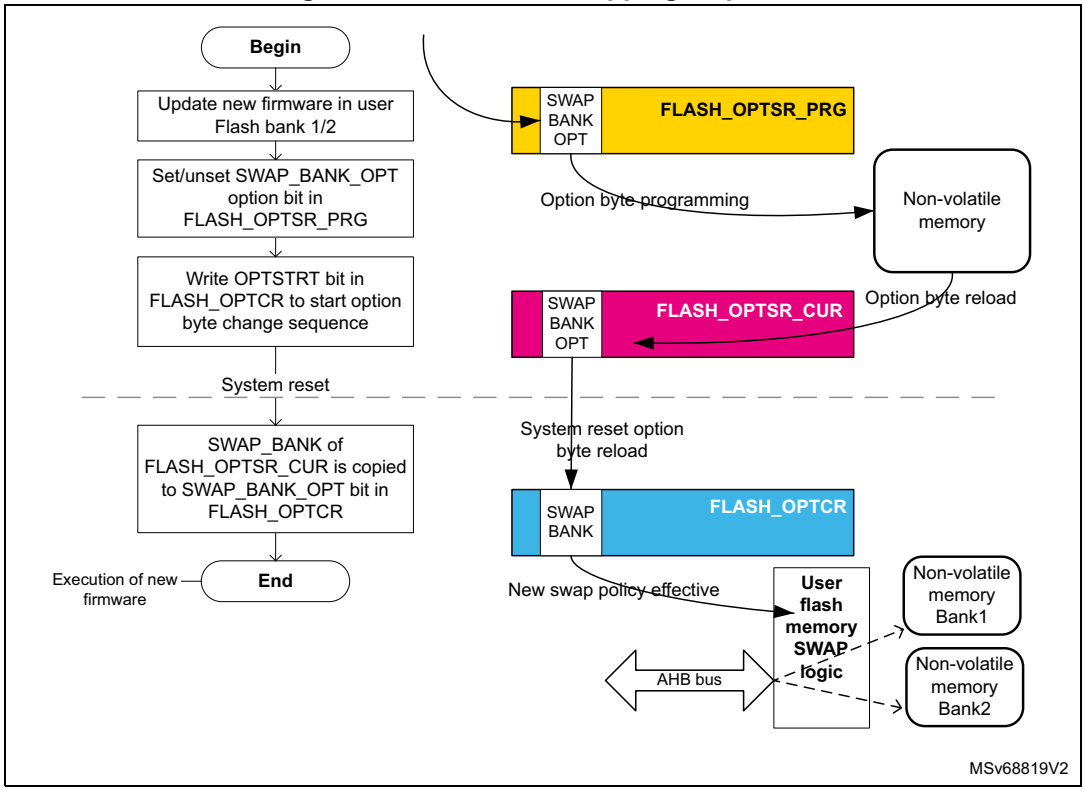
1. Check that no memory operations are ongoing by checking the BSY and DBNE bits in the FLASH_NS/SECSR register and that the write buffer is empty by checking the WBNE bit in the FLASH_NS/SECSR register.
2. Clear all error flags due to a previous operation.
3. Unlock OPTLOCK bit, if not already unlocked.
4. Set the new desired SWAP_BANK value in the FLASH_OPTSR_PRG register.
5. Start the option byte change sequence by setting the OPTSTRT bit in the FLASH_OPTCR register.
6. Once the option byte change has completed, FLASH_OPTSR_CUR contains the expected SWAP_BANK value, but SWAP_BANK bit in FLASH_OPTCR has not yet been modified and the bank swapping is not yet effective.
7. Force a system reset or a POR. When the reset rises up, the bank swapping is effective (SWAP_BANK value updated in FLASH_OPTCR) and the new firmware shall be executed.

Note: The SWAP_BANK bit in FLASH_OPTCR is read-only, and cannot be modified by the application software.

The SWAP_BANK option bit in FLASH_OPTSR_PRG can be modified whatever the product state. Instead of being locked by PRODUCT_STATE, it is locked by (NS/SEC)BOOT_LOCK User OB.

Figure 25 gives an overview of the bank swapping sequence.

Figure 25. Flash bank swapping sequence



7.3.12 FLASH reset and clocks

Reset management

The embedded flash memory can be reset by a core domain reset, driven by the reset and clock control (RCC). The main effects of this reset are the following:

- All registers, except for option byte registers, are cleared, including read and write latencies. If the bank swapping option is changed, it is applied.
- Most control registers are automatically protected against write operations. To unprotect them, new unlock sequences must be used as described in *Section 7.6.7*.

The memory can be reset by a power-on core domain reset, driven by the reset and clock control (RCC). When the reset falls, all option byte registers are reset. When the reset rises up, the option bytes are loaded, potentially applying new features. During this loading sequence, the device remains under reset, and the memory is not accessible.

The reset signal can have a critical impact on the memory: the content is not guaranteed if a device reset occurs during a write or erase operation.

Reset occurring during flash operation

If a reset occurs during a flash operation (programing, erase or option change), the content of the memory is not guaranteed. It is mandatory for integrity to restart the operation. The status register FLASH_OPSR gives information about operations interrupted by a reset.

FLASH_OPSR.CODE_OP gives opcode of operation. *Table 43* indicates how to use FLASH_OPSR, and which operation is required.

Table 43. Recommended reactions to FLASH_OPSR contents

CODE_OP	Operation interrupted	OTP_OP	SYSF_OP	BK_OP	DATA_OP	Flash area	ADDR_OP min	ADDR_OP max	Recommended action
0x000	No operation ongoing while reset	0	0	0	0	-(1)	-	-	No extra action
0x001	Write operation	0	0	0/1	0	User flash	0x0000	0xFFFF	Erase sector and rewrite
		0	1	0/1	0	System flash	0x0000	0x0FFF	
		1	0	0	0	OTP	0x0600	0x07FF	
		1	0	1	0	OBKeys(2)	0x0000	0x03FF	
		0	0	0/1	1	Data area(3)	0xF000	0xFFFF	
0x010	OBK alternate sector erase	0	0	1	0	OBKeys	0	0	Relaunch the alternate sector erase
0x011	Sector erase(4)	0	0	0/1	0	User flash	0x0000	0xFFFF	Relaunch sector erase
		0	1	0/1	0	System flash	0x0000	0x0FFF	

Table 43. Recommended reactions to FLASH_OPSR contents (continued)

CODE_OP	Operation interrupted	OTP_OP	SYSF_OP	BK_OP	DATA_OP	Flash area	ADDR_OP min	ADDR_OP max	Recommended action
0x100	Bank erase	0	0	0/1	0	User flash	-	-	Relaunch bank erase
0x101	Mass erase	0	0	0	0		-	-	Relaunch mass erase
0x110	Option change	0	0	0	0	User configuration	-	-	New attempt on option change
0x111	OBK swap sector	0	0	1	0	OBKeys	-	-	Erase alternate sector, reprogram new OBKeys and relaunch swap

1. Dash represents “does not matter”.
2. Depends on current OBK sector.
3. Depends on EDATA setting in the OB.
4. Addresses indicated are aligned to sector start, data area sectors are erased by erase request to corresponding user flash memory sector.

Clock management

The memory uses the microcontroller system clock (sys_ck), here the AHB interface clock.

7.4 FLASH option bytes

7.4.1 About option bytes

The memory includes a set of nonvolatile option bytes. They are loaded at power-on reset and can be read and modified only through configuration registers.This section documents:

- when option bytes are loaded
- how application software can modify them
- their detailed list, together with their initial values (before the first option byte change, user default configuration).

7.4.2 Option bytes loading

There are multiple ways of loading the option bytes:

- **Power-on wake-up**

  When the device is first powered, the embedded flash memory automatically loads all the option bytes. During the option byte loading sequence, the device remains under reset and the embedded flash memory cannot be accessed.
- **Wake-up from system Standby**

  When the core power domain, which contains the embedded flash memory, is switched from Standby mode to Run mode, the embedded flash memory behaves as during a power-on sequence. **During loading time the device is not under reset, unlike power-on sequence.**
- **Dedicated option byte reloading by the application**

  When the user application successfully modifies the option byte content through the memory registers, the nonvolatile option bytes are programmed and the memory automatically reloads all option bytes to update the option registers.

Note: The option byte read sequence is protected by error correction code.In case of error, the option bytes are loaded with default values (see Section 7.4.3), different from the initial values (user default configuration), and more restrictive.

7.4.3 Option byte modification

Changing user option bytes

A user option byte change operation can be used to modify the configuration and the protection settings saved in the nonvolatile option byte area.

There are several rules enforced when attempting to change a user option byte, they are summarized in *Section 7.4.7*. Failing to stick to those rules usually results in errors, described in *Section 7.9.12*.

The embedded flash memory features two sets of option byte registers:

- The first register set contains the current values of the option bytes. Their names have the _CUR extension. All these registers are read-only. Their values are automatically loaded from the nonvolatile memory after power-on reset, wake-up from system standby or after an option byte change operation.
- The second register set allows the modification of the option bytes. Their names contain the _PRG extension. All “_PRG” registers can be accessed in read/write mode.

When the OPTLOCK bit in FLASH_OPTCR register is set, it is not possible to modify the FLASH_XXX_PRG registers.

When OPTSTRT bit is set to 1, the memory checks the programming sequence (PGSERR) and the conditions described in *Section 7.4.7* (OPTCHANGEERR). If no error has been detected (PGSERR/OPTCHANGEERR), the flash interface launches the option byte modification, and updates the option byte registers with _CUR extension.

If one of the condition described in *Section 7.4.7*, *Section 7.9.12* or *Section 7.9.5*, alternatively *Section 7.9.4* is not respected, the memory aborts the option byte change operation. In this case, the FLASH_XXX_PRG registers are not overwritten by the current option value. The user application can check what was wrong in their configuration.

Unlocking the option byte modification

After reset, the OPTLOCK bit is set to 1 and the FLASH_OPTCR is locked. As a result, the application software must unlock the option configuration register before attempting to change the option bytes. The FLASH_OPTCR unlock sequence is described in *Section 7.6.7*.

Option byte modification sequence

To modify user option bytes, follow the sequence below:

1. Check that no memory operations are ongoing by checking the BSY bit in the FLASH_NS/SECSR register and that the write buffer is empty by checking the WBNE bit in the FLASH_NS/SECSR register.
2. Check the data buffer is empty (DBNE = 0) in FLASH_NS/SECSR register.
3. Clear all error flags due to a previous operation.
4. Unlock FLASH_OPTCR register as described in *Section 7.6.7*, unless the register is already unlocked.
5. Write the desired new option byte values in the corresponding option registers (FLASH_XXX_PRG).
6. Set the option byte start change OPTSTRT bit to 1 in the FLASH_OPTCR register.
7. Wait until BSY bit is cleared in FLASH_NS/SECSR register.
8. OPTSTRT bit is cleared automatically at the end of the sequence (or in case of error).
9. Reset the device. This step is always recommended, becomes mandatory when one of the following option bytes is impacted:
   a) SECBOOTADDR
   b) NSBOOTADDR
   c) TZEN
   d) BOOT_UBE

Note: If a reset or a power-down occurs while the option byte modification is ongoing, the original option byte value is kept. A new option byte modification sequence is required to program it.

Option byte overview

Table 44 lists all the user option bytes managed through the memory registers, as well as the initial values before the first option byte change (user default configuration).

Table 44. Option byte organization

Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLASH _OPTSR	SWAP_BANK	Res.	BOOT_UBE								IWDG_STDBY	IWDG_STOP	Res.	Res.	IO_VDDIO2_HSLV	IO_VDD_HSLV	PRODUCT_STATE								NRST_STDBY	NRST_STOP	Res.	WWDG_SW	IWDG_SW	BORH_EN	BOR_LEV	
	0		1	0	1	1	0	1	0	0	1	1			0	0	1	1	1	0	1	1	0	1	1	1		1	1	0	0	0
FLASH _OPTSR2	TZEN								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	USBPD_DIS	Res.	SRAM2_ECC	SRAM3_ECC	BKPRAM_ECC	SRAM2_RST	SRAM1345_RST	Res.	Res.
	1	1	0	0	0	0	1	1									0							1		1	1	1	1	1		
FLASH_ BOOTR	SECBOOTADD[23:8]																SECBOOTADD[7:0]								SECBOOT_LOCK							
	0x0C00																0x00								0xC3							
FLASH_ NSBOOTR	NSBOOTADD[23:8]																NSBOOTADD[7:0]								NSBOOT_LOCK							
	0x0800																0x00								0xC3							
FLASH_ SECWM1R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM1_END								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM1_STRT							
									1	1	1	1	1	1	1	1									0	0	0	0	0	0	0	0
FLASH_ SECWM2R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM2_END								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM2_STRT							
									1	1	1	1	1	1	1	1									0	0	0	0	0	0	0	0
FLASH_ WRPSGN11R	WRPSG[127:124]	WRPSG[123:120]	...												WRPSG[71:68]	WRPSG[67:64]	WRPSG[63:60]	WRPSG[59:56]	...												WRPSG[7:4]	WRPSG[3:0]
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FLASH_ WRPSGN12R	WRPSG[255:252]	WRPSG[251:248]	...												WRPSG[199:196]	WRPSG[195:192]	WRPSG[191:188]	WRPSG[187:184]	...												WRPSG[135:132]	WRPSG[131:128]
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 44. Option byte organization (continued)

Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLASH_ WRPSGN21R	WRPSG[127:124]	WRPSG[123:120]	...												WRPSG[71:68]	WRPSG[67:64]	WRPSG[63:60]	WRPSG[59:56]	...												WRPSG[7:4]	WRPSG[3:0]
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FLASH_ WRPSGN22R	WRPSG[255:252]	WRPSG[251:248]	...												WRPSG[199:196]	WRPSG[195:192]	WRPSG[191:188]	WRPSG[187:184]	...												WRPSG[135:132]	WRPSG[131:128]
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FLASH_ OTPBLR	LOCKBL																															
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FLASH_ EDATA1R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATA_EN1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECTOR _START_1			
																	0												0	0	0	0
FLASH_ EDATA2R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATA_EN1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECTOR _START_2			
																	0												0	0	0	0
FLASH_ NSEPOCHR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NS_EPOCH																							
									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
FLASH_ SECEPOCHR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEC_EPOCH																							
									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
FLASH_ HDP1R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP1_END								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP1_STRT							
									0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	1
FLASH_ HDP2R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP2_END								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP2_STRT							
									0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	1

7.4.4 Description of user and system option bytes

The general-purpose option bytes that can be used by the application are listed below:

- Watchdog management
  - IWDG_STOP: independent watchdog IWDG counter active in Stop mode if 1 (stop counting or freeze if 0)
  - IWDG_STDBY: independent watchdog IWDG counter active in Standby mode if 1 (stop counting or freeze if 0)
  - IWDG_SW: hardware (0) or software (1) IWDG watchdog control selection

Note: If the hardware watchdog "control selection" feature is enabled (set to 0), the watchdog is automatically enabled at power-on, thus generating a reset unless the watchdog key register is written to or the down-counter is reloaded before the end-of-count is reached.

Depending on the configuration of IWDG_STOP and IWDG_STDBY options, the IWDG can continue counting (1) or not (0) when the device is, respectively, in Stop or Standby mode. When the IWDG is kept running during Stop or Standby mode, it can wake up the device from these modes.

- Reset management
  - BOR_LEV: Brownout level option, indicating the supply level threshold that activates/releases the reset
  - BORH_EN: enabling a high BOR level
  - NRST_STDBY: generates a reset when entering Standby mode if cleared to 0
  - NRST_STOP: generates a reset when entering Stop mode if cleared to 0.

Note: Whenever a Standby (Stop) mode entry sequence is successfully executed, the device is reset instead of entering Standby (Stop) mode if NRST_STDBY (NRST_STOP) is cleared to 0.

- Device options
  - IO_VDDIO2_HSLV: enables the configuration of pads below 2.7 V for VDDIO2 power rail if set to 1
  - IO_VDD_HSLV: enables the configuration of pads below 2.7 V for VDD power rail if set to 1
  - USBPD_DIS: enables USB Type-C® dead battery pull-down behavior on UCPDx_CC1 pin.

At delivery, the values programmed in the user option bytes are the following:

- Watchdog management
  - IWDG active in Standby and Stop modes: 0x1
  - IWDG not automatically enabled at power-on: 0x1
- Reset management
  - BOR: brownout level option (reset level = 2.1 V): 0x0. A reset is not generated when the device enters Standby, Stop low-power mode (value = 0x1)
- Device working in the full voltage range with I/O speed optimization at low-voltage disabled (IO_VDDIO2_HSLV = 0 and IO_VDD_HSLV = 0)

Refer to *Section 7.11* for details.

7.4.5 Description of data protection option bytes

The option bytes that can be used to enhance data protection are listed below:

- PRODUCT_STATE[7:0]: A product life cycle state (see *Section 7.6.11* for details).
- WRPSGn1/2: write protection option of the corresponding group of four consecutive sectors in bank1 (respectively bank2). It is active low. Refer to *Section 7.6.8* for details.
  - Bit N: Group embedding sectors 4 x N to 4 x N + 3
- SECWMx: TrustZone® secure only watermark area definition (refer to *Section 7.6.1* for details).
  - SECWM1_STRT (respectively SECWM1_END) contains the first (respectively last) sector of the secure access only zone in bank1
  - SECWM2_STRT (respectively SECWM1_END) contains the first (respectively last) sector of the secure access only zone in bank2.
- TZEN: this nonvolatile option can be used by the application to activate the secure access mode, as described in *Section 7.6*. For security reasons the TZEN is stored with redundancy on 8 bits. While the TZEN OB value is set immediately after programming, to actually use TZ features, reset is required to set the TZ_STATE in SBS.

  When TZEN is activated, secure watermark settings and secure boot address can be reset to default to prevent a deadlock in case the previous values were not correct.
- HDPx: Secure hide protection - HDPL exclusive area control in the user flash memory.

When factory programmed values of the data protection option bytes are the following:

- Product state depends on sales type
- Flash bank erase operations do not impact watermarked secure data areas
- Secure watermark areas protections disabled (start addresses higher than end addresses)
- Write protection disabled (all option byte bits set to 1)
- TrustZone Secure access mode disabled (TZEN option byte value = 0xC3)

Refer to *Section 7.11* for details.

7.4.6 Description of boot address option bytes

Below the list of option bytes that can be used to configure the appropriate boot address for an application:

- PRODUCT_STATE
- BOOT_UBE: Available only on cryptography enabled devices.
  Selects either ST-iRoT or User flash as default boot address. Also used by RSS(SFI) to choose either Bootloader or ST-iRoT as next stage.
- NSBOOTADD: Selects default boot address when TZ is disabled.
- SECBOOTADD: Selects default boot address when TZ is enabled.
- (NS/SEC)BOOT_LOCK: Protects the boot configuration from further modification attempts.
- SWAP_BANK: bank swapping option, set to 1 to swap user flash banks after boot (see *Section 7.3.11*). If BOOT_LOCK corresponding to TZEN state (SEC/NS) is active, the value in SWAP_BANK is fixed, read-only.

When STMicroelectronics delivers the device, the PRODUCT_STATE is Open, BOOT_LOCK is not set (0xC3) and the BOOT_UBE is set to user flash (0xB4). Addresses are SECBOOTADD = 0x0C00 0000, NSBOOTADD = 0x0800 0000.

Refer to *Section 7.11* for details.

7.4.7 Specific rules for modifying option bytes

On top of OPTLOCK bit and register access rules, there are other protections for selected security-sensitive option byte fields.

Different option bytes can be modified simultaneously, but if they rely on each other for protection, both states are checked. For example, when trying to modify PRODUCT_STATE and TZEN simultaneously, resulting state must be coherent with the rules. With few exceptions, listed in this section, failing to uphold the rules results in raising OPTCHANGEERR flag (*Section 7.9.12* for additional details).

Table 45. Specific OB modifying rules

Option byte	HDPL	TZ secure	Value	Product state
PRODUCT_STATE	1(1)	Some values only when TZ is enabled	Set of possible transitions	Set of possible transitions (*Table 39*)
HDP	1(2)	-(3)	-	Refer to *Table 46*
TZEN	-	-	-	Regression, Open or Provisioning
EPOCH	-	-	PRG > CUR	Regression
EPOCH_NS	-	-	PRG > CUR	NS-Regression, Regression
SECWM	-	Secure mode only(2)	-	Refer to *Table 46*
BOOT_UBE	-	-	-	Open or Provisioning, SECBOOT_LOCK disabled
SECBOOTADD	-	Secure mode only(2)	-	
NSBOOTADD	-	-	-	Open or Provisioning, NSBOOT_LOCK disabled
LOCKBL	-	-	One way switch(2)	-
SWAP_BANK	-	Fixed if BOOT_LOCK corresponding to TZEN is set	-	-
SECBOOT_LOCK	-	Secure mode only(2)	-	Open, Regression or Provisioning to unlock
NSBOOT_LOCK	-	-	-	

1. Most transitions are possible regardless of HDPL, only a few require specific HDPL, see text below.
2. No OPTCHANGEERR raised in violation of this.
3. Dash means there is no limitation from this side.

Even in the closed PRODUCT_STATE progression, some OBs can still be modified, if all the other constraints are satisfied. An overview is presented in *Table 46*.

Table 46. OB modifiable in closed product

PRODUCT_STATE	OBs that can be modified
TZ-Closed	SWAP_BANK, LOCKBL, PRODUCT_STATE, SECWM, HDP
Closed	SWAP_BANK, LOCKBL, PRODUCT_STATE
Locked	SWAP_BANK, LOCKBL

Specific rules must be respected to update the following OB:

- **PRODUCT_STATE**

  PRODUCT_STATE transitions follow a state machine with two types of transition. Locking down the product is allowed without restriction. Opening the product is possible only using a debug interface and following a digital signature verification. The regression to a less secure state results in the erase of the protected content. More details are given in *Section 7.6.11*.

  Summary: Selected changes are possible only in HDPL1. Some states are accessible only when TZEN is enabled.
- **HDP**

  Can be modified only in HDPL1. Do not set it to overlap with flash high-cycle data area.
- **TrustZone access mode (TZEN)**

  Can be changed only in Open, Regression and Provisioning.
- **SEC_EPOCH and NS_EPOCH**

  The value programmed must be greater than current value.The increment is done in specific product states: Regression and NS-Regression.
- **Secure watermark area (SECWM1/2_STRT and SECWM1/2_END)**

  Can be changed only in secure mode (TZ_state = 0xB4). Automatically reset to default value when TZEN is enabled. Do not set it to to overlap with flash high-cycle data area.
- **BOOT_UBE**

  Available only on cryptography enabled devices. Can be changed only in product states open for debug like Open and also in Provisioning. SECBOOT_LOCK must be disabled to change.
- **SECBOOTADD**

  Can be changed only in Open and Provisioning. Locked by SECBOOT_LOCK. Automatically reset to default value when TZEN is enabled.
- **NSBOOTADD**

  Can be changed only in Open and Provisioning. Locked by NSBOOT_LOCK.
- **LOCKBL**

  Can be changed freely only in one direction. A permanent irreversible switch.
- **SWAP_BANK**

  Not modifiable when both TZEN and SECBOOT_LOCK are 0xB4 (set) or when TZEN = 0xC3 (disabled) and NSBOOT_LOCK is active (0xB4).
- **SECBOOT_LOCK**

  Can be changed only freely in locking direction. Unlock is possible in Open,

Provisioning and Regression.

- **NSBOOT_LOCK**

  Can be changed only freely in locking direction. Unlock is possible in Open, Provisioning and Regression.

Note: For all user option bytes above: default values are loaded and Tamper is signaled when a double ECC error occurs during OBL.

7.5 Option byte key management

This section describes the key storage tied with SAES and OBK-HDPL value set by the SBS (refer to *Section 14.3.7: SBS hardware secure storage control*). The OBKs are stored in 128 bits and protected by 9-bit ECC (SEC/DED). They are written alternatively in two sectors.

7.5.1 OBK loading

OBKs are memory mapped, and accessible through the main AHB bus (C-Bus), starting from address 0x0FFD 0000. A 9-bit ECC is associated to each 128-bit data flash word.

Note: Read access is allowed in the current and alternate sector, except for the last address of the current and alternate sector. In case of read access, no error is reported but the read data is always 0x0 (see Section 7.6.12).

7.5.2 OBK access per HDPL level

Table 47 describes the option byte key areas. The key storage is not dedicated to a particular key, and the usage is defined by the application.

An option byte key can be accessed only if the OBK-HDPL (set in SBS) matches the HDPL associated to the storage offset, indicated below (refer to *Section 14.3.7: SBS hardware secure storage control*). If this is not the case, an OBKERR error is raised.

Table 47. Option byte key area

OBK-HDPL	Address offset start	Address offset end	Comment
-	0x0000	0x00FF	Reserved
1	0x0100	0x08FF	OEM iRoT keys
2	0x0900	0x0FFF	uRoT, OS or secure application
3	0x1000	0x17FF	HDPL 3 secure keys
3	0x1800	0x1FEF	HDPL 3 nonsecure keys

7.5.3 OBK programming sequence

The sequence to write OBK is the same as a write to main flash except that the “alternate sector” (ALT_SECT) bit must be set to write in the alternate OBK sector. The ALT_SECT bit is checked each time a write access is received. If it does not match the one stored in the write buffer, an error is raised.

Note: Before writing in the alternate OBK sector the user must ensure that the whole key space (128, 256, or 512 bits) is free, by reading the alternate OBK sector.

If the alternate sector is not free, erase the sector using the command ALT_SECT_ERASE.

Secure programming method

Using the secure register if TrustZone is active (TZ_STATE = 0xB4):

1. Program the ALT_SECT bit.
2. Make sure protection mechanism does not prevent programming (TZ, PRIV and OBK-HDPL).
3. Check that no memory operations are ongoing by checking the BSY and DBNE bits in the FLASH_SECSR register and that the write buffer is empty by checking the WBNE bit in the FLASH_SECSR register.
4. Check and clear all the secure error flags due to previous operation.
5. Unlock the FLASH_SECCR register only if this register is not already unlocked, as described in *Section 7.6.7*.
6. Enable write operations by setting the SECPG bit in the FLASH_SECCR register.
7. Write one flash-word corresponding to 16-byte data starting at 16-byte aligned address.

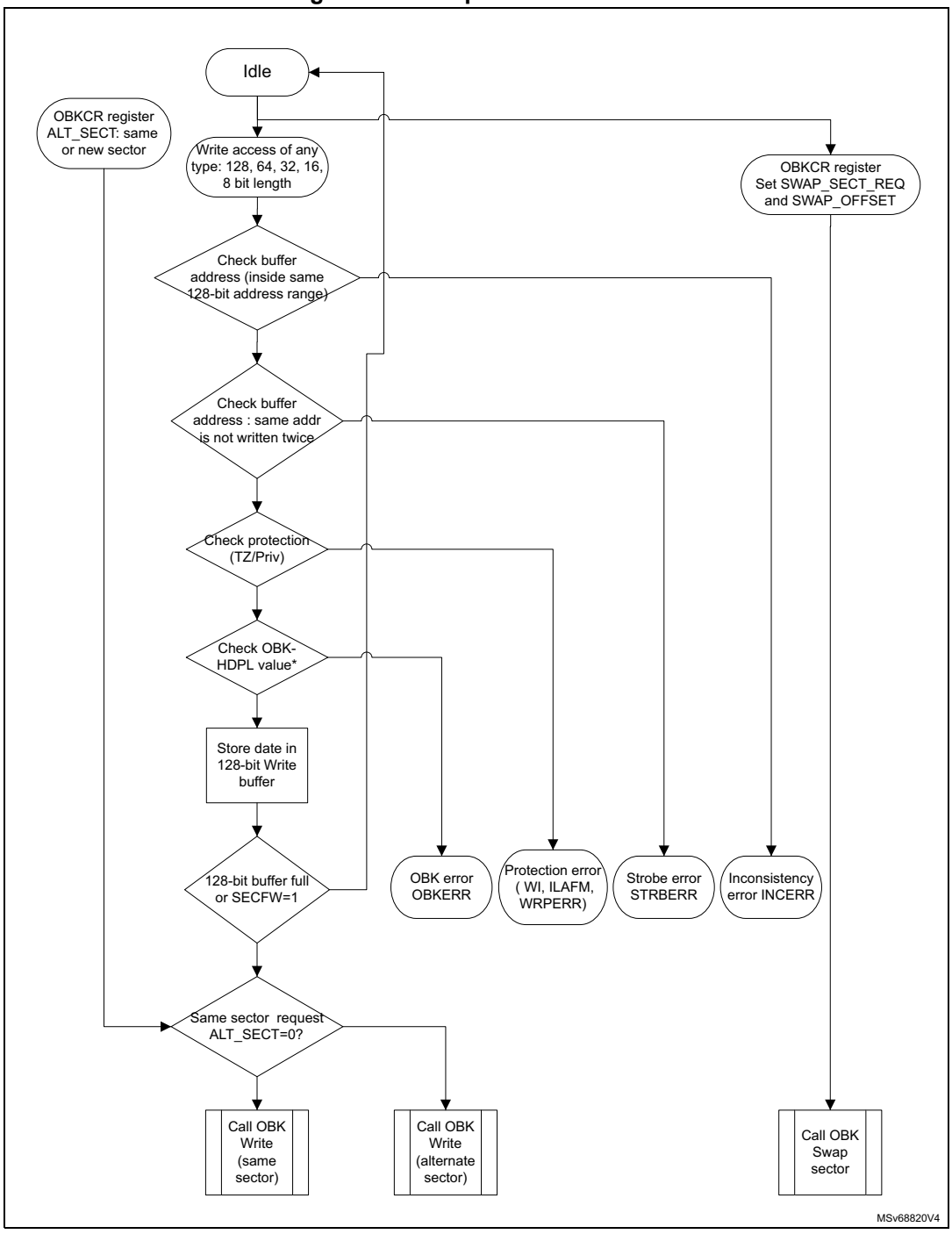
Note: WBNE flag indicates if the 128-bit write buffer is waiting for new data.

Note: No erase request, options change request, OBK swap sector or OBK alternate sector erase is allowed between first write and the completion of flash write operation.

8. Wait for the BSY bit to be cleared in the corresponding FLASH_SECSR register.
9. Clear PG bit in FLASH_SECCR register if there is not any programming request anymore in the bank.

If step *7* is executed incrementally (byte per byte), the write buffer can become partially filled. In this case the application software can decide to force-write what is stored in the write buffer by using FW bit in FLASH_SECCR register. In this particular case, the unwritten bits are automatically set to 1. If no bit in the write buffer is cleared to 0, the FW bit has no effect.

Figure 26. OBK protection checks

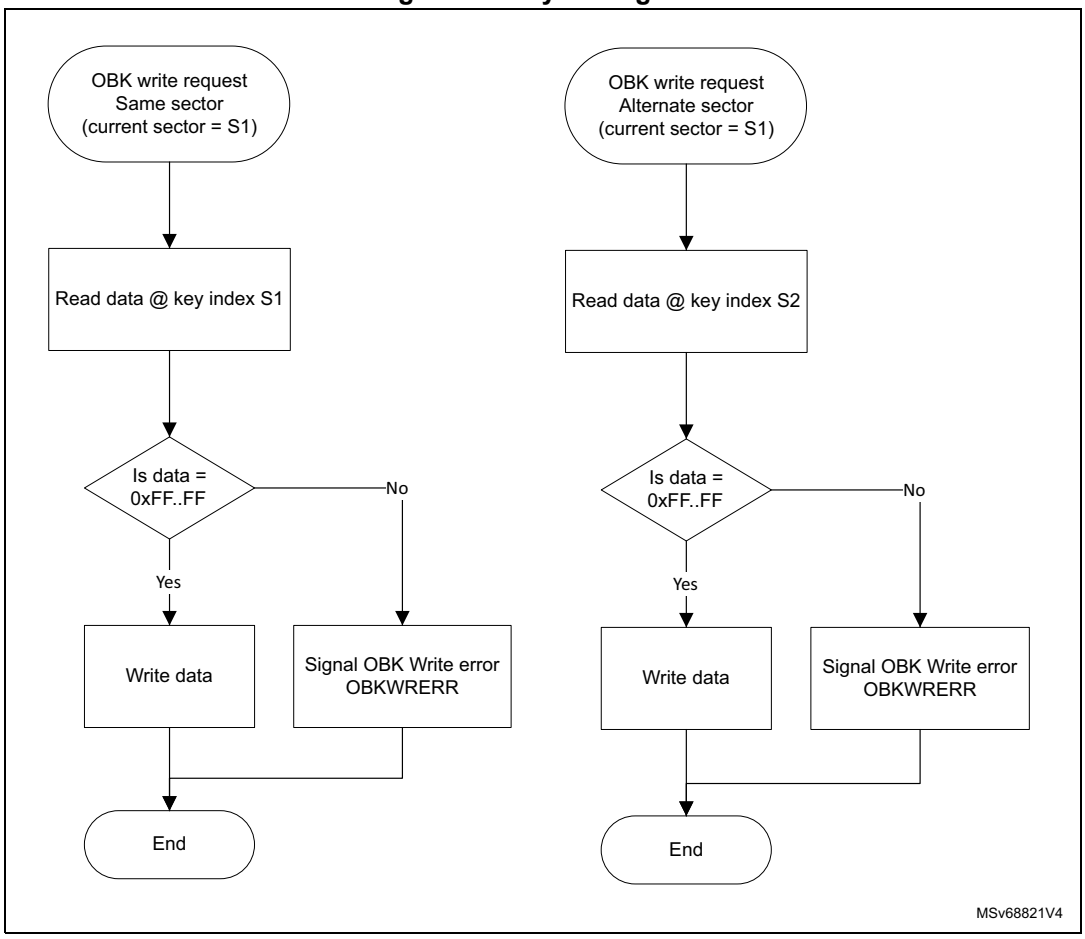


7.5.4 OBK programming finite state machine

When the OBK write buffer is filled, the OBK programing is launched automatically either in the current OBK sector or in the alternate OBK sector depending on the ALT_SECT bit.

If the address is not virgin, the OBKWRERR is raised.

Figure 27. Key writing flow



7.5.5 OBK swap sector

The user can request a swap of the option byte keys by setting the bit SWAP_SECT_REQ in the NS/SECOBKCFGR register. The number of keys swapped is defined by the SWAP_OFFSET in NS/SECOBKCFGR register.

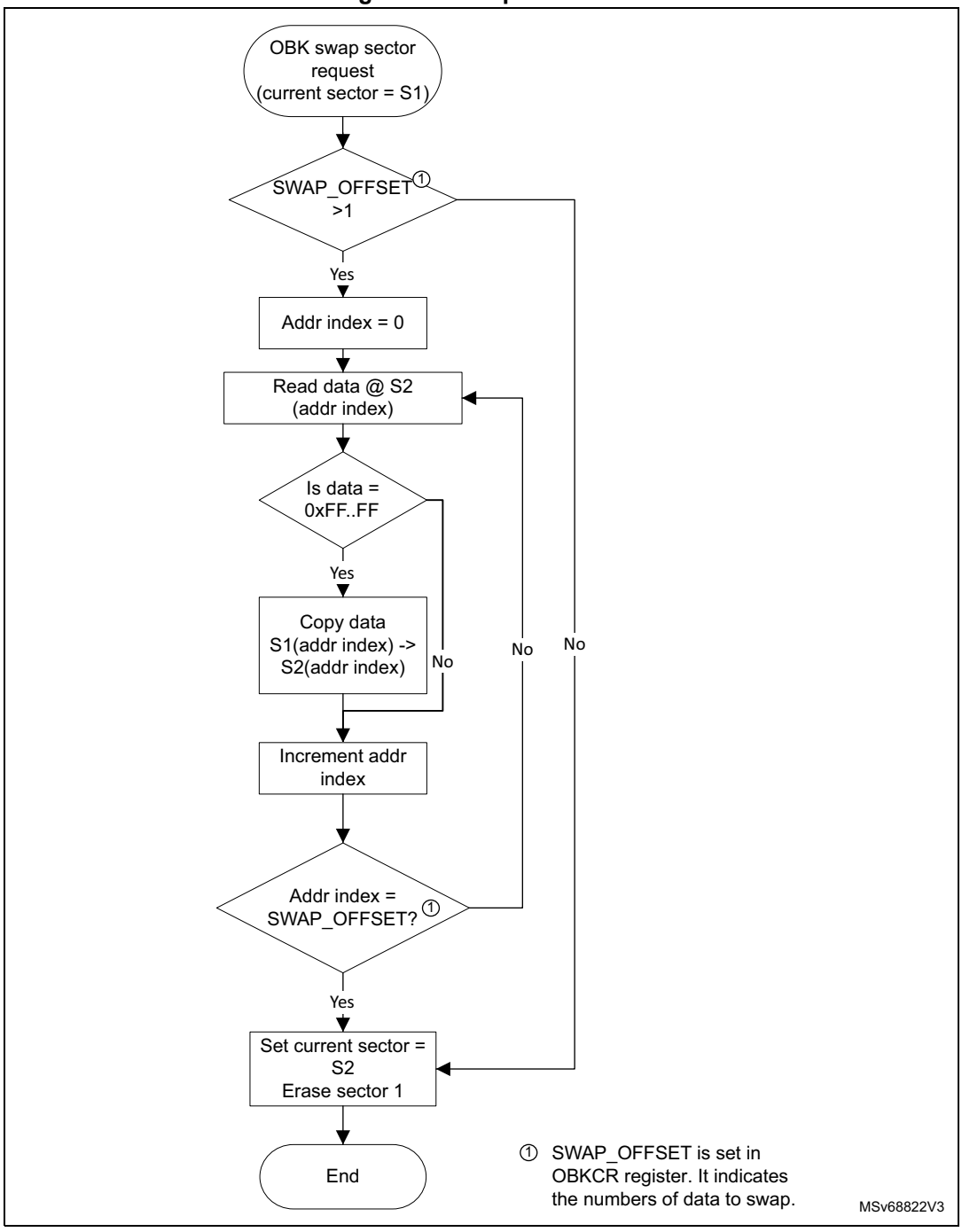
Swap is limited by OBK-HDPL value, the following SWAP_OFFSET values are permitted:

- OBK_HDPL1_OFFSET = 144
- OBK_HDPL2_OFFSET = 192
- OBK_HDPL3SEC_OFFSET = 384
- OBK_HDPL3NS_OFFSET = 511

The programming sequence is the following:

1. Check that no memory operations are ongoing by checking the BSY and DBNE bit in the FLASH_SEC/NSSR register and that the write buffer is empty by checking the WBNE bit in the FLASH_SEC/NSSR register.
2. Check and clear all the secure/nonsecure error flags due to previous operation.
3. Unlock NS/SECOBKCFGR register if not unlocked already thanks to FLASH_NS/SECOBKKEYR.
4. Define the numbers of keys to be swapped thanks to SWAP_OFFSET field in NS/SECOBKCFGR. SWAP_OFFSET must be equal to or greater than OBK_HDPL<N-1>_OFFSET.
5. Set bit SWAP_SECT_REQ in NS/SECOBKCFGR.
6. Wait for BSY bit to be cleared. In case of error OBKERR flag is set.
7. SWAP_SECT_REQ is cleared automatically at the end of the operation or in case of error.

Figure 28. Swap workflow



While the OBK SWAP operation is ongoing, the BSY flag is set and no other operation (write, erase, user opt change) can be launched in parallel.

7.5.6 OBK alternate sector erase

The user can request the erase of the alternate OBK sector by setting the bit ALT_SECT_ERASE in the FLASH_NS/SECOBKCFGR register.

The programming sequence must be:

1. Check that no memory operations are ongoing by checking the BSY and DBNE bits in the FLASH_SEC/NSSR register and that the write buffer is empty by checking the WBNE bit in the FLASH_SEC/NSSR register.
2. Check and clear all the secure/nonsecure error flags due to previous operation.
3. Set bit ALT_SECT_ERASE in NS/SECOBKCFGR.
4. Wait for BSY bit to be cleared.
5. ALT_SECT_ERASE is cleared automatically at the end of the operation or in case of error.

7.6 FLASH security and protections

To protect sensitive information against unwanted operations (such as reading confidential areas, illegal programming of immutable sectors, or malicious flash memory erasing), the FLASH implements the following protection mechanisms:

- TrustZone backed watermark and block security protection
- Temporal isolation protection (HDP)
- Configuration protection
- User flash write protection
- Device nonvolatile security life cycle and application boot state management
- OTP locking

The microcontroller can have TrustZone active (TZ_STATE = 0xB4) or not (TZ_STATE = 0xC3).

While TrustZone is active the flash memory can be accessed in four basic modes:

- nonsecure and unprivileged
- nonsecure and privileged
- secure and privileged
- secure and unprivileged

While TrustZone is disabled, only two modes are possible:

- nonsecure and unprivileged
- nonsecure and privileged

The flash interface evaluates the access restrictions in the following order:

1. TrustZone security
2. Write protection (for write access)
3. HDP
4. Privilege

7.6.1 TrustZone security protection

The global TrustZone system security is activated by setting the TZEN option in the FLASH_OPTSR2_PRG register. The actual state of TZ is however determined by the SBS and the setting of TZ_STATE (refer to *Section 14.3.5: SBS boot control*).

When TrustZone is active (TZ_STATE = 0xB4), additional security features are available:

- Secure watermark-based user options bytes defining secure areas
- Secure or nonsecure block-based areas can be configured on-the-fly after reset. This is a volatile secure area
- Additional product states (TZ-Closed, NS-Regression) provide protection of secure domain against external access (debug or bootloader)
- Erase or program operation can be performed in secure or nonsecure mode with associated configuration bit. When the TrustZone is disabled (TZ_STATE = 0xC3), the above features are deactivated and all secure registers are RAZ/WI.

Activating TrustZone security

When the TrustZone is activated (TZ_STATE = 0xB4), the SECBOOTADD and the secure watermark areas are set to a secure default value. Default settings are also used in case of corrupted configuration. In this default state, user flash memory is secure (see *Table 48*).

Table 48. Default secure watermark

Secure watermark in case of configuration error	Security attribute
SECWMx_STRT = 0 SECWMx_END = 0xFF	All flash memory is secure

Illegal access generation

A nonsecure access to a secure flash memory area is RAZ/WI, it generates an illegal access event. An illegal access interrupt is generated if the FLASHIE illegal access interrupt is enabled in the TZIC_IER2 register.

A nonsecure access to a secure flash register generates an illegal access event. An illegal access interrupt is generated if the FLASH_REGIE illegal access interrupt is enabled in the TZIC_IER2 register.

Table 49. Flash memory TZ protection summary

TZ protection (TZ_STATE = 0xB4)		Main flash	
		Nonsecure sector	Secure sector
Secure	Fetch	BUS ERROR	OK
	Read	RAZ, ILAFM	
	Write	WI, WRPERR, ILAFM	If not WRP: OK else: WI, WRPERR
	Erase		

Table 49. Flash memory TZ protection summary (continued)

TZ protection (TZ_STATE = 0xB4)		Main flash	
		Nonsecure sector	Secure sector
Nonsecure	Fetch	OK	BUS ERROR
	Read		RAZ, ILAFM
	Write	If not WRP: OK else: WI, WRPERR	WI, WRPERR, ILAFM
	Erase		

Table 50. TZ protection and bank or mass erase summary

TZ protection (TZ_STATE = 0xB4)	Main flash		
	Nonsecure flash	Secure flash	Mix of secure and nonsecure
MES	WI, WRPERR, ILAFM	OK	WI, WRPERR, ILAFM
MENS	OK	WI, WRPERR, ILAFM	WI, WRPERR, ILAFM

Deactivate TrustZone security

Reversing of the TZ setting in OB (TZEN) is possible when the product state is ST-RoT-Ready or Provisioning. Deactivating TZEN from other states requires full regression (Regression state).

When the TrustZone is deactivated (TZ_STATE = 0xC3) after option bytes loading, the following security features are deactivated:

- Watermark-based secure area (refer to *Watermark-based secure flash area protection*)
- block-based secure area (refer to *Section 7.6.3*)
- Secure interrupts (refer to *Section 7.9.11*)
- All secure registers are RAZ/WI.

Watermark-based secure flash area protection

When TrustZone security is active (TZ_STATE = 0xB4), a part of the flash memory can be protected against nonsecure read and write accesses. Up to two different nonvolatile secure areas can be defined by option bytes and can be read or written by a secure access only: one area per bank can be selected with a sector granularity.

The secure areas are defined by a start sector offset and end sector offset using the SECWMx_STRT and SECWMx_END option bytes. These offsets are defined in the secure watermark registers address registers *FLASH security watermark for bank1 (FLASH_SECWM1R_CUR)*, *FLASH security watermark for bank2 (FLASH_SECWM2R_CUR)* and modified by corresponding FLASH_XXX_PRG registers.

The SECWMx_STRT and SECWMx_END option bytes can be modified only by secure firmware.

Table 51. Secure watermark-based area

Secure watermark option bytes values (x = 1,2)	Secure watermark protection area
SECWMx_STRT > SECWMx_END	No secure area
SECWMx_STRT = SECWMx_END	One sector defined by SECWMx_STRT is secure watermark-based protected
SECWMx_STRT < SECWMx_END	The area between SECWMx_STRT and SECWMx_END is secure watermark-based protected

Caution: Switching a memory area from secure to no-secure does not erase its content. The user secure software must perform the needed operation to erase the secure area before switching an area to nonsecure attribute whenever is needed. It is also recommended to flush the instruction cache.

7.6.2 Hide protection (HDP)

The HDP area is independent of the flash watermark-based secure area. One nonvolatile secure hide protection (HDP) area per bank can be defined with a sector granularity. Access to the hide protection area can be denied by progressing the HDPL level in the SBS.

When the HDPL = 1, no user flash is protected by the HDP. With HDPL ≥ 2 the user OB defined HDP area in each bank is closed. No read, write, fetch or erase is allowed in the HDP area.

The HDP area can be extended, the extension setting is only a register value, not stored in OB. With HDPL = 3 the HDP area remains activated and the extension is added. If extension is added while the base user OB defined area is not active, the extension covers one more sector, because HDPx_END sector is also protected.

The HDPL level can be only cleared by a system reset, there is no means to deactivate the HDP area.

The protected HDP area is defined by setting its size using start and end sectors in a similar way as the secure watermark.

The size of the inaccessible area can be extended using register FLASH_HDPEXTR values HDPx_EXT, representing the number of sectors added to the HDP area (past the HDPx_END sector). The volatile HDPx_EXT value can be increased, but cannot decrement.

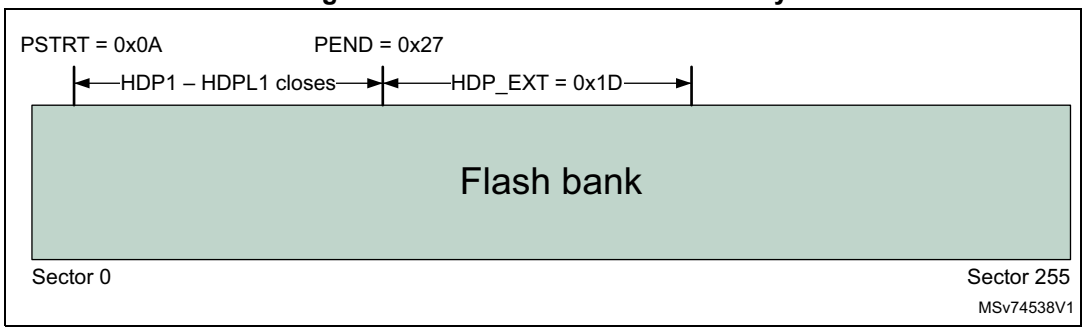
If HDPx_STRT > HDPx_END the extension covers (HDPx_EXT + 1) size area between sectors marked by HDPx_END and HDPx_END + HDPx_EXT.

By default HDPx_END is set to 0 and HDPx_STRT is set to 1. This means that the HDP area in user flash has a 0 size, and extends from the flash start address (first sector).

For example, to protect area by HDP from the address 0x0801 4000 (included) to the address 0x0804 FFFF (included):

- For physical bank1, the option byte registers must be programmed with:
  - HDP1_STRT = 0x0A
  - HDP1_END = 0x27

Figure 29. HDP[a] in user flash memory



- Once the HDPL is incremented to 2, the marked area becomes inaccessible. The HDPL = 2 code then sets the extension size to 29. Once the HDPL is incremented to 3, even the extension area becomes inaccessible.
- Alternatively, if:
  - HDP1_END = 0, HDP1_START = 1, HDPx_EXT = 1:
    Sector 0 and Sector 1 are HDP protected.
  - HDP1_END = 2, HDP1_START = 7, HDPx_EXT = 3 (a rather unusual example):
    Sectors 2 to 5 are HDP protected.
- If the two banks are swapped, the protection defined to physical bank1 remains on the physical bank1, unaffected by swapping. Separate protection applies to physical bank2 and the option bytes registers must also be programmed with:
  - HDP2_STRT = 0x0A
  - HDP2_END = 0x27

Note: For more details on the bank swapping mechanism, refer to Section 7.6.6.

Table 52. Secure hide protection

HDPx watermark option byte values (x = 1, 2)		Hide protection area
HDPL ≤ 1	-	No inaccessible HDP area in user flash memory
HDPL = 2	HDPx_END < HDPx_STRT	No inaccessible HDP area in user flash memory
	HDPx_END = HDPx_STRT	Exactly one sector is protected by HDP
	HDPx_END > HDPx_STRT	The area between HDPx_STRT and HDPx_END is HDP protected.
HDPL = 3	HDPx_END < HDPx_STRT and HDPx_EXT = 0	No inaccessible HDP area in user flash memory
	HDPx_END ≥ HDPx_STRT or HDPx_EXT > 0	The area between min (HDPx_STRT, HDPx_END) and (HDPx_END + HDPx_EXT) is HDP protected

a. The HDP works analogically, the number of sectors is the only differentiator.

Table 53. HDP protections summary

HDP protection	User flash			
	Access to OB HDP area		Access to EXT HDP area	
	HDPL 2 or 3	HDPL1	HDPL3	HDPL1 or HDPL 2
Fetch	BUS ERROR	OK	BUS ERROR	OK
Read	RAZ		RAZ	
Write	WI, WRPERR	If not WRP: OK Else: WI, WRPERR	WI, WRPERR	If not WRP: OK Else: WI, WRPERR
Erase (mass erase)				

7.6.3 Block-based secure flash memory area protection

Any sector can be programmed on-the-fly as secure or nonsecure using the block-based configuration registers. FLASH_SECBB1x/FLASH_SECBB2x registers are used to configure the security attribute for, respectively, sectors in bank1/bank2.

When the sector security attribute bit SECBByx[i] is set, the security attribute is the same as the secure watermark-based area. The secure sector is accessible only by a secure access.

If the SECBBy[i] bit is set or reset for a sector already included in a secure watermark-based area, the sector keeps the watermark-based protection security attributes.

To modify a block-based sector security attribute, it is recommended to:

- Check that no flash operation is ongoing on the related sector.
- Add an ISB instruction after modifying the sector security attribute SECBByx[i].

Caution: Switching a sector from secure to nonsecure does not erase the content of the associated sector. User secure software must perform the needed operations before switching to non-secure attribute:

- Erase sector content.
- Invalidate the instruction cache.

Note: For SECBByx[i] access control, refer to Table 54.

Execute protection for S-Bus (AHB register bus) is done in AHB decoder, not in flash memory interface itself.

Table 54. Secure configuration block-based registers access conditions

Access			Corresponding sector privilege status	Sector setting in SECBBxy
Fetch	Secure/ nonsecure	Privilege/ unprivilege	-	BUS ERROR
Read			-	OK
Write	Secure	Privilege	-	OK
		Unprivilege	0	OK
			1	WI
	Nonsecure	Privilege/ unprivilege	-	WI, ILAP

7.6.4 Block-based privileged flash memory area protection

Any sector can be programmed on-the-fly as privileged or unprivileged using the block-based configuration registers. FLASH_PRIVBB1x and FLASH_PRIVBB2x registers are used to configure the privilege attribute for, respectively, sectors in bank1 and bank2.

When the sector privilege attribute PRIVBByx[i] bit is set, the sector is accessible only by a privileged access. An unprivileged sector is accessible by a privileged or unprivileged access.

To modify a block-based privilege attribution, it is recommended to:

- Check that no flash operation is ongoing on the related sector.
- Add an ISB instruction after modifying the sector security attribute PRIVBByx[i].

Caution: Switching a sector from privileged to unprivileged does not erase the content of the associated sector.

Table 55. Privilege protection summary

Access (TZ not relevant)		Main flash	
		Unprivileged sector	Privileged sector
Privilege	Fetch	OK	
	Read		
	Write		
	Erase		
Unprivilege	Fetch	OK	RAZ
	Read		
	Write		WI, WRPERR
	Erase		

Table 56. Privilege and mass or bank erase

Access (TZ state not relevant)	Main flash		
	Unprivileged FLASH	Privileged FLASH	Mix unprivileged and privileged FLASH
MEP	OK		
MENP	OK	WI, WRPERR	

Note: For PRIVBByx[i] access control, refer to Table 57 and Table 58.

Table 57. Privilege configuration register access conditions (TZ enabled)

Access			Corresponding sector secure status(1)	Sector setting access in PRIVBBxy
Fetch	Privileged/ unprivileged	Secure/ nonsecure	-	BUS ERROR
Read			-	OK (all sectors)

Table 57. Privilege configuration register access conditions (TZ enabled) (continued)

Access			Corresponding sector secure status(1)	Sector setting access in PRIVBBxy
Write	Privileged	Secure	-	OK (all sectors)
		Nonsecure	NS	OK (only the sector corresponding to the bit)
			S	WI (only the sector corresponding to the bit)
	Unprivileged	Secure/ nonsecure	-	WI

1. Either watermark or block-based.

Table 58. Privilege configuration register access conditions (TZ disabled)

Access		Sector setting access in PRIVBBRxy
Fetch	Privileged/ unprivileged	BUS ERROR
Read		OK
Write	Privileged	OK
	Unprivileged	WI

7.6.5 Flash memory register privileged and unprivileged modes

The flash registers can be read and written by privileged and unprivileged accesses depending on the SPRIV and NSPRIV bits in *FLASH privilege configuration register (FLASH_PRIVCFGR)*:

- When the SPRIV (respectively NSPRIV) bit is reset, all secure (respectively non-secure) flash registers can be read and written by both privileged or unprivileged access.
- When the SPRIV (respectively NSPRIV) bit is set, all secure (respectively nonsecure) flash registers can be read and written by privileged access only. Unprivileged access to a privileged registers is RAZ/WI.

The registers related to key storage (FLASH_NSOBKCFGR, FLASH_SECOBKCFGR, FLASH_NSOBKKEYR, FLASH_SECOBKEYR) are exceptions to this rule and can be only accessed in privilege, regardless of other settings.

The next table summarizes flash registers access control.

Table 59. Flash register accesses(1)

Access			Nonsecure register		Secure register	
			NSPRIV = 1	NSPRIV = 0	SPRIV = 1	SPRIV = 0
X	Secure/ nonsecure	Privileged/ unprivileged	Bus error			
R/W	Secure	Privileged	OK			
R/W		Unprivileged	RAZ, WI	OK	RAZ, WI	OK

Table 59. Flash register accesses(1) (continued)

Access			Nonsecure register		Secure register	
			NSPRIV = 1	NSPRIV = 0	SPRIV = 1	SPRIV = 0
R/W	Nonsecure	Privileged	OK		RAZ, WI, ILAP	
R/W		Unprivileged	RAZ, WI	OK		

1. Some registers are privilege only, not configurable.

7.6.6 Flash memory banks attributes in case of bank swap

The SWAP_BANK option bit modifies the address of each bank in the memory map. When SWAP_BANK is reset, flash bank1 is mapped at the lower address range. When SWAP_BANK is set, flash bank1 is mapped at the higher address range. flash bank attributes follow their bank contents so there is no need to modify their setting registers when swapping banks:

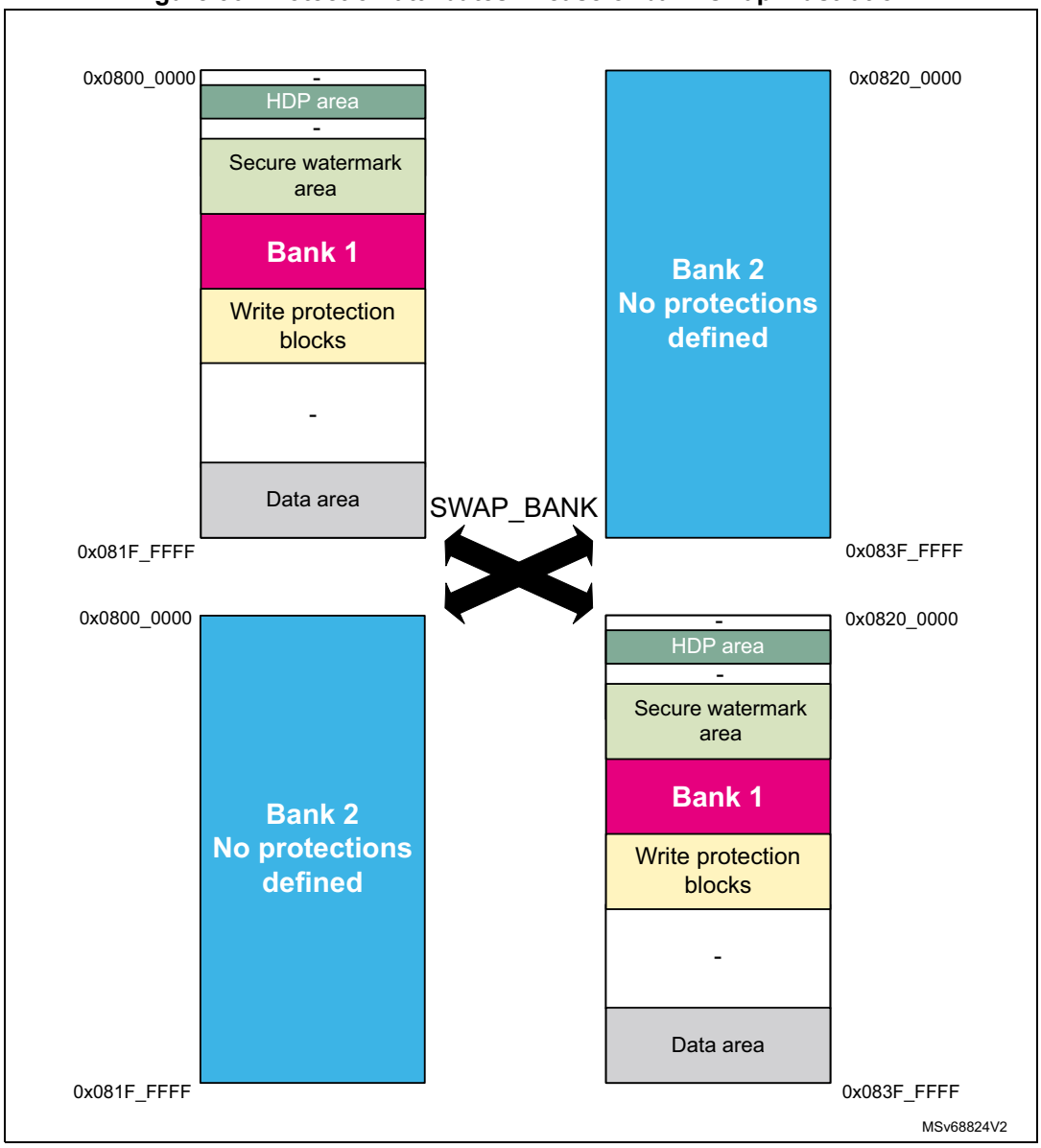
- Flash secure watermark x FLASH_SECWMx
- Flash write protection sector group FLASH_WRPSG (refer to *Section 7.6.8*)
- Hide protection in FLASH_HDPx registers
- Flash secure block based bank x register y FLASH_SECBBxy
- Flash privilege block based bank x register y FLASH_PRIVBBxy
- The data area configuration FLASH_EDATA

The SWAP_BANK is rendered immutable by setting BOOT_LOCK in the user OB. If TZEN is enabled, then SECBOOT_LOCK locks the option. If TZEN is disabled, then NSBOOT_LOCK locks the SWAP_BANK option.

Note: The BK_ECC bit in the FLASH ECC detection register (FLASH_ECCDETR) and FLASH ECC correction register (FLASH_ECCCORR), BKSEL bit in FLASH nonsecure control register (FLASH_NSCR) and BKSEL bit in FLASH secure control register (FLASH_SECCR) always refers to bank1 (respectively bank2) when it is low (respectively high), regardless of the SWAP_BANK value.

Figure 30 shows how security attributes and protections behave in case of bank swap.

Figure 30. Protection attributes in case of bank swap illustration



7.6.7 Flash memory configuration protection

The memory uses hardware mechanisms to protect the following assets against unwanted or spurious modifications (such as software bugs):

- Option bytes change
- Write operations
- Erase commands
- Interrupt masking

The memory configuration registers protection is summarized in *Table 60*. Registers not present in this table are not protected by a key.

Table 60. Flash interface register protection summary

Register name	Unlocking register	Protected asset
FLASH_NSCR	FLASH_NSKEYR	Write/erase control
FLASH_SECCR	FLASH_SECKEYR	Secure write/erase control
FLASH_OPTCR + all _PRG registers	FLASH_OPTKEYR	Flash bank option byte words change
FLASH_NSOBKCFGR	FLASH_NSOBKKEYR	Flash OBKey storage manipulation
FLASH_SECOBKCFGR	FLASH_SECOBKKEYR	

7.6.8 Write protection

The purpose of the write protection is to prevent unwanted modifications to code and/or data.

Any flash group of four consecutive 8-Kbyte sectors can be independently write-protected or unprotected by clearing/setting the corresponding WRPSGn1/2 bit in the FLASH_WRPSG1/2 register (see *FLASH write sector group 1 protection for bank1 (FLASH_WRP11R_CUR)* and *FLASH write sector group 1 protection for bank2 (FLASH_WRP21R_CUR)*).

A write-protected group of sectors cannot be erased nor programmed. As a result, a bank erase cannot be performed if one group of sectors is write-protected, unless a NVSTATE transition to OPEN is triggered (erasing the whole user flash memory).

Note: Write protection errors are documented in Section 7.9.

7.6.9 Flash high-cycle data protections

The embedded flash memory can be configured to have 96-Kbyte memory area with high-cycling capability (100 kcycles) to store data and emulate EEPROM, see *Section 7.3.10*.

Option byte controlled security features for user flash memory prevent sectors from being used as high-cycle data area. No OPTCHANGEERR is raised in case of setting conflict, it only makes the sectors unusable. Details are listed in *Table 61*.

Volatile settings using FLASH_SECBBxx and FLASH_PRIVBBxx can be applied. In this case the security setting of user flash sector 127 applies to flash high-cycle data sector 0 and so on, as indicated in *Figure 23* and *Figure 25*.

Volatile settings of HDP extension that extends into sectors of data area cause the data area to be inaccessible.

Table 61. High-cycle area protection summary: access to data area address range

<table>
<tr><th colspan="2" rowspan="3">TZ protection (when TZ_STATE = 0xB4)(1)</th><th colspan="6">Data sector enabled</th><th rowspan="3">Data sector not enabled</th></tr>
<tr><th rowspan="2">HDP protected</th><th rowspan="2">OB secure area</th><th colspan="2">SecBB protected</th><th colspan="2">NS sector</th></tr>
<tr><th>16/32 bits access</th><th>Other</th><th>16/32 bits access</th><th>Other</th></tr>
<tr><td rowspan="4">Secure</td><td>Fetch</td><td colspan="2" rowspan="3">BUS ERROR</td><td colspan="4">BUS ERROR</td><td rowspan="5">BUS ERROR</td></tr>
<tr><td>Read</td><td>OK</td><td rowspan="2">BUS ERROR</td><td colspan="2">RAZ, ILAC</td></tr>
<tr><td>Write</td><td>If not WRP: OK else WI, WRPERR</td><td colspan="2">WI, WRPERR, ILAFM</td></tr>
<tr><td>Erase</td><td colspan="6">Same protection as in corresponding classic user flash sector</td></tr>
<tr><td rowspan="4">Nonsecure</td><td>Fetch</td><td colspan="2" rowspan="3">BUS ERROR</td><td colspan="4">BUS ERROR</td></tr>
<tr><td>Read</td><td colspan="2">RAZ, ILAC</td><td>OK</td><td rowspan="2">BUS ERROR</td></tr>
<tr><td>Write</td><td colspan="2">WI, WRPERR, ILAFM</td><td>If not WRP: OK else WI, WRPERR</td></tr>
<tr><td>Erase</td><td colspan="6">Same protection as in corresponding classic user flash sector</td></tr>
</table>

1. If TZ_STATE = 0xC3, there is no secure state access, no SecBB, and no Secure Area. For HDP and NS access the rules remain the same.

Table 62. HDP protected definition

User flash	OB HDP Area enabled	HDP extension enabled
HDPL1	HDP protected = 0	HDP protected = 0
HDPL2	HDP protected = 1	HDP protected = 0
HDPL3	HDP protected = 1	HDP protected = 1

Table 63. Privileged sectors and data area - Access to data area address range

<table>
<tr><th colspan="2" rowspan="2">Access</th><th colspan="2">Data area address range access</th></tr>
<tr><th>Unprivileged sector</th><th>Privileged sector</th></tr>
<tr><td rowspan="3">Privileged</td><td>Fetch</td><td colspan="2">BUS ERROR</td></tr>
<tr><td>Read</td><td>OK</td><td>OK</td></tr>
<tr><td>Write</td><td>OK</td><td>OK</td></tr>
<tr><td rowspan="3">Unprivileged</td><td>Fetch</td><td colspan="2">BUS ERROR</td></tr>
<tr><td>Read</td><td>OK</td><td>RAZ, ILAC</td></tr>
<tr><td>Write</td><td>OK</td><td>WI, WRPERR</td></tr>
</table>

7.6.10 Life cycle management

Non-volatile or debug states are determined by the product state set by user option bytes. Debug possibility and possibility to change selected security settings are related to it. While the state is stored in the OB, it is the SBS that controls the debug policy.

OBK storage access conditions are unaffected by the PRODUCT_STATE, but keys can be evicted in regression transitions.

HDP works regardless of the debug state. Even in debug the HDP area is hidden when HDPL increments.

The following states are defined:

Table 64. Product states, debug states and debug policy

PRODUCT_STATE	Code in OB	Description
Open	0xED	User flash open (TZ secure and nonsecure open). External access (debug) N and NS enabled (~RDP0).
Provisioning	0x17	Provisioning - Immutable root of trust is being installed. Open if TZEN = 0xC3.
iROT-Provisioned	0x2E	The immutable root of trust is installed (~RDP 0.5).
TZ-Closed	0xC6	State for debugging the NS application. Debug is restrained to nonsecure areas.
Closed	0x72	State for running a secure application. Debug disabled, regression is possible.
Locked	0x5C	Transition to other state, policy change or debug not permitted(1).
Regression	0x9A	The temporary state initiated by the debug authentication system in transition to Open.
NS-Regression	0xA3	The temporary state initiated by the debug authentication system in transition to TZ-Closed.

1. The same situation is Closed state with incorrect or not defined debug certificates.

1. No debug protection

Read, program and erase operations into the flash main memory area are possible. Least restriction on the option bytes.

2. Nonsecure debug only

All read and write operations (if no write protection is set) from/to the nonsecure flash memory are possible. The debug access to secure area is prohibited. Debug access to nonsecure area remains possible.

The following rules are enforced:

- User mode: code executing in user mode (boot flash) can access flash main memory and option bytes with all operations (read, erase, program).
- Nonsecure debug mode: The secure flash memory areas are inaccessible; the nonsecure flash memory areas remain accessible for debug purpose.
- Boot RAM mode: boot from SRAM is not possible.
- Transition to Open state is possible with the consequence of flash mass erase and key slots revocation. Depends on debug unlock policy (see below).

3. Full product protection

All debug features are disabled and following rules enforced:

- User mode: code executing in user mode (boot flash) can access flash main memory and selected option bytes with all operations (read, erase, program).
- Boot RAM mode: boot from SRAM is not possible.
- Transition to TZ-Closed or Open state is possible with the consequence of flash mass erase and key slots revocation. Depends on debug unlock policy (see below).

7.6.11 Product state transitions

Progressing to more closed state is the normal product life cycle, that does not require security measures. Transition in direction to open state is a regression, controlled by the debug authentication control. If debug unlock policy is set to “locked”, no regression is accepted. Locked state can be reinforced by invalidating the debug authentication certificates.

All transitions not listed in this chapter are invalid.

There is no restriction on reading the current product state.

Transitions in progress direction

Transition from Open to any of the closed states is matter of correct product configuration and provisioning. The transitions must be done in correct order.

The normal progression is:

- Open, Provisioning or iROT-Provisioned
- Provisioning to iROT-Provisioned
- iROT-Provisioned to Closed, Locked or Closed
- Closed to Locked or Closed

Transition is managed either by a software running on the device, or directly, using a debug interface. Transitions from Closed are only possible by software running on the device. By software it is assumed that transitions are triggered by bootloader, or root-of-trust services, but generally any software running on the device can do a progress transition.

Transition to Open state

This transition is a full regression. The starting state is any except Open and Locked. The debug tools are used to authenticate debug regression access rights with the debug authentication library, running on the device in HDPL1 (refer to *Section 14.3.6: SBS debug control*). After verifying the credentials, it puts the device into intermediate state Regression. From this state the device regresses securely in HDPL0 to Open.

The transition has the following consequence:

- Epoch secure counter is incremented
- Key slots revocation
- Product state updated
- User options updated (security settings reset, TZEN reset)
- Flash memory mass erase
- Backup RAM erase is requested

Transition from closed to TZ-Closed debug state

This transition opens the device to authorize the debug of the nonsecure application software without compromising the security of the ROT functions.

The starting state is Closed. The debug tools are used to authenticate debug regression access rights with the debug authentication library, running on the device in the HDPL1 (refer to *Section 14.3.6: SBS debug control*). After verifying the credentials, it puts the device into intermediate state NS-Regression. From this state, the device regresses securely in HDPL0 to ZT-Closed.

The transition has the following consequence:

- Epoch nonsecure counter is incremented
- Nonsecure slots revocation
- Product state updated
- Flash memory sectors that are not covered by the secure watermark are erased
- Backup RAM erase is requested

Table 65. PRODUCT_STATE transitions

From	To[1]							
	Open	Provisioning	iROT-Provisioned	TZ-Closed[2]	Closed	Locked	Regression	NS-Regression[2]
Open	-	OK	OK	X	X	X	X	X
Provisioning	X	-	OK	OK	OK	OK	OK (HDPL1)	X
iROT-Provisioned	X	X	-	OK	OK	OK	OK (HDPL1)	X
TZ-Closed	X	X	X	-	OK	OK	OK (HDPL1)	X
Closed	X	X	X	X	-	X	OK (HDPL1)	OK (HDPL1)

Table 65. PRODUCT_STATE transitions (continued)

From	To[1]							
	Open	Provisioning	iROT-Provisioned	TZ-Closed[2]	Closed	Locked	Regression	NS-Regression[2]
Locked	X	X	X	X	X	-	X	X
Regression	OK (HDPL0)	X	X	X	X	X	-	X
NS-Regression	X	X	X	OK (HDPL0)	X	X	X	-

1. X = transitions not permitted (OPTCHANGEERR raised), - = no change, OK = valid transitions.
2. To transition into this state, both current and programmed value of TZEN must be enabled (TZEN = 0xB4), otherwise the change is ignored with OPTCHANGEERR.

In *Table 65*, X indicates transitions that are not permitted, dash indicates no change, OK indicates valid transitions. Some transitions are possible only in correct HDPL provided in parenthesis. Attempts to do an illegal transition result in OPTCHANGEERR.

Incorrect PRODUCT_STATE (no OBL) is interpreted as Locked.

7.6.12 OBK protection

At the receipt of an OBK access (read/write/execute), secure and privilege attributes are first checked, followed by OBK-HDPL. The OBK-HDPL value must exactly match the HDPL assigned to the key location, otherwise OBKERROR flag is raised. Flash interface response is described in *Table 66*.

Table 66. TZ OBK protection summary

TZ protection (when TZ_STATE = 0xB4)	OBK access		
	No tamper		Tamper
	HDPL0/1/2/3	OBK selector	
XS	BUS ERROR	BUS ERROR	RAZ, WI
RS	OK if privilege, otherwise RAZ	RAZ	
WS	OK if privilege, otherwise WI, WRPERR	WI, if not privilege also WRPERR	
XNS	BUS ERROR	BUS ERROR	
RNS	RAZ, ILAFM	RAZ, ILAFM	
WNS	WI, WRPERR, ILAFM	WI, WRPERR, ILAFM	
Erase	NA	NA	NA

Table 67. OBK protection summary with TZ disabled

TZ protection (when TZ_STATE = 0xC3)	OBK access		
	No tamper		Tamper
	HDPL1/2/3	OBK selector	
XNS	BUS ERROR	BUS ERROR	RAZ, WI
RNS	OK if privileged, otherwise RAZ	RAZ	
WNS	OK if privilege, otherwise WI, WRPERR	WI if privileged, otherwise WI, WRPERR	
Erase	NA	NA	NA

Note: Cacheable access is managed at system level and not in the 2flash interface. The MPU must be configured to disable cache where it is not desirable.

In case of tamper, all keys are read as 0x00s.

There are also rules for accessing the OBKFGCR and OBKKEYR registers.

Table 68. Access conditions to secure control register

-	S/NS	P/NP	TZ state	SECOBKCFGR and SECOBKKEYR access
X	-	-	-	Bus error
R/W	S	P	Active	OK

Table 68. Access conditions to secure control register (continued)

-	S/NS	P/NP	TZ state	SECOBKCFGR and SECOBKKEYR access
R/W	S	NP	Active	RAZ, WI
R/W	NS	P	Active	RAZ, WI, ILAP
R/W	NS	NP	Active	RAZ, WI, ILAP
R/W	-	-	Deactivated	RAZ, WI

Table 69. Access conditions to nonsecure control register

-	S/NS	P/NP	TZ state	NSOBKCFGR and NSOBKKEYR access
X	-	-	-	Bus error
R/W	-	-	Active	RAZ, WI
R/W	-	P	Deactivated	OK
R/W	-	NP	Deactivated	RAZ, WI

7.6.13 One-time-programmable and read-only memory protections

Sections of OTP/RO in the flash memory are described in details in *Section 7.3.9*. There is no protection provided by the flash memory interface other than the dedicated write protection.

No write is possible to the RO area, once it was established in manufacturing. The *OTP write protection* describes a method of locking out the OTP area.

The access conditions are summarized in *Table 70*.

Table 70. OTP/RO access constraints

<table>
<tr><th rowspan="2">-</th><th colspan="4">8 Kbytes sector dedicated to RO/OTP</th></tr>
<tr><th>0x08FF_E000 - E7FF</th><th>0x08FF_E800 - EFFF
Reserved</th><th>0x08FF_F000 - F7FF
OTP</th><th>0x08FF_F800 - FFFF
RO</th></tr>
<tr><td>XS</td><td rowspan="3">BUS ERROR</td><td colspan="3">BUS ERROR</td></tr>
<tr><td>RS</td><td colspan="3">RAZ, ILAC</td></tr>
<tr><td>WS</td><td colspan="3">WI, WRPERR, ILAFM</td></tr>
<tr><td>XNS</td><td rowspan="3">BUS ERROR</td><td colspan="3">BUS ERROR</td></tr>
<tr><td>RNS</td><td>If correct size(1) RAZ, else BUS ERROR</td><td colspan="2">If correct size OK, else BUS ERROR</td></tr>
<tr><td>WNS</td><td>If correct size WI, else BUS ERROR</td><td>BUS ERROR if incorrect size.
WRPERR if block is protected by LOCKBL, else OK.</td><td>If correct size WI, else BUS ERROR</td></tr>
<tr><td>Erase</td><td colspan="4">WI</td></tr>
</table>

1. Word size is 16 bits. 32-bit access is possible. Other access attempt leads to bus error.

7.7 System memory

7.7.1 Introduction

System memory stores RSS (root secure services) firmware programmed by ST during production. The RSS provides runtime services to user firmware.

When TrustZone is enabled (user sets TZEN bitfield to 0xB4) then RSS provides secure services to secure user firmware only; when TrustZone is disabled (user sets TZEN bitfield to 0xC3), RSS provides services to user firmware.

7.7.2 RSS user functions

The RSS provides runtime services thanks to RSS library, whose functions are exposed to user within the CMSIS device header file provided by the STM32CubeH5 firmware package (see UM3065 "*Getting started with STM32CubeH5 for STM32H5 Series*" for more details).

RSS provides services through two different libraries, RSSLIB and NSSLIB, dedicated to secure user firmware when system is configured, respectively, with TrustZone enabled (TZEN bitfield set to 0xB4) and TrustZone disabled (TZEN bitfield set to 0xC3).

Table 71. Macros for RSS services

TrustZone	C defined macro	Location in flash memory
Enabled	RSSLIB_PFUNC	0x0BFB6068
Disabled	NSSLIB_PFUNC	0x0BFB606C

RSSLIB

The secure user firmware calls RSSLIB functions using RSSLIB_PFUNC C defined macro, which points to a location within nonsecure system memory. Before calling RSSLIB functions, the secure user firmware must define a nonsecure region above this location within SAU of the Cortex®-M33, starting from RSSLIB_SYS_FLASH_NS_PFUNC_START (0x0BFB6068), up to RSSLIB_SYS_FLASH_NS_PFUNC_END (0x0BFB6084). These last addresses are provided within the CMSIS device header file.

The user can set this nonsecure region either by using the CMSIS system partition header file, or by implementing its own code for SAU setup. The CMSIS system partition header file is part of the STM32CubeH5 firmware package.

Table 72. RSS lib interface functions

Library	Function	Attributes
RSSLIB_PFUNC	JumpHDPLvl2	Secure callable function
	JumpHDPLvl3	
	JumpHDPLvl3NS	
	RSSLIB_DataProvisioning	Nonsecure callable function

RSSLIB_DataProvisioning

Secure attribute: Nonsecure callable function.

Prototype:

```
uint32_t RSSLIB_DataProvisioning_(RSSLIB_DataProvisioningConf_t *pConfig)
```

Arguments:

pConfig: input parameter. **RSSLIB_DataProvisioningConf_t**

C structure definition is described below:

```
typedef struct
{
  uint32_t *pSource;
  uint32_t *pDestination;
  uint32_t Size;
  uint32_t DoEncryption;
  uint32_t Crc;
} RSSLIB_DataProvisioningConf_t;
```

Structure elements

pSource Provides the address of data to be provisioned. Must be within SRAM3 address range (nonsecure aliases).

pDestination Provides the address where to store data to be provisioned. Must be within OBKeys address range. To be aligned on 16 bytes.

Size Provides the size of data to be provisioned (the number of bytes, must be a multiple of 16).

DoEncryption Notifies RSSLIB_DataProvisioning function if it must encrypt or not data within OBKeys.

DoEncrypt can be either 0xF5F5A0AAU or 0xCACA0AA0U (the only one allowed on STM32H5Exxx devices)

- 0xF5F5A0AAU: notifies RSSLIB_DataProvisioning to encrypt data with relevant DHUK before programming it within OBKeys. DHUK is selected according to **pDestination** value.
- 0xCACA0AA0U: notifies RSSLIB_DataProvisioning to program in clear data within OBKeys.

Crc CRC over full source data buffer, **pConfig->pDestination** value, **pConfig->Size** value and finally **pConfig->DoEncryption** value.

CRC computation uses CRC-32 (Ethernet):

- CRC polynomial: 0x04C11DB7U
- Initial value: 0xFFFFFFFFU

Returned values

0xEAEAEAEAU	Success
0xF5F5E0E0U	Error: – **pConfig** or **pSource** are not in SRAM3 – **pDestination** is not aligned on 16 bytes – **pDestination + Size** does not fit within an OBKey section
0xF5F50E0EU	Error: **Size** is not a multiple of 16
0xF5F58080U	Error: computed CRC is not the expected one provided within **pConfig->CRC**
0xF5F58008U	Error: cannot program data within OBKeys destination section
0xF5F5E00EU	Error: wrong **DoEncryption** parameter value
0xF5F50880U	Error: encryption requested, butw platform does not support it
0xF5F50EE0U	Error: encryption error
0xF5F50808U.	Error: OBKeys programming error

RSSLIB_DataProvisioning receives in input a data buffer and programs it within OBKeys. A CRC prevents any data and parameters tampering issue.

The destination address (**pDestination**) added to the size (**Size**) of the data to be provisioned must not cross the OBKeys section boundaries, listed below.

OBKeys Level1	Start address: 0x0FFD0100UL
	End address: 0x0FFD08FFUL
OBKeys Level2	Start address: 0x0FFD0900UL
	End address: 0x0FFD0FFFUL
OBKeys Level3 secure	Start address: 0x0FFD1000UL
	End address: 0x0FFD17FFUL
OBKeys Level3 nonsecure	Start address: 0x0FFD1800UL
	End address: 0x0FFD1FEFUL

When requested through **pConfig->DoEncryption** parameter, RSSLIB_DataProvisioning encrypts data before programming them within OBKeys.

RSSLIB_DataProvisioning uses AES CBC 128 bits with:

- IV: defined as (using C definition format)

  ```
  uint32_t IV = {0x8001D1CEU, 0xD1CED1CEU, 0xD1CE8001U, 0xCED1CED1U};
  ```

- Key: DHUK corresponding to the targeted OBKeys section defined by **pConfig->pDestination** parameter.

Note: Data encryption within OBkeys is supported only by STM32H5Fxxx devices.

JumpHDPLvl2

Secure attribute: Secure callable function.

Prototype:

```
uint32_t JumpHDPLvl2(uint32_t VectorTableAddr, uint32_t MPUIndex)
```

User code function call example:

```
RSSLIB_PFUNC->S.JumpHDPLvl2((uint32_t)NextVectorTableAddr, 1U );
```

Arguments:

- VectorTableAddr:
  - Input parameter, address of the next vector table to apply.
  - The vector table format is the one used by the Cortex-M33 core.
- MPUIndex:
  - Input parameter, MPU region index. Caller function must define (but keep disabled) the corresponding MPU region before calling JumpHDPLvl2. The function enables the MPU region before jumping to the reset handler of the vector table. The vector table reset handler function belongs to the MPU region.

User calls JumpHDPLvl2 to close user Flash HDPL1 area by incrementing HDPL to 2, then jump to the reset handler embedded within the vector table, whose address is passed as input parameter.

After closing HDPL1, JumpHDPLvl2 enables the MPU region provided as input parameter. Once the MPU is enabled, the function sets the SP to the address provided by the passed vector table, and jumps to the reset handler function supported by it. JumpHDPLvl2 does not set the new vector table.

On successful execution, the function does not return and does not push LR onto the stack.

In case of failure (bad input parameter value), RSSLIB_Sec_JumpHDPLvl2 returns 0xF5F5F5F5.

JumpHDPLvl3

Secure attribute: Secure callable function.

Prototype:

```
uint32_t JumpHDPLvl3(uint32_t VectorTableAddr, uint32_t MPUIndex)
```

User code function call example:

```
RSSLIB_PFUNC->S.JumpHDPLvl3((uint32_t)NextVectorTableAddr, 1U );
```

Arguments:

- VectorTableAddr:
  - Input parameter, address of the next vector table to apply.
  - The vector table format is the one used by the Cortex-M33 core.
- MPUIndex:
  - Input parameter, MPU region index. Caller function must define but keep disabled the corresponding MPU region before calling JumpHDPLvl3. The function enables the MPU region before jumping to the reset handler of the vector table, whose function belongs to the MPU region.

User calls JumpHDPLvl3 to close user Flash HDPL1 and HDPL2 areas by incrementing HDPL up to 3, then jump to the reset handler embedded within the vector table, whose address is passed as input parameter.

After closing HDPL1/2, JumpHDPLvl3 enables the MPU region provided as input parameter. Once the MPU is enabled, the function sets the SP to the address provided by the passed vector table, and jumps to the reset handler function supported by the vector table. JumpHDPLvl3 does not set the new vector table.

On successful execution, the function does not return and does not push LR onto the stack.

In case of failure (bad input parameter value), JumpHDPLvl3 returns 0xF5F5F5F5.

JumpHDPLvl3NS

Secure attribute: Secure callable function.

Prototype:

```
uint32_t JumpHDPLvl3NS(uint32_t VectorTableAddr)
```

User code function call example:

```
RSSLIB_PFUNC->S.JumpHDPLvl3NS((uint32_t)NextVectorTableAddr, 1U );
```

Arguments:

- VectorTableAddr:
  - Input parameter, address of the next vector table to apply.
  - The vector table format is the one used by the Cortex-M33 core.

User calls JumpHDPLvl3NS to close user flash HDPL1 and HDPL2 areas by incrementing HDPL up to 3, to move from secure to nonsecure domain, then jump to the nonsecure reset handler embedded within the vector table, whose address is passed as input parameter.

After closing HDPL1/2, JumpHDPLvl3 jumps to the nonsecure reset handler function supported by the vector table. JumpHDPLvl3NS does not set the new vector table.

On successful execution, the function does not return and does not push LR onto the stack.

In case of failure (bad input parameter value), JumpHDPLvl3NS returns 0xF5F5F5F5.

NSSLIB

The user firmware calls only the NSSLIB function when TrustZone is disabled (TZEN bitfield is set to 0xC3).

The user firmware calls NSSLIB functions using NSSLIB_PFUNC C defined macro, which points to a location within system memory.

Table 73. NSS lib interface functions

Library	Function	Attributes
NSSLIB_PFUNC	JumpHDPLvl2	Nonsecure function
	JumpHDPLvl3	

JumpHDPLvl2

Prototype:

```
uint32_t JumpHDPLvl2(uint32_t VectorTableAddr, uint32_t MPUIndex)
```

User code function call example:

```
NSSLIB_PFUNC->JumpHDPLvl2((uint32_t)NextVectorTableAddr, 1U );
```

Arguments:

- VectorTableAddr:
  - Input parameter, address of the next vector table to apply.
  - The vector table format is the one used by the Cortex-M33 core.
- MPUIndex:
  - Input parameter, MPU region index. Caller function shall define but keep disable the corresponding MPU region before calling JumpHDPLvl2. The function enables the MPU region before jumping to the reset handler of the vector table. The vector table reset handler function belongs to the MPU region.

User calls JumpHDPLvl2 to close user Flash HDPL1 area by incrementing HDPL to 2, and to jump to the reset handler embedded within the vector table which address is passed as input parameter

After closing HDPL1, JumpHDPLvl2 enables the MPU region provided as input parameter. Once the MPU is enabled, the function sets the SP to the address provided by the passed vector table and jumps to the reset handler function supported by the vector table too. JumpHDPLvl2 does not set the new vector table.

On successful execution, the function does not return and does not push LR onto the stack.

In case of failure (bad input parameter value), RSSLIB_Sec_JumpHDPLvl2 returns 0xF5F5F5F5.

JumpHDPLvl3

Prototype:

```
uint32_t JumpHDPLvl3(uint32_t VectorTableAddr, uint32_t MPUIndex)
```

User code function call example:

```
NSSLIB_PFUNC->JumpHDPLvl3((uint32_t)NextVectorTableAddr, 1U );
```

Arguments:

- VectorTableAddr:
  - Input parameter, address of the next vector table to apply.
  - The vector table format is the one used by the Cortex-M33 core.
- MPUIndex:
  - Input parameter, MPU region index. Caller function shall define but keep disable the corresponding MPU region before calling JumpHDPLvl3. The function enables the MPU region before jumping to the reset handler of the vector table. The vector table reset handler function belongs to the MPU region.

User calls JumpHDPLvl3 to close user Flash HDPL1 and HDPL2 areas by incrementing HDPL up to 3, and then jump to the reset handler embedded within the vector table, whose address is passed as input parameter

After closing HDPL1/2, JumpHDPLvl3 enables the MPU region provided as input parameter. Once the MPU is enabled, the function sets the SP to the address provided by the passed vector table, and jumps to the reset handler function supported by it. JumpHDPLvl3 does not set the new vector table.

On successful execution, the function does not return and does not push LR onto the stack.

In case of failure (bad input parameter value), JumpHDPLvl3 returns 0xF5F5F5F5.

7.8 FLASH low-power modes

Table 74 summarizes the memory behavior in STM32 low-power modes. Embedded flash memory belongs to the core domain.

Table 74. Effect of low-power modes on the embedded flash memory

Power mode	Core domain voltage range	Allowed if FLASH busy	FLASH power mode
Run	VOS0/1/2/3	Yes	Run
Stop1 (clock stopped)	SVOS3/4/5	No	Clock gated or stopped in case of SVOS5
Standby	Off	No	Off

When the system state changes or within a given system state, the memory can operate with a different voltage supply range (VOS), according to the application. The procedure to switch the memory into power modes (run, clock gated, stopped, off) is described hereafter.

Note: For more information on the microcontroller power states, refer to Section 10: Power control (PWR).

Managing the FLASH domain switching to Stop or Standby

As explained in *Table 74*, if the memory informs the reset and clock controller (RCC) that it is busy (BSY, DBNE, WBNE is set), the microcontroller cannot switch the core domain to Stop or Standby mode.

There are two ways to release the memory:

- Reset the WBNE busy flag in FLASH_NS/SECSR register by any of the following actions:
  - Complete the write buffer with missing data.
  - Force the write operation without filling the missing data by activating the FW bit in FLASH_NS/SECCR register. This forces all missing data “high”.
- Poll BSY busy bits in FLASH_NS/SECSR register until they are cleared. This indicates that all recorded write, erase and option change operations are complete.

The microcontroller can then switch the domain to Stop or Standby mode.

7.9 FLASH error management

7.9.1 Introduction

The memory automatically reports when an error occurs during a read, program or erase operation. A wide range of errors are reported:

- *Nonsecure write protection error (WRPERR)*
- *Secure write protection error (WRPERR)*
- *Nonsecure programming sequence error (PGSERR)*
- *Secure programming sequence error (PGSERR)*
- *Secure strobe error (STRBERR)*
- *Error correction code error (ECCC, ECCD)*
- *Illegal access (ILAFM/ILAP)*
- *Option byte change error (OPTCHANGEERR)*
- OBK nonsecure general error (OBKERR)
- OBK secure general error (OBKERR)
- OBK nonsecure write error (OBKWERR)
- OBK secure write error (OBKWERR)

The application software can individually enable the interrupt for each error, as detailed in *Section 7.10*.

The flash memory interface uses different interrupt lines to trigger the event. There are two direct lines to NVIC, one for secure interrupts, other for nonsecure. Third line leads to TZIC, for the ILAFM interrupt.

Note: For all errors, the application software must clear the error flag before attempting a new modify operation.

Since there is just one write buffer and only one operation is allowed at a time, the write control bits and status bits are shared by both banks:

- Write control bits (PG, FW, EOPIE, WRPERRIE, PGSERRIE, STRBERRIE, INCERRIE, CLR_EOP, CLR_WRPERR, CLR_STRBERR, CLR_INCERR, CLR_PGSERR) controls bank1 and 2 at the same time.
- Write status flag reports (WBNE, DBNE, EOP, WRPERR, PGSERR, STRBERR, INCERR, BSY) error for bank1 and 2 at the same time.

7.9.2 Nonsecure write protection error (WRPERR)

When an illegal nonsecure erase/program operation is attempted to the nonvolatile memory, the flash interface sets the write protection error flag WRPERR in FLASH_NSSR register.

An erase operation is rejected and flagged as illegal if it targets one of the following memory areas:

- A sector write-protected with WRPSGn
- An HDP area while the HDPL has made it inaccessible
- Secure (TZ) state not matching the erased memory attribute
- Attempt to erase privilege sector within unprivileged mode

A program operation is ignored and flagged as illegal if it targets one of the following memory areas:

- System flash memory
- A user sector write-protected with WRPSGn
- An OTP block, locked with LOCKBL
- A read-only section
- A reserved area
- Secure area
- Privileged area from within unprivileged mode
- OBK access conditions check error

When WRPERR flag is raised, the operation is rejected and nothing is changed in the corresponding bank. If this error is detected, the write buffer is invalidated.

Note: WRPERR flag must be cleared before any erase/program operation.

WRPERR flag is cleared by setting CLR_WRPERR bit to 1 in FLASH_NSCCR register.

If WRPERRIE bit in FLASH_NSCR register is set to 1, an interrupt is generated when WRPERR flag is raised (see *Section 7.10* for details).

7.9.3 Secure write protection error (WRPERR)

When an illegal secure erase/program operation is attempted to the nonvolatile memory, the flash interface sets the write protection error flag WRPERR in FLASH_SECSR register.

An erase operation is rejected and flagged as illegal if it targets one of the following memory areas:

- A sector write-protected with WRPSGn
- An HDP area while the HDPL has made it inaccessible
- Secure (TZ) state not matching the erased memory attribute
- Attempt to erase privilege sector within unprivileged mode

A program operation is ignored and flagged as illegal if it targets one of the following memory areas:

- System flash memory
- A user sector write-protected with WRPSGn
- An OTP block, locked with LOCKBL
- A read-only section
- A reserved area
- Nonsecure area
- Privileged area from within unprivileged mode
- OBK access condition check error

When WRPERR flag is raised, the operation is rejected and nothing is changed in the corresponding bank.

If this error is detected the write buffer is invalidated.

Note: WRPERR flag must be cleared before any erase/program operation.

WRPERR flag is cleared by setting CLR_WRPERR bit to 1 in FLASH_SECCCR register.

If WRPERRIE bit in FLASH_SECCR register is set to 1, an interrupt is generated when WRPERR flag is raised (see *Section 7.10* for details).

7.9.4 Nonsecure programming sequence error (PGSERR)

When the nonsecure programming sequence is incorrect, the flash interface sets the programming sequence error flag PGSERR in FLASH_NSSR register.

More specifically, PGSERR flag is set when one of below conditions is met:

- An error like INCERR, WRPERR, PGSERR, STRBERR, OPTCHANGEERR, OBKERR or OBKWERR have not been cleared before requesting a new write or erase operation, OBK operation or options change.
- For erase, PGSERR is set if:
  - missing erase operation (FLASH_NSCR): STRT = 1 with (MER = 0, SER = 0 and BER = 0)
  - sector and bank erase requested at the same time (NSSTRT and more than one of MER, SER and BER)
  - PG set during erase operation (it ensures that no erase req and write req happen at the same time): (STRT = 1) with (PG = 1)

  - Erase operation is started while write buffer is waiting for next data: (STRT = 1) with WBNE = 1.
  - STRT = 1 set by secure access.
  - Erase operation is started while DBNE = 1.
- For programming, PGSERR is set if:
  - missing write flag: A write operation is requested but the program enable bit PG has not been set in FLASH_NSCR register prior to the request.
  - write operation to flash high-cycle data is requested but PG = 0.
  - AHB write request is received and (SER = 1, BER = 1 or MER = 1)
  - 16 bit data access requested while WBNE = 1
- For options change, PGSERR is set if:
  - option change is started while write buffer is waiting for next data: OPTSTRT = 1 with WBNE = 1
  - OPTSTRT set with nonsecure DBNE = 1.
- For options byte key storage access, PGSERR is set if:
  - error flags from previous operation not cleared
  - ALT_SECT_ERASE and SWAP_SECT_REQ in FLASH_NSOBKCFGR are set at the same time
  - SWAP_OFFSET value is wrong: when SWAP_SECT_REQ is set to 1, the SWAP_OFFSET should be equal or greater than OBK_HDPL< N - 1 > _SWAP_OFFSET
  - ALT_SECT_ERASE or OBK_SWAP set while DBNE = 1
  - OBK-HDPL is incorrect and nonsecure OBK_SWAP is requested
  - If OBKSWAP or OBK alternate erase is started while write buffer is waiting for new data (WBNE = 1).

When PGSERR flag is raised as consequence of failed write attempt (flash programming), the current program operation is aborted and nothing is changed in the corresponding bank. The write data buffer is also invalidated.

Note: When PGSERR flag is raised, there is a risk that the last write operation performed by the application has been lost because of the above protection mechanism. It is recommended to generate interrupts on PGSERR and verify in the interrupt handler if the last write operation has been successful, by reading back the value in the flash memory.

The PGSERR flag also blocks any new program operation. This means that PGSERR must be cleared before starting a new program operation.

PGSERR flag is cleared by setting CLR_PGSERR bit to 1 in FLASH_NSCCR register.

If PGSERRIE bit in FLASH_NSCR register is set to 1, an interrupt is generated when PGSERR flag is raised. See *Section 7.10* for details.

7.9.5 Secure programming sequence error (PGSERR)

When the secure programming sequence is incorrect, the flash interface sets the programming sequence error flag PGSERR in FLASH_SECSR register.

More specifically, PGSERR flag is set when one of below conditions is met:

- An error like INCERR, WRPERR, PGSERR, STRBERR, OBKERR, or OBKWERR has not been cleared before requesting a new write or erase operation, OBK operation or options change.
- For erase, PGSERR is set if:
  - missing erase operation (FLASH_SECCR): STRT = 1 with (SER = 0 and BER = 0, MER = 0)
  - sector and bank erase requested at the same time (SECSTRT and more than one of MER, SER, and BER)
  - PG set during erase operation (it ensures that no erase request and write request happen at the same time): (STRT = 1) with (PG = 1)
  - erase operation is started while write buffer is waiting for next data: (STRT = 1) with WBNE = 1.
  - operation started while secure DBNE = 1.
- For programming, PGSERR is set if:
  - missing write flag: a write operation is requested but the program enable bit PG has not been set in FLASH_SECCR register prior to the request
  - write operation to flash high-cycle data is requested but PG = 0
  - AHB write request is received and (SER = 1, SBER = 1, or MER = 1)
  - 16 bit data access requested while WBNE = 1
- For options change, PGSERR is set if:
  - Option change is started while write buffer is waiting for next data: OPTSTRT = 1 with WBNE = 1
  - OPTSTRT set with secure DBNE = 1
- For options byte key storage access, SECPGSERR is set if:
  - error flags from previous operation not cleared
  - ALT_SECT_ERASE and SWAP_SECT_REQ are set at the same time
  - SWAP_OFFSET value is wrong: when SWAP_SECT_REQ = 1, SWAP_OFFSET must be equal or greater than OBK_HDPL<N-1>_SWAP_OFFSET.
  - SWAP_SECT_REQ or OBK_SWAP set while DBNE = 1
  - OBK-HDPL is incorrect and secure OBK_SWAP is requested
  - If OBKSWAP or OBK alternate erase is started while write buffer is waiting for new data (WBNE = 1)

When PGSERR flag is raised as consequence of failed write attempt (flash programming), the current program operation is aborted and nothing is changed in the corresponding bank. The write data buffer is also invalidated.

Note: When PGSERR flag is raised, there is a risk that the last write operation performed by the application has been lost because of the above protection mechanism. It is recommended to generate interrupts on PGSERR and verify in the interrupt handler if the last write operation has been successful by reading back the value in the flash memory.

The PGSERR flag also blocks any new program operation. This means that PGSERR must be cleared before starting a new program operation.

PGSERR flag is cleared by setting CLR_SECPGSERR bit to 1 in FLASH_SECCCR register.

If PGSERRIE bit in FLASH_SECCR register is set to 1, an interrupt is generated when PGSERR flag is raised. See *Section 7.10* for details.

7.9.6 Nonsecure strobe error (STRBERR)

When the nonsecure application software writes several times to the same byte in the write buffer, the flash interface sets the strobe error flag STRBERR (FLASH_NSSR) whatever the target bank of the write access.

When STRBERR flag is raised, the current program operation is aborted and the write buffer is invalidated.

STRBERR flag is cleared by setting CLR_STRBERR bit to 1 in FLASH_NSCCR register.

If STRBERRIE bit in FLASH_NSCR register is set to 1, an interrupt is generated when STRBERR flag is raised. See *Section 7.10* for details.

7.9.7 Secure strobe error (STRBERR)

When the secure application software writes several times to the same byte in the write buffer, the memory sets the strobe error flag STRBERR (FLASH_SECSR) whatever the target bank of the write access.

When STRBERR flag is raised, the current program operation is aborted and the write buffer is invalidated.

STRBERR flag is cleared by setting CLR_STRBERR bit to 1 in FLASH_SECCCR register.

If STRBERRIE bit in FLASH_SECCR register is set to 1, an interrupt is generated when STRBERR flag is raised. See *Section 7.10* for details.

7.9.8 Nonsecure inconsistency error (INCERR)

When a programming inconsistency in nonsecure access is detected, the flash interface sets the inconsistency error flag INCERR in register FLASH_NSSR.

More specifically, INCERR flag is set when one of the following conditions is met:

- A write operation is attempted before completion of the previous write operation, for example:
  - The application software starts a write operation to fill the 128-bit write buffer, but sends a new write burst request to a different flash memory address before the buffer is full.
  - One master starts a write operation, but before the buffer is full, another master starts a new write operation to the same address or to a different address.
  - ALT_SECT in FLASH_NSOBKCFGR changed while filling the write buffer.

Note: INCERR flag must be cleared before starting a new write operation, otherwise a sequence error (PGSERR) is raised.

It is recommended to follow the following sequence to avoid losing data when an inconsistency error occurs:

1. Execute a handler routine when INCERR flag is raised.
2. Stop all write requests to the memory.
3. Clear INCERR bit.
4. Restart the write operations from where they have been interrupted.

INCERR flag is cleared by setting CLR_INCERR bit to 1 in FLASH_NSCCR register.

If INCERRIE bit in FLASH_NSCR register is set to 1, an interrupt is generated when INCERR flag is raised (see *Section 7.10* for details).

7.9.9 Secure inconsistency error (INCERR)

When a programming inconsistency is detected, the flash interface sets the inconsistency error flag INCERR in register FLASH_SECSR.

More specifically, INCERR flag is set when one of the following conditions is met:

- A write operation is attempted before completion of the previous write operation, for example:
  - The application software starts a write operation to fill the 128-bit write buffer, but sends a new write burst request to a different flash memory address before the buffer is full.
  - One master starts a write operation, but before the buffer is full, another master starts a new write operation to the same address or to a different address.

Note: INCERR flag must be cleared before starting a new write operation, otherwise a sequence error (PGSERR) is raised.

It is recommended to follow the sequence below to avoid losing data when an inconsistency error occurs:

1. Execute a handler routine when INCERR flag is raised.
2. Stop all write requests to the flash memory.
3. Clear INCERR bit.
4. Restart the write operations from where they have been interrupted.

INCERR flag is cleared by setting CLR_INCERR bit to 1 in FLASH_SECCCR register.

If INCERRIE bit in FLASH_SECCR register is set to 1, an interrupt is generated when INCERR flag is raised (see *Section 7.10* for details).

7.9.10 Error correction code error (ECCC, ECCD)

When a single-error correction is detected during a read, the flash interface sets the single-error correction flag ECCC in FLASH_ECCCORR register.

When two ECC errors are detected during a read, the flash interface sets the double error detection flag ECCD in FLASH_ECCDETR register.

When the ECCC flag is raised, the corrected read data are returned. The application can ignore the error, and request new read operations. When the ECCD the flag is raised, an NMI is generated, it can be masked in SBS registers (*SBS flift ECC NMI mask register (SBS_ECCNMIR)*) for data access (OTP, data area, RO data). Software must invalidate the instruction cache (CACHEINV = 1) in the NMI interrupt service routine when the ECCD flag is set.

When ECCC or ECCD flag is raised, the address of the flash word that generated the error is saved in the FLASH_ECCCORR (FLASH_ECCDETR) register. If the address corresponds to a read-only area or to an OTP area or flash high-cycle data, the OTP_ECC bit is also set to 1 in the FLASH_ECCCORRR (FLASH_ECCDETR) register. This register is automatically cleared when the associated flag that generated the error is reset.

A BK_ECC flag indicates in which flash bank the error occurred.

A SYSF_ECC flag indicates an error detected in the system flash area.

Table 75. Locating ECC failure

OTP_ECC	SYSF_ECC	BK_ECC	EDATA_ECC	OBK_ECC	Flash area	ADDR_ECC min	ADDR_ECC max
0	0	0/1	0	0	User flash	0x0000	0xFFFF
0	1	0/1	0	0	System flash	0x0000	0x0FFF
1	0	0	0	0	OTP	0x0600	0x07FF
0	0	1	0	1	OBKeys	0x0000	0x03FF
0	0	0/1	1	0	Data area sector (0x200 per sector)	0xE000	0xFFFF

Note: In case of successive single correction or double detection errors, only the address corresponding to the first error is stored in FLASH_ECCCORR (FLASH_ECCDETR) *register.*

It is mandatory to clear ECCC or ECCD flags before starting a new read operation.

As the ECC interface is shared by the two banks, if the same error is registered simultaneously, a physical bank1 error is registered. Both errors are registered if one bank reports ECCD and the other bank ECCC.

ECCC (respectively ECCD) flag is cleared by setting to 1 ECCC bit (respectively ECCD bit) in FLASH_ECCCORR (FLASH_ECCDETR) register.

If ECCC bit in FLASH_ECCCORR register is set to 1, an interrupt is generated when ECCC flag is raised. Only NMI is generated for the ECCD. See *Section 7.10* for details.

7.9.11 Illegal access (ILAFM/ILAP)

Illegal access is a signal to the TZIC, triggering a secure interrupt in there. It is complementary to the other interrupts and only generated when the TZ is enabled (TZ_STATE = 0xB4).

It can be masked only on GTZC level.

ILAFM is generated when rules on secure flash memory access are violated:

- Attempt to access secure memory location in nonsecure mode.
- Attempt to access nonsecure memory location in secure mode.

ILAP is generated on:

- Attempt to access secure register in nonsecure mode.

If ILAFM is detected during write, the write buffer is invalidated.

Note: ILAFM *and ILAP has no flag within the flash memory controller to clear to resume operation. It is dealt within the TZIC.*

7.9.12 Option byte change error (OPTCHANGEERR)

When the flash interface finds an error during an option change operation, it aborts the operation and sets the option byte change error flag OPTCHANGEERR in FLASH_NSSR register.

The error is raised after OPTSTRT bit set if:

- TZEN is not set and transition to TZ-Closed or NS-Regression state is requested. Also any other forbidden PRODUCT_STATE transition (*Table 65*).
- SWAP_BANK is locked out by combination of TZEN and BOOT_LOCK.
- OB modification is attempted in wrong HDPL (selected PRODUCT_STATE transitions)
- Attempt to modify OB with invalid value
  - New EPOCH value not greater than current
  - Value not recognized by the specification (enumerated magic numbers only)
- Attempt to modify OB in product state where it is not allowed (usually a state open for debug is required for change).

Note: Exceptions and details provided in the OB description (see Section 7.4.7 and Table 45).

OPTCHANGEERR flag is cleared by setting CLR_OPTCHANGEERR bit to 1 in FLASH_NSCCR register.

If OPTCHANGEERRIE bit in FLASH_NSCR register is set to 1, an interrupt is generated when OPTCHANGEERR flag is raised (see *Section 7.10* for details).

It is mandatory to clean the OPTCHANGEERR flag before starting a new operation (option change, erase or write).

7.9.13 Miscellaneous HardFault errors

The following events generate a bus error on the corresponding bus interface:

- On main AHB system bus for access targeting code and data with 9 bits ECC.
  - Fetching from secure user flash memory in nonsecure mode.
  - Fetching from nonsecure user flash memory in secure mode.
  - Access to invalid address (including data addresses forbidden for code use).
  - Fetching from HDP area with incorrect HDPL value.
  - Fetching from privilege area in unprivilege mode.
- On AHB configuration or system bus for accesses targeting OTP/RO (all addresses using 6bits ECC):
  - wrong key input to FLASH_NS/SECKEYR or FLASH_OPTKEYR.
  - 8-bit accesses to system AHB interface.
  - Wrong unlock sequence on a register.

7.9.14 OBK error cases (OBKERR, OBKWERR)

Four error types can be detected while filling the OBK write buffer: STRBERR, INCERR, WRPERR or OBKERR. The OBKERR is specific to the OBK access and cannot be raised by access to any other flash memory asset.

Note: For STRBERR, INCERR and WRPERR, nonsecure or secure flags are used depending on the AHB access type (sec or nonsecure). If a nonsecure access is received, the nonsecure error flags are used. If a secure access is received, the secure error flags are used.

For OBKERR and OBKWERR, nonsecure or secure flags are used depending on the value of the secure state. If the SOC is in secure state (TZ_STATE active), the secure error flags (OBKERR and OBKWERR) are used. Otherwise the nonsecure error flags (OBKERR and OBKWERR) are used.

OBKERR is raised when:

- the OBK-HDPL (input signal from SBS) does not match the HDPL associated to the key during a read or write access, and the TZ and PRIV attributes are correct (See *Section 7.5.2* for more details).

If OBKERR is raised during write access, the write buffer is flushed. If the OBKERR is raised on read access, the write buffer is intact. In both cases the flag must be cleared to enable write/erase access to flash memory.

OBKWERR is detected after filling the write buffer and raised if:

- the address is not virgin during a write access.
- OBK selector in the alternate sector is not virgin during a SWAP operation.

If OBKWERR is raised, the write buffer is flushed. The flag must be cleared to enable write/erase access to flash memory.

7.10 FLASH interrupts

The flash interface can generate a maskable interrupt to signal the following events on a given bank:

- Read and write errors (see *Section 7.9*)
  - Single ECC error correction during read operation
  - Write inconsistency error
  - Bad programming sequence
  - Strobe error during write operations
  - option change operation error
- Security errors (see *Section 7.9*)
  - Write protection error
  - Illegal access error - signal to TZIC
- Miscellaneous events (described below)
  - End of programming

A NMI is raised on double ECC error detection during read operation.

Two interrupt lines gather all the error sources, one for errors in nonsecure access and second for errors that happen in secure access.

The user can individually enable or disable flash interface interrupt sources by changing the mask bits in the FLASH_NS/SECCR, FLASH_ECCCORR and FLASH_ECCDETR register. Setting the appropriate mask bit to 1 enables the interrupt.

Note: Prior to writing, FLASH_NS/SECCR register must be unlocked as explained in Section 7.6.7.

Table 76 gives a summary of the available flash interface interrupt features. As mentioned in the table below, some flags need to be cleared before a new operation is triggered.

Table 76. Flash interrupt request

Interrupt event Event flag	Error flag label in register	Enable control bit	Clear flag to resume operation
End of operation event	EOP	EOPIE	N/A
Write protection error	WRPERR	WRPERRIE	Yes
Programming sequence error	PGSERR	PGSERRIE	Yes
Strobe error	STRBERR	STRBERRIE	Yes
OBK write error	OBKWERR	OBKWERRIE	Yes
OBK general error	OBKERR	OBKERRIE	Yes
Inconsistency error	INCERR	INCERRIE	Yes
Illegal access error	ILAFM	TZEN	No
Option byte error	OPTCHANGEERR	-	Yes
ECC single error correction event	ECCC	ECCCIE	No
ECC double error detection event(1)	ECCD	Disabled	No

1. NMI.

The status of the individual maskable interrupt sources described in *Table 76* (except for option byte error and ECC) can be read from the FLASH_NS/SECSR register. They can be cleared by setting to 1 the adequate bit in FLASH_NS/SECCCR register.

Note: No unlocking mechanism is required to clear an interrupt.

End of operation event

Setting the end of operation interrupt enable bit (EOPIE) in the FLASH_NS/SECCR register enables the generation of an interrupt at the end of an erase operation, a program operation, or an option byte change.

When managing the OBKey storage area, the EOP is associated also with the OBK swap operation and the alternate area erase operation. EOP bit in the FLASH_NS/SECSR register is also set when one of these events occurs.

Setting CLR_EOP bit to 1 in FLASH_NS/SECCCR register clears EOP flag.

7.11 FLASH registers

Each register has an offset address and a reset value. In case of registers representing option bytes, the reset value is determined by the OBL process. In case of success the reset value is loaded from OB, in case of failure, a highly restrictive default value is set.

7.11.1 FLASH access control register (FLASH_ACR)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

For more details, refer to *Section 7.3.4* and *Section 7.3.5*.

Address offset: 0x000

Reset value: 0x0000 0013

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRFTEN	Res.	Res.	WRHIGHFREQ[1:0]		LATENCY[3:0]			
							rw			rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **PRFTEN**: Prefetch enable. When bit value is modified, user must read back ACR register to be sure PRFTEN has been taken into account.
Bits used to control the prefetch.
0: prefetch disabled.
1: prefetch enabled when latency is at least one wait state.

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **WRHIGHFREQ[1:0]**: Flash signal delay
These bits are used to control the delay between nonvolatile memory signals during programming operations. Application software has to program them to the correct value depending on the memory interface frequency. Please refer to *Table 39* for details.
Note: No check is performed to verify that the configuration is correct.
Two WRHIGHFREQ values can be selected for some frequencies.

Bits 3:0 **LATENCY[3:0]**: Read latency
These bits are used to control the number of wait states used during read operations on both nonvolatile memory banks. The application software has to program them to the correct value depending on the memory interface frequency and voltage conditions.
0000: no wait states used to read a word from nonvolatile memory
0001: one wait state used to read a word from nonvolatile memory
0010: two wait states used to read a word from nonvolatile memory
...
0111: seven wait states used to read a word from nonvolatile memory
1111: 15 wait states used to read a word from nonvolatile memory
Note: No check is performed by hardware to verify that the configuration is correct.

7.11.2 FLASH nonsecure key register (FLASH_NSKEYR)

This register is nonsecure. It can written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

FLASH_NSKEYR is a write-only register. The following values must be programmed consecutively to unlock FLASH_NSCR register and allow programming/erasing it.

- First key = 0x4567 0123
- Second key = 0xCDEF 89AB

A wrong sequence locks the FLASH_NSCR register until next system reset.

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NSKEY[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NSKEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **NSKEY[31:0]**: Non-volatile memory nonsecure configuration access unlock key

7.11.3 FLASH secure key register (FLASH_SECKEYR)

This register is secure. It can be written only by secure access. A nonsecure read/write access is RAZ/WI. This register can be protected against unprivileged access when SPRIV = 1 in the FLASH_PRIVCFGR register.

FLASH_SECKEYR is a write-only register. The following values must be programmed consecutively to unlock FLASH_SECCR register and allow programming/erasing it. A wrong sequence locks the FLASH_SECCR register until next system reset.

First key = 0x4567 0123

Second key = 0xCDEF 89AB

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SECKEY[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SECKEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **SECKEY[31:0]**: Non-volatile memory secure configuration access unlock key

7.11.4 FLASH option key register (FLASH_OPTKEYR)

This write-only register is nonsecure. It can be written by both secure and nonsecure accesses, and can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

The following values must be programmed consecutively to unlock FLASH_OPTCR register

- First key = 0x0819 2A3B
- Second key = 0x4C5D 6E7F

A wrong sequence locks FLASH_OPTCR register until next system reset.

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OPTKEY[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OPTKEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **OPTKEY[31:0]**: FLASH option bytes control access unlock key

7.11.5 FLASH nonsecure OBK key register (FLASH_NSOBKKEYR)

This is a write-only register. The following values must be programmed consecutively to unlock it register (a wrong sequence locks the register until next system reset).

- First key = 0x192A 083B
- Second key = 0x6E7F 4C5D

This register is nonsecure. This register can be written only by privileged access.

Address offset: 0x0010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NSOBKKEY[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NSOBKKEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **NSOBKKEY[31:0]**: FLASH nonsecure option bytes keys control access unlock key

7.11.6 FLASH secure OBK key register (FLASH_SECOBKKEYR)

This is a write-only register. The following values must be programmed consecutively to unlock it (a wrong sequence locks the register until the next system reset)

- First key = 0x192A 083B
- Second key = 0x6E7F 4C5D

This register is secure, it can be written only by privileged access.

Address offset: 0x0014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SECOBKKEY[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SECOBKKEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **SECOBKKEY[31:0]**: FLASH secure option bytes keys control access unlock key

7.11.7 FLASH operation status register (FLASH_OPSR)

This register is nonsecure. This register can be read by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

Address offset: 0x0018

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CODE_OP[2:0]			Res.	Res.	Res.	Res.	OTP_OP	SYSF_OP	BK_OP	DATA_OP	Res.	ADDR_OP[19:16]			
r	r	r					r	r	r	r		r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDR_OP[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:29 **CODE_OP[2:0]**: Flash memory operation code
000: No flash operation ongoing during previous reset
001: Single write operation interrupted
010: OBK alternate sector erase
011: Sector erase operation interrupted
100: Bank erase operation interrupted
101: Mass erase operation interrupted
110: Option change operation interrupted
111: OBK swap sector request

Bits 28:25 Reserved, must be kept at reset value.

Bit 24 **OTP_OP**: OTP operation interrupted
Indicates that reset interrupted an ongoing operation in OTP area (or OBKeys area).

Bit 23 **SYSF_OP**: Operation in system flash memory interrupted
Indicates that reset interrupted an ongoing operation in system flash.

Bit 22 **BK_OP**: Interrupted operation bank
It indicates which bank was concerned by operation.

Bit 21 **DATA_OP**: Flash high-cycle data area operation interrupted
It indicates if flash high-cycle data area is concerned by operation.

Bit 20 Reserved, must be kept at reset value.

Bits 19:0 **ADDR_OP[19:0]**: Interrupted operation address

7.11.8 FLASH option control register (FLASH_OPTCR)

This register is nonsecure. It can be read and written by both secure and nonsecure access, and protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

Access: No wait states when no memory operations are ongoing. The FLASH_OPTCR register is not accessible in write mode when the BSY bit is set. Any attempt to write to it while the BSY bit set causes the AHB bus to stall until the BSY bit is cleared.

Address offset: 0x01C

Reset value: 0xX000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SWAP_BANK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OPTSTRT	OPTLOCK
														rw	rs

Bit 31 **SWAP_BANK**: Bank swapping option configuration bit
SWAP_BANK controls whether bank1 and bank2 are swapped or not. This bit is loaded with the SWAP_BANK bit of FLASH_OPTSR_CUR register only after reset or POR.
0: Bank1 and bank2 not swapped
1: Bank1 and bank2 swapped

Bits 30:2 Reserved, must be kept at reset value.

Bit 1 **OPTSTRT**: Option byte start change option configuration bit
OPTSTRT triggers an option byte change operation. The user can set OPTSTRT only when the OPTLOCK bit is cleared to 0. It is set only by Software and cleared when the option byte change is completed or an error occurs (PGSERR or OPTCHANGEERR). It is reset at the same time as BSY bit.
The user application cannot modify any FLASH_XXX_PRG flash interface register until the option change operation has been completed.
Before setting this bit, the user has to write the required values in the FLASH_XXX_PRG registers. The FLASH_XXX_PRG registers are locked until the option byte change operation has been executed in nonvolatile memory.

Bit 0 **OPTLOCK**: FLASH_OPTCR lock option configuration bit

The OPTLOCK bit locks the FLASH_OPTCR register as well as all _PRG registers. The correct write sequence to FLASH_OPTKEYR register unlocks this bit. If a wrong sequence is executed, or the unlock sequence to FLASH_OPTKEYR is performed twice, this bit remains locked until next system reset.

It is possible to set OPTLOCK by programming it to 1. When set to 1, a new unlock sequence is mandatory to unlock it. When OPTLOCK changes from 0 to 1, the others bits of FLASH_OPTCR register do not change.

0: FLASH_OPTCR register unlocked

1: FLASH_OPTCR register locked.

7.11.9 FLASH nonsecure status register (FLASH_NSSR)

This register is nonsecure. It can be read by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

Address offset: 0x020

Reset value: 0x0000 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OPT CHANGE ERR	OBKW ERR	OBK ERR	INC ERR	STRB ERR	PGS ERR	WRP ERR	EOP
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBNE	Res.	WBNE	BSY
												r		r	r

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **OPTCHANGEERR**: Option byte change error flag

OPTCHANGEERR flag indicates that an error occurred during an option byte change operation. When OPTCHANGEERR is set to 1, the option byte change operation did not successfully complete. An interrupt is generated when this flag is raised if the OPTCHANGEERRIE bit of FLASH_NSCR register is set to 1.

Writing 1 to CLR_OPTCHANGEERR of register FLASH_NSCCR clears OPTCHANGEERR.

0: no option byte change errors occurred

1: one or more errors occurred during an option byte change operation.

Note: The OPTSTRT bit in FLASH_OPTCR cannot be set while OPTCHANGEERR is set.

Bit 22 **OBKWERR**: OBK write error flag

OBKWERR flag is raised when the address is not virgin on a write access to the OBK storage. Alternatively also when the OBK selector in the alternate sector is not virgin during a swap operation.

0: no OBK write error occurred

1: an OBK write error occurred

Bit 21 **OBKERR**: OBK general error flag

OBKERR flag is raised when the OBK-HDPL signal from the SBS does not match the HDPL value associated with the key slot during access to the key location. Alternatively also when the ALT_SECT is unexpectedly changed while the write buffer is being filled.

0: no OBK general error occurred

1: an OBK general error occurred

Bit 20 **INCERR:** inconsistency error flag

NSINCERR flag is raised when a inconsistency error occurs. An interrupt is generated if INCERRIE is set to 1. Writing 1 to CLR_INCERR bit in the FLASH_NSCCR register clears NSINCERR.

0: no inconsistency error occurs

1: a inconsistency error occurs

Bit 19 **STRBERR:** strobe error flag

STRBERR flag is raised when a strobe error occurs (when the master attempts to write several times the same byte in the write buffer). An interrupt is generated if the STRBERRIE bit is set to 1. Writing 1 to CLR_STRBERR bit in FLASH_NSCCR register clears STRBERR.

0: no strobe error occurred

1: a strobe error occurred

Bit 18 **PGSERR:** programming sequence error flag

PGSERR flag is raised when a sequence error occurs. An interrupt is generated if the PGSERRIE bit is set to 1. Writing 1 to CLR_PGSERR bit in FLASH_NSCCR register clears PGSERR.

0: no sequence error occurred

1: a sequence error occurred

Bit 17 **WRPERR**: write protection error flag

WRPERR flag is raised when a protection error occurs during a program operation. An interrupt is also generated if the WRPERRIE is set to 1. Writing 1 to CLR_WRPERR bit in FLASH_NSCCR register clears WRPERR.

0: no write protection error occurred

1: a write protection error occurred

Bit 16 **EOP**: end of operation flag

EOP flag is set when a operation (program/erase) completes. An interrupt is generated if the EOPIE is set to 1. It is not necessary to reset EOP before starting a new operation. EOP bit is cleared by writing 1 to CLR_EOP bit in FLASH_NSCCR register.

0: no operation completed

1: a operation completed

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **DBNE**: data buffer not empty flag

DBNE flag is set when the flash interface is processing 6-bits ECC data in dedicated buffer. This bit cannot be set to 0 by software. The hardware resets it once the buffer is free.

0: data buffer not used

1: data buffer used, wait

Bit 2 Reserved, must be kept at reset value.

Bit 1 **WBNE**: write buffer not empty flag

WBNE flag is set when the flash interface is waiting for new data to complete the write buffer. In this state, the write buffer is not empty. WBNE is reset by hardware each time the write buffer is complete or the write buffer is emptied following one of the events below:

– the application software forces the write operation using FW bit in FLASH_NSCR
– the memory detects an error that involves data loss

This bit cannot be reset by software writing 0 directly. To reset it, clear the write buffer by performing any of the above listed actions, or send the missing data.

0: write buffer empty or full

1: write buffer waiting data to complete

Bit 0 **BSY**: busy flag

BSY flag indicates that a flash memory is busy by an operation (write, erase, option byte change, OBK operation). It is set at the beginning of a flash memory operation and cleared when the operation finishes, or an error occurs.

0: no programming, erase or option byte change operation being executed

1: programming, erase or option byte change operation being executed

7.11.10 FLASH secure status register (FLASH_SECSR)

This register is secure. It can be read only by secure access. A nonsecure read/write access is RAZ/WI. This register can be protected against unprivileged access when SPRIV = 1 in the FLASH_PRIVCFGR register.

Address offset: 0x024

Reset value: 0x0000 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OBKWERR	OBKERR	INCERR	STRBERR	PGSERR	WRPERR	EOP
									r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBNE	Res.	WBNE	BSY
												r		r	r

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **OBKWERR**: OBK write error flag

OBKWERR flag is raised when the address is not virgin on a write access to the OBK storage. Alternatively also when the OBK selector in the alternate sector is not virgin during a swap operation.

0: no OBK write error occurred

1: an OBK write error occurred

Bit 21 **OBKERR**: OBK general error flag

OBKERR flag is raised when the OBK-HDPL signal from the SBS does not match the HDPL value associated with the key slot during access to the key location. Alternatively also when the ALT_SECT is unexpectedly changed while the write buffer is being filled.

0: no OBK general error occurred

1: an OBK general error occurred

Bit 20 **INCERR:** inconsistency error flag

INCERR flag is raised when a inconsistency error occurs. An interrupt is generated if INCERRIE is set to 1. Writing 1 to CLR_INCERR bit in the FLASH_SECCCR register clears INCERR.

0: no inconsistency error occurred

1: a inconsistency error occurred

Bit 19 **STRBERR:** strobe error flag

STRBERR flag is raised when a strobe error occurs (when the master attempts to write several times the same byte in the write buffer). An interrupt is generated if the STRBERRIE bit is set to 1. Writing 1 to CLR_STRBERR bit in FLASH_SECCCR register clears STRBERR.

0: no strobe error occurred

1: a strobe error occurred

Bit 18 **PGSERR:** programming sequence error flag

PGSERR flag is raised when a sequence error occurs. An interrupt is generated if the PGSERRIE bit is set to 1. Writing 1 to CLR_PGSERR bit in FLASH_SECCCR register clears PGSERR.

0: no sequence error occurred

1: a sequence error occurred

Bit 17 **WRPERR**: write protection error flag

WRPERR flag is raised when a protection error occurs during a program operation. An interrupt is also generated if the WRPERRIE is set to 1. Writing 1 to CLR_WRPERR bit in FLASH_SECCCR register clears WRPERR.

0: no write protection error occurred

1: a write protection error occurred

Bit 16 **EOP**: end of operation flag

EOP flag is set when a operation (program/erase) completes. An interrupt is generated if the EOPIE is set to. It is not necessary to reset EOP before starting a new operation. EOP bit is cleared by writing 1 to CLR_EOP bit in FLASH_SECCCR register.

0: no operation completed

1: a operation completed

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **DBNE**: data buffer not empty flag

DBNE flag is set when the memory interface is processing 6-bits ECC data in dedicated buffer. This bit cannot be set to 0 by software. The hardware resets it once the buffer is free.

0: data buffer not used

1: data buffer used, wait

Bit 2 Reserved, must be kept at reset value.

Bit 1 **WBNE**: write buffer not empty flag

WBNE flag is set when the flash interface is waiting for new data to complete the write buffer. In this state, the write buffer is not empty. WBNE is reset by hardware each time the write buffer is complete or the write buffer is emptied following one of the events below:

- the application software forces the write operation using FW bit in FLASH_SECCR
- the flash interface detects an error that involves data loss

This bit cannot be reset by writing 0 directly by software. To reset it, clear the write buffer by performing any of the above listed actions, or send the missing data.

0: write buffer empty or full

1: write buffer waiting data to complete

Bit 0 **BSY**: busy flag

BSY flag indicates that a FLASH memory is busy (write, erase, option byte change, OBK operations). It is set at the beginning of a flash memory operation and cleared when the operation finishes or an error occurs.

0: no programming, erase or option byte change operation being executed

1: programming, erase or option byte change operation being executed

7.11.11 FLASH nonsecure control register (FLASH_NSCR)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses, and can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

Access: No wait states when no memory operations are ongoing. The FLASH_NSCR register is not accessible in write mode when the BSY bit is set. Any attempt to write to it with the BSY bit set causes the AHB bus to stall until the BSY bit is cleared.

Address offset: 0x028

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BKSEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OPT CHANGE ERRIE	OBKW ERRIE	OBK ERRIE	INC ERRIE	STRB ERRIE	PGS ERRIE	WRP ERRIE	EOPIE
rw								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MER	Res.	SNB[7:0]								STRT	FW	BER	SER	PG	LOCK
rw		rw	rw	rw	rw	rw	rw	rw	rw	rs	rw	rw	rw	rw	rs

Bit 31 **BKSEL**: Bank selector bit

Can be programmed only when LOCK is cleared to 0. The bit selects physical bank, SWAP_BANK setting is ignored.

0: Bank1 is selected for Bank erase / sector erase / interrupt enable

1: Bank2 is selected for BER / SER

Bits 30:24 Reserved, must be kept at reset value.

Bit 23 **OPTCHANGEERRIE**: Option byte change error interrupt enable bit

This bit controls if an interrupt must be generated when an error occurs during an option byte change. It can be programmed only when LOCK bit is cleared to 0.

0: no interrupt is generated when an error occurs during an option byte change

1: an interrupt is generated when and error occurs during an option byte change.

Bit 22 **OBKWERRIE**: OBK write error interrupt enable bit

OBKWERRIE enables generation of interrupt in case of OBK specific write error. This bit can be programmed only when LOCK bit is cleared to 0.

0: no interrupt is generated on OBK write error

1: an interrupt is generated on OBK write error

Bit 21 **OBKERRIE**: OBK general error interrupt enable bit

OBKERRIE enables generating an interrupt in case of OBK specific access error. This bit can be programmed only when LOCK bit is cleared to 0.

0: no interrupt is generated on OBK general access error

1: an interrupt is generated on OBK general access error

Bit 20 **INCERRIE**: inconsistency error interrupt enable bit

When INCERRIE bit is set to 1, an interrupt is generated when an inconsistency error occurs during a write operation. INCERRIE can be programmed only when LOCK is cleared to 0.

0: no interrupt generated when a inconsistency error occurs

1: interrupt generated when a inconsistency error occurs.

Bit 19 **STRBERRIE**: strobe error interrupt enable bit

When STRBERRIE bit is set to 1, an interrupt is generated when a strobe error occurs (the master programs several times the same byte in the write buffer) during a write operation. STRBERRIE can be programmed only when LOCK is cleared to 0.

0: no interrupt generated when a strobe error occurs

1: interrupt generated when strobe error occurs.

Bit 18 **PGSERRIE**: programming sequence error interrupt enable bit

When this bit is set to 1, an interrupt is generated when a sequence error occurs during a program operation. PGSERRIE can be programmed only when LOCK is cleared to 0.

0: no interrupt generated when a sequence error occurs

1: interrupt generated when sequence error occurs

Bit 17 **WRPERRIE**: write protection error interrupt enable bit

When this bit is set to 1, an interrupt is generated when a protection error occurs during a program operation. WRPERRIE can be programmed only when LOCK is cleared to 0.

0: no interrupt generated when a protection error occurs

1: interrupt generated when a protection error occurs

Bit 16 **EOPIE**: end of operation interrupt control bit

Setting EOPIE bit to 1 enables the generation of an interrupt at the end of a program or erase operation. EOPIE can be programmed only when LOCK is cleared to 0.

0: no interrupt generated at the end of operation.

1: interrupt enabled when at the end of operation

Bit 15 **MER**: mass erase request

Setting MER bit to 1 requests a mass erase operation (user flash memory only). MER can be programmed only when LOCK is cleared to 0.

If BER or SER are both set, a PGSERR is raised.

0: mass erase not requested

1: mass erase requested

Note: An error is triggered when a mass erase is required and some sectors are protected.

Bit 14 Reserved, must be kept at reset value.

Bits 13:6 **SNB[7:0]**: sector erase selection number

These bits are used to select the target sector for an erase operation, otherwise they are not used. They can be programmed only when LOCK is cleared to 0.

0x00: Sector 0 selected

0x01: Sector 1 selected

..

0xFF: Sector 255 selected

Bit 5 **STRT**: erase start control bit

STRT bit is used to start a sector erase or a bank erase operation. STRT can be programmed only when LOCK is cleared to 0.

STRT is reset at the end of the operation or when an error occurs. It cannot be reset by software.

Bit 4 **FW:** write forcing control bit

FW forces a write operation even if the write buffer is not full. In this case all bits not written are set to 1 by hardware. FW can be programmed only when LOCK is cleared to 0.

The memory resets FW when the corresponding operation has been acknowledged.

Note: Using a force-write operation prevents the application from updating later the missing bits with something else than 1, because it is likely that it leads to permanent ECC error.

Write forcing is effective only if the write buffer is not empty and was filled by nonsecure access (in particular, FW does not start several write operations when the force-write operations are performed consecutively).

Since there is just one write buffer, FW can force a write in bank1 or bank2.

Bit 3 **BER**: erase request

Setting BER bit to 1 requests a bank erase operation (user flash memory only). BER can be programmed only when LOCK is cleared to 0.

If MER and SER are also set, a PGSERR is raised.

0: bank erase not requested

1: bank erase requested

Note: Write protection error is triggered when a bank erase is required and some sectors are protected.

Bit 2 **SER**: sector erase request

Setting SER bit to 1 requests a sector erase. SER can be programmed only when LOCK is cleared to 0.

If MER and SER are also set, a PGSERR is raised.

0: sector erase not requested

1: sector erase requested

Bit 1 **PG**: programming control bit

PG can be programmed only when LOCK is cleared to 0.

PG allows programming in bank1 and bank2.

0: programming disabled

1: programming enabled

Bit 0 **LOCK**: configuration lock bit

This bit locks the FLASH_NSCR register. The correct write sequence to FLASH_NSKEYR register unlocks this bit. If a wrong sequence is executed, or if the unlock sequence to FLASH_NSKEYR is performed twice, this bit remains locked until the next system reset.

LOCK can be set by programming it to 1. When set to 1, a new unlock sequence is mandatory to unlock it. When LOCK changes from 0 to 1, the other bits of FLASH_NSCR register do not change.

0: FLASH_NSCR register unlocked

1: FLASH_NSCR register locked

7.11.12 FLASH secure control register (FLASH_SECCR)

This register is secure. It can be read and written only by secure access. A nonsecure read/write access is RAZ/WI. This register can be protected against unprivileged access when SPRIV = 1 in the FLASH_PRIVCFGR register.

Access: No wait states when no memory operations are ongoing. The FLASH_SECCR register is not accessible in write mode when the BSY bit is set. Any attempt to write to it with the BSY bit set causes the AHB bus to stall until the BSY bit is cleared.

Address offset: 0x02C

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BKSEL	Res.	INV	Res.	Res.	Res.	Res.	Res.	Res.	OBKW ERRIE	OBK ERRIE	INC ERRIE	STRB ERRIE	PGS ERRIE	WRP ERRIE	EOPIE
rw		rw							rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MER	Res.	SNB[7:0]								STRT	FW	BER	SER	PG	LOCK
rw		rw	rw	rw	rw	rw	rw	rw	rw	rs	rw	rw	rw	rw	rs

Bit 31 **BKSEL**: Bank selector bit

BKSEL can only be programmed when LOCK is cleared to 0. The bit selects physical bank, SWAP_BANK setting is ignored.

0: Bank1 is selected for bank erase / sector erase / interrupt enable

1: Bank2 is selected for BER / SER

Bit 30 Reserved, must be kept at reset value.

Bit 29 **INV**: Flash memory security state invert.

This bit inverts the flash memory security state.

Bits 28:23 Reserved, must be kept at reset value.

Bit 22 **OBKWERRIE**: OBK write error interrupt enable bit

OBKWERRIE enables generation of interrupt in case of OBK specific write error. OBKWERRIE can be programmed only when LOCK is cleared to 0.

0: no interrupt is generated on OBK write error

1: an interrupt is generated on OBK write error

Bit 21 **OBKERRIE**: OBK general error interrupt enable bit

OBKERRIE enables generating an interrupt in case of OBK specific access error. OBKERRIE can be programmed only when LOCK is cleared to 0.

0: no interrupt is generated on OBK general access error

1: an interrupt is generated on OBK general access error

Bit 20 **INCERRIE**: inconsistency error interrupt enable bit

When INCERRIE bit is set to 1, an interrupt is generated when an inconsistency error occurs during a write operation. INCERRIE can be programmed only when LOCK is cleared to 0.

0: no interrupt generated when a inconsistency error occurs

1: interrupt generated when a inconsistency error occurs.

Bit 19 **STRBERRIE**: strobe error interrupt enable bit

When STRBERRIE bit is set to 1, an interrupt is generated when a strobe error occurs (the master programs several times the same byte in the write buffer) during a write operation. STRBERRIE can be programmed only when LOCK is cleared to 0.

0: no interrupt generated when a strobe error occurs

1: interrupt generated when strobe error occurs.

Bit 18 **PGSERRIE**: programming sequence error interrupt enable bit

When PGSERRIE is set to 1, an interrupt is generated when a sequence error occurs during a program operation. PGSERRIE can be programmed only when LOCK is cleared to 0.

0: no interrupt generated when a sequence error occurs

1: interrupt generated when sequence error occurs

Bit 17 **WRPERRIE**: write protection error interrupt enable bit

When WRPERRIE bit is set to 1, an interrupt is generated when a protection error occurs during a program operation. WRPERRIE can be programmed only when LOCK is cleared to 0.

0: no interrupt generated when a protection error occurs

1: interrupt generated when a protection error occurs

Bit 16 **EOPIE**: end of operation interrupt control bit

Setting EOPIE bit to 1 enables the generation of an interrupt at the end of a program/erase operation. EOPIE can be programmed only when LOCK is cleared to 0.

0: no interrupt generated at the end of operation.

1: interrupt enabled when at the end of operation

Bit 15 **MER**: mass erase request

Setting MER bit to 1 requests a mass erase operation (user flash memory only). MER can be programmed only when LOCK is cleared to 0.

If BER or SER are also set, a PGSERR is raised.

0: mass erase not requested

1: mass erase requested

Note: An error is triggered when a mass erase is required and some sectors are protected.

Bit 14 Reserved, must be kept at reset value.

Bits 13:6 **SNB[7:0]**: sector erase selection number

These bits are used to select the target sector for an erase operation, otherwise they are unused. SNB can be programmed only when LOCK is cleared to 0.

0x00: Sector 0 selected

0x01: Sector 1 selected

...

0xFF: Sector 255 selected

Bit 5 **STRT**: erase start control bit

STRT bit is used to start a sector erase or a bank erase operation. STRT can be programmed only when LOCK is cleared to 0.

STRT is reset at the end of the operation or when an error occurs. It cannot be reset by software.

Bit 4 **FW:** write forcing control bit

FW forces a write operation even if the write buffer is not full. In this case all bits not written are set to 1 by hardware. FW can be programmed only when LOCK is cleared to 0.

The memory resets FW when the corresponding operation has been acknowledged.

Note: Using a force-write operation prevents the application from updating later the missing bits with something else than 1, because it is likely that it leads to permanent ECC error.

Write forcing is effective only if the write buffer is not empty and was filled by secure access (in particular, FW does not start several write operations when the force-write operations are performed consecutively).

Since there is just one write buffer, FW can force a write in bank1 or bank2.

Bit 3 **BER**: erase request

Setting BER bit to 1 requests a bank erase operation (user flash memory only). BER can be programmed only when LOCK is cleared to 0.

If MER and SER are also set, a PGSERR is raised.

0: bank erase not requested

1: bank erase requested

Note: A write protection error is triggered when a bank erase is required and some sectors are protected.

Bit 2 **SER**: sector erase request

Setting SER bit to 1 requests a sector erase. SER can be programmed only when LOCK is cleared to 0.

If BER and MER are also set, a PGSERR is raised.

0: sector erase not requested

1: sector erase requested

Bit 1 **PG**: programming control bit

PG can be programmed only when LOCK is cleared to 0.

PG allows programming in bank1 and bank2.

0: programming disabled

1: programming enabled

Bit 0 **LOCK**: configuration lock bit

This bit locks the FLASH_SECCR register. The correct write sequence to FLASH_SECKEYR register unlocks this bit. If a wrong sequence is executed, or if the unlock sequence to FLASH_NSKEYR is performed twice, this bit remains locked until the next system reset.

LOCK can be set by programming it to 1. When set to 1, a new unlock sequence is mandatory to unlock it. When LOCK changes from 0 to 1, the other bits of FLASH_SECCR register do not change.

0: FLASH_SECCR register unlocked

1: FLASH_SECCR register locked

7.11.13 FLASH nonsecure clear control register (FLASH_NSCCR)

This register is nonsecure. It can be written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

Address offset: 0x030

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLR_OPTCHANGEERR	CLR_OBKWERR	CLR_OBKERR	CLR_INCERR	CLR_STRBERR	CLR_PGSERR	CLR_WRPERR	CLR_EOP
								w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **CLR_OPTCHANGEERR:** Clear the flag corresponding flag in FLASH_NSSR by writing this bit.

Bit 22 **CLR_OBKWERR**: OBKWERR flag clear bit.

Setting this bit to 1 resets to 0 OBKWERR flag in FLASH_NSSR register.

Bit 21 **CLR_OBKERR**: OBKERR flag clear bit.

Setting this bit to 1 resets to 0 OBKERR flag in FLASH_NSSR register.

Bit 20 **CLR_INCERR**: INCERR flag clear bit

Setting this bit to 1 resets to 0 INCERR flag in FLASH_NSSR register.

Bit 19 **CLR_STRBERR**: STRBERR flag clear bit
Setting this bit to 1 resets to 0 STRBERR flag in FLASH_NSSR register.

Bit 18 **CLR_PGSERR**: PGSERR flag clear bit
Setting this bit to 1 resets to 0 PGSERR flag in FLASH_NSSR register.

Bit 17 **CLR_WRPERR**: WRPERR flag clear bit
Setting this bit to 1 resets to 0 WRPERR flag in FLASH_NSSR register.

Bit 16 **CLR_EOP**: EOP flag clear bit
Setting this bit to 1 resets to 0 EOP flag in FLASH_NSSR register.

Bits 15:0 Reserved, must be kept at reset value.

7.11.14 FLASH secure clear control register (FLASH_SECCCR)

This register is secure. It can be written only by secure access. A nonsecure read/write access is RAZ/WI. This register can be protected against unprivileged access when SPRIV = 1 in the FLASH_PRIVCFGR register.

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLR_ OBKW ERR	CLR_ OBK ERR	CLR_ INC ERR	CLR_ STRB ERR	CLR_ PGS ERR	CLR_ WRP ERR	CLR_ EOP
									w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **CLR_OBKWERR**: OBKWERR flag clear bit
Setting this bit to 1 resets to 0 OBKWERR flag in FLASH_SECSR register.

Bit 21 **CLR_OBKERR**: OBKWERR flag clear bit
Setting this bit to 1 resets to 0 OBKWERR flag in FLASH_SECSR register.

Bit 20 **CLR_INCERR**: INCERR flag clear bit
Setting this bit to 1 resets to 0 INCERR flag in FLASH_SECSR register.

Bit 19 **CLR_STRBERR**: STRBERR flag clear bit
Setting this bit to 1 resets to 0 STRBERR flag in FLASH_SECSR register.

Bit 18 **CLR_PGSERR**: PGSERR flag clear bit
Setting this bit to 1 resets to 0 PGSERR flag in FLASH_SECSR register.

Bit 17 **CLR_WRPERR**: WRPERR flag clear bit
Setting this bit to 1 resets to 0 WRPERR flag in FLASH_SECSR register.

Bit 16 **CLR_EOP**: EOP flag clear bit
Setting this bit to 1 resets to 0 EOP flag in FLASH_SECSR register.

Bits 15:0 Reserved, must be kept at reset value.

7.11.15 FLASH privilege configuration register (FLASH_PRIVCFGR)

Address offset: 0x03C

Reset value: 0x0000 0000

This register can be read by both privileged and unprivileged access. NSPRIV is a nonsecure bit. SPRIV is a secure bit. It can be written only by privileged mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NSPRIV	SPRIV
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **NSPRIV**: privilege attribute for nonsecure registers
0: access to nonsecure registers is always granted
1: access to nonsecure registers is denied in case of unprivileged access.

Bit 0 **SPRIV**: privilege attribute for secure registers
0: access to secure registers is always granted
1: access to secure registers is denied in case of unprivileged access.

7.11.16 FLASH nonsecure OBK configuration register (FLASH_NSOBKCFGR)

Register is only available when TZ_STATE = 0xC3. This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can only be accessed by privilege code.

The FLASH_NSOBKCFGR register is not accessible in write mode when the BSY bit is set. Any attempt to write to it with the BSY bit set causes the AHB bus to stall until the BSY bit is cleared.

Address offset: 0x040

Reset value: 0x01FF 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWAP_OFFSET[8:0]								
							rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALT_SECT_ERASE	ALT_SECT	SWAP_SECT_REQ	LOCK
												rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 24:16 **SWAP_OFFSET[8:0]**: Key index (offset /16 bits) pointing for next swap.
0x00: means that no OBK is copied from current to alternate OBK sector during SWAP operation.
0x01 means that only the first OBK data (128 bits) are copied from current to alternate OBK sector
0x02 means that the two first OBK data are copied
…
0x1FF: means that all OBK data (511) are copied

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **ALT_SECT_ERASE**: alternate sector erase bit
0: do not touch OBK sector
1: erase the alternate OBK sector
When ALT_SECT bit is set, use this bit to generate an erase command for the OBK alternate sector. It is set only by Software and cleared when the OBK swap operation is completed or an error occurs (PGSERR). It is reset at the same time as BUSY bit.

Bit 2 **ALT_SECT**: alternate sector bit
0: current OBK sector is mapped to OBK address range for access
1: alternate OBK sector is mapped to OBK address range for access
This bit must not change while filling the write buffer, otherwise an error (OBKERR) is generated

Bit 1 **SWAP_SECT_REQ**: OBK swap sector request bit
0: no swap requested
1: launch the sector swap
When set, all the OBKs not updated in the alternate sector are copied from current sector to alternate one.
The SWAP_OFFSET must have a minimum value to launched the swap. The minimum value is 16 for OBK-HDPL = 1, 144 for OBK-HDPL = 2, and 192 for OBK-HDPL = 3.

Bit 0 **LOCK**: OBKCFGR lock option configuration bit
This bit locks the register, the correct write sequence unlocks it. If a wrong sequence is executed, or if the unlock sequence is performed twice, this bit remains locked until the next system reset. LOCK can be set by programming it to 1. When set to 1, a new unlock sequence is mandatory to unlock it. When LOCK changes from 0 to 1, the other bits of FLASH_NSCR register do not change.
0: FLASH_NSOBKCFGR register unlocked
1: FLASH_NSOBKCFGR register locked

7.11.17 FLASH secure OBK configuration register (FLASH_SECOBKCFGR)

This register can be accessed only in secure privileged mode. The FLASH_SECOBKCFGR register is not accessible in write mode when the BSY bit is set. Any attempt to write to it with the BSY bit set causes the AHB bus to stall until the BSY bit is cleared.

Address offset: 0x044

Reset value: 0x01FF 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWAP_OFFSET[8:0]								
							rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALT_SECT_ERASE	ALT_SECT	SWAP_SECT_REQ	LOCK
												rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 24:16 **SWAP_OFFSET[8:0]**: key index (offset /16 bits) pointing for next swap.

0x0: no OBK is copied from current to alternate OBK sector during SWAP operation.
0x1: only the first OBK data (128 bits) are copied from current to alternate OBK sector
0x2: the two first OBK data are copied
…
0x1FF: the 511 first OBK data are copied

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **ALT_SECT_ERASE**: alternate sector erase bit

0: do not touch OBK sector
1: erase the alternate OBK sector
When ALT_SECT bit is set, use this bit to generate an erase command for the OBK alternate sector. It is set only by Software and cleared when the OBK swap operation is completed or an error occurs (PGSERR). It is reset at the same time as the BUSY bit.

Bit 2 **ALT_SECT**: alternate sector bit

0: current OBK sector is mapped to OBK address range for access
1: alternate OBK sector is mapped to OBK address range for access
This bit must not change while filling the write buffer, otherwise an error is generated

Bit 1 **SWAP_SECT_REQ**: OBK swap sector request bit

0: no swap requested
1: launch the sector swap
When set, all the OBKs not updated in the alternate sector are copied from current sector to alternate one.
SWAP_OFFSET must have a minimum value to launch the swap. The minimum value is 16 for OBK-HDPL = 1, 144 for OBK-HDPL = 2, and 192 for OBK-HDPL = 3.

Bit 0 **LOCK**: OBKCFGR lock option configuration bit

This bit locks the FLASH_OBKCFGR register. The correct write sequence to FLASH_SECOBKKEYR register unlocks this bit. If a wrong sequence is executed, or if the unlock sequence to FLASH_SECOBKKEYR is performed twice, this bit remains locked until the next system reset. LOCK can be set by programming it to 1. When set to 1, a new unlock sequence is mandatory to unlock it. When LOCK changes from 0 to 1, the other bits of FLASH_NSCR register do not change.
0: FLASH_OBKCFGR register unlocked
1: FLASH_OBKCFGR register locked

7.11.18 FLASH HDP extension register (FLASH_HDPEXTR)

All bits in this register are nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

The register can be modified only in HDPL ≤ 2.

The values in this register cannot be decremented. Attempts to write a value lower than the current one are ignored.

Address offset: 0x048

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP2_EXT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP1_EXT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **HDP2_EXT[7:0]**: HDP area extension in 8 Kbytes sectors in bank2. Extension is added after the HDP2_END sector (included).

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **HDP1_EXT[7:0]**: HDP area extension in 8 Kbytes sectors in bank1. Extension is added after the HDP1_END sector (included).

7.11.19 FLASH option status register (FLASH_OPTSR_CUR)

This register is nonsecure. It can be read by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

Default value: 0x0030 5CD8 (value in case of double ECC issue during OBL).

This read-only register reflects the current values of the corresponding option bits.

Address offset: 0x050

Reset value: 0xXXXX XXXX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SWAP_BANK	Res.	BOOT_UBE[7:0]								IWDG_STDBY	IWDG_STOP	Res.	Res.	IO_VDDIO2_HSLV	IO_VDD_HSLV
r		r	r	r	r	r	r	r	r	r	r			r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRODUCT_STATE[7:0]								NRST_STDBY	NRST_STOP	Res.	WWDG_SW	IWDG_SW	BORH_EN	BOR_LEV[1:0]	
r	r	r	r	r	r	r	r	r	r		r	r	r	r	r

Bit 31 **SWAP_BANK**: Bank swapping option status bit
SWAP_BANK reflects whether bank1 and bank2 are swapped or not.
SWAP_BANK is loaded to SWAP_BANK of FLASH_OPTCR after a reset.
0: Bank1 and bank2 not swapped
1: Bank1 and bank2 swapped

Bit 30 Reserved, must be kept at reset value.

Bits 29:22 **BOOT_UBE[7:0]:** Available only on cryptography enabled devices.
Unique boot entry control, selects either ST or OEM iRoT for secure boot.
0xC3: ST-iRoT (system flash) selected
0xB4: OEM-iRoT (user flash) selected. In Open PRODUCT_STATE this value selects bootloader. Defaut value.

Bit 21 **IWDG_STDBY**: IWDG Standby mode freeze option status bit
When set the independent watchdog IWDG is frozen in system Standby mode.
0: Independent watchdog frozen in Standby mode
1: Independent watchdog keep running in Standby mode.

Bit 20 **IWDG_STOP**: IWDG Stop mode freeze option status bit
When set the independent watchdog IWDG is in system Stop mode.
0: Independent watchdog frozen in system Stop mode
1: Independent watchdog keep running in system Stop mode.

Bits 19:18 Reserved, must be kept at reset value.

Bit 17 **IO_VDDIO2_HSLV**: High-speed IO at low V_{DDIO2} voltage configuration bit.
This bit can be set only with V_{DDIO2} below 2.7 V.
0: High-speed IO at low V_{DDIO2} voltage feature disabled (V_{DDIO2} can exceed 2.7 V)
1: High-speed IO at low V_{DDIO2} voltage feature enabled (V_{DDIO2} remains below 2.7 V)

Bit 16 **IO_VDD_HSLV**: High-speed IO at low V_{DD} voltage configuration bit.
This bit can be set only with V_{DD} below 2.7 V.
0: High-speed IO at low V_{DD} voltage feature disabled (V_{DD} can exceed 2.7 V)
1: High-speed IO at low V_{DD} voltage feature enabled (V_{DD} remains below 2.7 V)

Bits 15:8 **PRODUCT_STATE[7:0]**: Life state code (based on Hamming 8,4). See *Section 7.6.11*.

Bit 7 **NRST_STDBY**: Core domain Standby entry reset option status bit
0: a reset is generated when entering Standby mode on core domain
1: no reset generated when entering Standby mode on core domain.

Bit 6 **NRST_STOP**: Core domain Stop entry reset option status bit
0: a reset is generated when entering Stop mode on core domain
1: no reset generated when entering Stop mode on core domain.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **WWDG_SW**: WWDG control mode option status bit
0: WWDG watchdog is controlled by hardware
1: WWDG watchdog is controlled by software

Bit 3 **IWDG_SW**: IWDG control mode option status bit
0: IWDG watchdog is controlled by hardware
1: IWDG watchdog is controlled by software

Bit 2 **BORH_EN**: Brownout high enable
0: disable
1: enable

Bits 1:0 **BOR_LEV[1:0]**: Brownout level option status bit
These bits reflects the power level that generates a system reset.
00 or 11: BOR Level 1, the threshold level is low (around 2.1 V)
01: BOR Level 2, the threshold level is medium (around 2.4 V)
10: BOR Level 3, the threshold level is high (around 2.7 V)

7.11.20 FLASH option status register (FLASH_OPTSR_PRG)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This register is used to program values in corresponding option bits. Values after reset reflects the current values of the corresponding option bits.

Address offset: 0x054

Reset value: 0xXXXX XXXX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SWAP_BANK	Res.	BOOT_UBE[7:0]								IWDG_STDBY	IWDG_STOP	Res.	Res.	IO_VDDIO2_HSLV	IO_VDD_HSLV
rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRODUCT_STATE[7:0]								NRST_STDBY	NRST_STOP	Res.	WWDG_SW	IWDG_SW	BORH_EN	BOR_LEV[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bit 31 **SWAP_BANK**: Bank swapping option configuration bit
SWAP_BANK option bit is used to configure whether the bank1 and bank2 are swapped or not. This bit is loaded with the SWAP_BANK bit of FLASH_OPTSR_CUR register after a reset.
0: Bank1 and bank2 not swapped
1: Bank1 and bank2 swapped

Bit 30 Reserved, must be kept at reset value.

Bits 29:22 **BOOT_UBE[7:0]:** Available only on cryptography enabled devices.
Unique boot entry control, selects either ST or OEM iRoT for secure boot.
0xC3: ST-iRoT (system flash) selected
0xB4: OEM-iRoT (user flash) selected.
In Open PRODUCT_STATE this value selects bootloader. Defaut value.

Bit 21 **IWDG_STDBY**: IWDG Standby mode freeze option status bit
When set the independent watchdog IWDG is frozen in system Standby mode.
0: Independent watchdog frozen in Standby mode
1: Independent watchdog keep running in Standby mode.

Bit 20 **IWDG_STOP**: IWDG Stop mode freeze option status bit
When set the independent watchdog IWDG is in system Stop mode.
0: Independent watchdog frozen in system Stop mode
1: Independent watchdog keep running in system Stop mode.

Bits 19:18 Reserved, must be kept at reset value.

Bit 17 **IO_VDDIO2_HSLV**: High-speed IO at low V_{DDIO2} voltage configuration bit.
This bit can be set only with V_{DDIO2} below 2.7 V.
0: High-speed IO at low V_{DDIO2} voltage feature disabled (V_{DDIO2} can exceed 2.7 V)
1: High-speed IO at low V_{DDIO2} voltage feature enabled (V_{DDIO2} remains below 2.7 V)

Bit 16 **IO_VDD_HSLV**: High-speed IO at low VDD voltage configuration bit.
This bit can be set only with V_{DD} below 2.7 V.
0: High-speed IO at low V_{DD} voltage feature disabled (V_{DD} can exceed 2.7 V)
1: High-speed IO at low V_{DD} voltage feature enabled (V_{DD} remains below 2.7 V)

Bits 15:8 **PRODUCT_STATE[7:0]**: Life state code (based on Hamming 8,4). See *Section 7.6.11*.

Bit 7 **NRST_STDBY**: Core domain Standby entry reset option configuration bit
0: a reset is generated when entering Standby mode on core domain
1: no reset generated when entering Standby mode on core domain.

Bit 6 **NRST_STOP**: Core domain Stop entry reset option configuration bit
0: a reset is generated when entering Stop mode on core domain
1: no reset generated when entering Stop mode on core domain.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **WWDG_SW**: WWDG control mode option configuration bit
0: WWDG watchdog is controlled by hardware
1: WWDG watchdog is controlled by software

Bit 3 **IWDG_SW**: IWDG control mode option configuration bit
0: IWDG watchdog is controlled by hardware
1: IWDG watchdog is controlled by software

Bit 2 **BORH_EN**: Brownout high enable configuration bit
0: disabled
1: enabled

Bits 1:0 **BOR_LEV[1:0]**: Brownout level option configuration bit
These bits reflects the power level that generates a system reset.
00 or 11: BOR Level 1, the threshold level is low (around 2.1 V)
01: BOR Level 2, the threshold level is medium (around 2.4 V)
10: BOR Level 3, the threshold level is high (around 2.7 V)

7.11.21 FLASH nonsecure EPOCH register (FLASH_NSEPOCHR_CUR)

This register is nonsecure. It can be read by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This read-only register reflects the current values of the corresponding option bits.

Address offset: 0x060

Reset value: 0xXXXX XXXX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NS_EPOCH[23:16]							
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NS_EPOCH[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:0 **NS_EPOCH[23:0]:** Non-volatile nonsecure EPOCH counter

7.11.22 FLASH secure EPOCH register (FLASH_SECEPOCHR_CUR)

This register is nonsecure. It can be read by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This read-only register reflects the current values of the corresponding option bits.

Address offset: 0x068

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEC_EPOCH[23:16]							
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEC_EPOCH[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:0 **SEC_EPOCH[23:0]:** Non-volatile secure EPOCH counter

7.11.23 FLASH option status register 2 (FLASH_OPTSR2_CUR)

This register is nonsecure. It can be read by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

Default value: 0xB400 0170

This read-only register reflects the current values of the corresponding option bits.

Address offset: 0x070

Reset value: 0xXXXX XXXX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TZEN[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r	r	r	r								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	USBPD_DIS	Res.	SRAM2_ECC	SRAM3_ECC	BKPRAM_ECC	SRAM2_RST	SRAM1345_RST	Res.	Res.
							r		r	r	r	r	r		

Bits 31:24 **TZEN[7:0]**: TrustZone enable configuration bits
This bit enables the device is in TrustZone mode during an option byte change.
0xC3: TrustZone disabled
0xB4: TrustZone enabled.

Bits 23:15 Reserved, must be kept at reset value.

Bits 14:9 Reserved, must be kept at reset value.

Bit 8 **USBPD_DIS**: UCPD USB power delivery configuration option bit for UCPDx_CC1 pin only
Enables USB Type-C dead battery pull-down behavior on UCPDx_CC1 pin.
0: Enabled. For USB Type-C® and Power Delivery applications: enables correct dead-battery behavior of UCPDx_CC1 pin.
1: Disabled: Stops the dead battery pull-down behavior on the UCPDx_CC1 pin after power-up

Bit 7 Reserved, must be kept at reset value.

Bit 6 **SRAM2_ECC**: SRAM2 ECC detection and correction disable
0: SRAM2 ECC check enabled
1: SRAM2 ECC check disabled

Bit 5 **SRAM3_ECC**: SRAM3 ECC detection and correction disable
0: SRAM3 ECC check enabled
1: SRAM3 ECC check disabled

Bit 4 **BKPRAM_ECC**: Backup RAM ECC detection and correction disable
0: BKPRAM ECC check enabled
1: BKPRAM ECC check disabled

Bit 3 **SRAM2_RST**: SRAM2 erase when system reset
0: SRAM2 erased when a system reset occurs
1: SRAM2 not erased when a system reset occurs.

Bit 2 **SRAM1345_RST**: SRAM1, SRAM3, SRAM4, and SRAM5 erase upon system reset
0: SRAM1, SRAM3, SRAM4, and SRAM5 erased when a system reset occurs
1: SRAM1, SRAM3, SRAM4, and SRAM5 not erased when a system reset occurs

Bits 1:0 Reserved, must be kept at reset value.

7.11.24 FLASH option status register 2 (FLASH_OPTSR2_PRG)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This register is used to program values in corresponding option bits. Values after reset reflects the current values of the corresponding option bits.

Address offset: 0x074

Reset value: 0xXXXX XXXX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TZEN[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	USBPD_DIS	Res.	SRAM2_ECC	SRAM3_ECC	BKPRAM_ECC	SRAM2_RST	SRAM1345_RST	Res.	Res.
							rw		rw	rw	rw	rw	rw		

Bits 31:24 **TZEN[7:0]**: TrustZone enable configuration bits
This bit enables the device is in TrustZone mode during an option byte change.
0xC3: TrustZone disabled
0xB4: TrustZone enabled

Bits 23:15 Reserved, must be kept at reset value.

Bits 14:9 Reserved, must be kept at reset value.

Bit 8 **USBPD_DIS**: UCPD USB power delivery configuration option bit for UCPDx_CC1 pin only. Enables USB Type-C dead battery pull-down behavior on UCPDx_CC1 pin.
0: Enabled. For USB Type-C and Power Delivery applications: enables correct dead battery behavior of UCPDx_CC1 pin.
1: Disabled. Stops the dead battery pull-down behavior on the UCPDx_CC1 pin after power-up.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **SRAM2_ECC**: SRAM2 ECC detection and correction disable
0: SRAM2 ECC check enabled
1: SRAM2 ECC check disabled

Bit 5 **SRAM3_ECC**: SRAM3 ECC detection and correction disable
0: SRAM3 ECC check enabled
1: SRAM3 ECC check disabled

Bit 4 **BKPRAM_ECC**: Backup RAM ECC detection and correction disable
0: BKPRAM ECC check enabled
1: BKPRAM ECC check disabled

Bit 3 **SRAM2_RST**: SRAM2 erase when system reset
0: SRAM2 erased when a system reset occurs
1: SRAM2 not erased when a system reset occurs.
Note: SRAM erase is triggered by option byte change operation, when enabling this feature.

Bit 2 **SRAM1345_RST**: SRAM1, SRAM3, SRAM4, and SRAM5 erase upon system reset
0: SRAM1, SRAM3, SRAM4, and SRAM5 erased when a system reset occurs
1: SRAM1, SRAM3, SRAM4, and SRAM5 not erased when a system reset occurs
Note: SRAM erase is triggered by option byte change operation, when enabling this feature.

Bits 1:0 Reserved, must be kept at reset value.

7.11.25 FLASH nonsecure boot register (FLASH_NSBOOTR_CUR)

This register is nonsecure. It can be read by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This register reflects the current values of the corresponding option bits.

Address offset: 0x080

Reset value: 0xXXXX XXXX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NSBOOTADD[23:8]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NSBOOTADD[7:0]								NSBOOT_LOCK[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:8 **NSBOOTADD[23:0]**: Nonsecure unique boot entry address
These bits reflect the Nonsecure UBE address

Bits 7:0 **NSBOOT_LOCK[7:0]:** Field locking the values of SWAP_BANK, and NSBOOTADD settings.
0xC3: SWAP_BANK and NSBOOTADD can still be modified following their individual rules.
0xB4: NSBOOTADD is frozen. SWAP_ BANK can be modified only with TZEN set to 0xB4 (enabled).

7.11.26 FLASH nonsecure boot register (FLASH_NSBOOTR_PRG)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses, and protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This register is used to program values in corresponding option bits.

Address offset: 0x084

Reset value: 0xXXXX XXXX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NSBOOTADD[23:8]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NSBOOTADD[7:0]								NSBOOT_LOCK[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 **NSBOOTADD[23:0]**: Nonsecure unique boot entry address
These bits allow configuring the Nonsecure BOOT address

Bits 7:0 **NSBOOT_LOCK[7:0]:** Field locking the values of SWAP_ BANK, and NSBOOTADD settings.
0xC3: SWAP_ BANK and NSBOOTADD can still be modified following their individual rules.
0xB4: NSBOOTADD is frozen. SWAP_ BANK can be modified only with TZEN set to 0xB4 (enabled).

7.11.27 FLASH secure boot register (FLASH_SECBOOTR_CUR)

This register is secure. It can be read only by secure access. A nonsecure read/write access is RAZ/WI. This register can be protected against unprivileged access when SPRIV = 1 in the FLASH_PRIVCFGR register.

This register reflects the current values of the corresponding option bits.

Address offset: 0x088

Reset value: 0xXXXX XXXX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SECBOOTADD[23:8]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SECBOOTADD[7:0]								SECBOOT_LOCK[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:8 **SECBOOTADD[23:0]**: Unique boot entry secure address
These bits reflect the Secure UBE address

Bits 7:0 **SECBOOT_LOCK[7:0]:** Field locking the values of UBE, SWAP_BANK, and SECBOOTADD settings.
0xC3: BOOT_UBE, SWAP_BANK and SECBOOTADD can still be modified following their individual rules.
0xB4: BOOT_UBE and SECBOOTADD are frozen. SWAP_ BANK can be modified only with TZEN set to 0xC3 (disabled).

7.11.28 FLASH secure boot register (FLASH_BOOTR_PRG)

This register is secure. It can be read and written only by secure access. A nonsecure read/write access is RAZ/WI. This register can be protected against unprivileged access when SPRIV = 1 in the FLASH_PRIVCFGR register.

This register is used to program values in corresponding option bits.

Address offset: 0x08C

Reset value: 0xXXXX XXXX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SECBOOTADD[23:8]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SECBOOTADD[7:0]								SECBOOT_LOCK[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 **SECBOOTADD[23:0]**: Secure unique boot entry address.
These bits allow configuring the secure UBE address.

Bits 7:0 **SECBOOT_LOCK[7:0]:** Field locking the values of UBE, SWAP_ BANK, and SECBOOTADD setting.

0xC3: BOOT_UBE, SWAP_ BANK and SECBOOTADD can still be modified following their individual rules.

0xB4: BOOT_UBE and SECBOOTADD are frozen. SWAP_BANK can be modified only with TZEN set to 0xC3 (disabled).

7.11.29 FLASH nonsecure OTP block lock (FLASH_OTPBLR_CUR)

This register is nonsecure. It can be read by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This register reflects the current values of the corresponding option bits.

Address offset: 0x090

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LOCKBL[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LOCKBL[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **LOCKBL[31:0]**: OTP block lock

Block *n* corresponds to OTP 16-bit word 32 x *n* to 32 x *n* + 31.

LOCKBL[n] = 1 indicates that all OTP 16-bit words in OTP Block *n* are locked and attempt to program them results in WRPERR.

LOCKBL[n] = 0 indicates that all OTP 16-bit words in OTP Block *n* are not locked.

When one block is locked, it is not possible to remove the write protection.

Also if not locked, it is not possible to erase OTP words.

7.11.30 FLASH nonsecure OTP block lock (FLASH_OTPBLR_PRG)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This register is used to program values in corresponding option bits.

Address offset: 0x094

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LOCKBL[31:16]															
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LOCKBL[15:0]															
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs

Bits 31:0 **LOCKBL[31:0]**: OTP block lock

Block *n* corresponds to OTP 16-bit word 32 x *n* to 32 x *n* + 31.
LOCKBL[n] = 1 indicates that all OTP 16-bit words in OTP Block *n* are locked and attempt to program them results in WRPERR.
LOCKBL[n] = 0 indicates that all OTP 16-bit words in OTP Block *n* are not locked.
When one block is locked, it is not possible to remove the write protection.
LOCKBL bits can be set if the corresponding bit in FLASH_OTPBLR_CUR is cleared.

7.11.31 FLASH write sector group 2 protection for bank1 (FLASH_WRP12R_CUR)

This register is nonsecure. It can be read by both secure and nonsecure accesses, and can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This read-only register reflects the current values of the corresponding option bits.

Address offset: 0x098

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WRPSG12[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WRPSG12[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **WRPSG12[31:0]**: Bank1 sector group 2 protection option status byte

Each bit reflects the write protection status of the corresponding group of four consecutive sectors in bank1 (0: the group is write-protected; 1: the group is not write-protected)
Bit 0: Group embedding sectors 128 to 131
Bit 1: Group embedding sectors 132 to 135
Bit N: Group embedding sectors 128 + 4 x N to 128 + 4 x N + 3

Note: Bit 31: Group embedding sectors 252 to 255

7.11.32 FLASH write sector group 2 protection for bank1 (FLASH_WRP12R_PRG)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This register is used to program values in corresponding option bits.

Address offset: 0x09C

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WRPSG12[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WRPSG12[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **WRPSG12[31:0]**: Bank1 sector group 2 protection option status byte

Setting WRPSG12 bits to 0 write protects the corresponding group of four consecutive sectors in bank1 (0: the group is write-protected; 1: the group is not write-protected)

Bit 0: Group embedding sectors 128 to 131

Bit 1: Group embedding sectors 132 to 135

Bit N: Group embedding sectors 128 + 4 x N to 128 + 4 x N + 3

Note: Bit 31: Group embedding sectors 252 to 255

7.11.33 FLASH secure block based register for bank1 (FLASH_SECBB1Rx)

These registers are secure. They can be read and written only by secure access. A nonsecure read/write access is RAZ/WI.

Address offset: 0x0A0 + 0x004 * (x-1), (x = 1 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SECBB1[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SECBB1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SECBB1[31:0]**: Secure/nonsecure 8 Kbytes flash bank1 sector attributes (y= 0 to 31)

0: sector (32 * (x-1) + y) in bank1 is nonsecure.

1: sector (32 * (x-1) + y) in bank1 is secure.

7.11.34 FLASH privilege block based register for bank1 (FLASH_PRIVBB1Rx)

These registers are privileged. They can be read and written only by a privileged access. This register can be protected against nonsecure write access.

Address offset: 0x0C0 + 0x004 * (x-1), (x = 1 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRIVBB1[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRIVBB1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PRIVBB1[31:0]**: Privileged/unprivileged 8-Kbyte flash bank1 sector attribute (y = 0 to 31)
0: sectors (32 * (x-1) + y) in bank1 is unprivileged.
1: sector (32 * (x-1) + y) in bank1 is privileged.

7.11.35 FLASH security watermark for bank1 (FLASH_SECWM1R_CUR)

This read-only register is nonsecure, it can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register. It reflects the current values of the corresponding option bits.

Address offset: 0x0E0

Reset value: 0x00XX 00XX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM1_END[7:0]							
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM1_STRT[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **SECWM1_END[7:0]**: bank1 security WM area 1 end sector

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **SECWM1_STRT[7:0]**: bank1 security WM area 1 start sector

7.11.36 FLASH security watermark for bank1 (FLASH_SECWM1R_PRG)

This register is secure. It can be read and written only by secure access. A nonsecure read/write access is RAZ/WI. This register can be protected against unprivileged access when SPRIV = 1 in the FLASH_PRIVCFGR register. This register is used to program values in corresponding option bits.

Address offset: 0x0E4

Reset value: 0x00XX 00XX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM1_END[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM1_STRT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **SECWM1_END[7:0]**: bank1 security WM area 1 end sector

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **SECWM1_STRT[7:0]**: bank1 security WM area 1 start sector

7.11.37 FLASH write sector group 1 protection for bank1 (FLASH_WRP11R_CUR)

This register is nonsecure. It can be read by both secure and nonsecure accesses, and can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This read-only register reflects the current values of the corresponding option bits.

Address offset: 0x0E8

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WRPSG11[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WRPSG11[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **WRPSG11[31:0]**: bank1 sector group 1 protection option status byte

Each bit reflects the write protection status of the corresponding group of four consecutive sectors in bank1 (0: the group is write-protected; 1: the group is not write-protected)

Bit 0: Group embedding sectors 0 to 3

Bit 1: Group embedding sectors 4 to 7

Bit N: Group embedding sectors 4 x N to 4 x N + 3

Note: Bit 31: Group embedding sectors 124 to 127

7.11.38 FLASH write sector group 1 protection for bank1 (FLASH_WRP11R_PRG)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This register is used to program values in corresponding option bits.

Address offset: 0x0EC

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WRPSG11[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WRPSG11[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **WRPSG11[31:0]**: Bank1 sector group 1 protection option status byte
Setting WRPSG11 bits to 0 write protects the corresponding group of four consecutive sectors in bank1 (0: the group is write-protected; 1: the group is not write-protected)
Bit 0: Group embedding sectors 0 to 3
Bit 1: Group embedding sectors 4 to 7
Bit N: Group embedding sectors 4 x N to 4 x N + 3
Note: Bit 31: Group embedding sectors 124 to 127

7.11.39 FLASH data sector configuration bank1 (FLASH_EDATA1R_CUR)

This register is nonsecure, can be read by both secure and nonsecure accesses. The register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This read-only register reflects the current values of the corresponding options bits.

Address offset: 0x0F0

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EDATA1_EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EDATA1_STRT[3:0]			
r												r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **EDATA1_EN:** Bank1 flash high-cycle data enable
0: No flash high-cycle data area
1: Flash high-cycle data is used

Bits 14:4 Reserved, must be kept at reset value.

Bits 3:0 **EDATA1_STRT[3:0]:**
EDATA1_STRT contains the start sectors of the flash high-cycle data area in bank1. There is no hardware effect to those bits. They shall be managed by ST tools in Flasher.
0000: The last sector of bank1 is reserved for flash high-cycle data
0001: The two last sectors of bank1 are reserved for flash high-cycle data
0010: The three last sectors of bank1 are reserved for flash high-cycle data
...
1111: The sixteen last sectors of bank1 are reserved for flash high-cycle data

7.11.40 FLASH data sector configuration bank1 (FLASH_EDATA1R_PRG)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This register is used to program values in corresponding options bits.

Address offset: 0xF4

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EDATA1_EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EDATA1_STRT[3:0]			
rw												rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **EDATA1_EN:** Bank1 flash high-cycle data enable
0: No flash high-cycle data area
1: Flash high-cycle data is used

Bits 14:4 Reserved, must be kept at reset value.

Bits 3:0 **EDATA1_STRT[3:0]:**
EDATA1_STRT contains the start sectors of the flash high-cycle data area in bank1. There is no hardware effect to those bits. They shall be managed by ST tools in Flasher.
0000: The last sector of the bank1 is reserved for flash high-cycle data
0001: The two last sectors of the bank1 are reserved for flash high-cycle data
0010: The three last sectors of the bank1 are reserved for flash high-cycle data
...
Note: 1111: The sixteen last sectors of the bank1 are reserved for flash high-cycle data

7.11.41 FLASH HDP bank1 configuration (FLASH_HDP1R_CUR)

This register is nonsecure. It can be read by both secure and nonsecure accesses, and protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register. This register is initially loaded with the values of the corresponding option bits.

Address offset: 0x0F8

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP1_END[7:0]							
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP1_STRT[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **HDP1_END[7:0]:** HDPL barrier end set in number of 8-Kbyte sectors

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **HDP1_STRT[7:0]:** HDPL barrier start set in number of 8-Kbyte sectors

7.11.42 FLASH HDP bank1 configuration (FLASH_HDP1R_PRG)

This register is nonsecure. It can be read and written by both secure and nonsecure access, and can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

The register is accessible only in HDPL1. In HDPL2 or HDPL3 it is WI, RAZ.

This register is used to program values in corresponding option bits.

Address offset: 0x0FC

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP1_END[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP1_STRT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **HDP1_END[7:0]:** HDPL barrier end set in number of 8-Kbyte sectors

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **HDP1_STRT[7:0]:** HDPL barrier start set in number of 8-Kbyte sectors

7.11.43 FLASH ECC correction register (FLASH_ECCCORR)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

Address offset: 0x100

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	ECCC	Res.	Res.	Res.	Res.	ECCCIE	OTP_ECC	SYSF_ECC	BK_ECC	EDATA_ECC	OBK_ECC	Res.	Res.	Res.	ADDR_ECC[16]
	rw					rw	r	r	r	r	r				r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDR_ECC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bit 30 **ECCC:** ECC correction set by hardware when single ECC error has been detected and corrected.
Cleared by writing 1.

Bits 29:26 Reserved, must be kept at reset value.

Bit 25 **ECCCIE**: ECC single correction error interrupt enable bit
When ECCCIE bit is set to 1, an interrupt is generated when an ECC single correction error occurs during a read operation.
0: No interrupt generated when an ECC single correction error occurs
1: Nonsecure interrupt generated when an ECC single correction error occurs

Bit 24 **OTP_ECC**: OTP ECC error bit
This bit is set to 1 when one single ECC correction occurred during the last successful read operation from the read-only/ OTP area. The address of the ECC error is available in ADDR_ECC bitfield.

Bit 23 **SYSF_ECC**: ECC fail for corrected ECC error in system flash memory
It indicates if system flash memory is concerned by ECC error.

Bit 22 **BK_ECC**: ECC fail bank for corrected ECC error
It indicates which bank is concerned by ECC error

Bit 21 **EDATA_ECC**: ECC fail for corrected ECC error in flash high-cycle data area
It indicates if flash high-cycle data area is concerned by ECC error.

Bit 20 **OBK_ECC**: Single ECC error corrected in flash OB Keys storage area. It indicates the OBK storage concerned by ECC error.

Bits 19:17 Reserved, must be kept at reset value.

Bits 16:0 **ADDR_ECC[16:0]**: ECC error address
When an ECC error occurs (for single correction) during a read operation, ADDR_ECC contains the address that generated the error. It is reset when the flag error is reset.
The flash interface programs the address in this register only when no ECC error flags are set. This means that only the first address that generated an ECC error is saved.
The address in ADDR_ECC is relative to the flash memory area where the error occurred (user flash memory, system flash memory, data area, read-only/OTP area).

7.11.44 FLASH ECC detection register (FLASH_ECCDETR)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

Address offset: 0x104

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ECCD	Res.	Res.	Res.	Res.	Res.	Res.	OTP_ECC	SYSF_ECC	BK_ECC	EDATA_ECC	OBK_ECC	Res.	Res.	Res.	ADDR_ECC[16]
rw							r	r	r	r	r				r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDR_ECC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **ECCD:** ECC detection
Set by hardware when two ECC error has been detected.
When this bit is set, a NMI is generated.
Cleared by writing 1. Needs to be cleared in order to detect subsequent double ECC errors.

Bits 30:25 Reserved, must be kept at reset value.

Bit 24 **OTP_ECC**: OTP ECC error bit
This bit is set to 1 when double ECC detection occurred during the last read operation from the read-only/ OTP area. The address of the ECC error is available in ADDR_ECC bitfield.

Bit 23 **SYSF_ECC**: ECC fail for double ECC error in system flash memory
It indicates if system flash memory is concerned by ECC error.

Bit 22 **BK_ECC**: ECC fail bank for double ECC error
It indicates which bank is concerned by ECC error

Bit 21 **EDATA_ECC**: ECC fail double ECC error in flash high-cycle data area
It indicates if flash high-cycle data area is concerned by ECC error.

Bit 20 **OBK_ECC**: ECC fail double ECC error in flash OB Keys storage area. It indicates the OBK storage concerned by ECC error.

Bits 19:17 Reserved, must be kept at reset value.

Bits 16:0 **ADDR_ECC[16:0]**: ECC error address
When an ECC error occurs (double detection) during a read operation, the ADDR_ECC contains the address that generated the error. It is reset when the flag error is reset.
The flash interface programs the address in this register only when no ECC error flags are set. This means that only the first address that generated an double ECC error is saved.
The address in ADDR_ECC is relative to the flash memory area where the error occurred (user flash memory, system flash memory, data area, read-only/OTP area).

7.11.45 FLASH ECC data (FLASH_ECCDR)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

Address offset: 0x108

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA_ECC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **DATA_ECC[15:0]**: ECC error data
When an double detection ECC error occurs on special areas with 6-bit ECC on 16-bit data (data, read-only/OTP), the failing data is read to this register.
By checking if it is possible to determine whether the failure was on a real data, or due to access to uninitialized memory.

7.11.46 FLASH write sector group 2 protection for bank2 (FLASH_WRP22R_CUR)

This register is nonsecure, can be read by both secure and nonsecure access, and protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This read-only register reflects the current values of the corresponding option bits.

Address offset: 0x198

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WRPSG22[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WRPSG22[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **WRPSG22[31:0]**: Bank2 sector group protection option status byte

Each bit reflects the write protection status of the corresponding group of four consecutive sectors in bank2 (0: group is write-protected; 1: group is not write-protected)

Bit 0: Group embedding sectors 128 to 131

Bit 1: Group embedding sectors 132 to 135

Bit N: Group embedding sectors 128 + 4 x N to 128 + 4 x N + 3

Bit 31: Group embedding sectors 252 to 255

7.11.47 FLASH write sector group 2 protection for bank2 (FLASH_WRP22R_PRG)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This register is used to program values in corresponding option bits.

Address offset: 0x19C

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WRPSG22[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WRPSG22[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **WRPSG22[31:0]**: Bank2 sector group protection option status byte
Setting WRPSG22 bits to 0 write protects the corresponding group of four consecutive sectors in bank2 (0: group is write-protected; 1: group is not write-protected)
Bit 0: Group embedding sectors 128 to 131
Bit 1: Group embedding sectors 132 to 135
Bit N: Group embedding sectors 128 + 4 x N to 128 + 4 x N + 3
Bit 31: Group embedding sectors 252 to 255

7.11.48 FLASH secure block-based register for bank2 (FLASH_SECBB2Rx)

These registers are secure, they can be read and written only by secure access. A nonsecure read/write access is RAZ/WI. The registers can be protected against unprivileged access when SPRIV = 1 in the FLASH_PRIVCFGR register.

Address offset: 0x1A0 + 0x004 * (x-1), (x = 1 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SECBB2[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SECBB2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SECBB2[31:0]**: Secure/nonsecure flash bank2 sector attribute (y = 0 to 31)
0: sectors (32 * (x-1) + y) in bank2 is nonsecure
1: sector (32 * (x-1) + y) in bank2 is secure

7.11.49 FLASH privilege block-based register for bank2 (FLASH_PRIVBB2Rx)

These registers are privileged, they can be read and written only by a privileged access, and can be protected against nonsecure write access by watermark.

Address offset: 0x1C0 + 0x004 * (x-1), (x = 1 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRIVBB2[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRIVBB2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PRIVBB2[31:0]:** Privileged / non-privileged 8-Kbyte flash bank2 sector attribute (y = 0 to 31)
0: sectors (32 * (x-1) + y) in bank2 is unprivileged
1: sector (32 * (x-1) + y) in bank2 is privileged

7.11.50 FLASH security watermark for bank2 (FLASH_SECWM2R_CUR)

This register is nonsecure, it can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This read-only register reflects the current values of the corresponding option bits.

Address offset: 0x1E0

Reset value: 0x00XX 00XX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM2_END[7:0]							
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM2_STRT[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **SECWM2_END[7:0]**: Bank2 security WM end sector

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **SECWM2_STRT[7:0]**: Bank2 security WM area start sector

7.11.51 FLASH security watermark for bank2 (FLASH_SECWM2R_PRG)

This register is secure. It can be read and written only by secure access. A nonsecure read/write access is RAZ/WI. The register can be protected against unprivileged accesses when SPRIV = 1 in the FLASH_PRIVCFGR register.

This register is used to program values in corresponding option bits.

Address offset: 0x1E4

Reset value: 0x00XX 00XX

(Register bits 0 to 31 are loaded with values from the flash memory at OBL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM2_END[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM2_STRT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **SECWM2_END[7:0]**: Bank2 security WM area end sector

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **SECWM2_STRT[7:0]**: Bank2 security WM area start sector

7.11.52 FLASH write sector group 1 protection for bank2 (FLASH_WRP21R_CUR)

This register is nonsecure, can be read by both secure and nonsecure access, and protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This read-only register reflects the current values of the corresponding option bits.

Address offset: 0x1E8

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WRPSG21[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WRPSG21[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **WRPSG21[31:0]**: Bank2 sector group 1 protection option status byte

Each bit reflects the write protection status of the corresponding group of four consecutive sectors in bank2 (0: group is write-protected; 1: group is not write-protected)

Bit 0: Group embedding sectors 0 to 3

Bit 1: Group embedding sectors 4 to 7

Bit N: Group embedding sectors 4 x N to 4 x N + 3

Note: Bit 31: Group embedding sectors 124 to 127

7.11.53 FLASH write sector group 1 protection for bank2 (FLASH_WRP21R_PRG)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This register is used to program values in corresponding option bits.

Address offset: 0x1EC

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WRPSG21[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WRPSG21[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **WRPSG21[31:0]**: Bank2 sector group 1 protection option status byte

Setting WRPSGn2 bits to 0 write protects the corresponding group of four consecutive sectors in bank2 (0: group is write-protected; 1: group is not write-protected)

Bit 0: Group embedding sectors 0 to 3

Bit 1: Group embedding sectors 4 to 7

Bit N: Group embedding sectors 4 x N to 4 x N + 3

Note: Bit 31: Group embedding sectors 124 to 127

7.11.54 FLASH data sectors configuration bank2 (FLASH_EDATA2R_CUR)

This register is nonsecure. It can be read by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

This read-only register reflects the current values of the corresponding options bits.

Address offset: 0x1F0

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EDATA 2_EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EDATA2_STRT[3:0]			
r												r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **EDATA2_EN:** Bank2 flash high-cycle data enable

0: No flash high-cycle data area

1: Flash high-cycle data is used

Bits 14:4 Reserved, must be kept at reset value.

Bits 3:0 **EDATA2_STRT[3:0]:**

EDATA2_STRT contains the start sectors of the flash high-cycle data area in bank2 There is no hardware effect to those bits. They shall be managed by ST tools in Flasher.

0000: The last sector of bank2 is reserved for flash high-cycle data

0001: The two last sectors of bank2 are reserved for flash high-cycle data

0010: The three last sectors of bank2 are reserved for flash high-cycle data

...

Note: 1111: The sixteen last sectors of bank2 are reserved for flash high-cycle data

7.11.55 FLASH data sector configuration bank2 (FLASH_EDATA2R_PRG)

This register is nonsecure. It can be read and written by both secure and nonsecure accesses, and protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register. It is used to program values in corresponding options bits.

Address offset: 0x1F4

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EDATA2_EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EDATA2_STRT[3:0]			
rw												rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **EDATA2_EN:** bank2 flash high-cycle data enable
0: No flash high-cycle data area
1: Flash high-cycle data is used

Bits 14:4 Reserved, must be kept at reset value.

Bits 3:0 **EDATA2_STRT[3:0]:**
EDATA2_STRT contains the start sectors of the flash high-cycle data area in bank2 There is no hardware effect to those bits. They shall be managed by ST tools in Flasher.
0000: The last sector of bank2 is reserved for flash high-cycle data
0001: The two last sectors of bank2 are reserved for flash high-cycle data
0010: The three last sectors of bank2 are reserved for flash high-cycle data
...
Note: 1111: The sixteen last sectors of bank2 are reserved for flash high-cycle data

7.11.56 FLASH HDP bank2 configuration (FLASH_HDP2R_CUR)

This register is initially loaded with the values of the corresponding option bits.

This register is nonsecure. It can be read by both secure and nonsecure accesses, and can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

Address offset: 0x1F8

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP2_END[7:0]							
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP2_STRT[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **HDP2_END[7:0]:** HDPL barrier end set in number of 8-Kbyte sectors

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **HDP2_STRT[7:0]:** HDPL barrier start set in number of 8-Kbyte sectors

7.11.57 FLASH HDP bank2 configuration (FLASH_HDP2R_PRG)

This register is nonsecure. It can be read and written only by both secure and nonsecure accesses. This register can be protected against unprivileged access when NSPRIV = 1 in the FLASH_PRIVCFGR register.

Register is accessible only in HDPL1. In HDPL2 or HDPL3 it is WI, RAZ.

This register is used to program values in corresponding option bits.

Address offset: 0x1FC

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP2_END[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP2_STRT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **HDP2_END[7:0]:** HDPL barrier end set in number of 8-Kbyte sectors

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **HDP2_STRT[7:0]:** HDPL barrier start set in number of 8-Kbyte sectors

7.12 FLASH register map and reset values

Table 77. Register map and reset value table

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	FLASH_ACR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRFTEN	Res.	Res.	WRHIGHFREQ [1:0]		LATENCY [3:0]			
	Reset value																								0			0	1	0	0	1	1
0x004	FLASH_NSKEYR	NSKEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
0x008	FLASH_ SECKEYR	SECKEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C	FLASH_OPTKEYR	OPTKEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x010	FLASH_ NSOBKKEYR	NSOBKKEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	FLASH_ SECOBKKEYR	SECOBKKEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x018	FLASH_OPSR	CODE_OP [2:0]			Res.	Res.	Res.	Res.	OTP_OP	SYSF_OP	BK_OP	DATA_OP	Res.	ADDR_OP[19:0]																			
	Reset value	X	X	X					X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x01C	FLASH_OPTCR	SWAP_BANK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OPTSTRT	OPTLOCK
	Reset value	0																													0	1
0x020	FLASH_NSSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OPTCHANGERR	OBKWERR	OBKERR	INCERR	STRBERR	PGSERR	WRPERR	EOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SDBNE	Res.	WBNE	BSY
	Reset value									0	0	0	0	0	0	0	0													0		0	0
0x024	FLASH_SECSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OBKWERR	OBKERR	INCERR	STRBERR	PGSERR	WRPERR	EOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBNE	Res.	WBNE	BSY
	Reset value										0	0	0	0	0	0	0													X		X	X
0x028	FLASH_NSCR	BKSEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OPTCHANGEERRIE	OBKWIE	OBKIE	INCERRIE	STRBERRIE	PGSERRIE	WRPERRIE	EOPIE	MER	Res.	SNB[7:0]								STRT	FW	BER	SER	PG	LOCK
	Reset value	0									0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 77. Register map and reset value table (continued)

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x02C	FLASH_SECCR	BKSEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OBKWIE	OBKERRIE	INCERRIE	STRBERRIE	PGSERRIE	WRPERRIE	EOPIE	MER	Res.	SNB[7:0]								STRT	FW	BER	SER	PG	LOCK
	Reset value	0	0								0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x030	FLASH_NSCCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLR_OPTCHANGEERR	CLR_OBKWERR	CLR_OBKERR	CLR_INCERR	CLR_STRBERR	CLR_PGSERR	CLR_WRPERR	CLR_EOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value									0	0	0	0	0	0	0	0																
0x034	FLASH_ SECCCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLR_OBKWERR	CLR_OBKERR	CLR_INCERR	CLR_STRBERR	CLR_PGSERR	CLR_WRPERR	CLR_EOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value										0	0	0	0	0	0	0																
0x03C	FLASH_PRIVCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NSPRIV	SPRIV
	Reset value																														0	0
0x040	FLASH_ NSOBKCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWAP_OFFSET[8:0]									Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALT_SECT_ERASE	ALT_SECT	SWAP_SECT_REQ	LOCK
	Reset value								1	1	1	1	1	1	1	1	1													0	0	0	0
0x044	FLASH_ SECOBKCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWAP_OFFSET[8:0]									Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALT_SECT_ERASE	ALT_SECT	SWAP_SECT_REQ	LOCK
	Reset value								1	1	1	1	1	1	1	1	1													0	0	0	0
0x048	FLASH_HDPEXTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP2_EXT[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP1_EXT[7:0]							
	Reset value									0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0
0x04C	Reserved	Reserved																															
0x050	FLASH_ OPTSR_CUR	SWAP_BANK	Res.	BOOT_UBE[7:0]								IWDG_STDBY	IWDG_STOP	Res.	Res.	IO_VDDIO2_HSLV	IO_VDD_HSLV	PRODUCT_STATE[7:0]								NRST_STDBY	NRST_STOP	Res.	WWDG_SW	IWDG_SW	BORH_EN	BOR_LEV[1:0]	
	Reset value	X		X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X

Table 77. Register map and reset value table (continued)

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x054	FLASH_ OPTSR_PRG	SWAP_BANK	Res.	BOOT_UBE[7:0]								IWDG_STDBY	IWDG_STOP	Res.	Res.	IO_VDDIO2_HSLV	IO_VDD_HSLV	PRODUCT_STATE[7:0]								NRST_STDBY	NRST_STOP	Res.	WWDG_SW	IWDG_SW	BORH_EN	BOR_LEV[1:0]	
	Reset value	X		X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
0x058	Reserved	Reserved																															
0x05C	Reserved	Reserved																															
0x060	FLASH_ NSEPOCHR_CUR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NS_EPOCH[23:0]																							
	Reset value									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x064	FLASH_ NSEPOCHR_PRG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NS_EPOCH[23:0]																							
	Reset value									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x068	FLASH_ SECEPOCHR_CUR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEC_EPOCH[23:0]																							
	Reset value									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x06C	FLASH_ SECEPOCHR_PRG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEC_EPOCH[23:0]																							
	Reset value									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x070	FLASH_ OPTSR2_CUR	TZEN[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	USBPD_DIS	Res.	SRAM2_ECC	SRAM3_ECC	BKPRAM_ECC	SRAM2_RST	SRAM1345_RST	Res.	Res.
	Reset value	X	X	X	X	X	X	X	X																X		X	X	X	X	X		
0x074	FLASH_ OPTSR2_PRG	TZEN[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	USBPD_DIS	Res.	SRAM2_ECC	SRAM3_ECC	BKPRAM_ECC	SRAM2_RST	SRAM1345_RST	Res.	Res.
	Reset value	X	X	X	X	X	X	X	X																X		X	X	X	X	X		
0x080	FLASH_ NSBOOTR_CUR	NSBOOTADD[23:0]																								NSBOOT_LOCK[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x084	FLASH_ NSBOOTR_PRG	NSBOOTADD[23:0]																								NSBOOT_LOCK[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x088	FLASH_ SECBOOTR_CUR	SECBOOTADD[23:0]																								SECBOOT_LOCK[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x08C	FLASH_ SECBOOTR_PRG	SECBOOTADD[23:0]																								SECBOOT_LOCK[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x090	FLASH_ OTPBLR_CUR	LOCKBL[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x094	FLASH_ OTPBLR_PRG	LOCKBL[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 77. Register map and reset value table (continued)

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x098	FLASH_WRP12R_CUR	WRPSG12[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x09C	FLASH_WRP12R_PRG	WRPSG12[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x0A0 + 0x004 * x (x = 1 to 8)	FLASH_SECBB1R_x	SECBB1[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C0 + 0x004 * x (x = 1 to 8)	FLASH_PRIVBB1R_x	PRIVBB1[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0D0 - 0x0DC	Reserved	Reserved																															
0x0E0	FLASH_SECWM1R_CUR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM1_END[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM1_STRT[7:0]							
	Reset value									X	X	X	X	X	X	X	X									X	X	X	X	X	X	X	X
0x0E4	FLASH_SECWM1R_PRG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM1_END1[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM1_STRT[7:0]							
	Reset value									X	X	X	X	X	X	X	X									X	X	X	X	X	X	X	X
0x0E8	FLASH_WRP11R_CUR	WRPSG11[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x0EC	FLASH_WRP11R_PRG	WRPSG11[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x0F0	FLASH_EDATA1R_CUR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EDATA1_EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EDATA1_STRT[2:0]		
	Reset value																	X													X	X	X
0x0F4	FLASH_EDATA1R_PRG	Res.	Res	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EDATA1_EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EDATA1_STRT[2:0]		
	Reset value																	X													X	X	X
0x0F8	FLASH_HDP1R_CUR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP1_END[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP1_STRT[7:0]							
	Reset value									X	X	X	X	X	X	X	X									X	X	X	X	X	X	X	X
0x0FC	FLASH_HDP1R_PRG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP1_END[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP1_STRT[7:0]							
	Reset value									X	X	X	X	X	X	X	X									X	X	X	X	X	X	X	X
0x100	FLASH_ECCCORR	Res.	ECCC	Res.	Res.	Res.	Res.	ECCCIE	OTP_ECC	SYSF_ECC	BK_ECC	EDATA_ECC	OBK_ECC	Res.	Res.	Res.	Res.	ADDR_ECC[15:0]															
	0x0000 0000		0					0	0	0	0		0					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 77. Register map and reset value table (continued)

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x104	FLASH_ECCDETR	ECCD	Res.	Res.	Res.	Res.	Res.	Res.	OTP_ECC_FAIL	SYSF_ECC	BK_ECC	EDATA_ECC	OBK_ECC	Res.	Res.	Res.	Res.	ADDR_ECC[15:0]															
	Reset value	0							0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x108	FLASH_ECCDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATA_ECC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x198	FLASH_WRP22R_CUR	WRPSG22[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x19C	FLASH_WRP22R_PRG	WRPSG22[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x1A0 + 0x004 * x (x = 1 to 8)	FLASH_SECBB2R_x	SECBB2[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1A0 + 0x004 * x (x = 1 to 8)	FLASH_PRIVBB2R_x	PRIVBB2[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1D0 - 0x1DC	Reserved	Reserved																															
0x1E0	FLASH_SECWM2R_CUR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM2_END[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM2_STRT[7:0]							
	Reset value									X	X	X	X	X	X	X	X									X	X	X	X	X	X	X	X
0x1E4	FLASH_SECWM2R_PRG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM2_END1[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECWM2_STRT[7:0]							
	Reset value									X	X	X	X	X	X	X	X									X	X	X	X	X	X	X	X
0x1E8	FLASH_WRP21R_CUR	WRPSG21[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x1EC	FLASH_WRP21R_PRG	WRPSG21[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x1F0	FLASH_EDATA2R_CUR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EDATA2_EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EDATA2_STRT[2:0]		
	Reset value																	X													X	X	X
0x1F4	FLASH_EDATA2R_PRG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EDATA2_EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EDATA2_STRT[2:0]		
	Reset value																	X													X	X	X
0x1F8	FLASH_HDP2R_CUR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP2_END[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDP2_STRT[7:0]							
	Reset value									X	X	X	X	X	X	X	X									X	X	X	X	X	X	X	X

Table 77. Register map and reset value table (continued)

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x1FC	FLASH_HDP2R_PRG	Res	Res	Res	Res	Res	Res	Res	Res	HDP2_END[7:0]								Res	Res	Res	Res	Res	Res	Res	Res	HDP2_STRT[7:0]							
	Reset value									X	X	X	X	X	X	X	X									X	X	X	X	X	X	X	X

Refer to *Section 2.3* for the register boundary addresses.

8 Instruction cache (ICACHE)

8.1 ICACHE introduction

The instruction cache (ICACHE) is implemented on the C-AHB code bus of the Cortex®-M33 processor to improve performance when fetching instructions and data from internal and external memories.

Some specific features, like dual master ports, hit-under-miss, and critical-word-first refill policy, result in close to zero-wait-state performance in most use cases.

8.2 ICACHE main features

The main features of ICACHE are listed below:

- Bus interface
  - One 32-bit AHB slave port, the execution port (input from Cortex®-M33 C-AHB code interface)
  - Two AHB master ports: master1 and master2 ports, with outputs to Fast and Slow buses of main AHB bus matrix, respectively
  - One 32-bit AHB slave port for control (input from AHB peripherals interconnect, for ICACHE registers access)
- Cache access
  - 0 wait-state on hits
  - Hit-under-miss capability: ability to serve processor requests (access to cached data) during an ongoing line refill due to a previous cache miss
  - Dual master access: feature used to decouple the traffic according to targeted memory. For example, the ICACHE assigns fast traffic (addressing flash memories and SRAMs) to the AHB master1 port, and slow traffic (addressing external memories) to the AHB master2 port, thus preventing processor stalls on line refills from external memories. This allows ISR (interrupt service routine) fetching on internal flash memory to take place in parallel with a cache line refill from external memories.
  - Minimal impact on interrupt latency, thanks to dual master
  - Optimal cache line refill thanks to WRAPw bursts of the size of the cache line (32-bit word size, **w**, aligned on cache line size)
  - n-way set-associative default configuration with possibility to configure as 1-way, means direct mapped cache, for applications needing very-low-power consumption profile
- Memory address remap
  - Possibility to remap input address falling into up to four memory regions (used to remap aliased code in external memories to the code region, for execution from the C-AHB code interface)
- Replacement and refill
  - pLRU-t (pseudo-least-recently-used, based on binary tree) replacement policy, algorithm with best complexity/performance balance
  - Critical-word-first refill policy, minimizing processor stalls

  - Possibility to configure burst type of AHB memory transaction for remapped regions: INCRw or WRAPw (size w aligned on cache line size)
- Performance counters

  The ICACHE implements two performance counters:
  - Hit monitor counter (32-bit)
  - Miss monitor counter (16-bit)
- Error management
  - Possibility to detect an unexpected cacheable write access, to flag an error, and optionally, to raise an interrupt
- TrustZone® security support
- Maintenance operation
  - Cache invalidate: full cache invalidation, fast command, noninterruptible

8.3 ICACHE implementation

Table 78. ICACHE features for STM32H5E5/E4/F4/F5

Feature	ICACHE
Number of ways	2
Cache size	16 Kbytes
Cache line width	16 bytes
Range granularity of memory regions to be remapped	2 Mbytes
Number of regions to remap	4
Data size of AHB slave interface	32 bits
Data size of AHB fast master1 interface	128 bits
Data size of AHB slow master2 interface	32 bits

8.4 ICACHE functional description

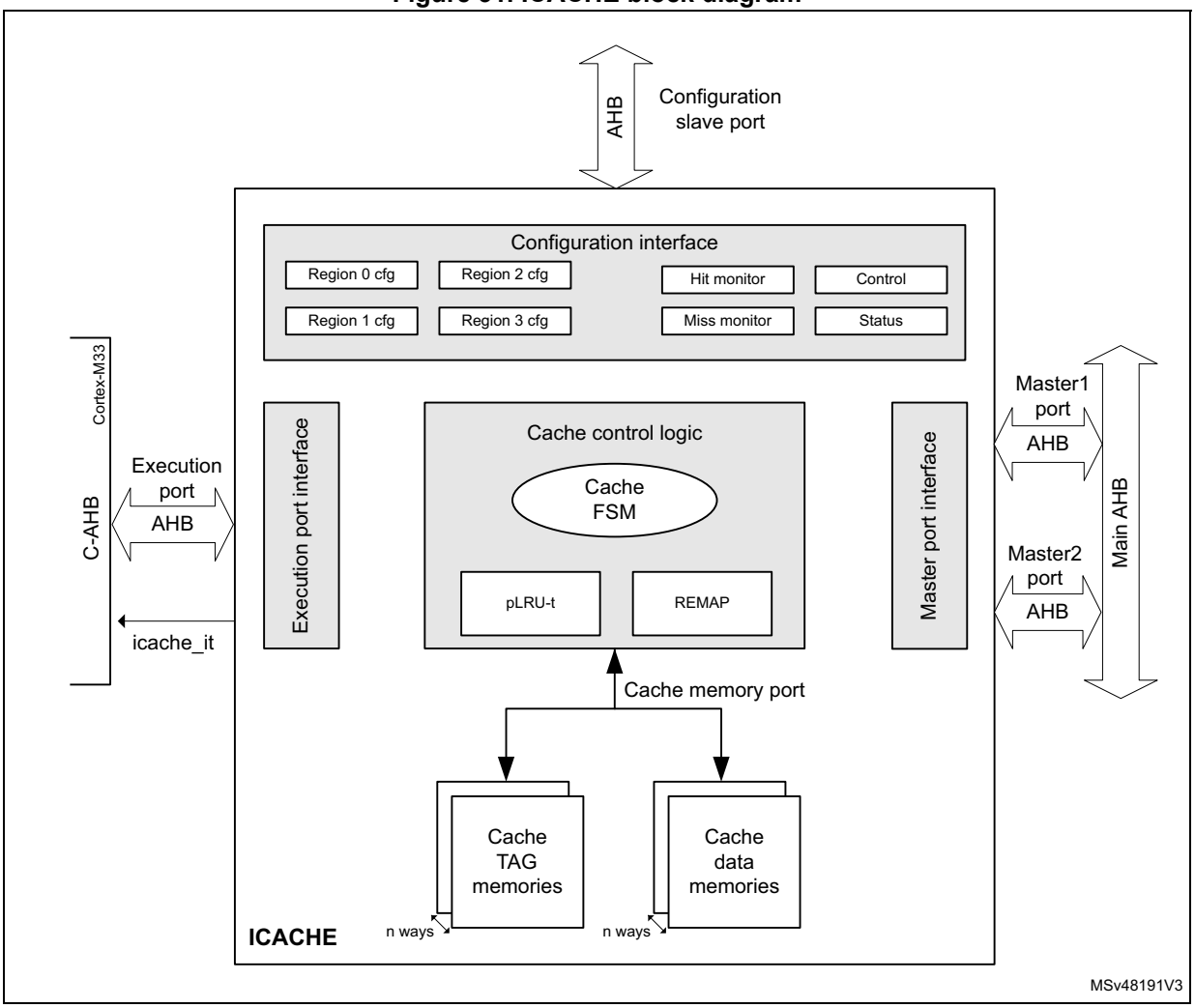
The purpose of this block is to cache instruction fetches or instruction memories loads, coming from the processor. As such, the ICACHE manages only cacheable read transactions, and does not manage cacheable write transactions.

The noncacheable transactions (both read and write) bypass the ICACHE.

For the error management purpose, if a write cacheable transaction is presented (this happens only in case of bad software programming), the ICACHE sets an error flag and, if enabled, raises an interrupt to the processor.

8.4.1 ICACHE block diagram

Figure 31. ICACHE block diagram



8.4.2 ICACHE reset and clocks

The ICACHE is clocked on the Cortex®-M33 C-AHB bus clock.

When the ICACHE reset signal is released, a cache invalidate procedure is automatically launched, making the ICACHE busy (ICACHE_SR = 0x0000 0001).

When this procedure is finished:

- the ICACHE is invalidated: “cold cache”, with all cache line valid bits = 0 (ICACHE must be filled up)
- ICACHE_SR = 0x0000 0002 (reflecting the cache is no longer busy)
- the ICACHE is disabled: the EN bit in ICACHE_CR holds its reset state (= 0).

Note: When disabled, the ICACHE is bypassed, except the remapping mechanism that is still functional: slave input requests (remapped or not) are forwarded to the master port(s).

8.4.3 ICACHE TAG memory

The ICACHE TAG memory contains:

- address tags indicating which data are contained in the cache data memories
- validity bits

There is one valid bit per cache line (per way).

The valid bit is set when a cache line is refilled (after a miss).

Valid bits are reset in any of the below cases:

- after the ICACHE reset is released
- when the cache is disabled, by setting EN = 0 in ICACHE_CR (by software)
- when executing an ICACHE invalidate command, by setting CACHEINV = 1 in ICACHE_CR (by software)

When a cacheable transaction is received at the execution input port, its AHB address (HADDR_in) is split into the following fields (see *Table 79* for B and W definitions):

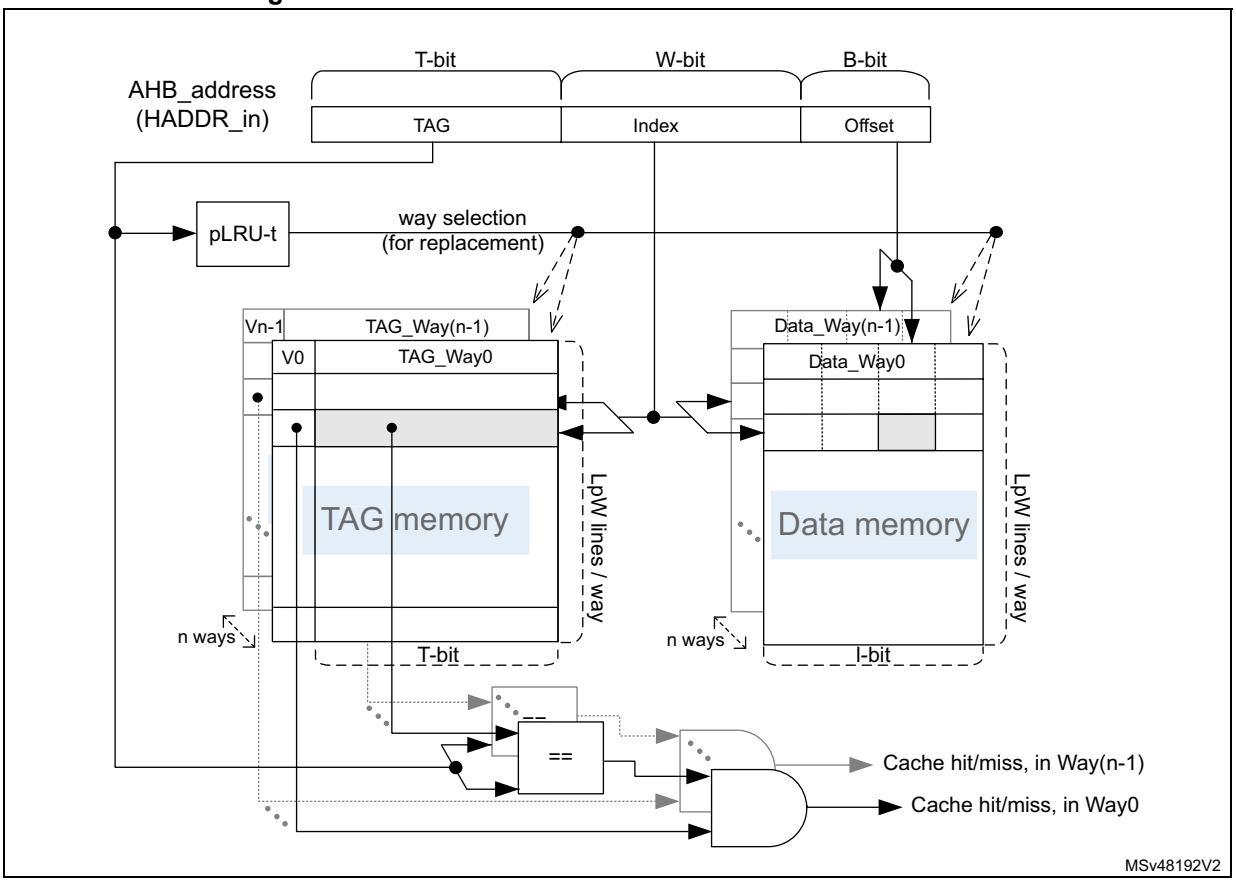
- HADDR_in[B-1:0]: address byte offset, indicates which byte to select inside a cache line.
- HADDR_in[B+W-1:B]: address way index, indicates which cache line to select inside each way.
- HADDR_in[31:B+W]: tag address, to be compared to the TAG memory address to check if the requested data is already available (meaning valid) inside the ICACHE.

The following table gives a summary of the ICACHE main parameters for TAG memory dimensioning. *Figure 32* shows the functional view of TAG and data memories, for an n-way set associative ICACHE.

Table 79. TAG memory dimensioning parameters for n-way set associative operating mode (default)

Parameter	Value	Example
Cache size	S Kbytes = s bytes (s = 1024 x S)	8 Kbytes = 8192 bytes
Cache number of ways	n	2
Cache line size	L-byte = l-bit (l = 8 x L)	16-byte = 128-bit
Number of cache lines	LpW = s / (n x L) lines / way	256 lines / way
Address byte offset size	B = $\log_2$(L) bit	4-bit
Address way index size	W = $\log_2$(LpW) bit	8-bit
TAG address size	T = (32 - W - B) bit	20-bit

Figure 32. ICACHE TAG and data memories functional view



8.4.4 Direct-mapped ICACHE (1-way cache)

The default configuration (at reset) is an n-way set associative cache (WAYSEL = 1 in ICACHE_CR), but the user can configure the ICACHE as direct mapped by writing WAYSEL = 0 (only possible when the cache is disabled, EN = 0 in ICACHE_CR).

The following table gives a summary of ICACHE main parameters for TAG memory when the direct-mapped cache operating mode is selected.

Table 80. TAG memory dimensioning parameters for direct-mapped cache mode

Parameter	Value	Example
Cache size	S Kbytes = s bytes (s = 1024 x S)	8 Kbytes = 8192 bytes
Cache number of ways	1	1
Cache line size	L-byte = l-bit (l = 8 x L)	16-byte = 128-bit
Number of cache lines	LpW = s / L lines	512 lines
Address byte offset size	B = $\log_2$(L) bit	4-bit
Address way index size	W = $\log_2$(LpW) bit	9-bit
TAG address size	T = (32 - W - B) bit	19-bit

All cache operations (such as read, refill, remapping, invalidation) remain the same in the direct-mapped configuration. The only difference is the absence of a replacement algorithm in case of line eviction (as explained in *Section 8.4.8*): only one way (the unique one) is possible for any data refill.

8.4.5 ICACHE enable

To activate the ICACHE, the EN bit in ICACHE_CR must be set to 1.

When the ICACHE is disabled, it is bypassed and all transactions are copied from the slave to the master ports in the same clock cycle.

It is recommended to initialize or modify the main memory content (region to be later cached) with the ICACHE disabled, and to enable the ICACHE only when this region remains unchanged (an enabled ICACHE detects cacheable write transactions as errors).

To ensure performance determinism, it is recommended to wait for the end of a potential cache invalidate procedure before enabling the ICACHE. This procedure occurs when the hardware reset signal is released, when CACHEINV is set, or when EN is cleared in ICACHE_CR. During the procedure, BUSYF is set in ICACHE_SR, and once finished, BUSYF is cleared and BSYENDF is set in the same register (raising the ICACHE interrupt if enabled on such a busy end condition).

The software must test BUSYF and/or BSYENDF values before enabling the ICACHE. Else, if the ICACHE is enabled before the end of an invalidate procedure, any cache access (while BUSYF = 1) is treated as noncacheable, and its performance depends on the main memory access time.

The address remapping is performed, whether the ICACHE is enabled or not, if the input transaction address falls into the memory regions defined and enabled in ICACHE_CRRx (see *Figure 33*).

The ICACHE is, by default, disabled at boot.

8.4.6 Cacheable and noncacheable traffic

The ICACHE is developed for the Cortex®-M33 core. It is placed on the C-AHB bus, and thus caches the code memory region, ranging from address 0x0000 0000 to 0x1FFF FFFF of the memory map.

To make other memory regions cacheable, the ICACHE supports a memory region remapping feature, used to define up to four external memory regions, whose addresses have an alias in the code region. Addressing these memory regions through their code alias address allows the memory request to be routed to the C-AHB bus, and to be managed by the ICACHE.

Any external memory space physically mapped at an address in the range [0x6000 0000:0xAFFF FFFF] or [0xC000 0000:0xDFFF FFFF] can be aliased with an address in the range [0x0000 0000:0x07FF FFFF] or [0x1000 0000:0x1FFF FFFF].

For a given memory request in the code region, the ICACHE implements the address remapping functionality first. If aliased, it is the remapped address, which is then cached, and, if needed, provided to the master port to address the main AHB bus matrix.
The destination physical address does not need further manipulation on the AHB bus.

The remapping functionality is available also for noncacheable traffic, and when the cache is disabled.

Additional details on address remapping are provided in *Section 8.4.7*.

An incoming memory request to the ICACHE is defined as cacheable according to its AHB transaction memory lookup attribute, as shown in *Table 81*. This AHB attribute depends on the MPU (memory protection unit) programming for the addressed region.

Table 81. ICACHE cacheability for AHB transaction

AHB lookup attribute	Cacheability
1	Cacheable
0	Noncacheable

In the case of a noncacheable access (read or write), the ICACHE is bypassed. The AHB transaction is propagated unchanged to the master output port, except the transaction address, which may be modified due to the address remapping feature (see *Section 8.4.7*).

The bypass, and eventual remap logic, does not increase the latency of the access to the targeted memory.

In the case of a cacheable access, the ICACHE behaves as explained in *Section 8.4.8*.

Cacheable memory regions are defined and programmed by the user in the MPU responsible for the generation of the AHB attribute signals for any transaction addressing a given region.

Table 82 summarizes programmable configurations of various memories.

Table 82. Memory configurations

Memory	Cacheable (MPU programming)	Remapped in the ICACHE (ICACHE_CRRx programming)
Flash	Yes or no	Not required
SRAM	Not recommended	Not required
External memories	Yes	Required
	No	Required if the user wants code in external memories fetched on C-AHB bus (else on S-AHB bus)

8.4.7 Address remapping

The ICACHE allows an alias address to be defined in the code region for up to four external memory regions.

The address remapping is applied on the code alias address, transforming it into the destination external physical address.

The remapping operation is fully software configurable by programming ICACHE_CRRx (x = 0 to 3, number of remapped regions). This programming can be done only when the ICACHE is disabled.

Each region x can be individually enabled with REN in ICACHE_CRRx. Once enabled, the remap operation occurs even if the ICACHE is disabled, or if the transaction is noncacheable.

Remap regions can have different size: each can be programmed in RSIZE of its ICACHE_CRRx. The size of each region is a power of two multiple of range granularity (2 Mbytes), with a minimum of 2 Mbytes, and a maximum of 128 Mbytes.

The address remapping mechanism is based on the matching of an incoming AHB address (HADDR_in) with a given code subregion base-address, and the modification of this address into its (remapped) physical address, as follows:

- HADDR_in belongs to region x if HADDR_in[31:RI] = 000:BASEADDR[28:RI], where:
  - 000:BASEADDR is the code subregion base-address programmed in BASEADDR of ICACHE_CRRx.
  - RI defines the number of significant bits to consider. RI = $\log_2$ (region size) with a minimum value of 21 (for a 2-Mbyte region) and a maximum value of 27 (for a 128-Mbyte region).
- If the region x is enabled, the master port output AHB address (HADDR_out) is composed by concatenating the two below parts:
  - REMAPADDR[31:RI] field of ICACHE_CRRx as MSBs
  - HADDR_in[RI-1:0] as LSBs

Figure 33 describes the matching and the output address generation.

Figure 33. ICACHE remapping address mechanism

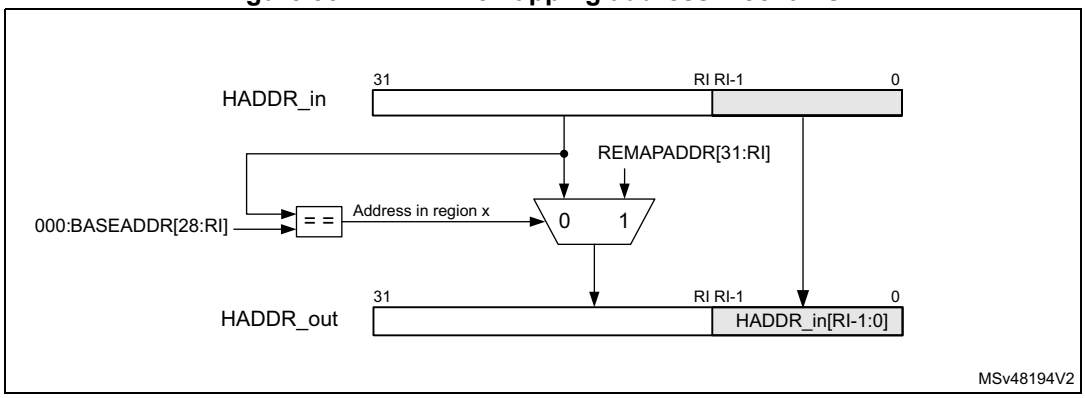


Table 83 summarizes all possible configurations of BASEADDR and REMAPADDR sizes (number of significant MSBs) in ICACHE_CRRx, depending upon RSIZE.

Table 83. ICACHE remap region size, base address, and remap address

Region size (Mbytes)	Base address size (MSBs)	Remap address (MSBs)
2	8	11
4	7	10
8	6	9
16	5	8
32	4	7
64	3	6
128	2	5

Care must be taken while programming BASEADDR and REMAPADDR in ICACHE_CRRx: if the programmed value is bigger than expected (number of MSBs, see *Table 83*), the unneeded extra LSBs are ignored.

Typical remapping example: a 128-Mbyte external RAM region physically located in the external address range [0x9000 0000:0x97FF FFFF], remapped in the code section range [0x1800 0000:0x1FFF FFFF]:

- REMAPADDR[31:21] = 0x480
- BASEADDR[28:21] = 0xC0
- HADDR_in[31:27] is compared to 000:BASEADDR[28:27], while HADDR_in and BASEADDR[26:21] are ignored.

If the comparison matches:

- HADDR_out[31:27] gets REMAPADDR[31:27] (in place of HADDR_in[31:27])
- HADDR_out[26:0] gets HADDR_in[26:0]

The software can program the kind of AHB burst generated by the ICACHE master ports on the bus matrix (for cache line refill), by setting HBURST in ICACHE_CRRx with:

- WRAP for remapped external memories accessed through interfaces that can support WRAP burst mode, providing the benefit of the critical-word-first feature performance:
  - WRAP burst size = cache line size
  - WRAP burst start address = word address of the first data requested by the core
- INCR: INCR burst mode for external memories accessed through the interfaces that do not support WRAP burst mode (losing the benefit of critical-word-first feature):
  - INCR burst size = cache line size
  - INCR burst start address = address aligned on the boundary of the cache line containing the requested word.

Note: Coherency is needed when programming the SAU (secure attribution unit) and the MPU (memory protection unit) attributes for both the external regions and their aliased code subregions.

8.4.8 Cacheable accesses

When the ICACHE receives a cacheable transaction from the Cortex®-M33, it checks if the address requested is present in its TAG memory, and if the corresponding cache line is valid.

There are then three alternatives:

- The address is present inside the TAG memory, the cache line is valid: **cache hit**, the data is read from the cache and provided to the processor in the same cycle.
- The address is not present in the TAG memory: **cache miss**, the data is read from the main memory and provided to the processor, and a cache line refill is performed.

  The critical-word-first policy ensures minimum wait cycles for the processor, since read data can be provided while the cache still performs a cache line refill (associated latency is the latency of fetching one word from the main memory).

  The burst generated on the ICACHE master bus is WRAPw (w being the cache line width, in words) if no address remap occurs. If an address remap occurs, the kind of burst depends upon the HBURST programmed in corresponding ICACHE_CRRx.

  The AHB transaction attributes are also propagated to the main AHB bus matrix on the master port selected for the line refill.

- The address is not present in TAG memory, but belongs to the refill burst from the main memory currently ongoing: **cache hit** (hit-under-miss feature).

  This happens during cache-line refill. The ICACHE can provide the requested data as soon as data are available at its master interface, thus avoiding a miss (fetching data from the main memory).

In the case of cache refill (due to cache miss), the ICACHE selects which cache line is written with the refill data:

- In direct map (1-way) mode, only one line can be used to store the refill data: the line pointed by the index of the input address.
- In n-way set associative mode, one line among n can be used (the line pointed by the address index, in each of the n ways). The way selection is based on a pLRU-t replacement algorithm that points, for each index, on the way candidate for the next refill.

If the cache line where the refill data must be written is already valid, the targeted cache line must be invalidated first. This is true whatever the direct map or n-way set associative cache mode.

8.4.9 Dual-master cache

The ICACHE implements a dual-port AHB master on the main AHB bus matrix: master1 and master2 ports. This is used to split the traffic going to different destination memories.

The nonremapped traffic goes systematically to master1 port. The remapped traffic can be routed on the master2 port by programming MSTSEL in ICACHE_CRRx (on a region basis).

The code can typically be fetched as follows:

- internal flash memory and internal SRAM on master1 port (Fast bus)
- external flash memory/RAM on master2 port (Slow bus)

For systems not implementing external memories, the traffic to the internal flash memory can be decoupled from the traffic to the internal SRAM (when remapped by the ICACHE). This feature is used to prevent further processor stalls on misses.

Alongside with hit-under-miss, this dual-master feature allows the processor to have an alternative path in case of fetching from different memories.

8.4.10 ICACHE security

The ICACHE implements an Armv8-M TrustZone.

ICACHE configuration registers are protected at system level.

8.4.11 ICACHE maintenance

The software can invalidate the whole content of the ICACHE by programming CACHEINV in the ICACHE_CR register.

When CACHEINV = 1, the ICACHE control logic sets the BUSYF flag in ICACHE_SR and launches the invalidate cache operation, resetting each TAG valid bit to 0 (one valid bit per cache line). CACHEINV is automatically cleared.

Once the invalidate operation is finished (all valid bits reset to 0), the ICACHE automatically clears BUSYF, and sets BSYENDF in the ICACHE_SR register.

If enabled on this flag condition (BSYENDIE = 1 in ICACHE_IER), the ICACHE interrupt is raised. Then, the (empty) cache is available again.

8.4.12 ICACHE performance monitoring

The ICACHE provides the following monitors for performance analysis:

- The 32-bit hit monitor counts the cacheable AHB-transactions on the slave cache port that hits the ICACHE content.

  It also takes into account all accesses whose address is present in the TAG memory or in the refill buffer (due to a previous miss, and whose data is coming, or is soon to come, from the cache master port) (see *Section 8.4.8*).
- The 16-bit miss monitor counts the cacheable AHB-transactions on the slave cache port that misses the ICACHE content.

  It also takes into account all accesses whose address is not present neither in the TAG memory nor in the refill buffer.

Upon reaching their maximum values, these monitors do not wrap over.

Hit and miss monitors can be enabled and reset by software allowing the analysis of specific pieces of code.

The software can perform the following tasks:

- Enable/stop the hit monitor through HITMEN in ICACHE_CR.
- Reset the hit monitor by setting HITMRST in ICACHE_CR.
- Enable/stop the miss monitor through MISSMEN in ICACHE_CR.
- Reset the miss monitor by setting MISSMRST in ICACHE_CR.

To reduce power consumption, these monitors are disabled (stopped) by default.

8.4.13 ICACHE boot

The ICACHE is disabled (EN = 0 in ICACHE_CR) at boot.

The code remapping at boot is not needed for a Cortex®-M33 as it implements the VTOR (vector tables) that allows a boot start address definition different than 0x0.

Once the boot is finished, the ICACHE can be enabled (software setting EN = 1 in CACHE_CR).

8.5 ICACHE low-power modes

At device level, using the ICACHE reduces the power consumption by fetching instructions from the internal ICACHE most of the time, rather than from the bigger and then more power consuming main memories. This reduction is even higher if the cached main memories are external.

Applications with lower performance profile (in terms of hit ratio) and stringent power consumption constraints may benefit from the lower power consumption of an ICACHE configured as direct mapped. This single-way cache configuration is obtained by programming WAYSEL = 0 in ICACHE_CR (see *Figure 32*). The power consumption is reduced by accessing, for each request, only the necessary cut of TAG and data memories. The cache effect still improves fetch performance, even if for most code execution, it is less efficient than with an n-way set associative cache mode.

8.6 ICACHE error management and interrupts

If an unsupported cacheable write request is detected (functional error), the ICACHE generates an error by setting the ERRF flag in ICACHE_SR. An interrupt is generated if the corresponding interrupt enable bit is set (ERRIE = 1 in ICACHE_IER).

The other possible interrupt generation is at the end of a cache invalidation operation. When the cache-busy state is finished, the ICACHE sets the BSYENDF flag in ICACHE_SR. An interrupt is generated if the corresponding interrupt enable bit is set (BSYENDIE = 1 in ICACHE_IER).

All ICACHE interrupt sources raise the same and unique interrupt signal, icache_it, and then use the same interrupt vector.

Table 84. ICACHE interrupts

Interrupt vector	Interrupt event	Event flag	Enable control bit	Interrupt clear method
ICACHE	Functional error	ERRF in ICACHE_SR	ERRIE in ICACHE_IER	Set CERRF to 1 in ICACHE_FCR
	End of busy state (invalidate finished)	BSYENDF in ICACHE_SR	BSYENDIE in ICACHE_IER	Set CBSYENDF to 1 in ICACHE_FCR

The ICACHE also propagates all AHB bus errors (such as security issues, address decoding issues) from the master1 or master2 port back to the execution port.

8.7 ICACHE registers

8.7.1 ICACHE control register (ICACHE_CR)

Address offset: 0x000

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MISSMRST	HITMRST	MISSMEN	HITMEN
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WAYSEL	CACHEINV	EN
													rw	w	rw

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **MISSMRST**: miss monitor reset
0: release the cache miss monitor reset (needed to enable the counting)
1: reset cache miss monitor

Bit 18 **HITMRST**: hit monitor reset
0: release the cache miss monitor reset (needed to enable the counting)
1: reset cache hit monitor

Bit 17 **MISSMEN**: miss monitor enable
0: cache miss monitor switched off. Stopping the monitor does not reset it.
1: cache miss monitor enabled

Bit 16 **HITMEN**: hit monitor enable
0: cache hit monitor switched off. Stopping the monitor does not reset it.
1: cache hit monitor enabled

Bits 15:3 Reserved, must be kept at reset value.

Bit 2 **WAYSEL**: cache associativity mode selection
This bit allows user to choose ICACHE set-associativity. It can be written by software only when cache is disabled (EN = 0).
0: direct mapped cache (1-way cache)
1: n-way set associative cache (reset value)

Bit 1 **CACHEINV**: cache invalidation
Set by software and cleared by hardware when the BUSYF flag is set (during cache maintenance operation). Writing 0 has no effect.
0: no effect
1: invalidate entire cache (all cache lines valid bit = 0)

Bit 0 **EN**: enable
0: cache disabled
1: cache enabled

8.7.2 ICACHE status register (ICACHE_SR)

Address offset: 0x004

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ERRF	BSYENDF	BUSYF
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **ERRF**: cache error flag
0: no error
1: an error occurred during the operation (cacheable write)

Bit 1 **BSYENDF**: busy end flag
0: cache busy
1: full invalidate CACHEINV operation finished

Bit 0 **BUSYF**: busy flag
0: cache not busy on a CACHEINV operation
1: cache executing a full invalidate CACHEINV operation

8.7.3 ICACHE interrupt enable register (ICACHE_IER)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ERRIE	BSYENDIE	Res.
													rw	rw	

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **ERRIE**: interrupt enable on cache error

Set by software to enable an interrupt generation in case of cache functional error (cacheable write access)

0: interrupt disabled on error

1: interrupt enabled on error

Bit 1 **BSYENDIE**: interrupt enable on busy end

Set by software to enable an interrupt generation at the end of a cache invalidate operation.

0: interrupt disabled on busy end

1: interrupt enabled on busy end

Bit 0 Reserved, must be kept at reset value.

8.7.4 ICACHE flag clear register (ICACHE_FCR)

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CERRF	CBSYENDF	Res.
													w	w	

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **CERRF**: clear cache error flag

Set by software.

0: no effect

1: clears ERRF flag in ICACHE_SR

Bit 1 **CBSYENDF**: clear busy end flag

Set by software.

0: no effect

1: clears BSYENDF flag in ICACHE_SR.

Bit 0 Reserved, must be kept at reset value.

8.7.5 ICACHE hit monitor register (ICACHE_HMONR)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HITMON[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HITMON[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **HITMON[31:0]**: cache hit monitor counter

8.7.6 ICACHE miss monitor register (ICACHE_MMONR)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MISSMON[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **MISSMON[15:0]**: cache miss monitor counter

8.7.7 ICACHE region x configuration register (ICACHE_CRRx)

Address offset: 0x020 + 0x4 * x, (x = 0 to 3)

Reset value: 0x0000 0200

Define an alias address in the code region for other regions, making them cacheable.

BASEDADDR and REMAPADDR fields are write locked (read only) when EN = 1 in ICACHE_CR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HBURST	Res.	Res.	MSTSEL	Res.	REMAPADDR[31:21]										
rw			rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REN	Res.	Res.	Res.	RSIZE[2:0]			Res.	BASEADDR[28:21]							
rw				rw	rw	rw		rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **HBURST**: output burst type for region x
0: WRAP
1: INCR

Bits 30:29 Reserved, must be kept at reset value.

Bit 28 **MSTSEL**: AHB cache master selection for region x
0: no action (master1 selected by default)
1: master2 selected

Bit 27 Reserved, must be kept at reset value.

Bits 26:16 **REMAPADDR[31:21]**: remapped address for region x
This field replaces the alias address defined by BASEADDR field.
The only useful bits are [31:RI], where 21 ≤ RI ≤ 27 is the number of bits of RSIZE (see *Section 8.4.7*). If the programmed value has more LSBs, the useless bits are ignored.

Bit 15 **REN**: enable for region x
0: disabled
1: enabled

Bits 14:12 Reserved, must be kept at reset value.

Bits 11:9 **RSIZE[2:0]**: size for region x
000: reserved
001: 2 Mbytes
010: 4 Mbytes
011: 8 Mbytes
100: 16 Mbytes
101: 32 Mbytes
110: 64 Mbytes
111: 128 Mbytes

Bit 8 Reserved, must be kept at reset value.

Bits 7:0 **BASEADDR[28:21]**: base address for region x
This alias address is replaced by REMAPADDR field.
The only useful bits are [28:RI], where 21 ≤ RI ≤ 27 is the number of bits of RSIZE (see *Section 8.4.7*). If the programmed value has more LSBs, the useless bits are ignored.

8.7.8 ICACHE register map

Table 85. ICACHE register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	ICACHE_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MISSMRST	HITMRST	MISSMEN	HITMEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WAYSEL	CACHEINV	EN
	Reset value													0	0	0	0														1	0	0
0x004	ICACHE_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ERRF	BSYENDF	BUSYF
	Reset value																														0	0	1

Table 85. ICACHE register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x008	ICACHE_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ERRIE	BSYENDIE	Res.
	Reset value																														0	0	
0x00C	ICACHE_FCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CERRF	CBSYENDF	Res.
	Reset value																														0	0	
0x010	ICACHE_HMONR	HITMON[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	ICACHE_MMONR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MISSMON[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x018-0x01C	Reserved	Reserved																															
0x020	ICACHE_CRR0	HBURST	Res.	Res.	MSTSEL	Res.	REMAPADDR[31:21]											REN	Res.	Res.	Res.	RSIZE [2:0]			Res.	BASEADDR[28:21]							
	Reset value	0			0		0	0	0	0	0	0	0	0	0	0	0	0				0	0	1		0	0	0	0	0	0	0	0
0x024	ICACHE_CRR1	HBURST	Res.	Res.	MSTSEL	Res.	REMAPADDR[31:21]											REN	Res.	Res.	Res.	RSIZE [2:0]			Res.	BASEADDR[28:21]							
	Reset value	0			0		0	0	0	0	0	0	0	0	0	0	0	0				0	0	1		0	0	0	0	0	0	0	0
0x028	ICACHE_CRR2	HBURST	Res.	Res.	MSTSEL	Res.	REMAPADDR[31:21]											REN	Res.	Res.	Res.	RSIZE [2:0]			Res.	BASEADDR[28:21]							
	Reset value	0			0		0	0	0	0	0	0	0	0	0	0	0	0				0	0	1		0	0	0	0	0	0	0	0
0x02C	ICACHE_CRR3	HBURST	Res.	Res.	MSTSEL	Res.	REMAPADDR[31:21]											REN	Res.	Res.	Res.	RSIZE [2:0]			Res.	BASEADDR[28:21]							
	Reset value	0			0		0	0	0	0	0	0	0	0	0	0	0	0				0	0	1		0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

9 Data cache (DCACHE)

9.1 DCACHE introduction

The data cache (DCACHE) is introduced on S-AHB system bus of the Cortex®-M33 processor to improve the performance of data traffic to/from external memories.

Some specific features, like hit-under-miss and critical-word-first refill policy, optimize performance on external memories data accesses.

9.2 DCACHE main features

The main features of DCACHE are described below:

- Bus interface
  - One 32-bit AHB slave port, the system port (input from Cortex®-M33 S-AHB system interface)
  - One 32-bit AHB master port (output to main AHB bus matrix)
  - One 32-bit AHB slave port for control (input from AHB peripherals interconnect, for access to DCACHE registers)
- Cache access
  - 0 wait-state on hits
  - Hit-under-miss capability: ability to serve processor requests (access to cached data) during an ongoing line refill due to a previous cache miss
  - Optimized cache line refill thanks to WRAP bursts of the size of the cache line (such as WRAP4 for 128-bit cache line)
  - 2-way set-associative
  - Supports both write-back and write-through policies (selectable with AHB bufferable attribute)
  - Read and write-back always allocate
  - Write-through always non-allocate (write-around)
  - Supports byte, half-word, and word writes
- Replacement and refill
  - pLRU-t replacement policy (pseudo-least-recently-used, based on binary tree), algorithm with best complexity/performance balance
  - Critical-word-first refill policy for read transactions, minimizing processor stalls
  - Possibility to configure burst type of all AHB memory transactions: INCRw or WRAPw (size w aligned on cache line size)
- Performance counters

  The DCACHE implements four performance counters:
  - Two hit-monitor counters (32-bit): number of read hits, number of write hits
  - Two miss-monitor counters (16-bit): number of read misses, number of write misses

- Error management
  - Possibility to detect error for master port request initiated by DCACHE itself (a cache line written back into main memory, because of an eviction or a clean operation), to flag this error, and optionally to raise an interrupt
- TrustZone security support
- Maintenance operations
  - Cache invalidate: full cache invalidation, fast command, non-interruptible
  - Cache invalidate range: invalidates cache lines whose address belongs to defined range, background task, interruptible
  - Cache clean range: cleans cache lines (if dirty bit = 1, write back line, then clear dirty bit) whose address belongs to defined range, background task, interruptible
  - Cache clean and invalidate range: cleans and invalidates cache lines (if dirty bit = 1, write back line, then invalidate it) whose address belongs to defined range, background task, interruptible

9.3 DCACHE implementation

The DCACHE1 is placed on Cortex®-M33 S-AHB bus, and caches only the external RAM memory region (OCTOSPI and FMC), in the address range [0x6000 0000:0x9FFF FFFF] and [0xC000 0000:0xDFFF FFFF] of the memory map.

Indeed, by placing a bus matrix demultiplexing node in front of the DCACHE1, S-AHB bus memory requests addressing SRAM region or peripherals region (respectively in ranges [0x2000 0000:0x3FFF FFFF] and [0x4000 0000:0x5FFF FFFF]) are routed directly to the main AHB bus matrix, and the DCACHE1 is bypassed.

Table 86. DCACHE features for STM32H5E5/E4/F4/F5

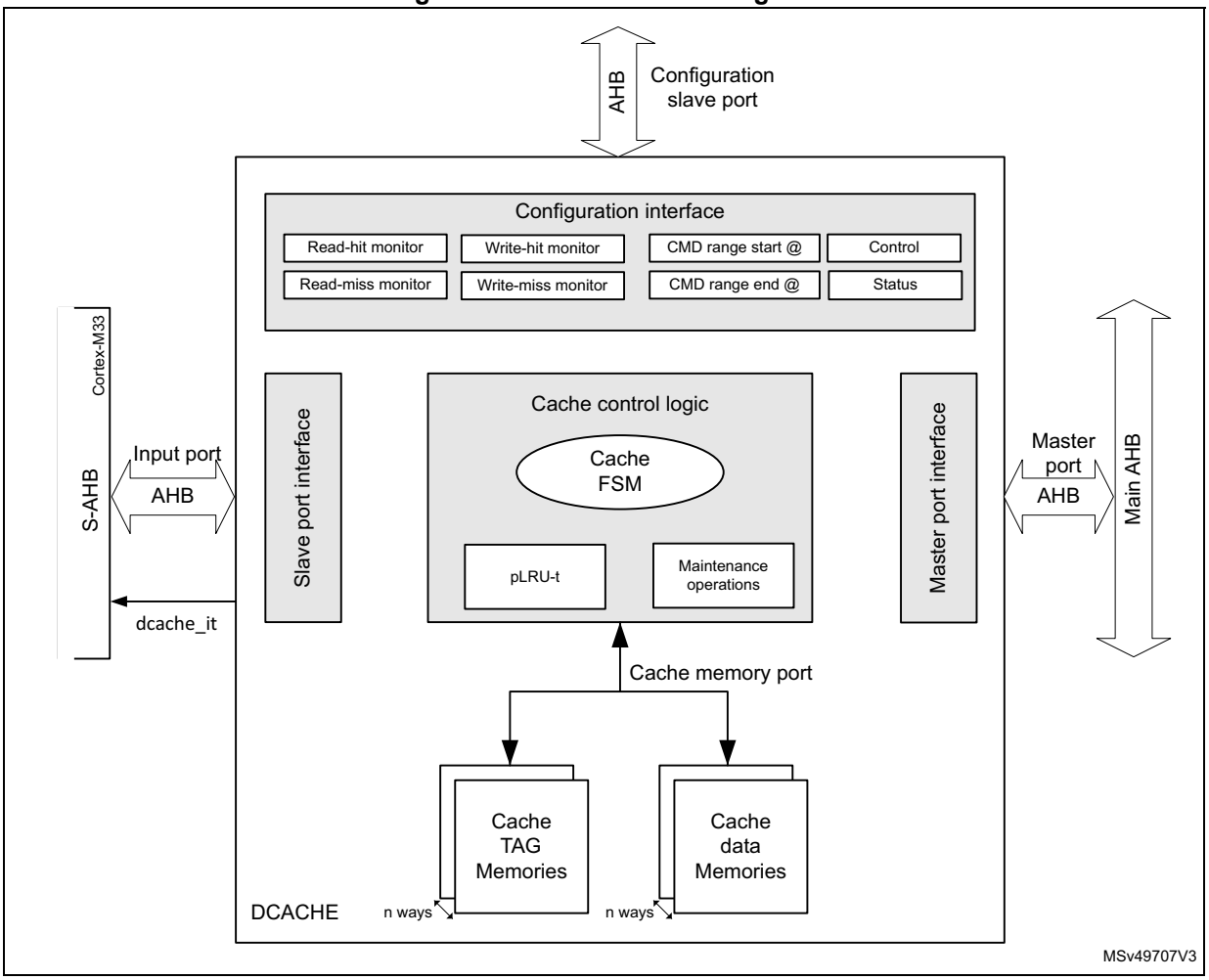
Features	DCACHE1
Number of ways	2
Cache size	8 Kbytes
Cache line width	16 bytes
Data size of AHB Master interface	32 bits

9.4 DCACHE functional description

The purpose of the data cache is to cache external memory data loads and stores, coming from the processor. These accesses include the instruction fetches that may occur at an external memory address. The DCACHE manages both read and write transactions.

9.4.1 DCACHE block diagram

Figure 34. DCACHE block diagram



9.4.2 DCACHE reset and clocks

The DCACHE is clocked on the Cortex®-M33 S-AHB bus clock.

When the DCACHE reset signal is released, a cache invalidate procedure is automatically launched, making the DCACHE busy (DCACHE_SR = 0x0000 0001).

When this procedure is finished:

- The DCACHE is invalidated: cold cache, with all cache line valid, dirty, and privilege bits = 0 (DCACHE must be filled up)
- DCACHE_SR = 0x0000 0002 (reflecting the cache is no longer busy)
- The DCACHE is disabled: the EN bit in DCACHE_CR holds its reset state (= 0).

Note: When disabled, the DCACHE is bypassed: slave input requests are just forwarded to the master port.

9.4.3 DCACHE TAG memory

The DCACHE TAG memory contains:

- address tags that indicate which data are contained in the cache data memories
- validity bits
- dirty bits
- privilege bits

There is one valid bit, one dirty bit, and one privilege bit per cache line (per way).

The valid bit enables/disables access to the data cache line: if the line is not valid, the data access (read or write) is performed in the main memory.

The valid bit is set when the cache line is written (refilled by either a read miss or a write-back miss).

Valid bits are reset in any of the below cases:

- after the DCACHE reset is released
- when the cache is disabled, by setting EN = 0 in DCACHE_CR (by software)
- when executing one of the DCACHE invalidate commands, setting by software CACHEINV = 0, or CACHECMD = 0b010 or 0b011 in DCACHE_CR (see *Section 9.4.8*).

The dirty bit indicates that the cache line has up-to-date values with respect to the main memory content (the cache has last right value, the main memory is not up to date).

The dirty bit is set when the cache line is written by a slave port write transaction (only in case of an access with write-back attribute).

Dirty bits are reset in any of the below cases:

- after the DCACHE reset is released
- when a line refill is performed on a read miss (on a write-back miss, the refilled cache line is modified by the written data, and dirty bit = 1)
- when the cache invalidation is performed
- when executing one of the DCACHE clean operations (cache line written back to the main memory), setting by software CACHECMD = 0b001 or 0b011 in DCACHE_CR (see *Section 9.4.8*).

The privilege bit indicates if the data is managed by a privileged entity. It is assigned according to the value of AHB privileged attribute at the input slave port, for the first access to this line (it is written only during the line refill, on read miss or write-back miss).

The privilege bit holds the same polarity as the privileged attribute: 1 for privileged access, 0 for unprivileged access.

Privilege bits are reset when the cache is invalidated, and after the DCACHE reset is released.

When a cacheable transaction is received at input slave port, its AHB address (HADDR_in) is split into the following fields (see the table below for B and W values):

- HADDR_in[B-1:0]: address byte offset, indicates which byte to select within a cache line.
- HADDR_in[B+W-1:B]: address way index, indicates which cache line to select inside each way.
- HADDR_in[31:B+W]: tag address, to be compared to TAG memory address to check if the requested data is already available (meaning valid) within the DCACHE

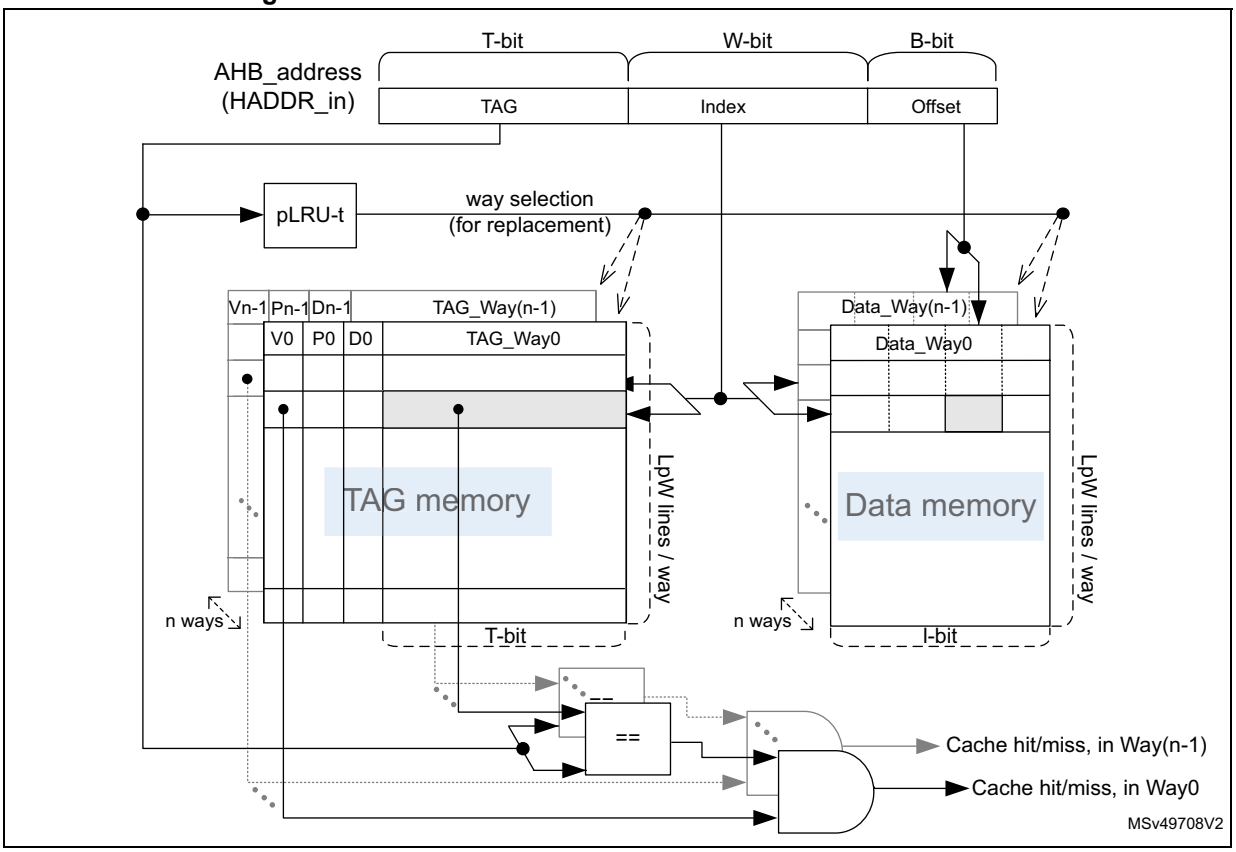
Table 87 gives DCACHE main parameters for TAG memory dimensioning.

Figure 35 shows the functional view of TAG and data memories, for an n-way set associative DCACHE.

Table 87. TAG memory dimensioning parameters

Parameter	Value	Example
Cache size	S Kbytes = s bytes (s = 1024 x S)	4 Kbytes = 4096 bytes
Cache number of ways	n	2
Cache line size	L-byte = l-bit (l = 8 x L)	16-byte = 128-bit
Number of cache lines (per way)	LpW = s / (n x L) lines/way	128 lines/way
Address byte offset size	B = $\log_2$(L) bit	4-bit
Address way index size	W = $\log_2$(LpW) bit	7-bit
TAG address size	T = (32 - W - B) bit	21-bit

Figure 35. DCACHE TAG and data memories functional view



9.4.4 DCACHE enable

To activate the DCACHE functioning, the EN bit must be set in DCACHE_CR control register.

When DCACHE is disabled, it is bypassed and all transactions are copied from slave port to master port in the same clock cycle, and no comparison is performed with TAG address.

DCACHE is by default disabled at boot.

9.4.5 Cacheable and noncacheable traffic

DCACHE is developed for a Cortex®-M33 core and caches the memory regions addressed by the AHB bus connected to it.

In addition, the AHB bus traffic to the memory regions can be cacheable or noncacheable. An incoming memory request to DCACHE is defined as cacheable according to its AHB transaction memory lookup attribute.

In case of write transaction, the DCACHE write policy is defined as write-through or write-back according to its AHB transaction memory bufferable attribute (see *Table 88*).

These AHB attributes depend on the memory protection unit (MPU) programming for the addressed region.

Table 88. DCACHE cacheability for AHB transaction

AHB lookup attribute	AHB bufferable attribute	Cacheability
0	x	Read and write: non cacheable
1	0	Read: cacheable Write: (cacheable) write-through
1	1	Read: cacheable Write: (cacheable) write-back

In case of noncacheable access, the DCACHE is bypassed, meaning that the AHB transaction is propagated unchanged to the master output port.

The bypass does not increase the latency of the access to the targeted memory.

In case of cacheable access, the DCACHE behaves as explained in *Section 9.4.6*.

Cacheable memory regions are defined and programmed by the user in the MPU, responsible for the generation of the AHB attribute signals for any transaction addressing a given region.

9.4.6 Cacheable accesses

When the DCACHE receives a cacheable transaction from Cortex®-M33 on its slave port, the DCACHE checks if the address requested is present in its TAG memory and if the corresponding cache line is valid.

For **read** transaction, there are three alternatives:

- The address is present inside the TAG memory, the cache line is valid: **cache read hit**, the data is read from cache and provided to the processor in the same cycle.
- The address is not present in the TAG memory: **cache read miss**, the data is read from the main memory and provided to the processor, and a cache line refill is performed.

  The critical-word-first refill policy insures minimum wait cycles for the processor, since read data can be provided while cache is still performing cache line refill (associated latency is the latency of fetching one word from main memory).

  The kind of burst generated on the DCACHE master bus depends on HBURST bit in DCACHE_CR: either INCRw or WRAPw (w being the cache line width, in words).

  The AHB transaction attributes are also propagated from the slave input (missing) request to the master output refill request.
- The address is not present in the TAG memory but belongs to the refill burst from main memory that is currently ongoing: **cache read hit** as well (hit-under-miss feature).

  Whatever the line refill is due to a read or write (missing) transaction, the DCACHE can provide the requested read data as soon as the data is available at its master interface, thus avoiding a miss (with data fetch from main memory).

For **write-back** transaction (write transaction, with write-back bufferable attribute), there are three alternatives as well:

- The address is present inside the TAG memory, cache line is valid: **cache write-back hit**, the data is written in cache.
- The address is not present in the TAG memory (or the cache line is not valid): **cache write-back miss**.

  First, a line allocation is performed by reading the entire cache line data from main memory. The kind of burst generated on the DCACHE master bus for this line refill depends on HBURST bit in DCACHE_CR: either INCRw or WRAPw (w being the cache line width, in words), and the AHB transaction attributes are propagated from the slave port initial request.

  Once the refilled line is written in the DCACHE, the initial data provided on the slave port is written in this DCACHE line (it overwrites the data part of the cache line that was refilled just before).
- The address is not present in the TAG memory but belongs to the refill burst from main memory that is currently ongoing: **cache write-back hit** as well (hit-under-miss feature).

  Whatever the line refill is due to a read or write (missing) transaction, the DCACHE can write incoming data directly inside the refilled line, thus avoiding a miss (with refill from main memory).

For **write-through** transaction (write transaction, with write-through bufferable attribute), only two alternatives exist:

- The address is present inside the TAG memory, cache line is valid: **cache write-through hit**, the data is written both in cache and in main memory (through master port).
- The address is not present in the TAG memory (or the cache line is not valid): **cache write-through miss**, the data incoming at slave port is written only in main memory (unlike the write-back miss, there is no line allocation and data written in cache).

In case of cache refill (due to cache miss), the DCACHE selects which cache line is written with the refill data: as a 2-way set associative cache, one line among two can be used (line pointed by the address index, in each of the two ways). The way selection is based on a pLRU-t replacement algorithm that points, for each index, on the way candidate for the next refill.

If the cache line where the refill data must be written is already valid, the targeted cache line must be evicted first:

- If the dirty tag of this line equals 0 (clean data), the line is simply invalidated.
- If it equals 1 (dirty data), the line must be written back in the main memory.

  The DCACHE generates a burst write transaction on its master port, with burst type set to INCRw (w being the cache line width, in words), and with AHB memory transaction attribute signals set as below:
  - data (not instruction)
  - privileged = TAG privilege bit
  - write-back (even if it does not care)
  - normal memory
  - cacheable
  - allocate (even if it does not care)

– nonshareable

These AHB attributes cannot be propagated from the slave port (as it is the case for all other transactions emitted by the DCACHE) because the evicting transaction has no relation with the initial missing transaction. Setting of the AHB attributes is fixed, except for the privileged bit that is copied from the TAG privilege bit of the evicted line.

9.4.7 DCACHE security

The DCACHE implements an Armv8-M TrustZone.

DCACHE configuration registers are protected at system level.

9.4.8 DCACHE maintenance

The DCACHE features several maintenance operations that the software can programmed in DCACHE_CR control register:

- **Full invalidate**: invalidates the whole cache, non interruptible task.

  The software can invalidate the whole DCACHE content by programming CACHEINV in DCACHE_CR.

  When CACHEINV = 1, the DCACHE control logic sets BUSYF flag in DCACHE_SR status register, and performs the operation of cache invalidation, resetting each TAG valid bit to 0 (one valid bit per cache line). Each dirty and privilege bits are also reset to 0 during cache invalidation to prevent unknown values at next cache line validation. CACHEINV is automatically cleared.

  Once the full invalidate operation is finished, the DCACHE automatically clears BUSYF flag, and sets BSYENDF in DCACHE_SR.

  If enabled on this flag condition (BSYENDIE = 1 in DCACHE_IER), the DCACHE interrupt is raised. Then, the (empty) cache is available again.

  This full invalidate operation is not interruptible, meaning that the cache does not treat any cacheable request while BUSYF = 1. However, non-cacheable traffic is treated (since the request address is not compared to TAG ones), the DCACHE being bypassed in the same clock cycle (same behavior as when the DCACHE is disabled).

- **Invalidate range**: invalidates a certain range of addresses in the cache, background task (interruptible).

  The software can invalidate a given data region in the DCACHE by programming STARTCMD = 1 and CACHECMD = 0b010 in DCACHE_CR, after the address range was programmed into DCACHE_CMDRSADDRR (range start address) and DCACHE_CMDREADDRR (range end address).

  The DCACHE control logic then parses the whole TAG memory. If the read line address (TAG address + line index) falls in the programmed address range (DCACHE_CMDRSADDRR ≤ Line Addr ≤ DCACHE_CMDREADDRR), the

corresponding cache line is invalidated (line TAG bits cleared, valid bit = dirty bit = privilege bit = 0).

When STARTCMD is set, the DCACHE control logic sets BUSYCMDF in DCACHE_SR and launches the invalidate range operation. STARTCMD is also automatically cleared.

Once the operation is finished (all TAG memory parsed), the DCACHE automatically clears BUSYCMDF and sets CMDENDF in DCACHE_SR.

If enabled on this flag condition (CMDENDIE = 1 in DCACHE_IER), the DCACHE interrupt is raised.

During this invalidate range operation, the DCACHE is interruptible, meaning it can accept new incoming requests that take higher priority than the invalidation process. The TAG memory is accessed for invalidate range operation only if not already accessed by an external cache request. This implies that invalidate range execution is usually not performed in one go, but can be interrupted.

- **Clean range**: cleans a certain range of addresses in the cache, background task (interruptible).

  Cleaning a cache line means making sure that the main memory content is up-to-date with the data, which may have been modified in the cache. The clean operation consists in performing the write-back in the main memory of the cache lines that are tagged as “dirty” (the ones with TAG dirty bit set).

  The software can clean a given data region in DCACHE by programming STARTCMD = 1, and CACHECMD = 0b001 in DCACHE_CR, after the address range was programmed into DCACHE_CMDRSADDRR (range start address) and DCACHE_CMDREADDRR (range end address).

  The DCACHE control logic then parses the whole TAG memory. If the read line address (TAG address + line index) falls in the programmed address range (DCACHE_CMDRSADDRR ≤ Line Addr ≤ DCACHE_CMDREADDRR), and the corresponding line is dirty, this line is cleaned, meaning the whole cache line is written-back in the memory through the DCACHE master port, and its TAG dirty bit is cleared.

  When STARTCMD is set, the DCACHE control logic sets BUSYCMDF in DCACHE_SR and launches the clean range operation. STARTCMD is also automatically cleared.

  Once the operation is finished (all TAG memory parsed), the DCACHE automatically clears BUSYCMDF and sets CMDENDF in DCACHE_SR.

  If enabled on this flag condition (CMDENDIE = 1 in DCACHE_IER), the DCACHE interrupt is raised.

  During this clean range operation, the DCACHE is interruptible, meaning it can accept new incoming requests that take higher priority than the cleaning process. The TAG memory is accessed for clean range operation only if not already accessed by an external cache request. This implies that clean range execution is usually not performed in one go, but can be interrupted.

  It is under the software responsibility that no bus initiator attempts to change the content of the region being cleaned until clean range is completed. For that, the software can take advantage of BUSYCMDF flag in DCACHE_SR, and can poll this flag to prevent any spurious access to the area being cleaned.

Alternatively it can also rely on the command end flag (CMDENDF) or on the DCACHE interrupt to detect the end of the clean range execution.

- **Clean and invalidate range**: cleans and invalidates a certain range of addresses in the cache, background task (interruptible).

  This operation cleans the “dirty” cache lines that belong to the operation address range (the same as the clean range operation), and also invalidates all the (valid) cache lines that belong to this address range (whether they are dirty or not).

  The software can launch this clean and invalidate range operation, by programming STARTCMD = 1, and CACHECMD = 0b011 in DCACHE_CR, after the address range was programmed into DCACHE_CMDRSADDRR (range start address) and DCACHE_CMDREADDRR (range end address).

  This sets and clears the same flags, and potentially the same interrupt as invalidate range or clean range operations.

9.4.9 DCACHE performance monitoring

The DCACHE provides the following monitors for performance analysis:

- The two 32-bit read-hit and write-hit monitors count the AHB transactions at the DCACHE input (slave port) that do not generate a transaction on the DCACHE output (master port).

  These monitors also take into account all accesses whose address is present in the TAG memory, or in the refill buffer (due to a previous miss, and whose data is coming, or is soon to come, from the cache master port) (see *Section 9.4.6*).
- The two 16-bit read-miss and write-miss monitors count the AHB transactions at the DCACHE input (slave port) that generate a transaction on the DCACHE output (master port).

  These monitors also take into account all accesses whose address is not present neither in the TAG memory, nor in the refill buffer.

Upon reaching their maximum values, the monitors do not wrap over.

The software can perform the following tasks:

- Enable/stop the read (write) hit monitor, through R(W)HITMEN in DCACHE_CR.
- Reset the read (write) hit monitor, by setting R(W)HITMRST in DCACHE_CR.
- Enable/stop the read (write) miss monitor, through R(W)MISSMEN in DCACHE_CR.
- Reset the read (write) miss monitor, by setting R(W)MISSMRST in DCACHE_CR.

To reduce power consumption, these monitors are disabled (stopped) by default.

9.4.10 DCACHE boot

The DCACHE is disabled (EN = 0 in DCACHE_CR) at boot.

Once the boot is finished, the DCACHE can be enabled (software setting EN = 1 in DCACHE_CR).

9.5 DCACHE low-power modes

At product level, the DCACHE reduces the power consumption by loading/storing data from/to the internal DCACHE most of the time, rather than from the bigger and then more power consuming main memories. This reduction is even much higher, since the cached main memories are external.

9.6 DCACHE error management and interrupts

A transaction initiated on the DCACHE master port may return an error (a write attempt into a read-only memory, for instance). If the master port request was propagated from a slave port request, the error is propagated back to the slave port. If ever the master port request is initiated by the DCACHE itself (a cache line is written back into the main memory because of an eviction or a clean operation), the DCACHE receives this functional error and flags it internally by setting the ERRF flag in DCACHE_SR.

In such a case, an interrupt is generated if the corresponding interrupt enable bit is set (ERRIE = 1 in DCACHE_IER).

Another case of potential interrupt generation is at the end of a full invalidate operation: when the cache busy state is finished, the DCACHE sets BSYENDF flag in DCACHE_SR.

An interrupt is then generated if the corresponding interrupt enable bit is set (BSYENDIE = 1 in DCACHE_IER).

Last case is at the end of invalidate and/or clean range operations: when the command busy state is finished, the DCACHE sets CMDENDF flag in DCACHE_SR.

An interrupt is also generated if the corresponding interrupt enable bit is set (CMDENDIE = 1 in DCACHE_IER).

All DCACHE interrupt sources raise the same and unique interrupt signal, dcache_it, and then use the same interrupt vector.

Table 89. DCACHE interrupts

Interrupt vector	Interrupt event	Event flag	Enable control bit	Interrupt clear method
DCACHE	Functional error	ERRF in DCACHE_SR	ERRIE in DCACHE_IER	Set CERRF to 1 in DCACHE_FCR
	End of busy state (full invalidate finished)	BSYENDF in DCACHE_SR	BSYENDIE in DCACHE_IER	Set CBSYENDF to 1 in DCACHE_FCR
	End of cache operations (address range based)	CMDENDF in DCACHE_SR	CMDENDIE in DCACHE_IER	Set CCMDENDF to 1 in DCACHE_FCR

The DCACHE also propagates all AHB bus errors (such as security issues, address decoding issues) from master port back to the S-AHB slave port.

9.7 DCACHE registers

9.7.1 DCACHE control register (DCACHE_CR)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HBURST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WMISSMRST	WHITMRST	WMISSMEN	WHITMEN	RMISSMRST	RHITMRST	RMISSMEN	RHITMEN
rw								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	STARTCMD	CACHECMD[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	CACHEINV	EN
				w	rw	rw	rw							w	rw

Bit 31 **HBURST:** output burst type for cache master port read accesses
Can be set by software, only when EN = 0.
Master port write accesses are always done in INCR burst type.
0: WRAP
1: INCR

Bits 30:24 Reserved, must be kept at reset value.

Bit 23 **WMISSMRST:** write-miss monitor reset
0: release the cache miss monitor reset (needed to enable the counting)
1: reset cache write-miss monitor

Bit 22 **WHITMRST:** write-hit monitor reset
0: release the cache miss monitor reset (needed to enable the counting)
1: reset cache write-hit monitor

Bit 21 **WMISSMEN:** write-miss monitor enable
0: cache write-miss monitor switched off. Stopping the monitor does not reset it.
1: cache write-miss monitor enabled

Bit 20 **WHITMEN:** write-hit monitor enable
0: cache write-hit monitor switched off. Stopping the monitor does not reset it.
1: cache write-hit monitor enabled

Bit 19 **RMISSMRST:** read-miss monitor reset
0: release the cache miss monitor reset (needed to enable the counting)
1: reset cache read-miss monitor

Bit 18 **RHITMRST:** read-hit monitor reset
0: release the cache miss monitor reset (needed to enable the counting)
1: reset cache read-hit monitor

Bit 17 **RMISSMEN:** read-miss monitor enable
0: cache read-miss monitor switched off. Stopping the monitor does not reset it.
1: cache read-miss monitor enabled

Bit 16 **RHITMEN:** read-hit monitor enable
0: cache read-hit monitor switched off. Stopping the monitor does not reset it.
1: cache read-hit monitor enabled

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **STARTCMD:** starts maintenance command (maintenance operation defined in CACHECMD).
Can be set by software, only when EN = 1, BUSYCMDF = 0, BUSYF = 0 and CACHECMD = 0b001, 0b010 or 0b011.
Cleared by hardware when the BUSYCMDF flag is set (during cache maintenance operation). Writing 0 has no effect.
0: command operation (cache maintenance) finished
1: start maintenance command (cache maintenance)

Bits 10:8 **CACHECMD[2:0]:** cache command maintenance operation (cleans and/or invalidates an address range)
Can be set and cleared by software, only when no maintenance command is ongoing (BUSYCMDF = 0).
000: no operation
001: clean range
010: invalidate range
011: clean and invalidate range
others: reserved

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **CACHEINV:** full cache invalidation
Can be set by software, only when EN = 1.
Cleared by hardware when the BUSYF flag is set (during full cache invalidation operation). Writing 0 has no effect.
0: no effect
1: invalidate entire cache (all cache lines valid bit = 0)

Bit 0 **EN:** enable
0: cache disabled
1: cache enabled

9.7.2 DCACHE status register (DCACHE_SR)

Address offset: 0x004

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMDENDF	BUSYCMDF	ERRF	BSYENDF	BUSYF
											r	r	r	r	r

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **CMDENDF:** command end flag
Cleared by writing DCACHE_FCR.CCMDENDF = 1.
0: cache busy or in idle
1: CACHECMD command finished

Bit 3 **BUSYCMDF:** command busy flag
0: cache not busy on a CACHECMD command
1: cache busy on a CACHECMD command (clean and/or invalidate an address range)

Bit 2 **ERRF:** cache error flag
Cleared by writing DCACHE_FCR.CERRF = 1.
0: no error
1: an error occurred during the operation (eviction or clean operation write-back error).

Bit 1 **BSYENDF:** full invalidate busy end flag
Cleared by writing DCACHE_FCR.CBSYENDF = 1.
0: cache busy or in idle
1: full invalidate CACHEINV operation finished

Bit 0 **BUSYF:** full invalidate busy flag
0: cache not busy on a CACHEINV operation
1: cache executing a full invalidate CACHEINV operation

9.7.3 DCACHE interrupt enable register (DCACHE_IER)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMDENDIE	Res.	ERRIE	BSYENDIE	Res.
											rw		rw	rw	

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **CMDENDIE**: interrupt enable on command end
Set by software to enable an interrupt generation at the end of a cache command (clean and/or invalidate an address range)
0: interrupt disabled on command end
1: interrupt enabled on command end

Bit 3 Reserved, must be kept at reset value.

Bit 2 **ERRIE:** interrupt enable on cache error
Set by software to enable an interrupt generation in case of cache functional error (eviction or clean operation write-back error)
0: interrupt disabled on error
1: interrupt enabled on error

Bit 1 **BSYENDIE:** interrupt enable on busy end
Set by SW to enable an interrupt generation at the end of a cache full invalidate operation.
0: Interrupt disabled on busy end
1: Interrupt enabled on busy end

Bit 0 Reserved, must be kept at reset value.

9.7.4 DCACHE flag clear register (DCACHE_FCR)

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCMDENDF	Res.	CERRF	CBSYENDF	Res.
											w		w	w	

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **CCMDENDF:** clear command end flag
Set by software.
0: no effect
1: clears CMDENDF flag in DCACHE_SR

Bit 3 Reserved, must be kept at reset value.

Bit 2 **CERRF:** clear cache error flag
Set by software.
0: no effect
1: clears ERRF flag in DCACHE_SR

Bit 1 **CBSYENDF:** clear full invalidate busy end flag
Set by software.
0: no effect
1: clears BSYENDF flag in DCACHE_SR

Bit 0 Reserved, must be kept at reset value.

9.7.5 DCACHE read-hit monitor register (DCACHE_RHMONR)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RHITMON[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RHITMON[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RHITMON[31:0]:** cache read-hit monitor counter

9.7.6 DCACHE read-miss monitor register (DCACHE_RMMONR)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RMISSMON[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **RMISSMON[15:0]:** cache read-miss monitor counter

9.7.7 DCACHE write-hit monitor register (DCACHE_WHMONR)

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WHITMON[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WHITMON[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **WHITMON[31:0]:** cache write-hit monitor counter

9.7.8 DCACHE write-miss monitor register (DCACHE_WMMONR)

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WMISSMON[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **WMISSMON[15:0]:** cache write-miss monitor counter

9.7.9 DCACHE command range start address register (DCACHE_CMDRSADDRR)

Address offset: 0x028

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CMDSTARTADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CMDSTARTADDR[15:4]												Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				

Bits 31:4 **CMDSTARTADDR[31:4]:** start address of range to which the cache maintenance command specified in DCACHE_CR.CACHECMD field applies

This register must be set before DCACHE_CR.CACHECMD is written.

Bits 3:0 Reserved, must be kept at reset value.

9.7.10 DCACHE command range end address register (DCACHE_CMDREADDRR)

Address offset: 0x02C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CMDENDADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CMDENDADDR[15:4]												Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				

Bits 31:4 **CMDENDADDR[31:4]:** end address of range to which the cache maintenance command specified in DCACHE_CR.CACHECMD field applies

This register must be set before DCACHE_CR.CACHECMD is written.

Bits 3:0 Reserved, must be kept at reset value.

9.7.11 DCACHE register map

Table 90. DCACHE register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	DCACHE_CR	HBURST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WMISSMRST	WHITMRST	WMISSMEN	WHITMEN	RMISSMRST	RHITMRST	RMISSMEN	RHITMEN	Res.	Res.	Res.	Res.	STARTCMD	CACHECMD [2:0]			Res.	Res.	Res.	Res.	Res.	Res.	CACHEINV	EN
	Reset value	0								0	0	0	0	0	0	0	0					0	0	0	0							0	0

Table 90. DCACHE register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x004	DCACHE_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMDENDF	BUSYCMDF	ERRF	BSYENDF	BUSYF
	Reset value																												0	0	0	0	1
0x008	DCACHE_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMDENDIE	Res.	ERRIE	BSYENDIE	Res.
	Reset value																												0		0	0	
0x00C	DCACHE_FCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCMDENDF	Res.	CERRF	CBSYENDF	Res.
	Reset value																												0		0	0	
0x010	DCACHE_ RHMONR	RHITMON[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	DCACHE_ RMMONR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RMISSMON[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	DCACHE_ WHMONR	WHITMON[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	DCACHE_ WMMONR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WMISSMON[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x028	DCACHE_ CMDRSADDRR	CMDSTARTADDR[31:4]																											Res.	Res.	Res.	Res.	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x02C	DCACHE_ CMDREADDRR	CMDENDADDR[31:4]																											Res.	Res.	Res.	Res.	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

10 Power control (PWR)

10.1 PWR introduction

The power controller manages the device power supplies and power modes transitions.

10.2 PWR main features

The power controller (PWR) main features are:

- Power supplies and supply domains
  - Core domain (V_{CORE})
  - V_{DD} domain
  - Backup domain (V_{SW})
  - Analog domain (V_{DDA})
  - Supply for the SMPS power stage (available on SMPS packages)
  - V_{DDIO2} supply for 10 I/Os (PD6, PD7, PG9:14, PB8, PB9)
  - V_{DDUSB} and optional $V_{DD11USB}$ for USB transceiver
- System supply voltage regulation
  - SMPS step-down converter
  - Linear voltage regulator (LDO)
- Power supply supervision
  - POR/PDR monitor
  - BOR monitor
  - PVD monitor
  - AVD monitor
  - Out of functional range temperature monitor
  - Out of functional range backup domain voltage monitor
- Power management
  - Operating modes
  - Voltage scaling control
  - Low-power modes
- V_{BAT} battery charging
- TrustZone security and privileged protection

10.3 PWR pins and internal signals

Table 91. PWR input/output pins

Pin name	Signal type	Description
VDD	Supply	Main supply
GND	Supply	Main ground

Table 91. PWR input/output pins

Pin name	Signal type	Description
VDDA	Supply	Analog peripherals supply
VSSA	Supply	Analog peripherals ground
VDDIO2	Supply	Independent I/O supply
VDDUSB	Supply	USB/OTG_FS/OTG_HS supply
VDD11USB(1)	Supply	OTG_HS transceiver supply (optional)
VCAP	Supply	Logic supply (V_{CORE})
VBAT	Supply	Backup domain supply
VDDSMPS	Supply	SMPS supply
VSSSMPS	Supply	SMPS ground
VLXSMPS	Supply	SMPS output
VREF+	Supply	ADC/DAC high reference voltage
VREF-	Supply	ADC/DAC low reference voltage
WKUPx (x = 1 to 8)	Input	Wake-up pins
CSLEEP	Output	MCU in Sleep mode
CDSTOP	Output	CPU in Stop modes

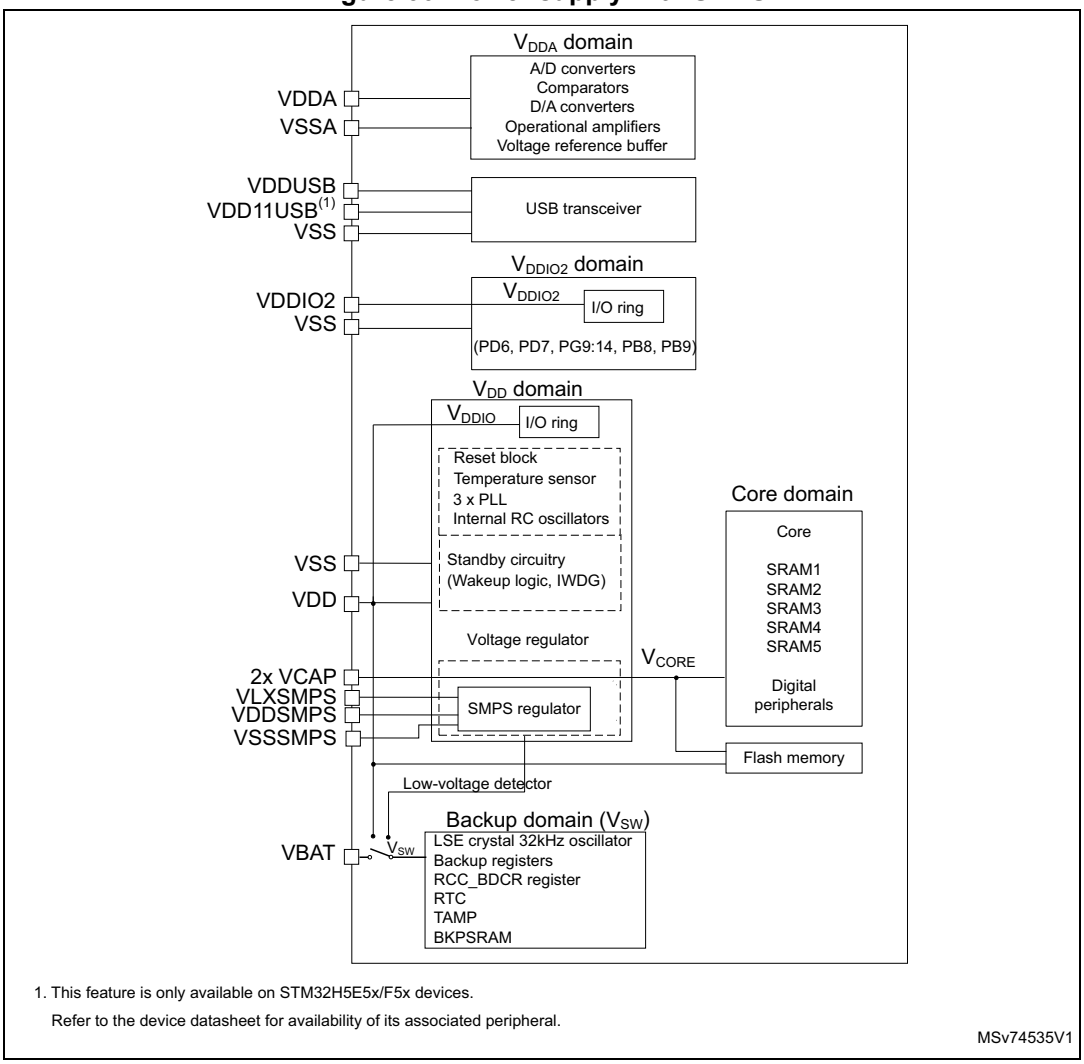
1. Only available on STM32H5E5x/F5x devices.

Table 92. PWR internal input/output signals

Internal signal name	Signal type	Description
WKUPx (x = 1 to 8)	Input	Wake-up event source

10.4 PWR power supplies and supply domains

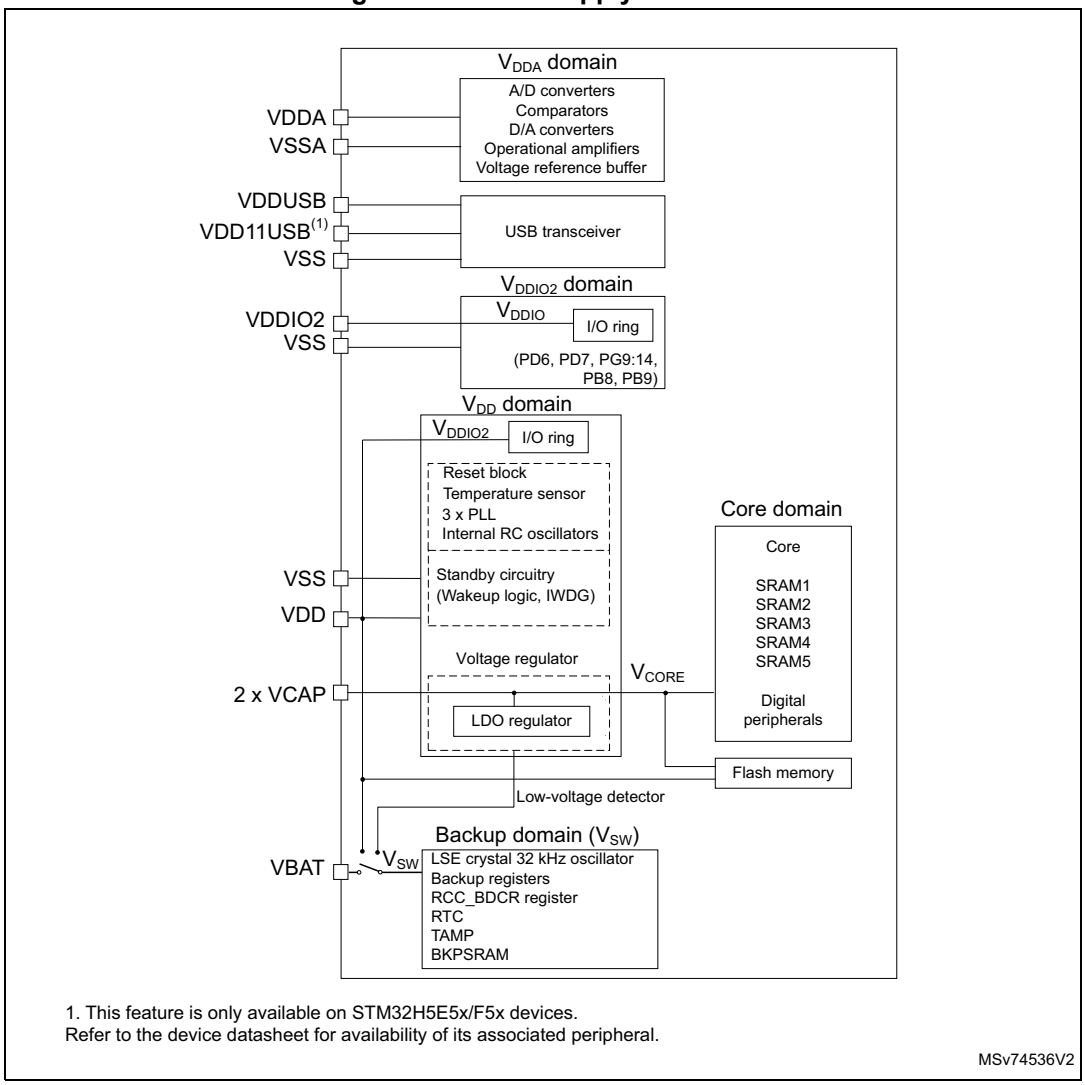
Figure 36. Power supply with SMPS



1. This feature is only available on STM32H5E5x/F5x devices.
   Refer to the device datasheet for availability of its associated peripheral.

MSv74535V1

Figure 37. Power supply with LDO



1. This feature is only available on STM32H5E5x/F5x devices.
Refer to the device datasheet for availability of its associated peripheral.

MSv74536V2

10.4.1 External power supplies

The devices require a 1.71 to 3.6 V V_{DD} operating voltage supply. Several independent supplies can be provided for specific peripherals, but must not be provided without a valid operating supply on the VDD pin:

- V_{DD} = 1.71 to 3.6 V

  V_{DD} is the external power supply for the I/Os, the internal regulator, and the system analog (such as reset, power management, and internal clocks). It is provided externally through the VDD pins.

- V_{DDA} = 1.62 V (ADCs, COMP) or 1.8 V (DAC) or 2.0 V (OPAMP) or 2.1 V (VREFBUF) to 3.6 V

  V_{DDA} is the external analog power supply for A/D converters, D/A converters, and voltage reference buffer. The V_{DDA} voltage level is independent from the V_{DD} voltage, and must preferably be connected to V_{DD} when these peripherals are not used.

- V_{DDSMPS} = 1.71 to 3.6 V

V_{DDSMPS} is the external power supply for the SMPS step-down converter. It is provided externally through the VDDSMPS supply pin, and must be connected to the same supply as the VDD pin.

- V_{LXSMPS} is the switched SMPS step-down converter output.

Note: The SMPS power supply pins are available only on specific packages with SMPS step-down converter option.

- V_{DDUSB} = 3.0 to 3.6 V

  V_{DDUSB} is the external independent power supply for USB/OTG_FS/OTG_HS transceivers. The V_{DDUSB} voltage level is independent from the V_{DD} voltage and must preferably be connected to the V_{DD} when the USB is not used.

- $V_{DD11USB}$ = 0.95 to 1.40 V (only available on STM32H5E5x/F5x devices)
  $V_{DD11USB}$ is the dedicated digital power supply for the OTG_HS transceiver. This should be connected to VCAP when OTG_HS is used, and to GND when not used.

- V_{DDIO2} = 1.08 to 3.6 V

  V_{DDIO2} is the external power supply for 10 I/Os (PD6, PD7, PG9:14, PB8, PB9). The V_{DDIO2} voltage level is independent from the V_{DD} voltage and must preferably be connected to V_{DD} when those pins are not used.

- V_{CAP} = 1.0 V to 1.35 V: digital core domain supply

  This power supply is independent from all the other power supplies:

  – When the voltage regulator is enabled, V_{CORE} is delivered by the internal voltage regulator.

  – When the voltage regulator is disabled, V_{CORE} is delivered by an external power supply through the VCAP pin, or by the SMPS

- V_{BAT} = 1.62 to 3.6 V

  V_{BAT} is the power supply when V_{DD} is not present (through power switch) for RTC, external clock 32 kHz oscillator, backup registers, and, optionally, backup SRAM.

- V_{REF-}, V_{REF+}

  V_{REF+} is the input reference voltage for ADCs and DACs. It is also the output of the internal voltage reference buffer when enabled.

  V_{REF+} can be grounded when ADC and DAC are not active.

  The internal voltage reference buffer supports four output voltages, configured with the VRS bit in the VREFBUF_CSR register:

  – V_{REF+} ~ 1.8 V. (requires $V_{DDA} \geq 2.1$ V)

  – V_{REF+} ~ 2.048 V (requires $V_{DDA} \geq 2.4$ V)

  – V_{REF+} ~ 2.5 V (requires $V_{DDA} \geq 2.8$ V)

  VREF- and VREF+ pins are not available on all packages. When not available, they are bonded to VSSA and VDDA, respectively.

  When the VREF+ is double-bonded with VDDA in a package, the internal voltage reference buffer is not available and must be kept disabled.

  V_{REF-} must always be equal to V_{SSA}.

10.4.2 Internal regulators

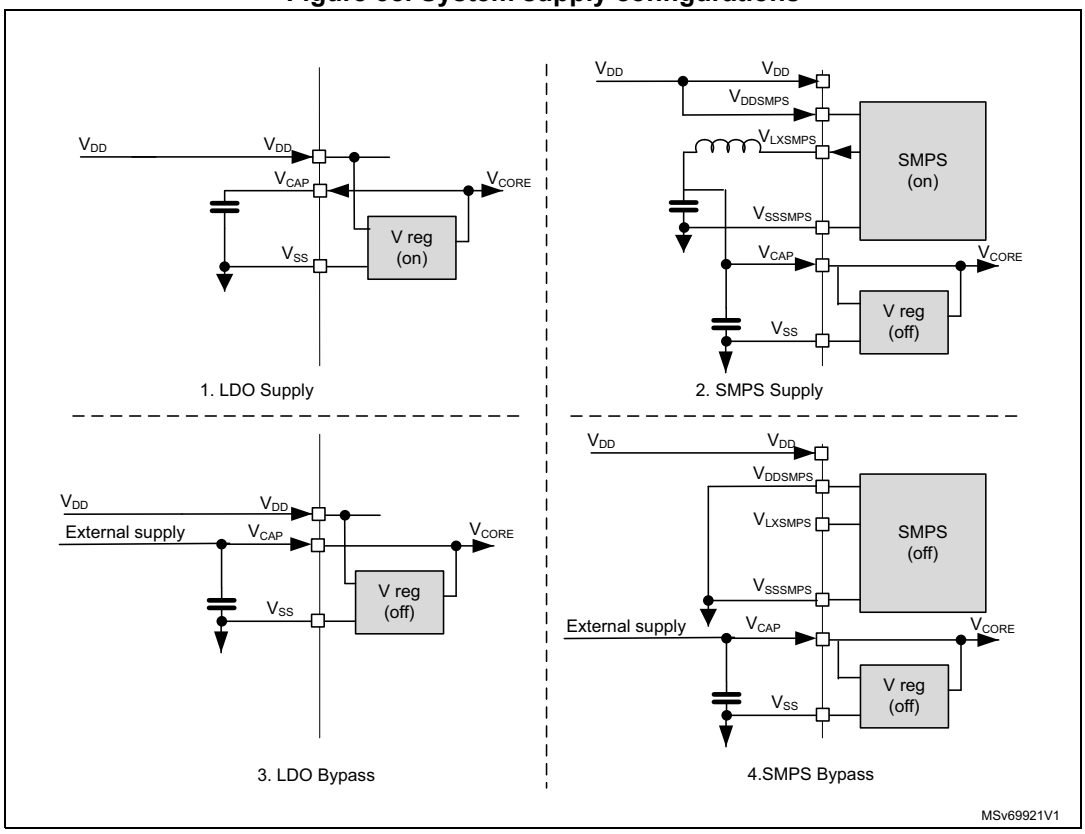
The devices embed two regulators: one LDO or one SMPS to provide the V_{CORE} supply for digital peripherals, SRAMs (except BKPSRAM), and embedded flash memory. The SMPS generates this voltage on VCAP (two pins), with a total external capacitor of 10 µF (typical) and requires an external coil of 2.2 µH (typical).

The LDO generates this voltage on VCAP, with a total external capacitance of 4.7 µF (typical).

Both regulators can provide four different voltages (voltage scaling), and can operate in Stop modes.

Depending on the package configuration (SMPS or LDO), the regulator is selected by hardware. SMPS and LDO regulator are exclusively selected. The supply configurations shown in *Figure 38* are supported for the V_{CORE} domain supply.

Figure 38. System supply configurations



Startup with V_{CORE} provided from an external supply (Bypass)

When supplied in Bypass mode, V_{CORE} must first settle at a default level (≥ 1.1 V), before V_{DD} reaches POR threshold level.

Due to the LDO default state after power-up (enabled by default), the external V_{CORE} voltage must remain higher than 1.1 V until the LDO is disabled by software. When the LDO is disabled, the external V_{CORE} voltage can be adjusted according to the user application needs (refer to section *General operating conditions* of the datasheet for details on V_{CORE} level versus the maximum operating frequency).

When operating in Bypass mode, the application must adjust VOS, using bits VOS[1:0] in the PWR_VOSCR register. VOS[1:0] must be set according to the external provided core voltage level and related performance.

To adjust the VOS level, the software must select sequentially the intermediate levels.

- When increasing the performance:
  - First, voltage scaling must be incremented (for example when changing from VOS3 to VOS0, lower levels must be selected in the VOS[1:0] bits: VOS2, VOS1, and then VOS0).
  - The external voltage can be increased
  - The system frequency can be increased
- When decreasing the performance:
  - The system frequency must be decreased
  - The external voltage must be decreased
  - The voltage scaling can be decremented (for example when changing from VOS1 to VOS3, lower levels must be selected in the VOS[1:0] bits: VOS2, and then VOS3)

10.4.3 Power-up and power-down power sequences

During power-up and power-down phases, the following power sequence requirements must be respected:

- When V_{DD} is below 1 V, other power supplies (V_{DDA}, V_{DDIO2}, V_{DDUSB}) must remain below V_{DD} + 300 mV.
- When V_{DD} is above 1 V, all power supplies are independent.

During the power-down phase, V_{DD} can temporarily become lower than other supplies only if the energy provided to the MCU remains below 1 mJ. This allows external decoupling capacitors to be discharged with different time constants during the power-down transient phase.

10.4.4 Independent analog peripherals supply

To improve ADC and DAC conversion accuracy and to extend the supply flexibility, the analog peripherals have an independent power supply that can be separately filtered and shielded from noise on the PCB:

- The voltage supply input of the analog peripherals is available on a separate VDDA pin.
- An isolated supply ground connection is provided on the VSSA pin.

The V_{DDA} supply voltage can be different from V_{DD}. The presence of V_{DDA} must be checked before enabling any of the analog peripherals supplied by V_{DDA} (A/D converter, D/A converter, voltage reference buffer).

Power supply level monitoring is available on the VDDA via the AVDO bit in the PWR_VMSR register.

When a single supply is used, V_{DDA} can be externally connected to V_{DD} through the external filtering circuit to ensure a noise-free V_{DDA} reference voltage.

ADC and DAC reference voltage

To ensure a better accuracy on low-voltage inputs and outputs, the user can connect to VREF+, a separate reference voltage lower than V_{DDA}. V_{REF+} is the highest voltage, represented by the full-scale value, for an analog input (ADC) or output (DAC) signal.

V_{REF+} can be provided either by an external reference of by an internal buffered voltage reference (VREFBUF). The internal voltage reference can output a configurable voltage, namely 1.8, 2.048 or 2.4 V. The internal voltage reference can also provide the voltage to external components through the VREF+ pin. Refer to the device datasheet and to *Section 33: Voltage reference buffer (VREFBUF)* for further information.

Note: The VREF+ and VREF- pins are not available on all packages (internally connected, respectively, to VDDA and VSSA). Do not enable the internal voltage reference buffer when an external power supply is applied to the VREF+ pin.

10.4.5 Independent I/O supply rail

Some I/Os (PD6, PD7, PG9:14, PB8, PB9) are supplied from a separate supply rail. The power supply for this rail can range from 1.08 to 3.6 V, and is provided externally through the VDDIO2 pin. The V_{DDIO2} voltage level is completely independent from V_{DD} or V_{DDA}. The VDDIO2 pin is available only for some packages. Refer to the pinout diagrams or tables in the related device datasheet(s), for the I/O list(s).

Power supply level monitoring is available on the VDDIO2 via the VDDIO2RDY bit in the PWR_VMSR register.

The V_{DDIO2} supply is monitored by the IO2 voltage monitoring (IO2VM) and compared with the internal reference voltage (3/4 V_{REFINT}, around 0.9 V). Refer to *Section 10.6.5: VDDIO2 voltage monitor (IO2VM)*, for more details.

10.4.6 Independent USB transceivers supply

The USB transceivers are supplied from a separate VDDUSB power supply pin. V_{DDUSB} range is from 3.0 to 3.6 V and is completely independent from V_{DD} or V_{DDA}.

Power supply level monitoring is available on the VDDUSB via the USB33RDY bit in PWR_VMSR register.

Before setting the USB33SV bit in the PWR USB supply control register (PWR_USBSCR), check that V_{DDUSB} is available by monitoring the USB33RDY bit in the PWR voltage monitor status register (PWR_VMSR). The $V_{DD33USB}$ supply voltage monitor be enabled through the USB33DEN bit in the PWR USB supply control register (PWR_USBSCR).

Setting the USB33SV bit is mandatory to use the OTG_FS peripheral. Similarly, setting the USB33SV and OTGHSEN bits is mandatory to enable the high-speed PHY and use the OTG_HS. The USB33SV bit must be used to validate the V_{DDUSB} supply for electrical and logical isolation purposes.

10.4.7 Backup domain

To retain the content of the backup registers and to supply the RTC function when V_{DD} is turned off, the VBAT pin can be connected to an optional backup voltage supplied by a battery or by another source.

The VBAT pin powers the RTC unit, the LSE oscillator, the PI8, and the PC13 to PC15 I/Os, allowing the RTC to operate even when the main power supply is turned off. The backup

SRAM is optionally powered by the VBAT pin when the BREN bit is set in the *PWR backup domain control register (PWR_BDCR)*. The switch to the V_{BAT} supply is controlled by the power-down reset embedded in the reset block.

Warning: **During $t_{RSTTEMPO}$ (temporization at V_{DD} startup) or after a PDR has been detected, the power switch between V_{BAT} and V_{DD} remains connected to V_{BAT}.**
During the startup phase, if V_{DD} is established in less than $t_{RSTTEMPO}$ (refer to the datasheet for the value of $t_{RSTTEMPO}$) and $V_{DD} > V_{BAT} + 0.6$ V, a current may be injected into V_{BAT} through an internal diode connected between V_{DD} and the power switch (V_{BAT}).
If the power supply/battery connected to the VBAT pin cannot support this current injection, it is strongly recommended to connect an external low-drop diode between this power supply and the VBAT pin.

If no external battery is used in the application, it is recommended to connect V_{BAT} externally to V_{DD} with a 100 nF external ceramic decoupling capacitor.

When the backup domain is supplied by V_{BAT} (analog switch connected to V_{BAT}), the following pins are available:

- PC13, PI8, PC14 and PC15, which can be configured by RTC or LSE (refer to *Section 57.3: RTC functional description*)
- PC13, PI8, PA0, PA1, and PA2 when they are configured by TAMP peripheral as tamper pins.

Note: As the analog switch can transfer only a limited amount of current, the use of GPIOs PC13 to PC15 and PI8 in output mode is restricted: the speed must be limited to 2 MHz with a maximum load of 30 pF, and these I/Os must not be used as a current source (for example to drive an LED).

Backup domain access

After a system reset, the backup domain (RCC backup domain control register RCC_BDCR, RTC registers, TAMP registers, backup registers, and backup SRAM) is protected against possible unwanted write accesses. To enable access to the backup domain, set the DBP bit in the *PWR backup domain control register (PWR_BDCR)* to enable access to the backup domain.

Backup RAM

The backup domain includes 4 Kbytes of backup RAM accessible in 32-, 16-, or 8-bit data mode. The backup RAM is supplied from the backup regulator in the backup domain. When the backup regulator is enabled through the BREN bit in the PWR_BDCR, the backup RAM content is retained in Standby, and/or VBAT mode (it can be considered as an internal EEPROM if VBAT is always present).

The backup regulator can be ON or OFF depending whether the application needs the backup RAM function in Standby or VBAT modes.

The backup RAM is read protected and mass erased when a tamper event occurs, this is to prevent confidential data (such as a cryptographic private key) from being accessed.

The backup RAM can be erased in the following ways:

- Through the flash interface after a full product state regression
- After a tamper event
- After a backup domain reset

V_{BAT} battery charging

When V_{DD} is present, it is possible to charge the external battery on VBAT through an internal resistance.

The V_{BAT} charging is done either through a 5 kΩ or a 1.5 kΩ resistor, depending upon the VBRS bit value in the PWR_BDCR register.

The battery charging is enabled by setting the VBE bit in the PWR_BDCR register. It is automatically disabled in V_{BAT} mode.

10.5 PWR system supply voltage regulation

10.5.1 SMPS and LDO embedded regulators

The devices embed two internal regulators, exclusively enabled by hardware, depending upon package configuration. The regulator is enabled on power-on reset. To supply the V_{CORE} from an external source, it is possible to disable the regulator by setting the BYPASS bit in the PWR_SCCR register.

The BYPASS bit is written once after power-on reset. Written-once mechanism locks the register and any further write access is ignored. The system must be power cycled before writing a new value.

When the V_{CORE} is supplied from an external source, the externally applied voltage level must be reflected in the VOSx bits in the PWR_VOSCR register.

Both regulators can provide four different voltages (voltage scaling) and can operate in Stop modes.

10.5.2 V_{CORE} supply versus reset, voltage scaling, and low-power modes

After reset, the V_{CORE} is in VOS3.

When exiting the Stop or Standby mode, the voltage range is the VOS3.

10.5.3 Embedded voltage regulator operating modes

There are three different power modes: Run, Stop, and Standby modes.

Run mode

The voltage regulator (LDO or SMPS) provides full power to the V_{CORE} domain (core, memories, and digital peripherals). The regulator output voltage (LDO or SMPS) can be scaled by software to different voltage levels (VOS0, VOS1, VOS2, and VOS3) that are configured through the VOS bits in the PWR voltage scaling control register (PWR_VOSCR).

The VOS voltage scaling allows optimization of the power consumption when the system is clocked below the maximum frequency. By default, VOS3 is selected after system reset.

VOSx bits can be changed on-the-fly to adapt to the required system performance.

Stop mode

The voltage regulator (LDO or SMPS) supplies the V_{CORE} domain to retain the content of registers and internal memories. The regulator mode is selected through the SVOS bits in the PWR power mode control register (PWR_PMCR).

Stop mode power consumption can be further reduced using SVO4 (lower voltage level than VOS3) and even further with SVOS5.

Standby mode

The regulator (LDO or SMPS) is OFF and the V_{CORE} domains are powered down. The content of the registers and memories is lost except for the Standby circuitry and the backup domain.

10.6 PWR power supply and temperature supervision

Power supply level monitoring is available on the following supplies:

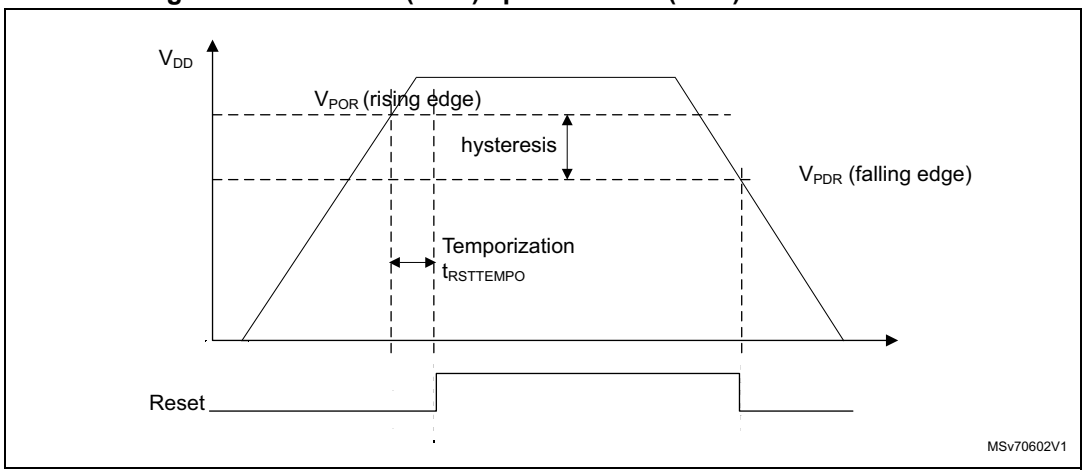
- V_{DD} via POR/PDR (see *Section 10.6.1*), BOR (see *Section 10.6.2*), and PVD monitor (see *Section 10.6.3*)
- V_{DDA} through AVD monitor see (*Section 10.6.4*)
- V_{BAT} through V_{BAT} threshold (see *Section 10.6.7*)
- V_{DDIO2} through IO2VM monitor bit (see *Section 10.6.5*)
- Temperature monitoring (see *Section 10.6.8*)
- V_{DDUSB} through UVM monitor (see *Section 10.6.7*)

10.6.1 Power-on reset (POR)/power-down reset (PDR)

The system has an integrated POR/PDR circuitry that ensures proper startup operation.

The system remains in reset mode when V_{DD} is below a specified VPOR threshold, without the need for an external reset circuit. Once the supply level is above the VPOR threshold, the system is taken out of reset (see *Figure 39*). For more details concerning the reset thresholds, refer to the electrical characteristics section of the datasheets.

Figure 39. Power-on (POR) / power-down (PDR) reset waveform



1. For thresholds and hysteresis values, refer to the datasheets.

10.6.2 Brownout reset (BOR)

During power-on, the brownout reset (BOR) keeps the system under reset until the V_{DD} supply voltage reaches the specified V_{BOR} threshold.

The V_{BOR} threshold is configured through system option bytes:

- BOR OFF (BORH_EN = 0)
- BOR level 1 (V_{BOR1})
- BOR level 2 (V_{BOR2})
- BOR level 3 (V_{BOR3})

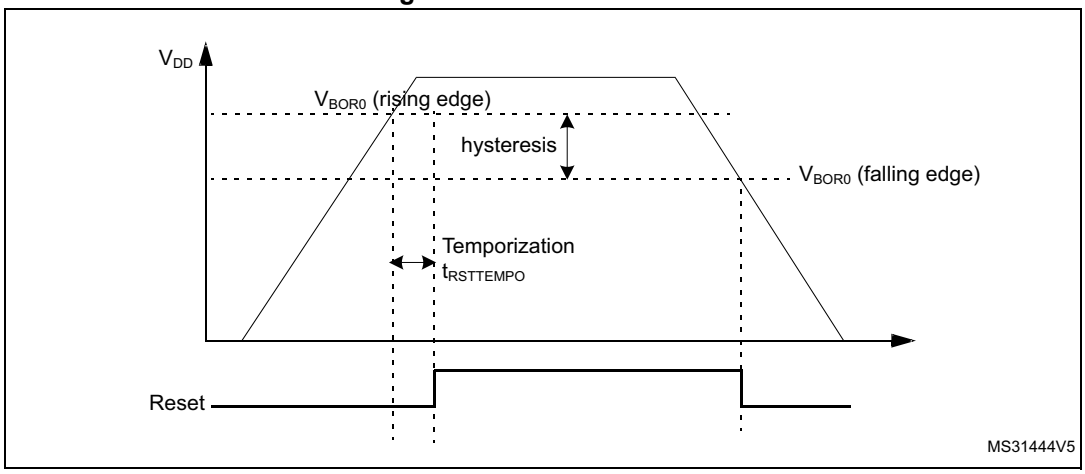
By default, BOR is OFF. It can be enabled by setting the BORH_EN option bit.

For more details on the brownout reset thresholds, refer to the section "*Electrical characteristics*" of the product datasheets.

A system reset is generated when the BOR is enabled and the V_{DD} supply voltage drops below the selected V_{BOR} threshold.

BOR can be disabled by programming the BORH_EN option bit to 0. To disable the BOR function, V_{DD} must have been higher than the POR threshold to start the system option byte programming sequence. Once BOR is disabled, the power-down is monitored by the PDR.

Figure 40. BOR thresholds



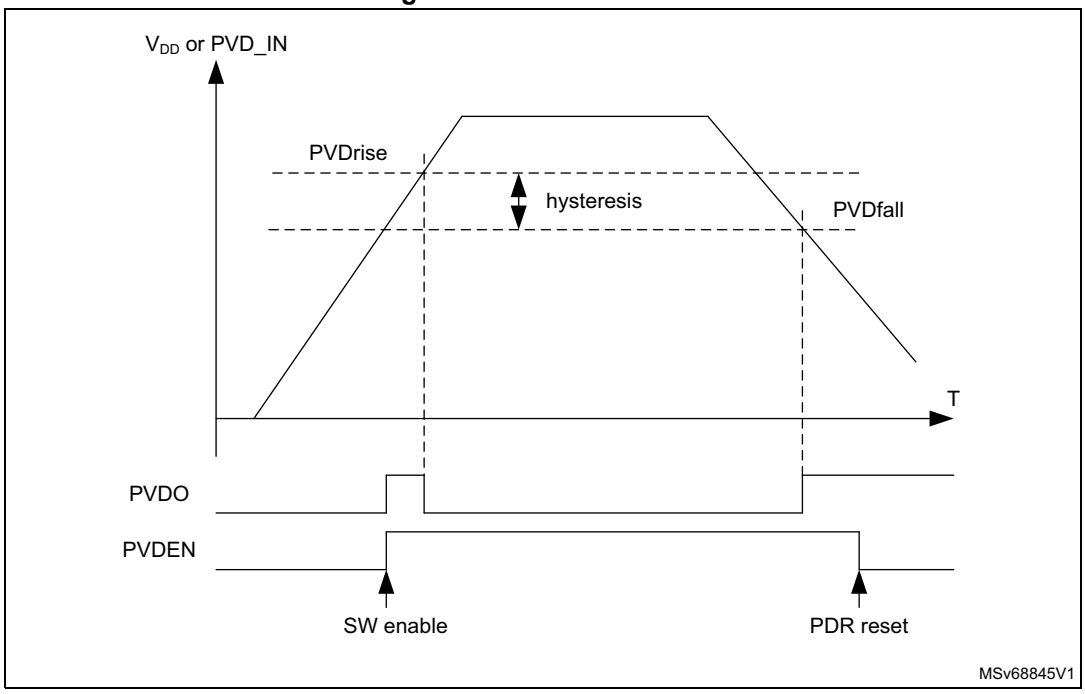
10.6.3 Programmable voltage detector (PVD)

The PVD can be used to monitor the V_{DD} power supply by comparing it to a threshold selected by the PLS[2:0] bits in the *PWR voltage monitor status register (PWR_VMCR)*. The PVD can also be used to monitor a voltage level on the PVD_IN pin. In this case the PVD_IN voltage is compared to the internal VREFINT level.

The PVD is enabled by setting the PVDE bit in *PWR voltage monitor status register (PWR_VMCR)*.

A PVDO flag is available in the *PWR voltage monitor status register (PWR_VMSR)* to indicate if the V_{DD} or PVD_IN voltage is higher or lower than the PVD threshold. This event is internally connected to the EXTI and can generate an interrupt, provided it has been enabled through the EXTI registers. The rising/falling edge sensitivity of the EXTI line must be configured according to PVD output behavior. As an example, if the EXTI line is configured to rising edge sensitivity, the interrupt is generated when the V_{DD} or PVD_IN voltage drops below the PVD threshold. The service routine can then start an emergency shutdown.

Figure 41. PVD thresholds



1. For thresholds and hysteresis values, refer to the datasheets.

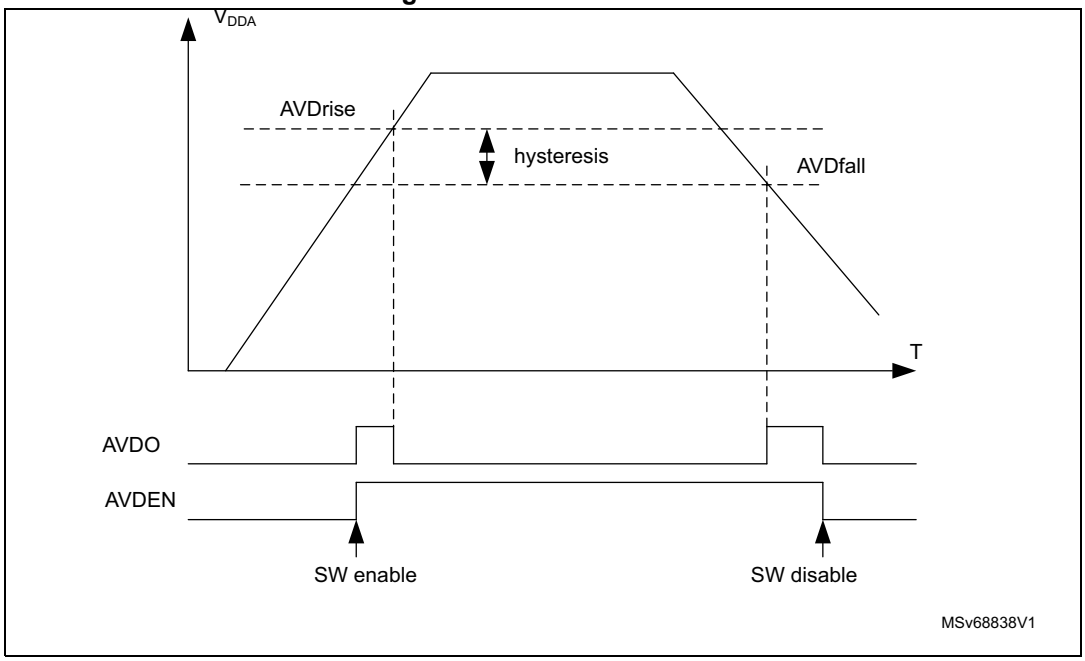
10.6.4 Analog voltage detector (AVD)

The AVD can be used to monitor the V_{DDA} supply by comparing it to a threshold selected by the ALS[1:0] bits in the *PWR voltage monitor status register (PWR_VMCR)*.

The AVD is enabled by setting the AVDEN bit in *PWR voltage monitor status register (PWR_VMCR)*.

An AVDO flag is available in the *PWR voltage monitor status register (PWR_VMSR)* to indicate whether V_{DDA} is higher or lower than the AVD threshold. This event is internally connected to the EXTI and can generate an interrupt if enabled through the EXTI registers. The AVDO interrupt can be generated when V_{DDA} drops below the AVD threshold and/or when V_{DDA} rises above the AVD threshold, depending on the EXTI rising/falling edge configuration. As an example, the service routine can indicate when the V_{DDA} supply drops below a minimum level.

Figure 42. AVD thresholds



1. For thresholds and hysteresis values, refer to the datasheets.

10.6.5 V_{DDIO2} voltage monitor (IO2VM)

The IO2VM monitors the independent supply voltage V_{DDIO2} to ensure that the peripheral is in its functional supply range. The VDDIO2RDY flag (see *PWR voltage monitor status register (PWR_VMSR)*) indicates whether a valid supply is present or not.

The IO2VM monitor output is connected to the EXTI66 line and can generate an interrupt if enabled through the EXTI registers. The IO2VM output interrupt is generated when the independent power supply drops below the IO2VM threshold, and/or when it rises above the IO2VM threshold, depending on the EXTI line rising/falling edge configuration.

10.6.6 V_{DDUSB} voltage monitor (UVM)

The UVM monitors the independent supply voltage VDDUSB to ensure that the peripheral is in its functional supply range. The USB33RDY flag (see *PWR voltage monitor status register (PWR_VMSR)* indicates whether a valid supply is present or not.

The UVM monitor output is connected to the EXTI53 line and can generate an interrupt if enabled through the EXTI registers. The UVM output interrupt is generated when the USB power supply drops below the UVM threshold and/or when it rises above the UVM threshold, depending on the EXTI line rising/falling edge configuration.

10.6.7 Backup domain voltage monitoring

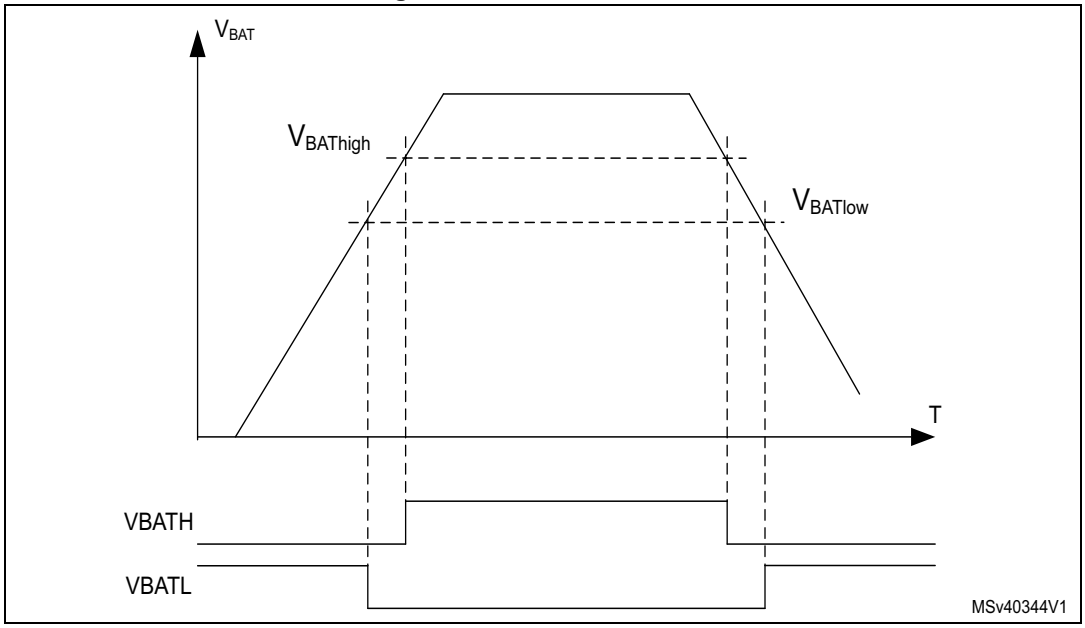
In VBAT mode, the battery voltage supply (backup domain) can be monitored by comparing it with two threshold levels: $V_{BAThigh}$ and V_{BATlow}. The V_{BAT} supply monitoring can be

enabled/disabled via MONEN bit in *PWR backup domain control register (PWR_BDCR)*. When it is enabled, the battery voltage thresholds increase power consumption.

If the backup domain voltage monitoring internal tamper is enabled in the TAMP peripheral (ITAMP1E = 1 in the TAMP_CR1 register), a tamper event is generated when the battery voltage is above the functional range.

Note: The backup domain voltage is V_{DD} when present, V_{BAT} otherwise.

Figure 43. VBAT thresholds



1. For thresholds and hysteresis values, refer to the datasheets.

10.6.8 Temperature monitoring

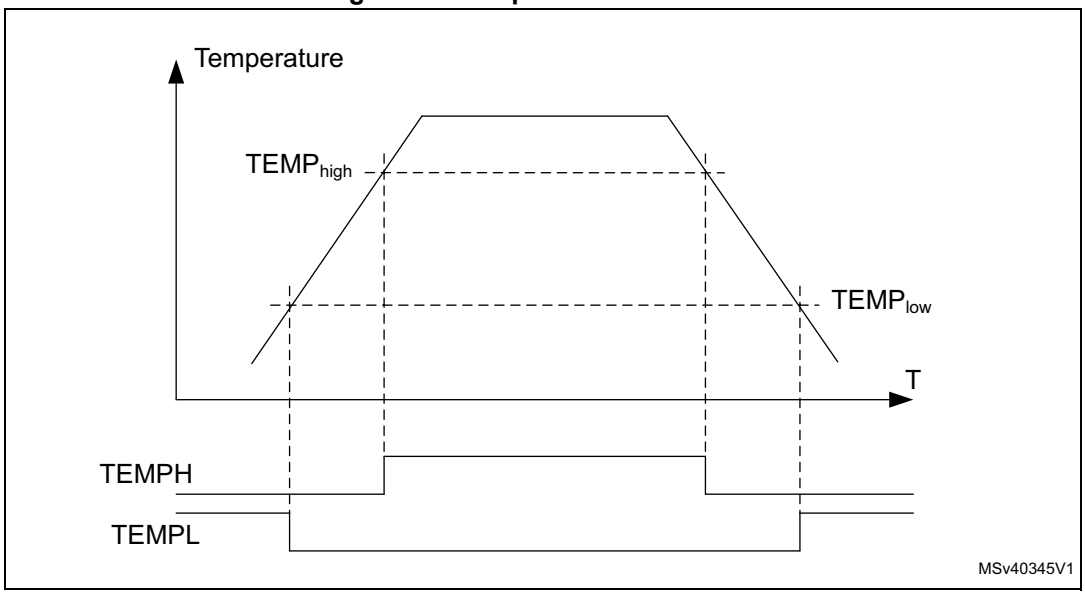
A dedicated temperature sensor cell is embedded in the power control. The junction temperature can be monitored by comparing it with two threshold levels, TEMPhigh and TEMPlow. TEMPH and TEMPL flags in the *PWR backup domain status register (PWR_BDSR)*, which indicates whether the device temperature is higher or lower than the threshold. The temperature monitoring can be enabled/disabled via the MONEN bit in *PWR backup domain control register (PWR_BDCR)*.

When enabled, the temperature thresholds increase power consumption. As an example the levels may be used to trigger a routine to perform temperature control tasks.

If the temperature monitoring internal tamper is enabled in the TAMP peripheral (ITAMP2E = 1 in the TAMP_CR1 register), a tamper event is generated when the temperature is above or below the functional range.

TEMPH and TEMPL wake-up interrupts are available on the RTC tamper signals (see *Section 58: Tamper and backup registers (TAMP)*).

Figure 44. Temperature thresholds



1. For thresholds and hysteresis values, refer to the datasheets.

10.7 PWR management

10.7.1 Voltage scaling

The voltage regulator supporting voltage scaling with the following features:

- Run mode voltage scaling
  - VOS0: scale 0
  - VOS1: scale 1
  - VOS2: scale 2
  - VOS3: scale 3
- Stop mode voltage scaling
  - SVOS3: scale 3
  - SVOS4: scale 4
  - SVOS5: scale 5

For more details on voltage scaling values, refer to the product datasheets.

After reset, the system starts on the lowest Run mode voltage scaling (VOS3). The voltage scaling can then be changed on-the-fly by software by programming VOS bits in the PWR_VOSCR register according to the required system performance. When exiting from the Stop mode or Standby mode, the Run mode voltage scaling is reset to the default VOS3 value.

Before entering Stop mode, the software should preselect the SVOS level in *PWR power mode control register (PWR_PMCR)*. The Stop mode voltage scaling for SVOS4 and SVOS5 also sets the voltage regulator in Low-power mode, to further reduce power consumption.

10.7.2 Power management examples

Example of V_{CORE} voltage scaling behavior in Run mode.

Figure 45. Dynamic voltage scaling in Run mode

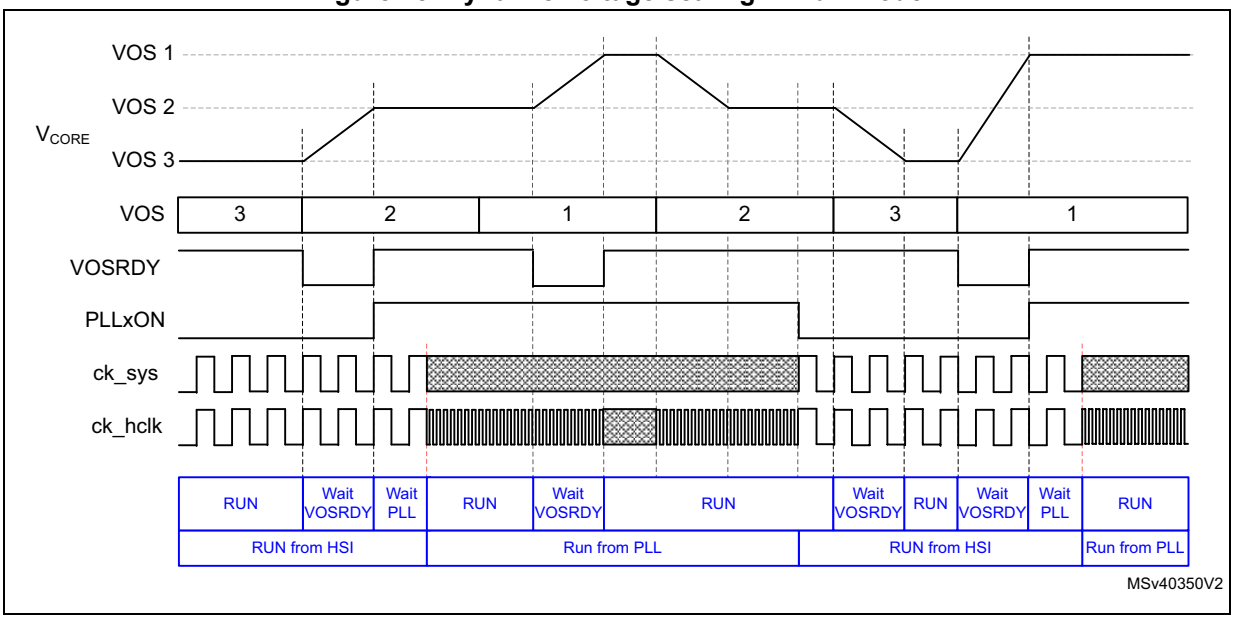


Figure 45 illustrates the following system operation sequence example:

1. After reset, the system starts from HSI with VOS3.
2. The system performance is first increased to a medium-speed clock from the PLL with voltage scaling VOS2. To do this:
   a) Program the voltage scaling to VOS2.
   b) Once the V_{CORE} supply has reached the required level indicated by VOSRDY, increase the clock frequency by enabling the PLL.
   c) Once the PLL is locked, switch the system clock.
3. The system performance is then increased to a high-speed clock from the PLL with voltage scaling VOS1. To do this:
   a) Program the voltage scaling to VOS1.
   b) Once the VCORE supply has reached the required level indicated by VOSRDY, increase the clock frequency.
4. The system performance is then reduced to a medium-speed clock with voltage scaling VOS2. To do this:
   a) First decrease the system frequency.
   b) Then decrease the voltage scaling to VOS2.
5. The next step is to reduce the system performance to the HSI clock with voltage scaling VOS3. To do this:
   a) Switch the clock to HSI.
   b) Disable the PLL.
   c) Decrease the voltage scaling to VOS3.

6. The system performance can then be increased to a high-speed clock from the PLL. To do this:
   a) Program the voltage scaling to VOS1.
   b) Once the V_{CORE} supply has reached the required level indicated by VOSRDY, increase the clock frequency by enabling the PLL.
   c) Once the PLL is locked, switch the system clock.

When the system performance (clock frequency) is changed, VOS must be set accordingly, otherwise the system can be unreliable.

10.8 Power modes

By default, the microcontroller is in Run mode after a system or a power reset. Several low-power modes are available to save power when there is no need to keep the CPU running, for example when waiting for an external event. The user can select the mode that gives the best compromise between low-power consumption, short startup time, and wake-up sources.

The device features the following low-power modes:

- Sleep mode

  CPU clock off, all peripherals including the Cortex-M33 core such as NVIC and SysTick can run and wake-up the CPU when an interrupt or an event occurs. Refer to *Section 10.8.4: Sleep mode*.

- Stop mode

  Stop mode achieves the lowest power consumption, while retaining the content of SRAM and registers. All clocks in the core domain are stopped. The PLL, the HSE crystal oscillators, HSI (except if HSIKERON is set), HSI48, and CSI RC (except if CSIKERON is set) are disabled. The LSE or LSI is still running.

  The RTC can remain active (Stop mode with RTC, Stop mode without RTC).

  The system clock when exiting from Stop mode can be either HSI up to 64 MHz or CSI, depending on software configuration.

  Refer to *Section 10.8.5: Stop mode*.

- Standby mode

  This mode achieves the lowest power consumption with BOR. The internal regulator is switched off so that the core domain is powered off. The PLL, the HSI RC, HSI48, the CSI RC, and the HSE crystal oscillators are also switched off.

  The RTC can remain active (Standby mode with RTC, Standby mode without RTC).

  The brownout reset (BOR) always remains active in Standby mode.

  The state of the I/O (except I/Os used by standby mode) during Standby mode can be retained.

  After entering Standby mode, SRAMs and register contents are lost except for registers and backup SRAM in the backup domain and Standby circuitry.

  The device exits Standby mode when an external reset (NRST pin), an IWDG reset, WKUP pin event (configurable rising or falling edge), an RTC event occurs (alarm, periodic wake-up, timestamp), or a tamper detection. The tamper detection can be

raised either due to external pins or due to an internal failure detection.

The system clock after wake-up is HSI at 32 MHz.

Refer to *Section 10.8.6: Standby mode*.

Table 93 shows the power modes overview.

Table 93. Low-power mode summary

Mode name	Entry	Wake-up source(1)	Wake-up system clock	Effect on clocks	Voltage regulators
Sleep (Sleep-now or Sleep-on-exit)	WFI or Return from ISR	Any interrupt	Same as before entering Sleep mode	– CPU clock OFF – No effect on other clocks or analog clock sources	VOS3, VOS2, VOS1, or VOS0
	WFE	Wake-up event			
Stop	LPMS = 0 + SLEEPDEEP bit + WFI or Return from ISR or WFE	– Any EXTI line (configured in the EXTI registers) – Specific peripherals events(2)	– CSI when STOPWUCK = 1 in RCC_CFGR – HSI with the frequency before entering Stop mode, up to 64 MHz, when STOPWUCK = 0	– All clocks OFF except LSI and LSE – HSI or CSI can be enabled temporarily when requested by software	SVOS3, SVOS4, or SVOS5
Standby	LPMS = 1 + SLEEPDEEP bit + WFI or Return from ISR or WFE	WKUP pin edge, RTC event, IWDG reset, external reset in NRST pin	HSI clock at 32 MHz	All clocks OFF except LSI and LSE	OFF

1. Refer to *Table 94*.
2. Peripherals are able to wake-up the system from Stop mode (this is only possible when SVOS3 is selected before entering Stop mode).

Table 94. Functionalities depending on the working mode(1)

Peripheral	Run	Sleep	Stop				Standby		VBAT
			Available	Wake-up capability			Available	Wake-up capability	
				SVOS3	SVOS4	SVOS5			
CPU	Y	-	-	-	-	-	-	-	-
Flash memory (4 Mbytes)	O	O	(2)	-	-	-	-	-	-
SRAM1 (256 Kbytes)	Y(3)	Y(3)	O(4)	-	-	-	-	-	-
SRAM2 (128 Kbytes)	Y(3)	Y(3)	O(4)	-	-	-	-	-	-
SRAM3 (384 Kbytes)	Y(3)	Y(3)	O(4)	-	-	-	-	-	-
SRAM4 (384 Kbytes)	Y(3)	Y(3)	O(4)	-	-	-	-	-	-
SRAM5 (384 Kbytes)	Y(3)	Y(3)	O(4)	-	-	-	-	-	-
BKPSRAM	O	O	O	-	-	-	O	-	O
FMC	O	O	-	-	-	-	-	-	-
OCTOSPIx (x = 1, 2)	O	O	-	-	-	-	-	-	-
LTDC	O	O	-	-	-	-	-	-	-

Table 94. Functionalities depending on the working mode[1] (continued)

Peripheral	Run	Sleep	Stop				Standby		VBAT
			Available	Wake-up capability			Available	Wake-up capability	
				SVOS3	SVOS4	SVOS5			
DMA2D	O	O	-	-	-	-	-	-	-
GFXTIM	O	O	-	-	-	-	-	-	-
JPEG	O	O	-	-	-	-	-	-	-
Backup registers	Y	Y	Y	-	-	-	Y	-	Y
Brownout reset (BOR)	Y	Y	Y	-	-	-	Y	-	-
Programmable voltage detector (PVD)	O	O	O	O	O	O	-	-	-
Analog voltage detector (AVD)	O	O	O	O	O	O	-	-	-
GPDMA	O	O	-	-	-	-	-	-	-
High-speed internal (HSI)	O	O	-	-	-	-	-	-	-
Oscillator HSI48	O	O	-	-	-	-	-	-	-
High-speed external (HSE)	O	O	-	-	-	-	-	-	-
Low-speed internal (LSI)	O	O	O	O	-	-	O	-	-
Low-speed external (LSE)	O	O	O	-	-	-	O	-	O
Low-power RC oscillator (CSI)	O	O	-	-	-	-	-	-	-
Clock security system (CSS)	O	O	-	-	-	-	-	-	-
Clock security system on LSE	O	O	O	O	O[5]	O[5]	O	O	O
Backup domain voltage and temperature monitoring	O	O	O	O	O[5]	O[5]	O	O	O
RTC/TAMP	O	O	O	O	O	O	O	O	O
Number of TAMP tamper pins	8	8	8	-	-	-	4	-	2
OTG_FS, OTG_HS, UCPD	O	O	O	O	-	-	-	-	-
USARTx	O	O	O	O	-	-	-	-	-
Low-power UART (LPUART)	O	O	O	O	-	-	-	-	-
I2Cx (x = 1, 2, 3, 4)	O	O	O	O	-	-	-	-	-
I3Cx (x = 1, 2)	O	O	O	O	-	-	-	-	-
HDMI_CEC	O	O	O	O	-	-	-	-	-
SPIx (x = 1..6)	O	O	O	O	-	-	-	-	-
FDCANx (x = 1, 2, 3)	O	O	-	-	-	-	-	-	-
SDMMCx	O	O	-	-	-	-	-	-	-
Ethernet	O	O	O	O	-	-	-	-	-
SAIx	O	O	-	-	-	-	-	-	-
ADF1	O	O	O	O	-	-	-	-	-

Table 94. Functionalities depending on the working mode[1] (continued)

Peripheral	Run	Sleep	Stop				Standby		VBAT
			Available	Wake-up capability			Available	Wake-up capability	
				SVOS3	SVOS4	SVOS5			
MDF1	O	O	O	O	-	-	-	-	-
PLAY	O	O	O	O	-	-	-	-	-
ADCx (x = 1, 2, 3)	O	O	-	-	-	-	-	-	-
DAC1 (2 converters)	O	O	O	-	-	-	-	-	-
COMPx (x = 1,2)	O	O	O	O	-	-	-	-	-
OPAMP1	O	O	-	-	-	-	-	-	-
VREFBUF	O	O	O	-	-	-	-	-	-
Temperature sensor (DTS)	O	O	O	O	-	-	-	-	-
Timers (TIMx)	O	O	-	-	-	-	-	-	-
Low-power timer LPTIMx (x = 1 to 6)	O	O	O	O	-	-	-	-	-
Independent watchdog (IWDG)	O	O	O	O	O	O	O	O	-
Window watchdog (WWDG)	O	O	-	-	-	-	-	-	-
SysTick timer (SYSTICK)	O	O	O	-	-	-	-	-	-
Digital camera interface (DCMI)	O	O	-	-	-	-	-	-	-
Parallel synchronous slave interface (PSSI)	O	O	-	-	-	-	-	-	-
CORDIC coprocessor (CORDIC)	O	O	-	-	-	-	-	-	-
Filter mathematical accelerator (FMAC)	O	O	-	-	-	-	-	-	-
Random number generator (RNG)	O	O	-	-	-	-	-	-	-
AES and secure AES (AES, SAES)	O	O	-	-	-	-	-	-	-
Public key accelerator (PKA)	O	O	-	-	-	-	-	-	-
On-the-fly decryption (OTFDEC)	O	O	-	-	-	-	-	-	-
Coupling and chaining bridge (CCB)	O	O	-	-	-	-	-	-	-
HASH accelerator	O	O	-	-	-	-	-	-	-
CRC calculation unit	O	O	-	-	-	-	-	-	-
GPIOs	O	O	-	-	-	-	O[6]	O[7]	-
EXTI	O	O	O	O	O	O	-	-	-

1. Y = yes (enabled). O = optional (disabled by default, can be enabled by software). - = not available.
HSI or CSI is available as kernel clock for peripherals only in SVOS3.

2. The memory can be configured in Low-power mode. By default, it is not in Low-power mode during Stop (SVOS3, SVOS4).

3. The SRAM clock can be gated on or off independently. By default the clock is enabled in Run and Sleep mode.
4. The SRAMs can be powered on or off independently. By default, they are not in Power-off mode during Stop.
5. Wake-up with internal tamper.
6. GPIOs state can be retained during Standby mode. By default GPIOs states are not retained.
7. 8-pin capable of wake-up from Standby mode PA0, PA2, PB7, PC1, PC13, PD2, PD3, and PI8.

In addition, the power consumption in Run mode can be reduced by slowing down the system clocks, configuring voltage scaling to lower-power ranges, and by gating the clocks to the APB and AHB peripherals when they are not used.

Debug mode

By default, the debug connection is lost if the application puts the MCU in Stop or Standby mode while the debug features are used. This is because the Cortex-M33 core is no longer clocked.

However, by setting some configuration bits in the DBGMCU control registers, the software can be debugged even when using the low-power modes extensively. For more details, refer to *Section 71.2.5: Debug and low-power modes*.

10.8.1 Slowing down system clocks

In Run mode, the speed of the system clocks (SYSCLK, HCLK, PCLK) can be reduced by programming the prescaler registers. These prescalers can also be used to slow down the peripherals before entering the Sleep mode.

For more details, refer to *Section 11: Reset and clock control (RCC)*.

10.8.2 Peripheral clock gating

In Run mode, the HCLK and PCLK for individual peripherals and memories can be stopped at any time to reduce the power consumption.

To further reduce the power consumption in Sleep mode, the peripheral clocks can be disabled before executing the WFI or WFE instructions.

The peripheral clock gating is controlled by the RCC_AHBxENR and RCC_APBxENR registers.

Disabling the peripherals clocks in Sleep mode can be performed automatically by resetting the corresponding bit in the RCC_AHBxLPENR and RCC_APBxLPENR registers.

10.8.3 Low-power modes

Entering into a low-power mode

The MCU enters in low-power modes by executing the WFI (wait for interrupt), or WFE (wait for event) instructions, or when the SLEEPONEXIT bit in the Cortex-M33 system control register is set on return from *ISR*.

Entering into a low-power mode through WFI or WFE is executed only if no interrupt is pending or no event is pending.

Exiting a low-power mode

The MCU exits the Sleep or Stop mode according to how the low-power mode was entered:

- If the WFI instruction or return from ISR was used to enter the low-power mode, any peripheral interrupt acknowledged by the NVIC can wake up the device.
- If the WFE instruction is used to enter the low-power mode, the MCU exits the low-power mode as soon as an event occurs. The wake-up event can be generated either by:
  - an NVIC IRQ interrupt:
    - When SEVONPEND = 0 in the Cortex-M33 system control register
      By enabling an interrupt in the peripheral control register and in the NVIC. When the MCU resumes from WFE, the peripheral interrupt pending bit and the NVIC peripheral IRQ channel pending bit (in the NVIC interrupt clear pending register) must be cleared. Only NVIC interrupts with high enough priority can wake up and interrupt the MCU.
    - When SEVONPEND = 1 in the Cortex-M33 system control register
      By enabling an interrupt in the peripheral control register and optionally in the NVIC. When the MCU resumes from WFE, the peripheral interrupt pending bit and when enabled the NVIC peripheral IRQ channel pending bit (in the NVIC interrupt clear pending register) must be cleared. All NVIC interrupts wake up the MCU, even the disabled ones. Only enabled NVIC interrupts with high enough priority can wake up and interrupt the MCU.
  - an event:
    - Configuring an EXTI line in event mode. When the CPU resumes from WFE, it is not necessary to clear the EXTI peripheral interrupt pending bit or the NVIC IRQ channel pending bit, as the pending bits corresponding to the event line are not set. It may be necessary to clear the interrupt flag in the peripheral.

The MCU exits Standby mode through an external reset (NRST pin), an IWDG reset, a rising edge on one of the enabled WKUPx pins or a RTC/TAMP event (see *Figure 764: RTC block diagram*).

After waking up from Standby mode, the program execution restarts in the same way as after a reset (boot pin sampling, option bytes loading, reset vector is fetched).

Caution: When the device is in Stop mode, a peripheral interrupt powers on an internal oscillator. The corresponding NVIC interrupt channel must be enabled to allow the interrupt to exit the device from Stop mode. It is not allowed to disable a peripheral interrupt by disabling only the NVIC channel while keeping the peripheral interrupt enable, as the device could remain in Stop mode with the clock ON.

10.8.4 Sleep mode

I/O states in Sleep mode

In Sleep mode, all I/O pins keep the same state as in Run mode.

Entering the Sleep mode

The MCU enters the Sleep mode as described in *Entering into a low-power mode*, when the SLEEPDEEP bit in the Cortex-M33 system control register is clear (see the table below for details on how to enter the Sleep mode).

Exiting the Sleep mode

The MCU exits the Sleep mode as described in *Exiting a low-power mode* (see the table below for details on how to exit the Sleep mode).

Table 95. Sleep mode

Sleep mode	Description
Mode entry	WFI (wait for interrupt) or WFE (wait for event) while: – SLEEPDEEP = 0 – No interrupt (for WFI) or event (for WFE) pending Refer to the Cortex-M33 system control register.
	On return from ISR while: – SLEEPDEEP = 0 and – SLEEPONEXIT = 1 – No interrupt pending Refer to the Cortex-M33 system control register.
Mode exit	If WFI or Return from ISR was used for entry Interrupt (see *Table 166: Interrupt vector mapping*) If WFE was used for entry and SEVONPEND = 0: Wake-up event (see *Section 20.3: EXTI functional description*) If WFE was used for entry and SEVONPEND = 1: Interrupt even when disabled in NVIC (see *Table 166: Interrupt vector mapping*) or wake-up event (see *Section 20.3: EXTI functional description*)
Wake-up latency	None

10.8.5 Stop mode

The Stop mode is based on the Cortex-M33 Deepsleep mode combined with the peripheral clock gating. The voltage regulator is configured by SVOSx bits (the selected SVOS4 and SVOS5 levels add an additional startup delay when exiting from system Stop mode). In Stop mode, all clocks in the core domain are stopped. The PLL, HSI, HSI48, CSI, and HSE oscillators are disabled.

It is possible to keep the HSI or CSI clock enabled during Stop mode, to be quickly available as a kernel clock for peripherals.

All SRAMs and register contents are preserved, but the SRAMs can be totally or partially switched off to further reduce consumption. The user can select which memory is discarded during Stop mode by means of xxSO bits in *PWR power mode control register (PWR_PMCR)*.

Table 96. Memory shut-off block selection

Selection bit	Shut-off block in Stop mode
SRAM1SO	AHB SRAM1
SRAM2_48HSO	AHB SRAM2 48-Kbyte high (0x2005 4000 to 0x2005 FFFF)
SRAM2_16HSO	AHB SRAM2 16-Kbyte high (0x2005 0000 to 0x2005 3FFF)
SRAM2_48LSO	AHB SRAM2 48-Kbyte low (0x2004 4000 to 0x2004 FFFF)

Table 96. Memory shut-off block selection (continued)

Selection bit	Shut-off block in Stop mode
SRAM2_16LSO	AHB SRAM2 16-Kbyte low (0x2004 0000 to 0x2004 3FFF)
SRAM3SO	AHB SRAM3
SRAM4SO	AHB SRAM4
SRAM5SO	AHB SRAM5
ETHERNETSO	ETHERNET RAM
LTDCSO	LTDC FIFO RAM

The BOR is always available in Stop mode.

I/O states in Stop mode

In the Stop mode, all I/O pins keep the same state as in the Run mode.

Entering the Stop mode

The MCU enters the Stop mode as described in *Entering into a low-power mode*, when the SLEEPDEEP bit in the Cortex-M33 system control register is set (see *Table 97* for details on how to enter the Stop mode).

If the flash memory programming is ongoing, the Stop mode entry is delayed until the memory access is finished.

If an access to the APB domain is ongoing, the Stop mode entry is delayed until the APB access is finished.

In Stop mode, the following features can be selected by programming the individual control bits:

- The independent watchdog (IWDG) is started by writing to its key register or by hardware option. Once started, it can be stopped only by a reset (see *Section 55: Independent watchdog (IWDG)*).
- The real-time clock (RTC) is configured by the RTCEN bit in the *Section 11.8.45: RCC backup domain control register (RCC_BDCR)*.
- The internal RC oscillator LSI clock is configured by the LSION bit in RCC_BCDR.
- The external 32.768 kHz oscillator (LSE) is configured by the LSEON bit in RCC_BCDR.

The AVD and the PVD can be used in Stop mode. If they are not needed, they must be disabled by software to save their power consumption.

The ADCx (x = 1, 2), the DAC1 (two channels), the temperature sensor, and the VREFBUF can consume power during the Stop mode, unless they are disabled before entering this mode.

Exiting the Stop mode

The MCU exits Stop mode by enabling an EXTI interrupt or event depending on how the low-power mode was entered. Some peripherals are able to wake up the system (refer to *Table 169: EXTI line connections*) from Stop mode, this is only possible when SVOS3 is selected before entering Stop mode.

Note: When wake-up from Stop with peripherals is needed, SVOS3 must be selected.

When exiting Stop mode by issuing an interrupt or a wake-up event, CSI is selected as the system clock if bit STOPWUCK is set in RCC clock configuration register 1 (RCC_CFGR). The HSI oscillator is selected as the system clock if STOPWUCK is cleared. The wake-up time is shorter when CSI is selected as the wake-up system clock. The HSI selection allows a wake-up at higher frequency (up to 64 MHz).

The MCU exits Stop mode by enabling an EXTI interrupt or event depending on how the low-power mode was entered.

When exiting the Stop mode, the MCU is in Run mode, VOS3.

Table 97. Stop mode

Stop mode	Description
Mode entry	WFI (wait for interrupt) or WFE (wait for event) while: – SLEEPDEEP bit is set in Cortex-M33 system control register – No interrupt (for WFI) or event (for WFE) pending – LPMS = 000 in PWR_CR1
	On Return from ISR while: – SLEEPDEEP bit is set in Cortex-M33 system control register – SLEEPONEXIT = 1 – No interrupt pending – LPMS = 0 in PWR_PMCR
	Note: To enter Stop mode, all EXTI line pending bits (in the Section 20.6.4: EXTI rising edge pending register (EXTI_RPR1)), and the peripheral flags generating wake-up interrupts must be cleared. Otherwise, the Stop mode entry procedure is ignored and the program execution continues.
Mode exit	If WFI or Return from ISR was used for entry: - any EXTI line configured in interrupt mode (the corresponding EXTI interrupt vector must be enabled in the NVIC). The interrupt source can be external interrupts or peripherals with wake-up capability (see *Table 166: Interrupt vector mapping*). - any peripheral interrupt occurring when the AHB/APB clocks are present due to an autonomous peripheral clock request (the peripheral vector must be enabled in the NVIC) If WFE was used for entry and SEVONPEND = 0: - any EXTI line configured in event mode (see *Section 20.3: EXTI functional description*). If WFE was used for entry and SEVONPEND = 1: - any EXTI line configured in interrupt mode (even if the corresponding EXTI interrupt vector is disabled in the NVIC). The interrupt source can be external interrupts or peripherals with wake-up capability (see *Table 166: Interrupt vector mapping*). - any EXTI line is configured in event mode (see *Section 20.3: EXTI functional description*)
	Note: All peripheral clocks must be enabled to allow this peripheral to generate a wake-up from Stop interrupt ([PERIPH]EN and [PERIPH]LPEN bits must be set in the RCC, and a functional independent clock must be selected).
Wake-up latency	Longest wake-up time between: HSI or CSI wake-up time and flash memory wake-up time from Stop mode.

10.8.6 Standby mode

The lowest power mode in which the BOR is active is the Standby mode. It is based on the Cortex-M33 Deepsleep mode, with the voltage regulators disabled. The PLL, HSI, HSI48, CSI, and HSE oscillators are also switched off.

The SRAMs and register contents are lost except for registers in the backup domain and Standby circuitry (see *Figure 36: Power supply with SMPS*).

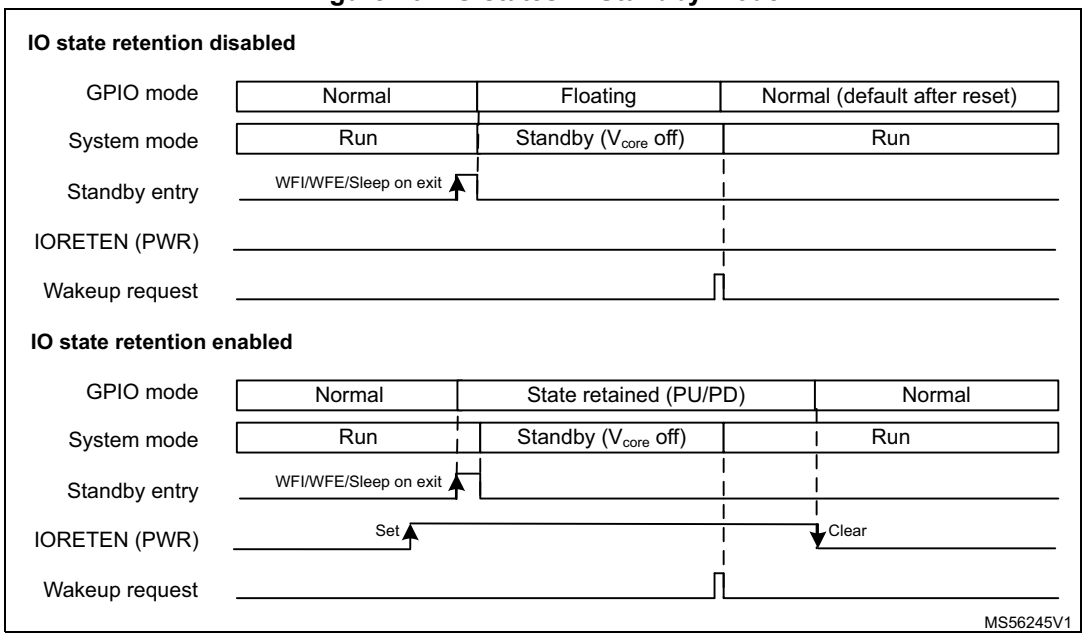
The BOR is always available in Standby mode.

I/O states in Standby mode

In the Standby mode, the I/Os are by default in floating state. If the IORETEN bit in the PWR_IORETR register is set, the I/Os output state is retained. I/O retention mode is enabled for all I/Os except those supporting the standby functionality and JTAG IOs (PA13, PA14, PA15, and PB4). When entering into Standby mode, the state of the output is sampled, and the pull-up or pull-down resistor is set to maintain the I/O output during Standby mode.

If the JTAGIORETEN bit in the PWR_IORETR register is set, the I/Os output state is retained. I/O retention mode is enabled for PA13, PA14, PA15, and PB4 (default JTAG pull-up/pull-down after wake-up is not enabled).

Figure 46. I/O states in Standby mode



After waking up from Standby mode, as long as IORETEN (or JTAGIORETEN for JTAG IOs) is set, the retained state (pull-up/pull-down) remains applied.

The GPIO pin state before standby can be identified with the GPIO_IDR register (when both GPIO port clock and input buffer are enabled).

The application can release the IO state (clear the retained Pull-up/Pull-down) by clearing the IORETEN (or JTAGIORETEN for JTAG IOs) bit, this can be done before or after reconfiguring the GPIOs and related peripherals. This lets the application configure the GPIO to a known state before releasing the retained state.

The RTC outputs on PC13 and PI8 are functional in Standby mode. PC14 and PC15 used for LSE are also functional. The eight wake-up pins (WKUPx, x = 1 to 8) and four RTC tampers pins are available.

Entering Standby mode

The MCU enters the Standby mode as described in *Entering into a low-power mode*, when the SLEEPDEEP bit in the Cortex-M33 system control register is set (see *Table 98* for details on how to enter Standby mode).

In Standby mode, the following features can be selected by programming individual control bits:

- The independent watchdog (IWDG) is started by writing to its Key register or by hardware option. Once started, it can be stopped only by a reset (see *Section 55.4: IWDG functional description*).
- The real-time clock (RTC) is configured by the RTCEN bit in *Section 11.8.45: RCC backup domain control register (RCC_BDCR)*.
- The internal RC oscillator LSI clock is configured by the LSION bit in RCC_BDCR.
- The external 32.768 kHz oscillator (LSE) is configured by the LSEON bit in RCC_BDCR.
- The IOs retention is configured by the IORETEN bit in the PWR_IORETR register.

Exiting Standby mode

The MCU exits the Standby mode as described in *Exiting a low-power mode*. The SBF status flag in the *PWR status register (PWR_PMSR)* indicates that the MCU was in Standby mode. All registers are reset after wake-up from Standby except for *PWR backup domain control register (PWR_BDCR)* and *PWR I/O retention register (PWR_IORETR)* (see *Table 98* for more details on how to exit Standby mode).

When exiting Standby mode, I/Os output state that were retained during the Standby through IORETEN bit, keep this configuration upon exiting Standby mode until the IORETEN bit in the PWR_IORETR register is cleared. Once IORETEN is cleared, the I/Os are either configured to their reset values or to the pull-up/pull-down state according to the GPIOx_PUPDR registers.

For I/Os, with a pull-up or pull-down predefined after reset (some JTAG/SWD I/Os), in case those pull-up or pull-down are different from the retained values during Standby, both a pull-down and pull-up are applied until IORETEN is cleared, releasing the retained value.

Also in case the GPIOx_PUPDR values programed after exiting from Standby are different from the retained values during Standby, both a pull-down and pull-up are applied until IORETEN is cleared, releasing the retained value.

Table 98. Standby mode

Standby mode	Description
Mode entry	WFI (wait for interrupt) or WFE (wait for event) while: – SLEEPDEEP bit is set in Cortex-M33 system control register – No interrupt (for WFI) or event (for WFE) pending – LPMS = 1 in PWR_PMCR – WUFx bits cleared in PWR_WUSR
	On Return from ISR while: – SLEEPDEEP bit is set in Cortex-M33 system control register – SLEEPONEXIT = 1 – No interrupt pending – LPMS = 1 in PWR_PMCR – WUFx bits cleared in PWR_WUSR – RTC/TAMP flags corresponding to the chosen wake-up source, cleared
Mode exit	WKUPx pin edge, RTC event, external Reset in NRST pin, IWDG Reset, BOR reset
Wake-up latency	Reset phase

10.8.7 Power modes output pins

To help the debug, three signals are available as device pins alternate functions:

- **CSLEEP**

  When set, CSLEEP indicates that the system is in Sleep mode: WFI or WFE has been executed.

  When cleared, CSLEEP indicates that the system is in Run mode.

- **CDSTOP**

  When set, CDSTOP indicates that the system is in CStop mode, meaning that the following conditions are fulfilled:

  – WFI or WFE has been executed with CPU SLEEPDEEP = 1.

  – No AHB/APB clock is running.

  When cleared, CDSTOP indicates that the system is not in CStop mode: AHB/APB clocks are running.

The table below explains the MCU power mode depending on these signals states.

Table 99. Power modes output states versus MCU power modes

CSLEEP	CSTOP	MCU power modes(1)
0	0	Run mode
1	0	Sleep mode or Stop mode, with AHB/APB clocks running
1	1	Stop mode

1. CSLEEP and CDSTOP are generated in the core domain, consequently they are not driven in Standby mode.

10.9 PWR security and privileged protection

10.9.1 PWR security protection

When the TrustZone security is activated by the TZEN option byte in the flash memory option byte configuration register, some PWR register fields can be secured against nonsecure access.

The PWR TrustZone security allows the following features to be secured through the PWR_SECCFGR register:

- Low-power mode
- Wake-up (WKUP) pins
- Voltage detection and monitoring
- VBAT mode
- I/Os retention configuration

Other PWR configuration bits are secure when:

- The system clock selection is secure in RCC: the voltage scaling (VOS) configuration is secure.
- The UCPD1 is secure in the GTZC: the PWR_UCPDR register is secure.

Table 100 gives a summary of the PWR secured bits following the security configuration bit in PWR_SECCFGR.

A nonsecure access to a secure-protected register bit is denied:

- The secured bits are not written (WI) with a nonsecure write access.
- The secured bits are read as 0 (RAZ) with a nonsecure read access.

A nonsecure write access to PWR_SECCFGR is WI and generates an illegal access event and an interrupt if enabled in the GTZC. It can be read with a nonsecure read access.

When the TrustZone security is disabled (TZEN = 0xC3), PWR_SECCFGR is RAZ/WI and all other registers are nonsecure.

Table 100. PWR security configuration summary

Secure configuration register	Security configuration bit	Register name	Secured bits	Nonsecure access on secure bits
PWR_SECCFGR	Not applicable(1)	PWR_SECCFGR	All bits	Read OK. WI and illegal access event
PWR_SECCFGR	At least one bit is set	PWR_PRIVCFGR	SPRIV	Read OK. WI
PWR_SECCFGR	LPMSEC	PWR_PMCR	All bits	WI
PWR_SECCFGR	VUSBSEC	PWR_USBSCR	All bits	WI
PWR_SECCFGR	VBSEC	PWR_BDCR	All bits	WI
		PWR_DBPCR	All bits	WI
PWR_SECCFGR	RETSEC	PWR_IORETR	All bits	WI

Table 100. PWR security configuration summary (continued)

Secure configuration register	Security configuration bit	Register name	Secured bits	Nonsecure access on secure bits
PWR_SECCFGR	WUPxSEC (x = 1 to 8)	PWR_WUCR	WUPENx	RAZ/WI
			WUPPx	RAZ/WI
			WUPPUPD	RAZ/WI
		PWR_WUSCR	CWUFx	WI
GTZC_TZSC_SECCFGR	UCPD1SEC	PWR_UCPDR	All bits	RAZ/WI
RCC_SECCFGR	SYSCLKSEC	PWR_VOSCR	VOS[1:0]	RAZ/WI
RCC_SECCFGR	SCMSEC	PWR_SCCR	All bits	WI
RCC_SECCFGR	SCMSEC	PWR_VMCR	All bits	WI

1. PWR_SECCFGR is always secure.

10.9.2 PWR privileged protection

By default, after a reset, all registers can be read or written with both privileged and unprivileged accesses, except PWR_PRIVCFGR, which can be written only with privileged access. PWR_PRIVCFGR can be read by secure and nonsecure, privileged, and unprivileged accesses.

The SPRIV bit in PWR_PRIVCFGR can be written only with secure privileged access. This bit configures the privileged access of all PWR secure functions (defined by PWR_SECCFGR, GTZC, RCC, or GPIO, as shown in *Table 100*).

When the SPRIV bit is set in PWR_PRIVCFGR:

- The PWR secure bits can be written only with privileged access, including PWR_SECCFGR.
- The PWR secure bits can be read only with privileged access except PWR_SECCFGR and PWR_PRIVCFGR that can be read by privileged or unprivileged access.
- An unprivileged access to a privileged PWR bit or register is discarded: the bits are read as 0 and the write to these bits is ignored (RAZ/WI).

The NSPRIV bit of PWR_PRIVCFGR can be written only with privileged access, secure, or nonsecure. It configures the privileged access of all PWR securable functions configured as nonsecure (defined by PWR_SECCFGR, GTZC, RCC, or GPIO, see *Table 100*).

When the NSPRIV bit is set in PWR_PRIVCFGR:

- The PWR securable bits configured as nonsecure, can be written only with privileged access.
- The PWR securable bits configured as nonsecure, can be read only with privileged access except PWR_PRIVCFGR, which can be read by privileged or unprivileged accesses.
- The VOSRDY and BOOSTRDY bits in PWR_VOSR, PWR_SR, PWR_SVMSR, PWR_BDSR and PWR_WUSR, can be read with privileged or unprivileged accesses.
- An unprivileged access to a privileged PWR bit or register is discarded: the bits are read as 0, and the write to these bits is ignored (RAZ/WI).

10.10 PWR interrupts

Table 101 gives a summary of the interrupt sources and the way to control them.

Table 101. PWR interrupt requests

Interrupt vector	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit Sleep, Stop modes	Exit Standby modes
PVD/AVD output	Programmable voltage detector through EXTI line 16	PVDO/ AVDO	EXTI line 16 enabled	Write EXTI PIF16 = 1	Yes	No
UVM	USB supply voltage monitor through EXTI line 53	USB33DRY	EXTI line 53 enabled	Write EXTI PIF53 = 1	Yes	No
IO2VM	VDDIO2 supply voltage monitor through EXTI line 66	VDDIO2RDY	EXTI line 66 enabled	Write EXTI| PIF66 = 1	Yes	No

10.11 PWR registers

The PWR registers can be accessed in word, half-word and byte format, unless otherwise specified.

10.11.1 PWR power mode control register (PWR_PMCR)

This register is protected against nonsecure access when LPMSEC = 1 in the PWR_SECCFGR register.

This register is protected against unprivileged access when LPMSEC = 1 and SPRIV = 1 in the PWR_PRIVCFGR register, or when LPMSEC = 0 and NSPRIV = 1.

Address offset: 0x000

Reset value: 0x0000 000C

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SRAM1SO	SRAM2_48HSO	SRAM2_48LSO	SRAM2_16HSO	SRAM2_16LSO	SRAM3SO	SRAM4SO	SRAM5SO	Res.	Res.	Res.	Res.	Res.	Res.	LTDCSO	ETHERNETSO
rw	rw	rw	rw	rw	rw	rw	rw							rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	AVD_READY	BOOSTE	Res.	Res.	FLPS	Res.	CSSF	Res.	Res.	Res.	SVOS[1:0]		Res.	LPMS
		rw	rw			rw		rw				rw	rw		rw

Bit 31 **SRAM1SO**: AHB SRAM1 shut-off in Stop mode
0: AHB RAM1 content is kept in Stop mode.
1: AHB RAM1 content is lost in Stop mode.

Bit 30 **SRAM2_48HSO**: AHB SRAM2 48-Kbyte High shut-off in Stop mode
0: AHB RAM2 48-Kbyte content is kept in Stop mode.
1: AHB RAM2 48-Kbyte content is lost in Stop mode.

Bit 29 **SRAM2_48LSO**: AHB SRAM2 48-Kbyte Low shut-off in Stop mode
0: AHB RAM2 48-Kbyte content is kept in Stop mode.
1: AHB RAM2 48-Kbyte content is lost in Stop mode.

Bit 28 **SRAM2_16HSO**: AHB SRAM2 16-Kbyte High shut-off in Stop mode
0: AHB RAM2 16-Kbyte content is kept in Stop mode.
1: AHB RAM2 16-Kbyte content is lost in Stop mode.

Bit 27 **SRAM2_16LSO**: AHB SRAM2 16-Kbyte Low shut-off in Stop mode
0: AHB RAM2 16-Kbyte content is kept in Stop mode.
1: AHB RAM2 16-Kbyte content is lost in Stop mode.

Bit 26 **SRAM3SO**: AHB SRAM3 shut-off in Stop mode
0: AHB RAM3 content is kept in Stop mode.
1: AHB RAM3 content is lost in Stop mode.

Bit 25 **SRAM4SO**: AHB SRAM4 shut-off in Stop mode
0: AHB RAM4 content is kept in Stop mode.
1: AHB RAM4 content is lost in Stop mode.

Bit 24 **SRAM5SO**: AHB SRAM5 shut-off in Stop mode
0: AHB RAM5 content is kept in Stop mode.
1: AHB RAM5 content is lost in Stop mode.

Bits 23:18 Reserved, must be kept at reset value.

Bit 17 **LTDCSO**: LTDC FIFO RAM shut-off in Stop mode
0: LTDC FIFO RAM content is kept in Stop mode.
1: LTDC FIFO RAM content is lost in Stop mode.

Bit 16 **ETHERNETSO**: ETHERNET RAM shut-off in Stop mode
0: ETHERNET RAM content is kept in Stop mode.
1: ETHERNET RAM content is lost in Stop mode.

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **AVD_READY**: Analog voltage ready
This bit is used only when the analog switch boost needs to be enabled (see BOOSTE bit). It must be set by software when the expected V_{DDA} analog supply level is available.
The correct analog supply level is indicated by the AVDO bit (PWR_VMSR register) after setting the AVDEN bit (PWR_VMCR register) and selecting the supply level to be monitored (ALS bits).
0: Peripheral analog voltage V_{DDA} not ready (default)
1: Peripheral analog voltage V_{DDA} ready.

Bit 12 **BOOSTE**: Analog switch V_{BOOST} control
This bit enables the booster to guarantee the analog switch AC performance when the V_{DD} supply voltage is below 2.7 V (reduction of the total harmonic distortion to have the same switch performance over the full supply voltage range) The V_{DD} supply voltage can be monitored through the PVD and the PLS bits.
0: Booster disabled (default)
1: Booster enabled if analog voltage ready (AVD_READY = 1)

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **FLPS**: flash memory low-power mode in Stop mode

This bit is used to obtain the best trade-off between low-power consumption and restart time when exiting from Stop mode.

When it is set, the flash memory enters low-power mode when the system is in Stop mode.

0: flash memory remains in normal mode when the system enters Stop mode (quick restart time).

1: flash memory enters low-power mode when the system enters Stop mode (low-power consumption).

Note: When system enters Stop mode with SVOS5 enabled, flash memory is automatically forced in low-power mode.

Bit 8 Reserved, must be kept at reset value.

Bit 7 **CSSF**: Clear Standby and Stop flags (always read as 0)

This bit is cleared to 0 by hardware.

0: No effect

1: STOPF and SBF flags cleared

Bits 6:4 Reserved, must be kept at reset value.

Bits 3:2 **SVOS[1:0]**: System Stop mode voltage scaling selection

These bits control the V_{CORE} voltage level in system Stop mode, to obtain the best trade-off between power consumption and performance.

00: Reserved

01: SVOS5 scale 5

10: SVOS4 scale 4

11: SVOS3 scale 3 (default)

Bit 1 Reserved, must be kept at reset value.

Bit 0 **LPMS**: Low-power mode selection

This bit defines the Deepsleep mode.

0: Keeps Stop mode when entering DeepSleep.

1: Allows Standby mode when entering DeepSleep.

10.11.2 PWR status register (PWR_PMSR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SBF	STOPF	Res.	Res.	Res.	Res.	Res.
									r	r					

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **SBF**: System standby flag

This bit is set by hardware and cleared only by a POR or by setting the CSSF bit.

0: system has not been in Standby mode.

1: system has been in Standby mode.

Bit 5 **STOPF**: Stop flag

This bit is set by hardware and cleared only by any reset or by setting the CSSF bit.

0: system has not been in Stop mode.

1: system has been in Stop mode.

Bits 4:0 Reserved, must be kept at reset value.

10.11.3 PWR voltage scaling control register (PWR_VOSCR)

Some register fields are protected against nonsecure access depending on the RCC_SECCFGR register.

These fields can be protected against unprivileged access depending on the PWR_PRIVCFGR register configuration.

Address offset: 0x0010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VOS[1:0]		Res.	Res.	Res.	Res.
										rw	rw				

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:4 **VOS[1:0]**: voltage scaling selection according to performance

These bits control the V_{CORE} voltage level and allow to obtain the best trade-off between power consumption and performance:

- In bypass mode, these bits must also be set according to the external provided core voltage level and related performance.
- When increasing the performance, the voltage scaling must be changed before increasing the system frequency.
- When decreasing performance, the system frequency must first be decreased before changing the voltage scaling.

00: scale 3 (default)

01: scale 2

10: scale 1

11: scale 0

Bits 3:0 Reserved, must be kept at reset value.

10.11.4 PWR voltage scaling status register (PWR_VOSSR)

Address offset: 0x0014

Reset value: 0x0000 2008

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACTVOS[1:0]		ACTVOSRDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VOSRDY	Res.	Res.	Res.
r	r	r										r			

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:14 **ACTVOS[1:0]**: voltage output scaling currently applied to V_{CORE}
This field provides the last VOS value.
00: VOS3 (lowest power)
01: VOS2
10: VOS1
11: VOS0 (highest frequency)

Bit 13 **ACTVOSRDY**: Voltage level ready for currently used VOS
0: V_{CORE} is above or below the current voltage scaling provided by ACTVOS[1:0]
1: V_{CORE} is equal to the current voltage scaling provided by ACTVOS[1:0]

Bits 12:4 Reserved, must be kept at reset value.

Bit 3 **VOSRDY**: Ready bit for V_{CORE} voltage scaling output selection.
0: Not ready, voltage level below VOS selected level
1: Ready, voltage level at or above VOS selected level
The VOSRDY flag must be used only when switching from low to high-voltage scale (like switching from VOS3 to VOS0).

Bits 2:0 Reserved, must be kept at reset value.

10.11.5 PWR backup domain control register (PWR_BDCR)

This register is protected against nonsecure access when VBSEC = 1 in the PWR_SECCFGR register.

This register is protected against unprivileged access when VBSEC = 1 and SPRIV = 1 in the PWR_PRIVCFGR register, or when VBSEC = 0 and NSPRIV = 1.

This register is not reset by wake-up from Standby mode, RESET signal, and VDD POR. It is only reset by VSW POR and VSWRST reset. This register must not be accessed when the VSWRST bit in the RCC_BDCR register resets the VSW domain.

MONEN and BREN bits must not be accessed when the VSWRST bit in the RCC_BDCR register resets the VSW domain. After reset, MONEN and BREN of this register are write-

protected. Prior to modifying their content, the DBP bit in the PWR_DBPCR register must be set to disable the write protection.

Address offset: 0x20

Power-on reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	VBRS	VBE	Res.	Res.	Res.	Res.	Res.	Res.	MONEN	BREN
						rw	rw							rw	rw

Bits 31:10 Reserved, must be kept at reset value.

Bit 9 **VBRS**: V_{BAT} charging resistor selection
0: Charge V_{BAT} through a 5 kΩ resistor.
1: Charge V_{BAT} through a 1.5 kΩ resistor.

Bit 8 **VBE**: V_{BAT} charging enable
0: V_{BAT} battery charging disabled.
1: V_{BAT} battery charging enabled.
Note: Reset only by POR.

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **MONEN**: Backup domain voltage and temperature monitoring enable
0: Backup domain voltage and temperature monitoring disabled
1: Backup domain voltage and temperature monitoring enabled

Bit 0 **BREN**: Backup RAM retention in Standby and V_{BAT} modes
When this bit set, the backup regulator (used to maintain the backup RAM content in Standby and V_{BAT} modes) is enabled.
If BREN is cleared, the backup regulator is switched off. The backup RAM can still be used in Run and Stop modes. However its content is lost in Standby and V_{BAT} modes.
If BREN is set, the application must wait till the backup regulator ready flag (BRRDY) is set to indicate that the data written into the SRAM is maintained in Standby and V_{BAT} modes.
0: Backup RAM content lost in Standby and V_{BAT} modes.
1: Backup RAM content preserved in Standby and V_{BAT} modes

10.11.6 PWR backup domain control register (PWR_DBPCR)

This register is protected against nonsecure access when VBSEC = 1 in the PWR_SECCFGR register.

This register is protected against unprivileged access when VBSEC = 1 and SPRIV = 1 in the PWR_PRIVCFGR register, or when VBSEC = 0 and NSPRIV = 1.

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBP
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **DBP**: Disable backup domain write protection

In reset state, all registers and SRAM in backup domain are protected against parasitic write access. This bit must be set to enable write access to these registers.

0: Write access to backup domain disabled

1: Write access to backup domain enabled

10.11.7 PWR backup domain status register (PWR_BDSR)

This register is not reset by wake-up from Standby mode, RESET signal and VDD POR. It is only reset by VSW POR and VSWRST reset.

Address offset: 0x028

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TEMPH	TEMPL	VBATH	VBATL	Res.	Res.	Res.	BRRDY
								r	r	r	r				r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **TEMPH**: temperature level monitoring versus high threshold

0: temperature below high threshold level

1: temperature equal or above high threshold level

Bit 22 **TEMPL**: temperature level monitoring versus low threshold

0: temperature above low threshold level

1: temperature equal or below low threshold level

Bit 21 **VBATH**: V_{BAT} level monitoring versus high threshold
0: V_{BAT} level below high threshold level
1: V_{BAT} level equal or above high threshold level

Bit 20 **VBATL**: V_{BAT} level monitoring versus low threshold
0: V_{BAT} level above low threshold level
1: V_{BAT} level equal or below low threshold level

Bits 19:17 Reserved, must be kept at reset value.

Bit 16 **BRRDY**: backup regulator ready
This bit is set by hardware to indicate that the backup regulator is ready.
0: backup regulator not ready
1: backup regulator ready

Bits 15:0 Reserved, must be kept at reset value.

10.11.8 PWR USB Type-C® power delivery register (PWR_UCPDR)

This register is protected against nonsecure access when UCPD1SEC = 1 in the TZSC_SECCFGR register.

This register is protected against unprivileged access when UCPD1SEC = 1 and SPRIV = 1 in the PWR_PRIVCFGR register, or when UCPD1SEC = 0 and NSPRIV = 1.

Address offset: 0x02C

Reset value: 0x0000 0000

Not affected by exit Standby mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UCPD_STBY	UCPD_DBDIS
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **UCPD_STBY**: USB Type-c and Power delivery Standby mode
When set, this bit is used to memorize the UCPD configuration in Standby mode. This bit must be written to 1 just before entering Standby mode when using UCPD, and it must be written to 0 after exiting the standby mode and before writing any UCPD register.

Bit 0 **UCPD_DBDIS**: USB Type-C and power delivery dead battery disable
After exiting reset, the USB Type-C “dead battery” behavior is enabled, which may have a pull-down effect on CC1 and CC2 pins. It is recommended to disable it in all case, either to stop this pull-down or to hand over control to the UCPD (which should therefore be initialized before doing the disable).
0: Enable USB Type-C dead battery pull-down behavior on UCPDx_CC1 and UCPDx_CC2 pins.
1: Disable USB Type-C dead battery pull-down behavior on UCPDx_CC1 and UCPDx_CC2 pins.

10.11.9 PWR supply configuration control register (PWR_SCCR)

This register is protected against nonsecure access when SCMSEC = 1 in the PWR_SECCFGR register.

This register is protected against unprivileged access when SCMSEC = 1 and SPRIV = 1 in the PWR_PRIVCFGR register, or when SCMSEC = 0 and NSPRIV = 1.

Address offset: 0x030

Reset value: 0x0000 0X00

The reset value of the register change according to the package. The bits 9 and 8 indicate the power configuration. Their values are exclusive.

Reset by POR only, not reset by wake-up from Standby mode and RESET pad. The BYPASS bit of this register is written once after POR. Written-once mechanism locks the register and any further write access is ignored. The system must be power cycled before writing a new value.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	SMPSEN	LDOEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BYPASS
						r	r								rwo

Bits 31:10 Reserved, must be kept at reset value.

Bit 9 **SMPSEN**: SMPS enable
The value is set by hardware when the package uses the SMPS regulator.

Bit 8 **LDOEN**: LDO enable
The value is set by hardware when the package uses the LDO regulator.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **BYPASS**: power management unit bypass
0: Power management unit normal operation. Use the internal regulator.
1: Power management unit bypassed. Use the external power (voltage monitoring still active)

10.11.10 PWR voltage monitor status register (PWR_VMCR)

This register is protected against nonsecure access when SCMSEC = 1 in the PWR_SECCFGR register.

This register is protected against unprivileged access when SCMSEC = 1 and SPRIV = 1 in the PWR_PRIVCFGR register, or when SCMSEC = 0 and NSPRIV = 1.

The PVDE and PLS bits are protected by a lock mechanism. The lock control is in the SBS module controlled by the PVDL bit in the SBS_CFGR2 register. By default, the PVDE and PLS are unlocked.

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	ALS[1:0]		AVDEN	Res.	Res.	Res.	Res.	PLS[2:0]			PVDE
					rw	rw	rw					rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:9 **ALS[1:0]**: analog voltage detector (AVD) level selection
These bits select the analog voltage detector (AVD) thresholds.
00: AVD level0 (V_{AVD0} ~ 1.7 V)
01: AVD level1 (V_{AVD1} ~ 2.1 V)
10: AVD level2 (V_{AVD2} ~ 2.5 V)
11: AVD level3 (V_{AVD3} ~ 2.8 V)

Bit 8 **AVDEN**: peripheral voltage monitor on V_{DDA} enable
0: peripheral voltage monitor on V_{DDA} disabled
1: peripheral voltage monitor on V_{DDA} enabled

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:1 **PLS[2:0]**: programmable voltage detector (PVD) level selection
These bits select the programmable voltage detector (PVD) thresholds.
000: PVD level0 (VPVD0 ~ 1.95 V)
001: PVD level1 (VPVD1 ~ 2.10 V)
010: PVD level2 (VPVD2 ~ 2.25 V)
011: PVD level3 (VPVD3 ~ 2.40 V)
100: PVD level4 (VPVD4 ~ 2.55 V)
101: PVD level5 (VPVD5 ~ 2.70 V)
110: PVD level6 (VPVD6 ~ 2.85 V)
111: PVD_IN pin

Bit 0 **PVDE**: PVD enable
0: PVD disabled
1: PVD enabled

10.11.11 PWR USB supply control register (PWR_USBSCR)

This register is protected against nonsecure access when VUSBSEC = 1 in the PWR_SECCFGR register.

This register is protected against unprivileged access when VUSBSEC = 1 and SPRIV = 1 in the PWR_PRIVCFGR register, or when VUSBSEC = 0 and NSPRIV = 1.

Address offset: 0x038

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	OTGHSEN	Res.	USB33SV	USB33DEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
				rw		rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **OTGHSEN:** OTGHS PHY enable
This bit is used to enable the OTGHS PHY
0: OTGHS PHY disabled.
1: OTGHS PHY enabled.

Bit 26 Reserved, must be kept at reset value.

Bit 25 **USB33SV:** independent USB supply valid
This bit is used to validate the V_{DDUSB} supply for electrical and logical isolation purpose. Setting this bit is mandatory to use the OTG_FS or OTG_HS peripheral. If V_{DDUSB} is not always present in the application, the V_{DDUSB} voltage monitor can be used to determine whether this supply is ready or not.
0: V_{DDUSB} is not present. Logical and electrical isolation is applied to ignore this supply.
1: V_{DDUSB} is valid.

Bit 24 **USB33DEN**: V_{DDUSB} voltage monitor enable
0: V_{DDUSB} voltage monitor disabled
1: V_{DDUSB} voltage monitor enabled

Bits 23:0 Reserved, must be kept at reset value.

10.11.12 PWR voltage monitor status register (PWR_VMSR)

Address offset: 0x03C

Reset value: 0x00X0 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	USB33RDY	Res.	PVDO	Res.	VDDIO2RDY	AVDO	Res.	Res.	Res.
							r		r		r	r			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **USB33RDY**: V_{DDUSB} ready
0: V_{DDUSB} is below the threshold of the V_{DDUSB} voltage monitor.
1: V_{DDUSB} is equal or above the threshold of the V_{DDUSB} voltage monitor.

Bit 23 Reserved, must be kept at reset value.

Bit 22 **PVDO**: programmable voltage detect output
This bit is set and cleared by hardware. It is valid only if the PVD has been enabled by the PVDE bit.
0: V_{DD} is equal or higher than the PVD threshold selected through the PLS[2:0] bits.
1: V_{DD} is lower than the PVD threshold selected through the PLS[2:0] bits.
Note: Since the PVD is disabled in Standby mode, this bit is equal to 0 after Standby or reset until the PVDE bit is set.

Bit 21 Reserved, must be kept at reset value.

Bit 20 **VDDIO2RDY**: voltage detector output on V_{DDIO2}
This bit is set and cleared by hardware.
0: V_{DDIO2} is below the threshold of the IO2VM voltage monitor.
1: V_{DDIO2} is above or equal to the threshold of the IO2VM voltage monitor.

Bit 19 **AVDO**: analog voltage detector output on V_{DDA}
This bit is set and cleared by hardware. It is valid only if AVD on VDDA is enabled by the AVDEN bit.
0: V_{DDA} is equal or higher than the AVD threshold selected with the ALS[2:0] bits.
1: V_{DDA} is lower than the AVD threshold selected with the ALS[2:0] bits.
Note: Since the AVD is disabled in Standby mode, this bit is equal to 0 after standby or reset until the AVDEN bit is set.

Bits 18:0 Reserved, must be kept at reset value.

10.11.13 PWR wake-up status clear register (PWR_WUSCR)

Each register bit CWUFx (x = 1 to 8) is protected against nonsecure access when WUPxSEC = 1 in the PWR_SECCFGR register.

Each bit of CWUFx is protected against unprivileged access when WUPxSEC = 1 in PWR_SECCFGR and SPRIV = 1 in PWR_PRIVCFGR, or when WUPxSEC 0 and NSPRIV = 1.

Address offset: 0x040

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CWUF 8	CWUF 7	CWUF 6	CWUF 5	CWUF 4	CWUF 3	CWUF 2	CWUF 1
								w	w	w	w	w	w	w	w

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **CWUFx**: clear wake-up pin flag for WUFx (x = 8 to 1)
These bits are always read as 0.
0: no effect
1: writing 1 clears the WUFx wake-up pin flag (bit is cleared to 0 by hardware).

10.11.14 PWR wake-up status register (PWR_WUSR)

Address offset: 0x044

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUF8	WUF7	WUF6	WUF5	WUF4	WUF3	WUF2	WUF1
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **WUFx**: wake-up pin WUFx flag (x = 8 to 1)

This bit is set by hardware and cleared only by a RESET pin or by setting the CWUFx bit in PWR_WUSCR register.

0: no wake-up event occurred.

1: a wake-up event received from WUFx pin.

10.11.15 PWR wake-up configuration register (PWR_WUCR)

Each register bit WUPPUPDx (x = 1 to 8) and WUPPx (x = 1 to 8) and WUPENx (x = 1 to 8) is protected against nonsecure access when WUPxSEC = 1 (x = 1 to 8) in the PWR_SECCFGR register.

Each bit of WUPENx is protected against unprivileged access when WUPxSEC = 1 in PWR_SECCFGR and SPRIV = 1 in PWR_PRIVCFGR, or when WUPxSEC = 0 and NSPRIV=1.

Address offset: 0x048

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WUPPUPD8[1:0]		WUPPUPD7[1:0]		WUPPUPD6[1:0]		WUPPUPD5[1:0]		WUPPUPD4[1:0]		WUPPUPD3[1:0]		WUPPUPD2[1:0]		WUPPUPD1[1:0]	
rw	rw	rw	rw	rw	rw	rw	w	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WUP P8	WUP P7	WUP P6	WUP P5	WUP P4	WUP P3	WUP P2	WUP P1	WUP EN8	WUP EN7	WUP EN6	WUP EN5	WUP EN4	WUP EN3	WUPE N2	WUP EN1
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **WUPPUPDx[1:0]**: wake-up pin pull configuration for WKUPx (x = 8 to 1)

These bits define the I/O pad pull configuration used when WUPENx = 1. The associated GPIO port pull configuration must be set to the same value or to 00. The wake-up pin pull configuration is kept in Standby mode.

00: no pull-up

01: pull-up

10: pull-down

11: reserved

Bits 15:8 **WUPPx**: wake-up pin polarity bit for WUPx (x = 8 to 1)

These bits define the polarity used for event detection on WUPx external wake-up pin.

0: detection on high level (rising edge)

1: detection on low level (falling edge)

Bits 7:0 **WUPENx**: enable wake-up pin WUPx (x = 8 to 1)

These bits are set and cleared by software.

0: an event on WUPx pin does not wake-up the system from Standby mode.

1: a rising or falling edge on WUPx pin wakes up the system from Standby mode.

Note: An additional wake-up event is detected if WUPx pin is enabled (by setting the WUPENx bit) when WUPx pin level is already high when WUPPx selects rising edge, or low when WUPPx selects falling edge.

10.11.16 PWR I/O retention register (PWR_IORETR)

This register is protected against nonsecure access when RETSEC=1 in the PWR_SECCFGR register.

This register is protected against unprivileged access when RETBSEC=1 and SPRIV=1 in the PWR_PRIVCFGR register, or when RETSEC=0 and NSPRIV=1.

Address offset: 0x050

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JTAGIORETEN
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IORETEN
															rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **JTAGIORETEN**: I/O retention enable for JTAG I/Os

0: I/O retention mode is disable.

1: I/O retention mode is enabling for PA13, PA14, PA15 and PB4.

when entering Standby mode, the output is sampled, and apply to the output I/O during the standby power mode

Bits 15:1 Reserved, must be kept at reset value.

Bit 0 **IORETEN:** I/O retention enable

0: I/O retention mode is disabled.

1: I/O retention mode is enabling for all IO except the I/O support the standby functionality and PA13, PA14, PA15 and PB4.

When entering Standby mode, the output is sampled, and apply to the output I/O during the standby power mode.

Note: The IO state is not retained if the DBG_STANDBY bit is set in DBGMCU_CR register.

10.11.17 PWR security configuration register (PWR_SECCFGR)

This register can be written only when the access is secure. It can be read by secure or nonsecure access.

This register is write-protected against unprivileged write access when SPRIV=1 in the PWR_PRIVCFGR.

Address offset: 0x100

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VUSB SEC	VB SEC	SCM SEC	LPM SEC	RET SEC	Res.	Res.	Res.	WUP8 SEC	WUP7 SEC	WUP6 SEC	WUP5 SEC	WUP4 SEC	WUP3 SEC	WUP2 SEC	WUP1 SEC
rw	rw	rw	rw	rw				rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **VUSBSEC**: voltage USB secure protection
0: PWR_USBSCR can be read and written with secure or nonsecure access.
1: PWR_USBSCR can be read and written only with secure access..

Bit 14 **VBSEC**: Backup domain secure protection
0: PWR_BDCR, PWR_DBPCR can be read and written with secure or nonsecure access.
1: PWR_BDCR, PWR_DBPCR can be read and written only with secure access.

Bit 13 **SCMSEC**: supply configuration and monitoring secure protection.
0: PWR_SCCR and PWR_VMCR can be read and written with secure or nonsecure access.
1: PWR_SCCR and PWR_VMCR can be read and written only with secure access.

Bit 12 **LPMSEC**: low-power modes secure protection
0: PWR_PMCR can be read and written with secure or nonsecure access.
1: PWR_PMCR can be read and written only with secure access.

Bit 11 **RETSEC**: retention secure protection
0: PWR_IORETR can be read and written with secure or nonsecure access.
1: PWR_IORETR can be read and written only with secure access.

Bits 10:8 Reserved, must be kept at reset value.

Bits 7:0 **WUPxSEC**: WUPx secure protection (x = 8 to 1)
0: The bits related to the WKUPx wake-up pin in PWR_WUSCR and PWR_WUCR can be read and written with secure or nonsecure access.
1: The bits related to the WKUPx wake-up pin in PWR_WUSCR and PWR_WUCR can be read and written only with secure access.

10.11.18 PWR privilege configuration register (PWR_PRIVCFGR)

This register can be written only when the access is privileged. It can be read by privileged or unprivileged access.

Address offset: 0x104

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NSPRIV	SPRIV
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **NSPRIV**: PWR nonsecure functions privilege configuration

Set and reset by software. This bit can be written only by privileged access, secure or nonsecure.

0: Read and write to PWR nonsecure functions can be done by privileged or unprivileged access.

1: Read and write to PWR nonsecure functions can be done by privileged access only.

Bit 0 **SPRIV**: PWR secure functions privilege configuration

Set and reset by software. This bit can be written only by a secure privileged access.

0: Read and write to PWR secure functions can be done by privileged or unprivileged access.

1: Read and write to PWR secure functions can be done by privileged access only.

10.11.19 PWR register map

Table 102. PWR register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	PWR_PMCR	SRAM1SO	SRAM2_48HSO	SRAM2_48LSO	SRAM2_16HSO	SRAM2_16LSO	SRAM3SO	SRAM4SO	SRAM5SO	Res.	Res.	Res.	Res.	Res.	Res.	LTDCSO	ETHERNETSO	Res.	Res.	AVD_READY	BOOSTE	Res.	Res.	FLPS	Res.	CSSF	Res.	Res.	Res.	SVOS[1:0]		Res.	LPMS
	Reset value	0	0	0	0	0	0	0	0							0	0			0	0			0		0				1	1		0
0x04	PWR_PMSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SBF	STOPF	Res.	Res.	Res.	Res.	Res.
	Reset value																										0	0					
0x008-0x00F	Reserved	Reserved																															
0x10	PWR_VOSCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VOS[1:0]		Res.	Res.	Res.	Res.
	Reset value																											0	0				
0x14	PWR_VOSSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ACTVOS[1:0]		ACTVOSRDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VOSRDY	Res.	Res.	Res.
	Reset value																	0	0	1										1			

Table 102. PWR register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x018-0x01F	Reserved	Reserved																															
0x20	PWR_BDCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VBRS	VBE	Res.	Res.	Res.	Res.	Res.	Res.	MONEN	BREN
	Reset value																							0	0							0	0
0x24	PWR_DBPCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBP
	Reset value																																0
0x28	PWR_BDSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TEMPH	TEMPL	VBATH	VBATL	Res.	Res.	Res.	BRDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value									0	0	0	0				0																
0x2C	PWR_UCPDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UCPD_STBY	UCPD_DBDIS
	Reset value																															0	0
0x30	PWR_SCCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SMPSEN	LDOEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BYPASS
	Reset value																							X	X								0
0x34	PWR_VMCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALS [1:0]		AVDEN	Res.	Res.	Res.	Res.	PLS [2:0]			PVDE
	Reset value																						0	0	0							0	0
0x38	PWR_USBSCR	Res.	Res.	Res.	Res.	OTGHSEN	Res.	USB33SV	USB33DEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0		0	0																								
0x3C	PWR_VMSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	USB33RDY	Res.	PVDD	Res.	VDDIO2RDY	AVDD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value								0		0		X	0																			
0x40	PWR_WUSCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CWUF8	CWUF7	CWUF6	CWUF5	CWUF4	CWUF3	CWUF2	CWUF1
	Reset value																									0	0	0	0	0	0	0	0
0x44	PWR_WUSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUF8	WUF8	WUF6	WUF5	WUF4	WUF3	WUF2	WUF1
	Reset value																									0	0	0	0	0	0	0	0
0x48	PWR_WUCR	WUPPUPD8 [1:0]		WUPPUPD7 [1:0]		WUPPUPD6 [1:0]		WUPPUPD5 [1:0]		WUPPUPD4 [1:0]		WUPPUPD3 [1:0]		WUPPUPD2 [1:0]		WUPPUPD1 [1:0]		WUPP8	WUPP7	WUPP6	WUPP5	WUPP4	WUPP3	WUPP2	WUPP1	WUPEN8	WUPEN7	WUPEN6	WUPEN5	WUPEN4	WUPEN3	WUPEN2	WUPEN1
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04C	Reserved	Reserved																															

Table 102. PWR register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x50	PWR_IORETR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JTAGIORETEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IORETEN
	Reset value																0																0
0x054-0x0FF	Reserved	Reserved																															
0x100	PWR_SECCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VUSBSEC	VBSEC	SCMSEC	LPMSEC	RETSEC	Res.	Res.	Res.	Res.	WUP7SEC	WUP6SEC	WUP5SEC	WUP4SEC	WUP3SEC	WUP2SEC	WUP2SEC
	Reset value																	0	0	0	0	0					0	0	0	0	0	0	0
0x104	PWR_PRIVCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NSPRIV	SPRIV
	Reset value																															0	0

Refer to *Section 2.3* for the register boundary addresses.

11 Reset and clock control (RCC)

11.1 RCC introduction

The reset and clock control (RCC) manages the different resets, and generates the clocks for the bus and peripherals.

11.2 RCC pins and internal signals

The table below lists the RCC inputs and output signals connected to package pins or balls.

Table 103. RCC input/output signals connected to package pins or balls

Signal name	Signal type	Description
NRST	I/O	System reset, can be used to provide reset to external devices
OSC32_IN	I	32 kHz oscillator input
OSC32_OUT	O	32 kHz oscillator output
OSC_IN	I	System oscillator input
OSC_OUT	O	System oscillator output
MCO	O	Output clock for external devices
LSCO	O	Low-speed output clock for external devices
AUDIOCLK	I	External kernel clock input for SAI1, SAI2, I2S1, I2S2, and I2S3

11.3 RCC reset functional description

There are three types of reset:

- a system reset
- a power reset
- a backup domain reset

11.3.1 Power reset

A power reset is generated when one of the following events occurs:

- a brownout reset (BOR)
- when exiting Standby mode

A brownout reset, including power-on or power-down reset (POR/PDR), sets all registers to their reset values except those in the backup domain.

When exiting Standby mode, all registers in the core domain are set to their reset value. The other registers (RTC, WKUP, IWDG, and GPIO pull-up/down configuration during Standby and Standby mode exit) are not impacted.

11.3.2 System reset

A system reset sets all registers to their reset values except the reset flags in *RCC reset status register (RCC_RSR)*, and the registers in the backup domain.

A system reset is generated when one of the following events occurs:

- a low level on the NRST pin (external reset)
- a window watchdog event (WWDG reset)
- an independent watchdog event (IWDG reset)
- a software reset (SW reset), see *Software reset*
- a low-power mode security reset, see *Low-power mode security reset*
- a brownout reset

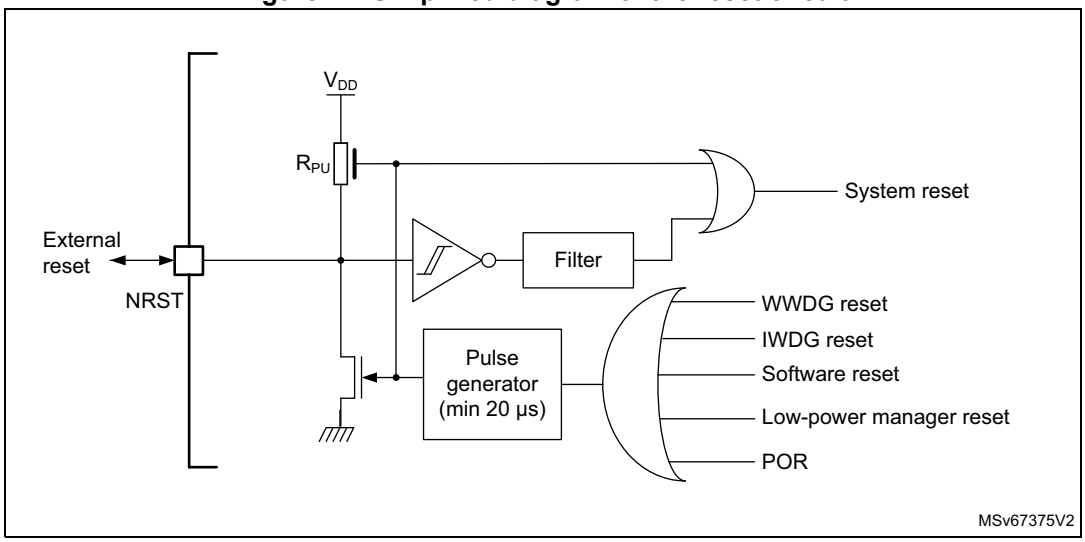
The reset source can be identified by checking the reset flags in the *RCC reset status register (RCC_RSR)*.

These sources act on the NRST pin, and this pin is always kept low during the delay phase. The reset service routine vector is selected depending on product state, on Boot option bytes, or on both.

The system reset signal provided to the device is output on the NRST pin. The pulse generator guarantees a minimum reset pulse duration of 20 µs for each internal reset source. In case of an external reset, the reset pulse is generated while the NRST pin is asserted low.

In case of an internal reset, the internal pull-up R_{PU} is deactivated to save the power consumption through the pull-up resistor.

Figure 47. Simplified diagram of the reset circuit



Software reset

The SYSRESETREQ bit in Cortex-M33 application interrupt and reset control register must be set to force a software reset on the device.

Low-power mode security reset

To avoid that critical applications mistakenly enter a low-power mode, low-power mode security resets are available. If enabled in option bytes, the resets are generated in any of the following conditions:

- Entering Standby mode: enabled by resetting NRST_STDBY bit in user option bytes. In this case, whenever a Standby mode entry sequence is successfully executed, the device is reset instead of entering Standby mode.
- Entering Stop mode: enabled by resetting NRST_STOP bit in user option bytes. In this case, whenever a Stop mode entry sequence is successfully executed, the device is reset instead of entering Stop mode.

For further information on the user option bytes, refer to *Section 7.4: FLASH option bytes*.

11.3.3 Backup domain reset

The backup domain has two specific resets, generated when one of the following events occurs:

- Software reset, triggered by setting the VSWRST bit in the *RCC backup domain control register (RCC_BDCR)*. Write access to this domain must be enabled before setting VSWRST bit to perform the reset.
- V_{DD} or V_{BAT} power on, if both supplies have previously been powered off.

A backup domain reset affects the LSE oscillator, the RTC, the backup registers, the backup SRAM, and the RCC_BDCR register.

11.3.4 Reset source identification

The application can identify the reset source by checking the reset flags in the RCC_RSR register. The software can reset the flags by setting RMVF bit.

The following table shows how the status bits of the RCC_RSR register behave according to the situation that generated the reset. For example, when an IWDG timeout occurs, if the CPU is reading the RCC_RSR register during the boot phase, both PINRSTF and IWDGRSTF bits are set, indicating that the IWDG also generated a pin reset.

Table 104. Reset source identification (RCC_RSR)(1)

	Reset	SBF(2)	LPWRRSTF	WWDGRSTF	IWDGRSTF	SFTRSTF	BORRSTF	PINRSTF
1	Power-on reset	0	0	0	0	0	1	1
2	Pin/pad reset	0	0	0	0	0	0	1
3	Brownout (low or high) reset	0	0	0	0	0	1	1
4	System reset generated by CPU	0	0	0	0	1	0	1
5	WWDG reset	0	0	1	0	0	0	1
6	IWDG reset	0	0	0	1	0	0	1
7	Illegal Stop entry reset	0	1	0	0	0	0	1
8	The device exits from Standby mode	1	0	0	0	0	0	1

1. Gray cells highlight the register bits that are set.
2. The SBF bit is located in PWR status register (PWR_PMSR).

11.4 RCC clock functional description

Four different clock sources can be used to drive the system clock (SYSCLK):

- HSI: high-speed internal up to 64 MHz RC oscillator clock
- CSI: low-power internal RC oscillator clock
- HSE: high-speed external crystal or clock, from 4 to 50 MHz
- PLL1 clock

The HSI is used as system clock source after startup from reset, configured at 32 MHz.

The device has the following additional clock sources:

- LSI: 32 kHz low-speed internal RC that drives the independent watchdog and optionally the RTC used for auto-wake-up from Stop and Standby modes
- LSE: 32.768 kHz low-speed external crystal or clock that optionally drives the real-time clock (rtc_ck)
- HSI48: internal 48 MHz RC that potentially drives the OTG_FS and the RNG
- PLL2 and PLL3 clocks

Each clock source can be switched on or off independently when it is not used, to optimize power consumption.

Several prescalers can be used to configure the AHB frequency, the APB1 and APB2 domains. The maximum frequency of the AHB and APB domains is 250 MHz.

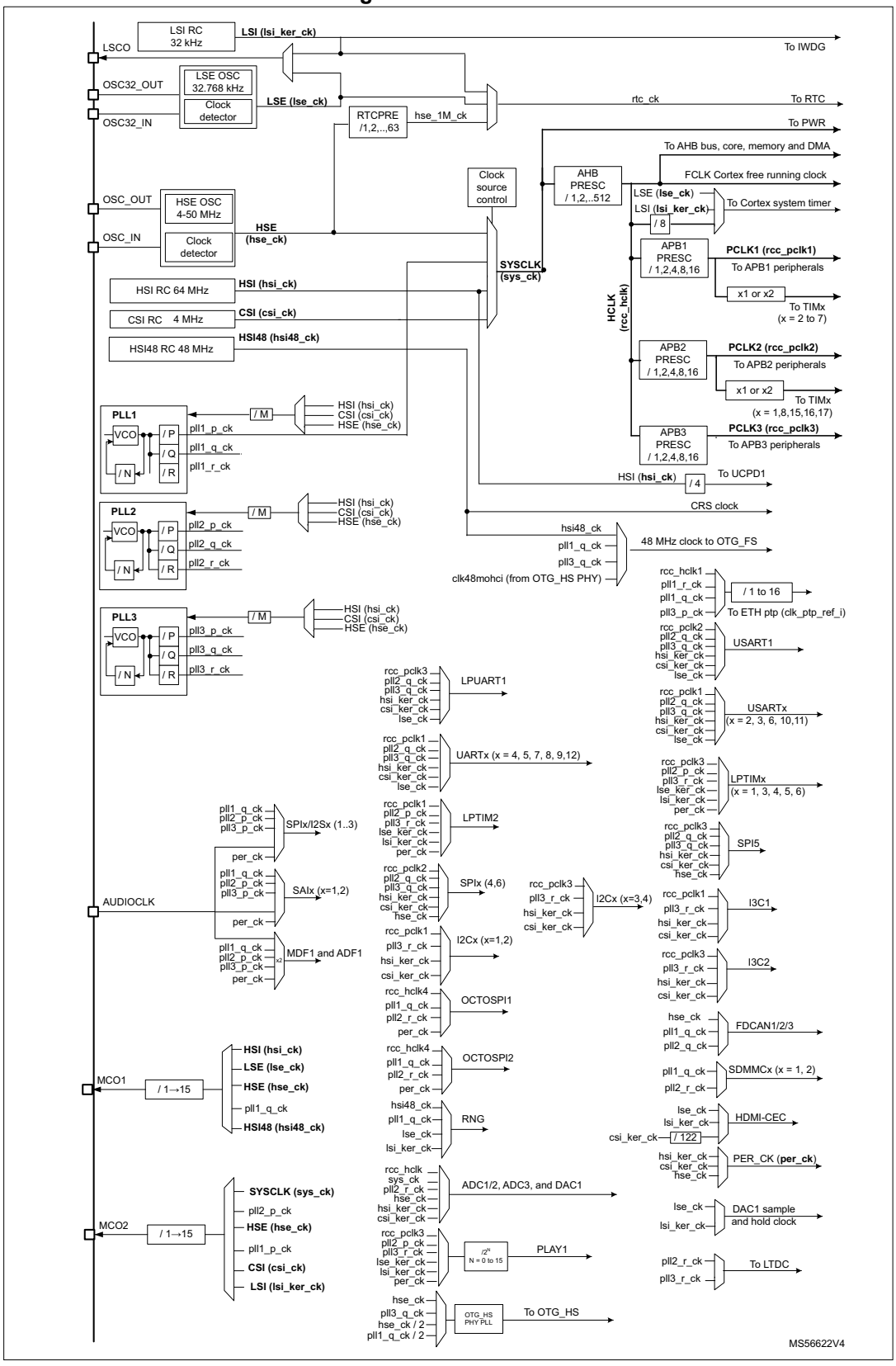
The peripheral clocks are derived from their bus clock (HCLK, PCLK1, PCLK2 or PCLK3), except those that receive an independent kernel clock. This kernel clock can be selected by software between several sources thanks to RCC_CCIPRx registers (x = 1,2,3,4,5).

In addition, the RTC kernel clock is selected by software in RCC_BDCR. The IWDG clock is always the LSI 32 kHz clock.

The RCC feeds the Cortex system timer (SysTick) external clock with the AHB clock (HCLK) divided by eight, or LSE or LSI. The SysTick can work either with this clock or directly with the Cortex clock (HCLK), configurable in the SysTick control and status register.

FCLK acts as Cortex-M33 free-running clock.

Figure 48. Clock tree

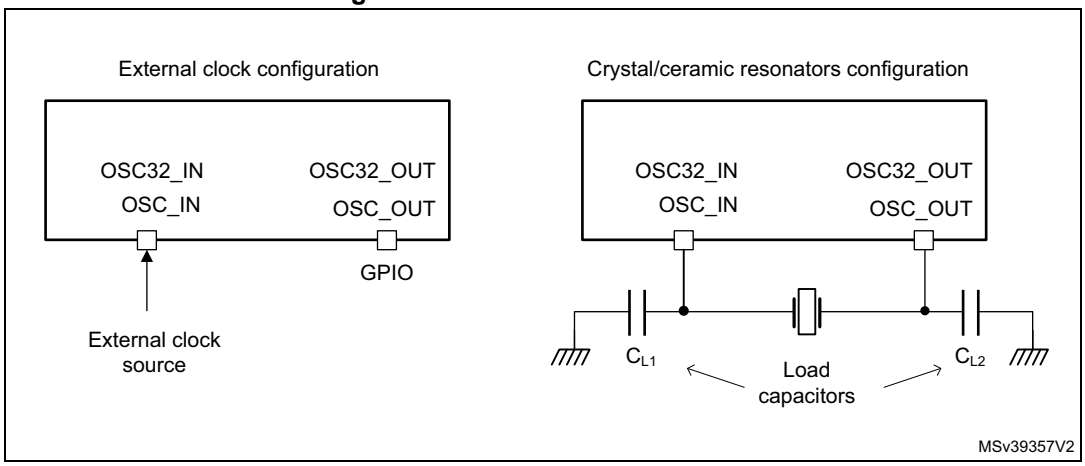


1. For details on the internal/external clock source, refer to the electrical characteristics in the datasheet.

11.4.1 HSE clock

The HSE block can generate a clock from an external crystal/ceramic resonator, or from an external clock source.

Figure 49. HSE/LSE clock sources



External clock source (HSE bypass)

In this mode, an external clock source must be provided to OSC_IN pin. The external clock can be low swing (analog) or digital. If this clock is directly used by a peripheral, the duty cycle requirement is defined by the peripheral and the application (refer to datasheet for more details). This external clock is provided to the OSC_IN pin while the OSC_OUT pin can be used as a GPIO (see *Figure 49: HSE/LSE clock sources*).

In case of an analog clock (low swing) the HSEBYP and HSEON bits must be set to 1 in the *RCC clock control register (RCC_CR)*.

In case of a digital clock, the HSEBYP and the HSEEXT bits must be set to 1 followed by setting the HSEON bit to 1 in the *RCC clock control register (RCC_CR)*.

External crystal/ceramic resonator

The oscillator is enabled by setting the HSEBYP bit to 0 and HSEON bit to 1.

The HSE can be used when the product requires a very accurate high-speed clock.

The associated hardware configuration is shown in *Figure 49*: the resonator and the load capacitors must be placed as close as possible to the oscillator pins to minimize output distortion and startup stabilization time. The loading capacitance values must be adjusted according to the selected crystal or ceramic resonator. Refer to the electrical characteristics section of the datasheet for more details.

The HSERDY flag of the *RCC clock control register (RCC_CR)* indicates whether the HSE oscillator is stable or not. At startup, the hse_ck clock is not released until this bit is set by hardware. An interrupt can be generated if enabled in the *RCC clock source interrupt enable register (RCC_CIER)*.

The HSE can be switched ON and OFF through the HSEON bit. The HSE cannot be switched OFF if one of the following two conditions is met:

- The HSE is used directly (via software mux) as system clock.
- The HSE is selected as reference clock for PLL1, with PLL1 enabled and selected to provide the system clock (via software mux).

In that case, the hardware does not allow programming the HSEON bit to 0.

The HSE is automatically disabled by hardware, when the system enters Stop or Standby mode.

In addition, the HSE clock can be driven to the MCO1 and MCO2 outputs and used as clock source for other application components.

11.4.2 HSI clock

The HSI block provides the default clock to the product.

The HSI is a high-speed internal RC oscillator that can be used directly as system clock, peripheral clock, or as PLL input. A predivider allows the application to select an HSI output frequency of 8, 16, 32, or 64 MHz. This predivider is controlled by the HSIDIV.

The HSI advantages are the following:

- low-cost clock source, as no external crystal is required
- faster startup time than HSE (a few microseconds)

The HSI frequency, even with frequency calibration, is less accurate than an external crystal oscillator or ceramic resonator.

The HSI can be switched ON and OFF using the HSION bit. Note that the HSI cannot be switched OFF if one of the two conditions is met:

- The HSI is used directly (via software mux) as system clock.
- The HSI is selected as reference clock for PLL1, with PLL1 enabled and selected to provide the system clock (via software mux).

In that case the hardware does not allow programming the HSION bit to 0. Note that the HSIDIV cannot be changed if the HSI is selected as reference clock for at least one enabled PLL (PLLxON bit set to 1). In that case, the hardware does not update the HSIDIV with the new value. However, it is possible to change the HSIDIV if the HSI is used directly as system clock.

The HSIRDY flag indicates if the HSI is stable or not. At startup, the HSI output clock is not released until this bit is set by hardware.

The HSI clock can also be used as a backup source (auxiliary clock) if the HSE fails (refer to *Section 11.4.10: Clock security system (CSS)*). The HSI can be disabled or not when the system enters Stop mode.

In addition, the HSI clock can be driven to the MCO1 output and used as clock source for other application components.

Care must be taken when the HSI is used as kernel clock for communication peripherals, the application must take into account the following parameters:

- the time interval between the moment where the peripheral generates a kernel clock request and the moment where the clock is really available
- the frequency accuracy

Note: The HSI can remain enabled when the system is in Stop mode.

HSI calibration

RC oscillator frequencies can vary from one chip to another due to manufacturing process variations. That is why each device is factory calibrated to achieve an accuracy of ACCHSI (refer to the product datasheet for more information).

After a power-on reset, the factory calibration value is loaded in the HSICAL[11:0] bits. If the application is subject to voltage or temperature variations, this may affect the RC oscillator frequency. The user application can trim the HSI frequency using the HSITRIM[6:0] bits.

Note: HSICAL[11:0] and HSITRIM[6:0] are located in the RCC CSI calibration register (RCC_CSICFGR).

11.4.3 CSI oscillator

The CSI is a low-power RC oscillator that can be used directly as system clock, peripheral clock, or PLL input.

The CSI advantages are the following:

- low-cost clock source since no external crystal is required
- faster startup time than HSE (a few microseconds)
- very low-power consumption

The CSI provides a clock frequency of about 4 MHz, while the HSI is able to provide a clock up to 64 MHz.

CSI frequency, even with frequency calibration, is less accurate than an external crystal oscillator or ceramic resonator.

The CSI can be switched ON and OFF through the CSION bit. The CSIRDY flag indicates whether the CSI is stable or not. At startup, the CSI output clock is not released until this bit is set by hardware.

The CSI cannot be switched OFF if one of the two conditions is met:

- The CSI is used directly (via software mux) as system clock.
- The CSI is selected as reference clock for PLL1, with PLL1 enabled and selected to provide the system clock (via software mux).

In that case, the hardware does not allow programming the CSION bit to 0.

The CSI can be disabled or not when the system enters Stop mode.

In addition, the CSI clock can be driven to the MCO2 output and used as clock source for other application components.

Even if the CSI settling time is faster than the HSI, care must be taken when the CSI is used as kernel clock for communication peripherals: the application must take into account the following parameters:

- the time interval between the moment where the peripheral generates a kernel clock request and the moment where the clock is really available
- the frequency precision

Note: CSION and CSIRDY bits are located in the RCC clock control register (RCC_CR).

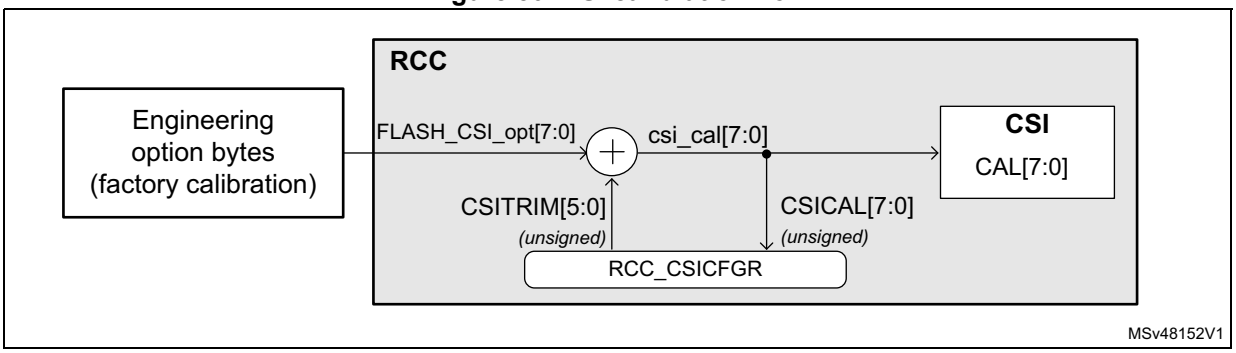
CSI calibration

RC oscillator frequencies can vary from one chip to another due to manufacturing process variations, this is why each device is factory calibrated to achieve ACC_{CSI} accuracy (refer to the product datasheet for more information). After reset, the factory calibration value is loaded in the CSICAL[7:0] bits.

Voltage and/or temperature variations affect the RC oscillator frequency. The user application can trim the CSI frequency using the CSITRIM[5:0] bits.

Note: Bits CSICAL[7:0] and CSITRIM[5:0] are located into the RCC CSI calibration register (RCC_CSICFGR).

Figure 50. CSI calibration flow



11.4.4 HSI48 clock

The HSI48 clock signal is generated from an internal 48 MHz RC oscillator, and can be used directly for USB and for random number generator (RNG).

The internal 48 MHz RC oscillator is mainly dedicated to provide a high-precision clock to the USB peripheral by means of a special clock recovery system (CRS) circuitry. The CRS can use the USB SOF signal, the LSE, or an external signal to automatically and quickly adjust the oscillator frequency on-the-fly. It is disabled as soon as the system enters Stop or Standby mode. When the CRS is not used, the HSI48 RC oscillator runs on its default frequency, subject to manufacturing process variations.

For more details on how to configure and use the CRS peripheral, refer to *Section 12: Clock recovery system (CRS)*.

The HSI48RDY flag in the RCC_CR register indicates whether the HSI48 RC oscillator is stable or not. At startup, the HSI48 RC oscillator output clock is not released until this bit is set by hardware.

The HSI48 can be switched ON and OFF using the HSI48ON bit in the RCC_CR register.

11.4.5 PLL description

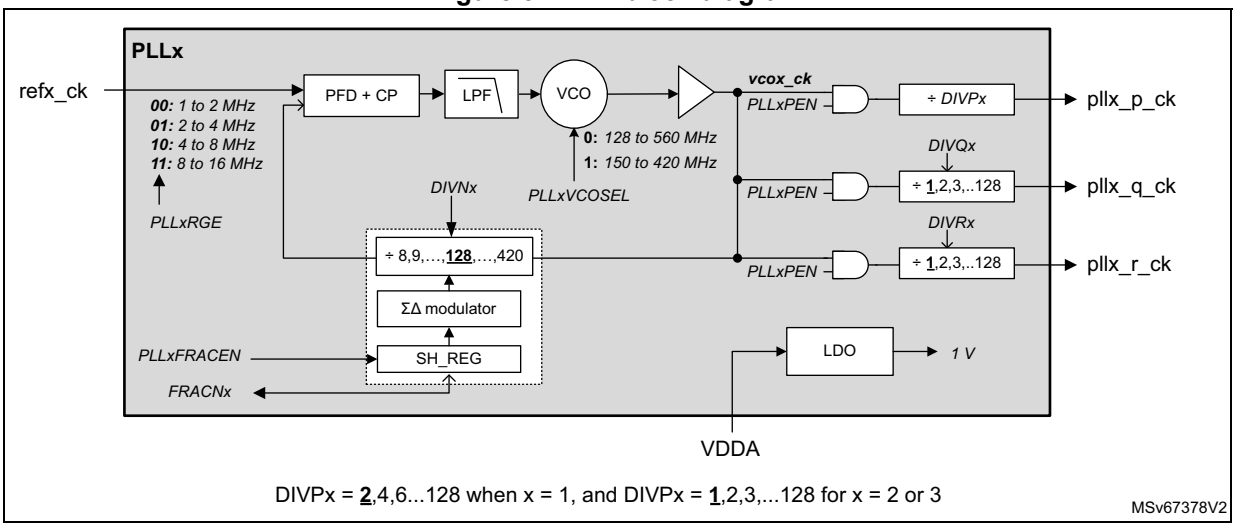
The RCC features three completely independent PLLs:

- a main PLL (PLL1), generally used to provide clocks to the CPU and some peripherals
- two dedicated PLLs (PLL2 and PLL3), used to generate the kernel clock for peripherals

PLLs main features:

- A VCO supporting two modes:
  - a wide-range
  - a low-range used, for instance, in audio applications
- Input frequency range:
  - 2 to 16 MHz for the VCO in wide-range mode
  - 1 to 2 MHz for the VCO in low-range mode
- Capability to work either in integer or fractional mode
- 13-bit sigma-delta modulator, allowing to fine-tune the VCO frequency by steps of 11 to 0.3 ppm
- The sigma-delta modulator can be updated on-the-fly without generating frequency overshoots on PLLs outputs
- Each PLL offers three outputs with post-dividers.

Figure 51. PLL block diagram



The PLLs are controlled via RCC_PLLxDIVR, RCC_PLLxFRACR, RCC_PLLCFGR, and RCC_CR registers.

The frequency of the reference clock provided to the PLLs (refx_ck) must range from 1 to 16 MHz. The PLLxM dividers of the RCC PLLx clock source selection register (RCC_PLLxCFGR) must be properly programmed to match this condition. In addition, the PLLxRGE[1:0] field of the RCC PLLx clock source selection register (RCC_PLLxCFGR) must be set according to the reference input frequency to optimize performance.

The user application can then configure the VCO. The smaller range (150 to 420 MHz) must be chosen when the reference clock frequency is lower than 2 MHz.

To reduce the power consumption, it is recommended to configure the VCO output to the smaller range.

DIVNx loop divider must be programmed to achieve the expected frequency at VCO output. In addition, the VCO output range must be respected.

The PLLs operate in integer mode when the value of SH_REG bit of the FRACNx shadow register is set to 0. The SH_REG bit is updated with the FRACNx value when PLLxFRACEN

bit goes from 0 to 1. The sigma-delta modulator is designed to minimize the jitter impact, while allowing very small frequency steps.

The PLLs can be enabled by setting PLLxON to 1. The PLLxRDY bits indicate that the PLL is ready (locked).

Note: Before enabling the PLLs, make sure that the reference frequency (refx_ck) is stable. The hardware does not allow changing PLLxM when the PLLx is ON, and it is not possible to change PLLSRC when one of the PLLs is ON.

The hardware prevents writing PLL1ON to 0 if the PLL1 is currently used to deliver the system clock. There are other hardware protections on the clock generators (refer to HSE clock, HSI clock, and CSI oscillator).

The following parameters cannot be changed once the PLL is enabled: DIVNx, PLLxRGE, PLLxVCOSEL, PLLxP (DIVP), PLLxQ (DIVQ), and PLLxR (DIVR).

To save power, when the PLLx output (pllx_p_ck, pllx_q_ck or pllx_r_ck) is not used, it should be disabled by clearing the corresponding bit in PLLxCFGR register (PLLxPEN, PLLxQEN or PLLxREN).

If the above rules are not respected, the PLL output frequency is not guaranteed.

Output frequency computation

When the PLL is configured in integer mode (SH_REG = 0), the VCO frequency is $F_{VCO} = F_{REF_CK}$ x DIVN, and $F_{PLL_y_CK} = F_{VCO}$ / (DIVy +1), with y = P, Q, or R.

When the PLL is configured in fractional mode (SH_REG different from 0), the DIVN divider must be initialized before enabling the PLLs. However, it is possible to change the value of FRACNx on-the-fly without disturbing the PLL output.

This feature can be used either to generate a specific frequency from any crystal value with a good accuracy, or to fine-tune the frequency on-the-fly.

For each PLL, the VCO frequency is given by the following formula:

$$F_{VCO} = F_{ref_ck} \times \left(DIVN + \frac{FRACN}{2^{(13)}} \right)$$

Note: For PLL1, DIVP can only take odd values.

The PLLs are disabled by hardware when:

- the system enters Stop or Standby mode
- an HSE failure occurs when HSE or PLL (clocked by HSE) are used as system clock

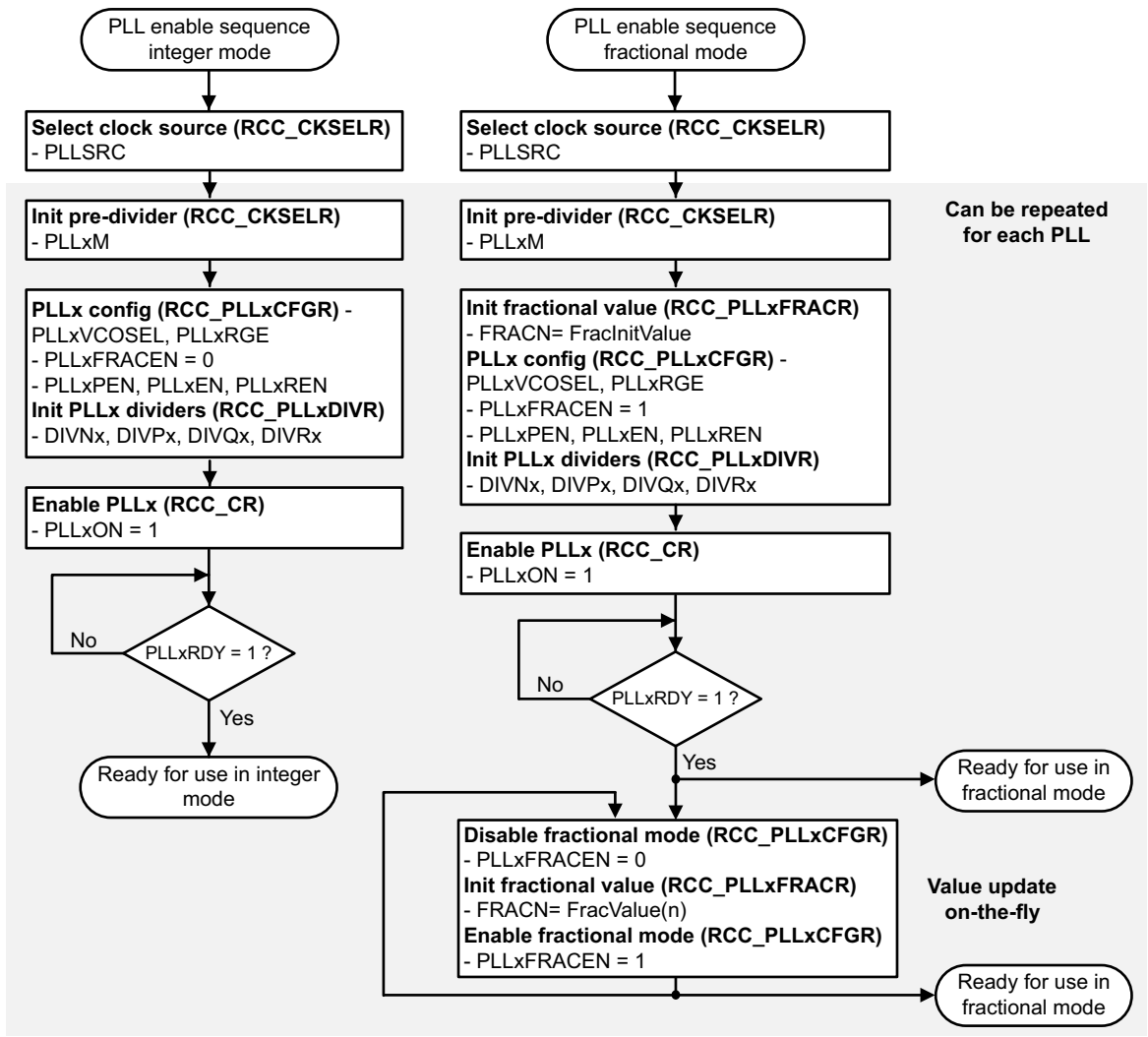
PLL initialization phase

Figure 52 shows the recommended PLL initialization sequence in integer and fractional mode. The PLLx are supposed to be disabled at the start of the initialization sequence:

1. Initialize the PLLs registers according to the required frequency.
   – Set PLLxFRACEN of RCC_PLLxCFGR register to 0 for integer mode. For fractional mode, set FRACN to the required initial value (FracInitValue) and then set PLLxFRACEN to 1.
2. Once the PLLxON bit is set to 1, the user application must wait until PLLxRDY bit is set to 1. If the PLLx is in fractional mode, the PLLxFRACEN bit must not be set back to 0 as long as PLLxRDY = 0.
3. Once the PLLxRDY bit is set to 1, the PLLx is ready to be used.
4. If the application intends to tune the PLLx frequency on-the-fly (possible only in fractional mode):
   a) PLLxFRACEN must be set to 0. When PLLxFRACEN = 0, the sigma-delta modulator is still operating with the value latched into SH_REG. The application must wait for three clock periods of refx_ck (PLLxFRACEN bit propagation delay).
   b) A new value must be uploaded into PLLxFRACR (FracValue(n)).
   c) PLLxFRACEN must be set to 1, to latch the content of PLLxFRACR into its shadow register.The new value is considered after three clock periods of refx_ck (PLLxFRACEN bit propagation delay).

Note: When the PLLxRDY goes to 1 the difference between the PLLx output frequency and the target value is lower than ±2%.

Figure 52. PLLs initialization flow



11.4.6 LSE clock

The LSE block can generate a clock from an external crystal/ceramic resonator, or from an external user clock (see *Figure 49*).

External clock source (LSE bypass)

In this mode, an external clock source must be provided to OSC32_IN pin. The input clock can have a frequency up to 1 MHz, and must be digital. A duty cycle close to 50% is recommended.

This external clock is provided to the OSC32_IN pin while the OSC32_OUT pin can be used as a GPIO (see *Figure 49*).

To enable LSE bypass, the LSEBYP and the LSEEXT bits must be set to 1 followed by setting the LSEON bit to 1 (*RCC backup domain control register (RCC_BDCR)*).

External crystal/ceramic resonator (LSE crystal)

The LSE clock is generated from a 32.768 kHz crystal or ceramic resonator. It has the advantage to provide a low-power, highly accurate clock source to the real-time clock (RTC) for clock/calendar or other timing functions.

The LSERDY flag of the *RCC backup domain control register (RCC_BDCR)*) indicates whether the LSE crystal is stable or not. At startup, the LSE crystal output clock signal is not released until this bit is set by hardware. An interrupt can be generated if enabled in the *RCC clock source interrupt enable register (RCC_CIER)*.

The LSE oscillator is switched ON and OFF using the LSEON bit. The LSE remains enabled when the system enters Stop or Standby mode.

In addition, the LSE clock can be driven to the MCO1 output and used as clock source for other application components.

The LSE also offers a programmable driving capability (LSEDRV[1:0]), which can be used to modulate the amplifier driving capability. This driving capability is chosen according to the external crystal/ceramic component requirement to ensure a stable oscillation.

The driving capability must be set before enabling the LSE oscillator.

11.4.7 LSI clock

The LSI acts as a low-power clock source that can be kept running when the system is in Stop or Standby mode for the independent watchdog (IWDG) and auto-wake-up unit (AWU).

The clock frequency is around 32 kHz. For more details, refer to the electrical characteristics section of the datasheet.

The LSI can be switched ON and OFF using the LSION bit. The LSIRDY flag indicates whether the LSI oscillator is stable or not. If an independent watchdog is started either by hardware or software, the LSI is forced ON and cannot be disabled.

The LSI remains enabled when the system enters Stop or Standby mode.

At LSI startup, the clock is not provided until the hardware sets the LSIRDY bit. An interrupt can be generated if enabled in the *RCC clock source interrupt enable register (RCC_CIER)*.

In addition, the LSI clock can be driven to the MCO2 output, and used as a clock source for other application components.

Note: Bits LSION and LSIRDY are located in the RCC backup domain control register (RCC_BDCR).

11.4.8 System clock (SYSCLK) selection

Four different clock sources can be used to drive the system clock (SYSCLK), namely HSI, CSI, or HSE oscillator, or PLL.

The system clock maximum frequency is 250 MHz. After a system reset (or after leaving Standby mode), the HSI oscillator, at 32 MHz, is selected as system clock. When a clock source is used directly or through the PLL as a system clock, it is not possible to stop it.

A switch from one clock source to another occurs only if the target clock source is ready (clock stable after startup delay or PLL locked). If a clock source not yet ready is selected, the switch occurs when the clock source becomes ready. Status bits in the *RCC clock*

control register (RCC_CR) indicate which clocks are ready, and which one is currently used as a system clock.

11.4.9 Handling clock generators in Stop and Standby modes

When the whole system enters Stop mode, all the clocks (system and kernel clocks) are stopped, as well as the following clock sources:

- CSI, HSI (depending on HSIKERON and CSIKERON bits)
- HSE
- PLL1, PLL2, and PLL3
- HSI48

The content of the RCC registers is not altered except for PLL1ON, PLL2ON, PLL3ON, HSEON, and HSI48ON, set to 0.

Exiting Stop mode

When the system exits this mode via a wake-up event, the application can select which oscillator (HSI and/or CSI) is used to restart. The STOPWUCK bit selects the oscillator used as system clock. The STOPKERWUCK bit selects the oscillator used as kernel clock for peripherals. The STOPKERWUCK bit is useful if after a system Stop, a peripheral needs a kernel clock generated by an oscillator different from the one used for the system clock.

These bits belong to the *RCC clock configuration register1 (RCC_CFGR1)*.

Table 105. STOPWUCK and STOPKERWUCK description

STOPWUCK	STOPKERWUCK	Activated oscillator(s) when the system exits Stop mode	Distributed clocks when the system exits Stop mode	
			System clock	Kernel clock
0	0	HSI	HSI	HSI
	1	HSI and CSI		HSI and/or CSI
1	0		CSI	
	1	CSI		CSI

During Stop mode

There are two specific cases where the HSI or CSI can be enabled during this mode.

- When a dedicated peripheral requests the kernel clock the peripheral receives the HSI or CSI according to the kernel clock source selected for this peripheral (via CKPERSEL[1:0]).
- When the HSIKERON or CSIKERON bits of the *RCC clock control register (RCC_CR)* are set, the HSI and CSI are kept running, but the outputs are gated. The clock is then available immediately when the system exits Stop mode, or when a peripheral requests the kernel clock (see *Table 103* for details).

Table 106. HSIKERON and CSIKERON behavior

HSIKERON (CSIKERON)	HSI (CSI) state during Stop mode	HSI (CSI) state setting time
0	OFF	$t_{su(HSI)}$ $t_{su(CSI)}$ (1)
1	Running and gated	Immediate

1. $t_{su(HSI)}$ and $t_{su(CSI)}$ are the startup times of, respectively, the HSI and CSI oscillators (refer to the product datasheet for the values of these parameters).

When the microcontroller exists system Standby mode, the HSI is selected as system and kernel clock. The RCC registers are reset to their initial values except for the RCC_RSR and

RCC_BDCR registers.

Note: The HSI and CSI outputs provide two clock paths:

- one path for the system clock (hsi_ck or csi_ck)
- one path for the peripheral kernel clock (hsi_ker_ck or csi_ker_ck).

When a peripheral requests the kernel clock in system Stop mode, only the path providing the hsi_ker_ck or csi_ker_ck is activated.

11.4.10 Clock security system (CSS)

Clock security system on HSE

The clock security system can be enabled by software via the HSECSSON bit, which can be enabled even when the HSEON is set to 0.

The CSS on HSE is enabled by the hardware when the HSE is enabled and ready, and HSECSSON set to 1. The CSS on HSE is disabled when the HSE is disabled. As a result, this function does not work when the system is in Stop mode.

It is not possible to clear directly the HSECSSON bit by software.

The HSECSSON bit is cleared by hardware when a system reset occurs or when the system enters Standby mode.

If a failure is detected on the HSE clock, the system automatically switches to the HSI or CSI, depending on STOPWUCK bit configuration in *RCC clock configuration register1 (RCC_CFGR1)*, to provide a safe clock. The HSE is then automatically disabled, a clock failure event is sent to the break inputs of the advanced-control timer TIM1, and an NMI is automatically generated to inform the application about the failure, allowing the MCU to perform rescue operations. If the HSE output was used as clock source for PLLs when the failure occurred, the PLLs are also disabled.

If an HSE clock failure occurs when the CSS is enabled, the CSS generates an interrupt that causes the automatic generation of an NMI. The HSECSSF flag in *RCC clock source interrupt flag register (RCC_CIFR)* is set to 1 to allow the application to identify the failure source. The NMI routine is executed indefinitely until the HSECSSF bit is cleared. As a consequence, the application must clear the HSECSSF flag in the NMI ISR by setting the HSECSSC bit in the *RCC clock source interrupt clear register (RCC_CICR)*.

Clock security system on LSE

A clock security system on LSE can be activated by software writing the LSECSSON bit in the *RCC backup domain control register (RCC_BDCR)*. This bit can be disabled only by a

hardware reset or RTC software reset, or after a failure detection on LSE. LSECSSON must be written after LSE is enabled (LSEON enabled) and ready (LSERDY set by hardware), and after the RTC clock has been selected by RTCSEL.

The CSS on LSE is working in all modes including VBAT. It works also under system reset (excluding power-on reset).

The clock security system on LSE detects when the LSE disappears or in case of over frequency.

If a failure is detected on the external 32 kHz oscillator, the LSE clock is no longer supplied to the RTC, but no hardware action is made to the registers.

The CSS on LSE detection event is connected to the internal tamper 3 of the TAMP peripheral. The internal tamper 3 must be enabled (ITAMP3E = 1 in TAMP_CR1 register) and the associated interrupt enabled (ITAMP3IE in TAMP_IER) to wake up from the low-power modes. This erases also the TAMP backup registers and backup SRAM unless the ITAMP3NOER = 1 in the TAMP_CR3 (see *Section 58: Tamper and backup registers (TAMP)* for more details).

In case of CSS on LSE detection event (LSECSSD = 1 in the RCC_BDCR), the software must disable the LSECSSON bit, stop the defective 32 kHz oscillator (disabling LSEON), and change the RTC clock source (no clock or LSI or HSE, with RTCSEL), or take actions to secure the application.

11.4.11 Clock output generation (MCO1/MCO2)

Two microcontroller clock output pins (MCO1 and MCO2) are available. A clock source can be selected for each output.The selected clock can be divided thanks to configurable prescaler (refer to *Figure 48* for additional information on signal selection).

MCO1 and MCO2 outputs are controlled via MCO1PRE[3:0], MCO1[2:0], MCO2PRE[3:0], and MCO2[2:0], located in the *RCC clock configuration register1 (RCC_CFGR1)*.

The GPIO port corresponding to each MCO pin must be programmed in alternate function mode.

The clock provided to the MCO outputs must not exceed the maximum pin speed (refer to the product datasheet for information on the supported speed).

Another output (LSCO) allows one of the low-speed clocks (LSI, LSE) to be output onto the external LSCO pin. This output is available in Stop mode, not available in Standby and VBAT modes. The selection is controlled by the LSCOSEL bit, and enabled by the LSCOEN bit in the *RCC backup domain control register (RCC_BDCR)*.

The MCO clock output requires the corresponding alternate function selected on the MCO pin. The LSCO pin must be left in default POR state.

11.4.12 Kernel clock selection

Some peripherals are designed to work with two different clock domains that operate asynchronously:

- a clock domain synchronous with the register and bus interface (ckg_bus_perx clock)
- a clock domain generally synchronous with the peripheral (kernel clock)

The benefit of having peripherals supporting these two clock domains is that the user application has more freedom to choose the optimal clock frequency for the CPU, bus matrix, and for the kernel part of the peripheral. The bus frequency can be changed without reprogramming the peripherals. As an example, an ongoing transfer with UART is not disturbed if its APB clock is changed on-the-fly.

The following table shows the kernel clock that the RCC can deliver to the peripherals. Each row represents a multiplexer and the peripherals connected to its output.

Table 107. Kernel clock distribution overview

Peripheral	Clock multiplexer control bit	pll1_p_ck	pll1_q_ck	pll1_r_ck	pll2_p_ck	pll2_q_ck	pll2_r_ck	pll3_p_ck	pll3_q_ck	pll3_r_ck	sys_ck	bus clocks[1]	hse_ck	hsi_ker_ck	csi_ker_ck	hsi48_ck	lse_ck	lsi_ck	per_ck[2]	AUDIOCLK	clk48mohci	Disabled
FMC	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-
OCTOSPI1	OCTOSPI1SEL	-	1	-	-	-	2	-	-	-	-	0	-	-	-	-	-	-	3	-	-	-
OCTOSPI2	OCTOSPI2SEL	-	1	-	-	-	2	-	-	-	-	0	-	-	-	-	-	-	3	-	-	-
SDMMC1[3]	SDMMC1SEL	-	0	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SDMMC2[3]	SDMMC2SEL	-	0	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FDCANx (x=1,2,3)	FDCANSEL	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
PLAY1	PLAYSEL	-	-	-	1	-	-	-	-	2	-	0	-	-	-	-	3	4	5	-	-	-
CEC	CECSEL	-	-	-	-	-	-	-	-	-	-	-	-	-	2[4]	-	0	1	-	-	-	-
I2Cx (x=1,2,3,4)	I2CxSEL	-	-	-	-	-	-	-	-	1	-	0	-	2	3	-	-	-	-	-	-	-
I3Cx (x=1,2)	I3CxSEL	-	-	-	-	-	-	-	-	1	-	0	-	2	3	-	-	-	-	-	-	-
LPTIMx (x=1,2,3,4,5,6)	LPTIMxSEL	-	-	-	1	-	-	-	-	2	-	0	-	-	-	-	3	4	5	-	-	-
RNG	RNGSEL	-	1	-	-	-	-	-	-	-	-	-	-	-	-	0	2	3	-	-	-	-
SAI1/2	SAIxSEL	-	0	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	4	3	-	-
SPI2Sx (x=1,2,3)	SPIxSEL	-	0	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	4	3	-	-
SPIx (x=4,5,6)	SPIxSEL	-	-	-	-	1	-	-	2	-	-	0	5	3	4	-	-	-	-	-	-	-
USARTx	USARTxSEL	-	-	-	-	1	-	-	2	-	-	0	-	3	4	-	5	-	-	-	-	-
UARTx	UARTxSEL	-	-	-	-	1	-	-	2	-	-	0	-	3	4	-	5	-	-	-	-	-
LPUART1	LPUART1SEL	-	-	-	-	1	-	-	2	-	-	0	-	3	4	-	5	-	-	-	-	-
OTG_FS	OTGFSSEL	-	1	-	-	-	-	-	2	-	-	-	-	-	-	0	-	-	-	-	3[5]	-
OTG_HS PHY	OTGHSSEL	-	3[6]	-	-	-	-	-	1	-	-	-	0[6]	-	-	-	-	-	-	-	-	-
OTG_HS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-
UCPD1	-	-	-	-	-	-	-	-	-	-	-	-	-	x[7]	-	-	-	-	-	-	-	-
ADC1,2,3 and DAC1[8]	ADCSEL	-	-	-	-	-	2	-	-	-	1	0	3	4	5	-	-	-	-	-	-	-
DAC1	DACSEL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	-	-	-	-
MDF1	MDF1SEL	-	0	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	4	3	-	-
ADF1	ADF1SEL	-	0	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	4	3	-	-
LTDC	LTDCSEL	-	-	-	-	-	1	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-
ETH CLK	ETHCLKSEL	-	1	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-
ETH (ptp)	ETHPTPCLKSEL	-	2	1	-	-	-	3	-	-	-	0	-	-	-	-	-	-	-	-	-	-

Table 107. Kernel clock distribution overview (continued)

Peripheral	Clock multiplexer control bit	pll1_p_ck	pll1_q_ck	pll1_r_ck	pll2_p_ck	pll2_q_ck	pll2_r_ck	pll3_p_ck	pll3_q_ck	pll3_r_ck	sys_ck	bus clocks(1)	hse_ck	hsi_ker_ck	csi_ker_ck	hsi48_ck	lse_ck	lsi_ck	per_ck(2)	AUDIOCLK	clk48mohci	Disabled
RTC	RTCSEL	-	-	-	-	-	-	-	-	-	-	-	3(9)	-	-	-	1	2	-	-	-	0
All	CKPERSEL	-	-	-	-	-	-	-	-	-	-	-	2	0	1	-	-	-	-	-	-	3

1. The bus (APB or AHB) clocks are the bus interface clocks to whom the peripherals are connected.
2. Can be hse_ck, hsi_ker_ck, or csi_ker_ck, according to CKPERSEL selection.
3. With a duty cycle close to 50%, meaning that pll1_q_ck or pll2_r_ck, values must be even. For SDMMCx the duty cycle must be 50% when supporting DDR.
4. CSI clock divided by 122.
5. The clk48mohci is available only on STM32H5E5x/H5F5x devices when OTG_HS PHY is enabled.
6. Clock divided by 2.
7. hsi_ker_ck divided by 4.
8. With a duty cycle close to 50%, meaning that pll2_r_ck, values must be even. For ADC the duty cycle must be 50%.
9. HSE clock divided by RTCPRE.

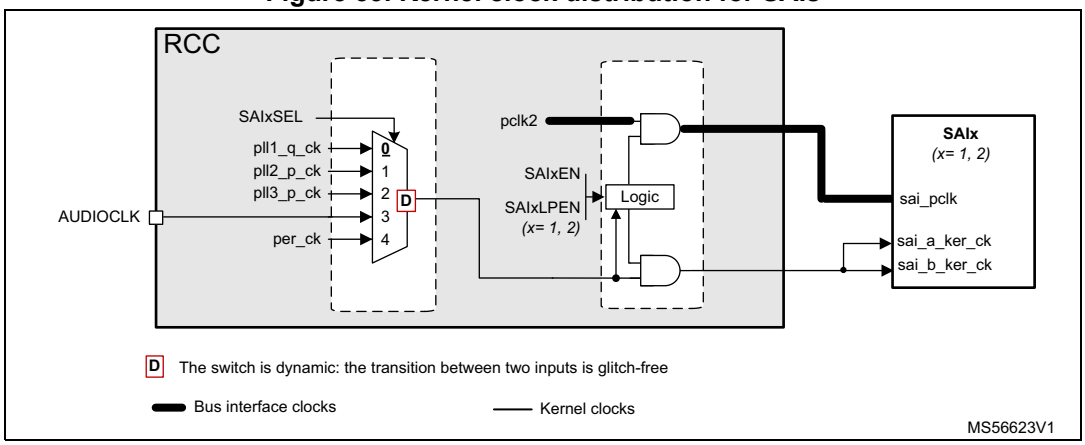
To reduce the number of switches, some peripherals share the same kernel clock source, but all have their dedicated enable signal.

Peripherals dedicated to audio applications

The audio peripherals generally need specific accurate frequencies. The kernel clock of the SAIs, or SPI(I2S)s, or MDF1/ADF1, can be generated by:

- PLL1 when the amount of active PLLs must be reduced (for SAIs and SPI1 to 3)
- APB2 peripheral clock (for SPI4 and 5)
- APB3 peripheral clock (for SPI6)
- PLL2 or PLL3 for optimal flexibility in frequency generation
- HSE, HSI, or CSI when the current consumption is critical
- AUDIOCLK when an external clock reference must be used

Figure 53. Kernel clock distribution for SAIs



Peripherals dedicated to control and data transfer

Peripherals such as SPIs, I2Cs, UARTs do not need a specific kernel clock frequency, but a clock fast enough to generate the correct baud rate, or the required bit clock on the serial interface. For this purpose the source can be selected among the following ones:

- PLL1 when the amount of active PLLs must be reduced
- PLL2 or PLL3 if higher flexibility is required. With this solution it is possible changing the frequency bus via PLL1 without affecting the speed of some serial interfaces.
- HSI or CSI for low-power use-cases or when the peripheral must quickly wake up from Stop mode (such as UART or I2C)

Note: UARTs also need the LSE clock when high baud rates are not required.

The OCTOSPI1/2 and SDMMC1/2 can also use a clock different from the one of the bus interface for more flexibility.

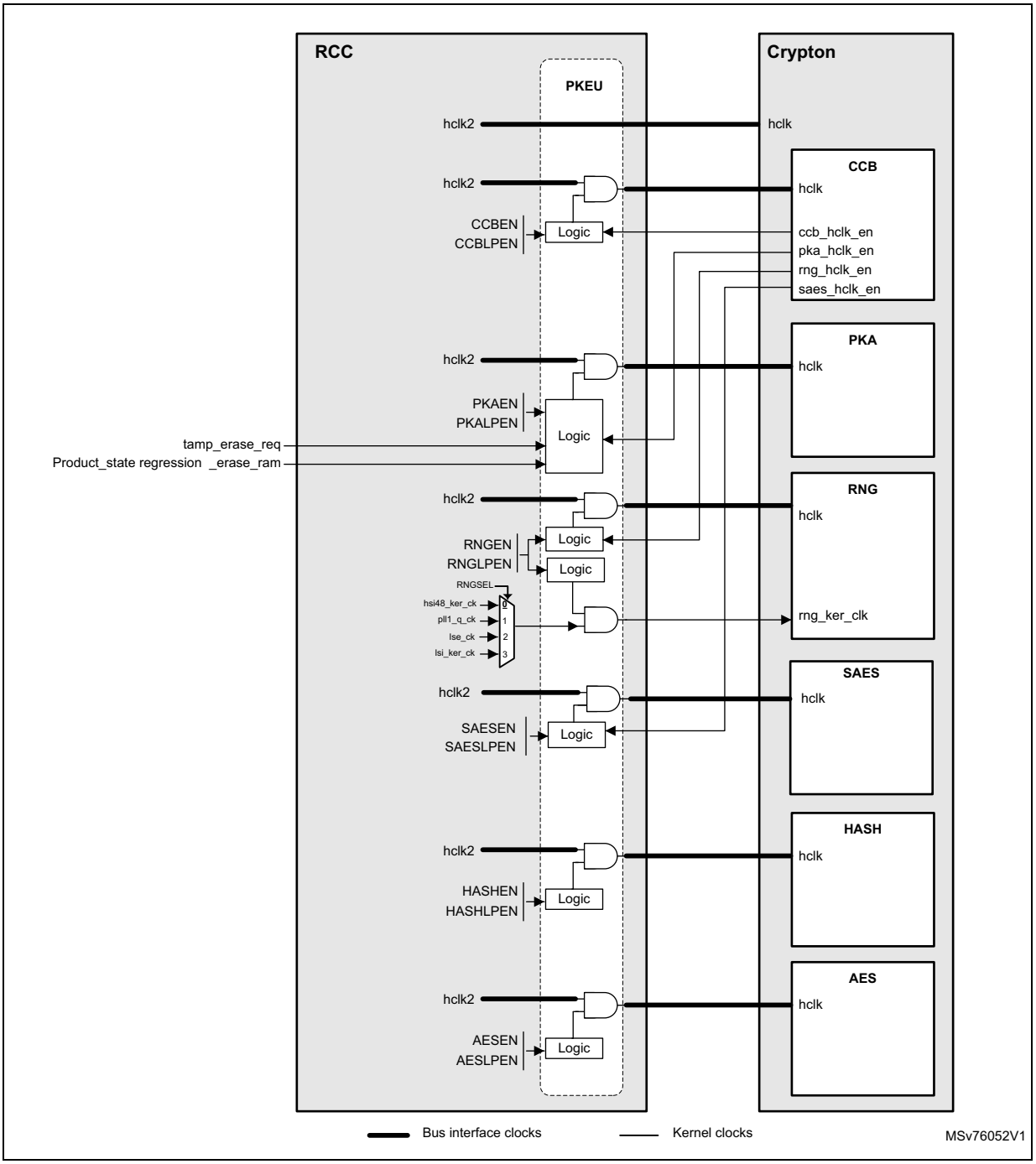
Clock distribution for CCB subsystem

When the coupling chaining bridge (CCB) is enabled, it internally requests the clocks of the PKA, SAES, and RNG peripherals. As illustrated in *Figure 54*, the RCC hardware automatically forces the corresponding enable bits (PKAEN, SAESEN, RNGEN) so that these clocks cannot be gated by any attempt to disable them while CCB is active. These internal request signals are fully transparent to the user and do not require any software handling. They only explain why the PKA, SAES, and RNG clocks appear enabled when CCB is used.

In addition, the PKA clock is automatically provided when either the tamp_erase_req signal or the product state regression erase_ram signal becomes active, regardless of the values of PKAEN and PKALPEN.

Software using the CCB must keep the PKA, SAES, and RNG clocks enabled in RCC during the entire CCB operation.

Figure 54. Clock distribution for CCB subsystem



Clock distribution for OTG_FS, OTG_HS and UCPD1

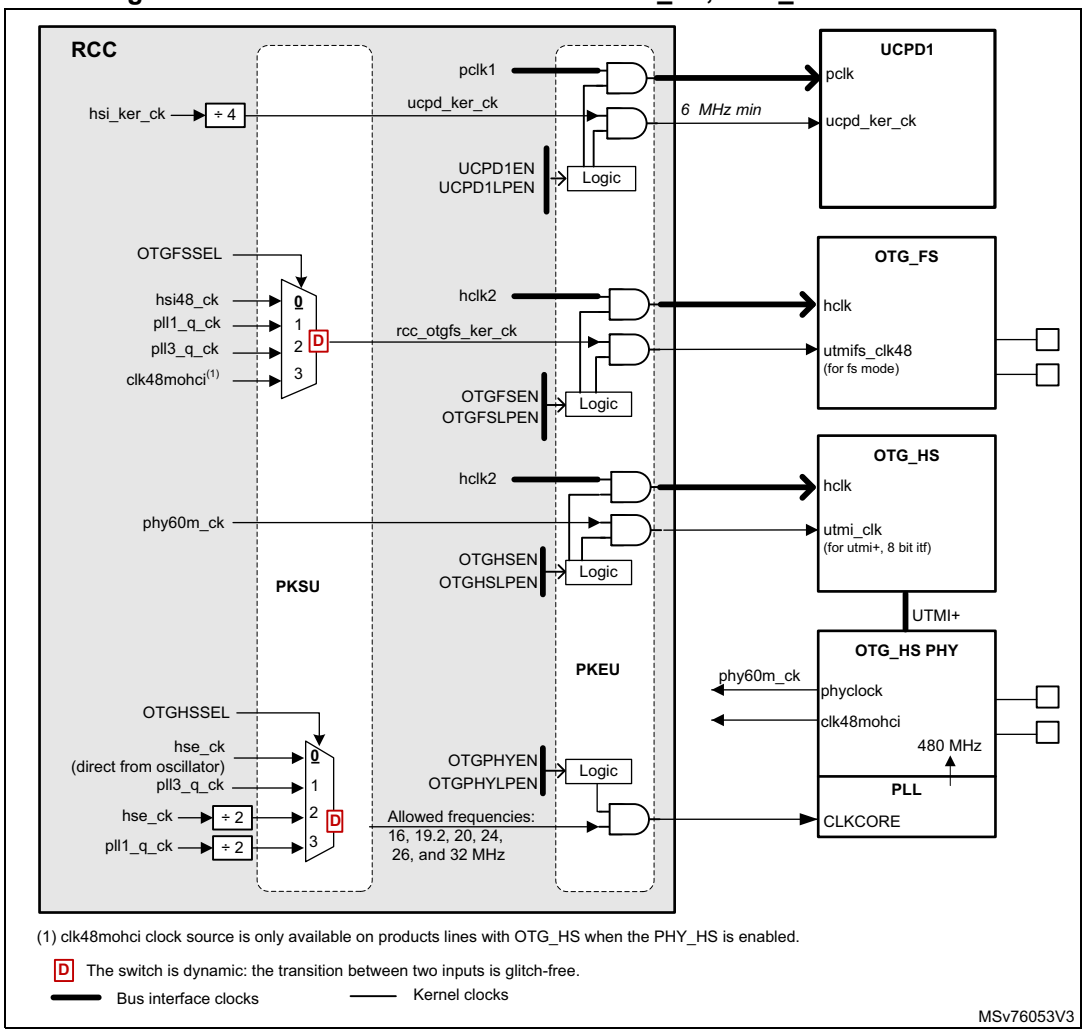
Figure 55 shows the clock distribution for the USB blocks.

- The USB type-C power delivery block (UCPD1), uses ucpd_ker_ck as kernel clock. The ucpd_ker_ck is directly generated from the HSI output divided by 4.
- The OTG_HS PHY, embeds a PLL accepting a reference input frequency of 16, 19.2, 20, 24, 26, or 32 MHz. The reference clock can be selected among:
  - hse_ck
  - pll3_q_ck
  - hse_ck / 2
  - pll1_q_ck / 2
- The OTG_HS PHY provides a 60 MHz clock to the OTG_HS block, and a 48 MHz clock to the OTG_FS block. The clock hse_ck is the direct output of the HSE oscillator.
- The OTG_HS receives the 60 MHz clock from the OTG_HS PHY (phy60m_ck), when working in HS or FS mode.
- The OTG_FS receives a 48 MHz clock. The application can select:
  - the hsi48_ck for crystal-less applications
  - the pll1_q_ck
  - the pll3_q_ck or
  - the clk48mohci (from OTG_HS PHY)

The selection of the reference clock for the OTG_HS PHY is performed by a simple MUX. To change the clock source, go through the following sequence:

1. Disable the OTG_HS PHY clock by setting OTGPHYEN to 0
2. Change the clock source selector (OTGHSSEL) to the wanted value
3. Enable the OTG_HS PHY clock by setting OTGPHYEN to 1.

Figure 55. Kernel clock distribution for OTG_FS, OTG_HS and UCPD1



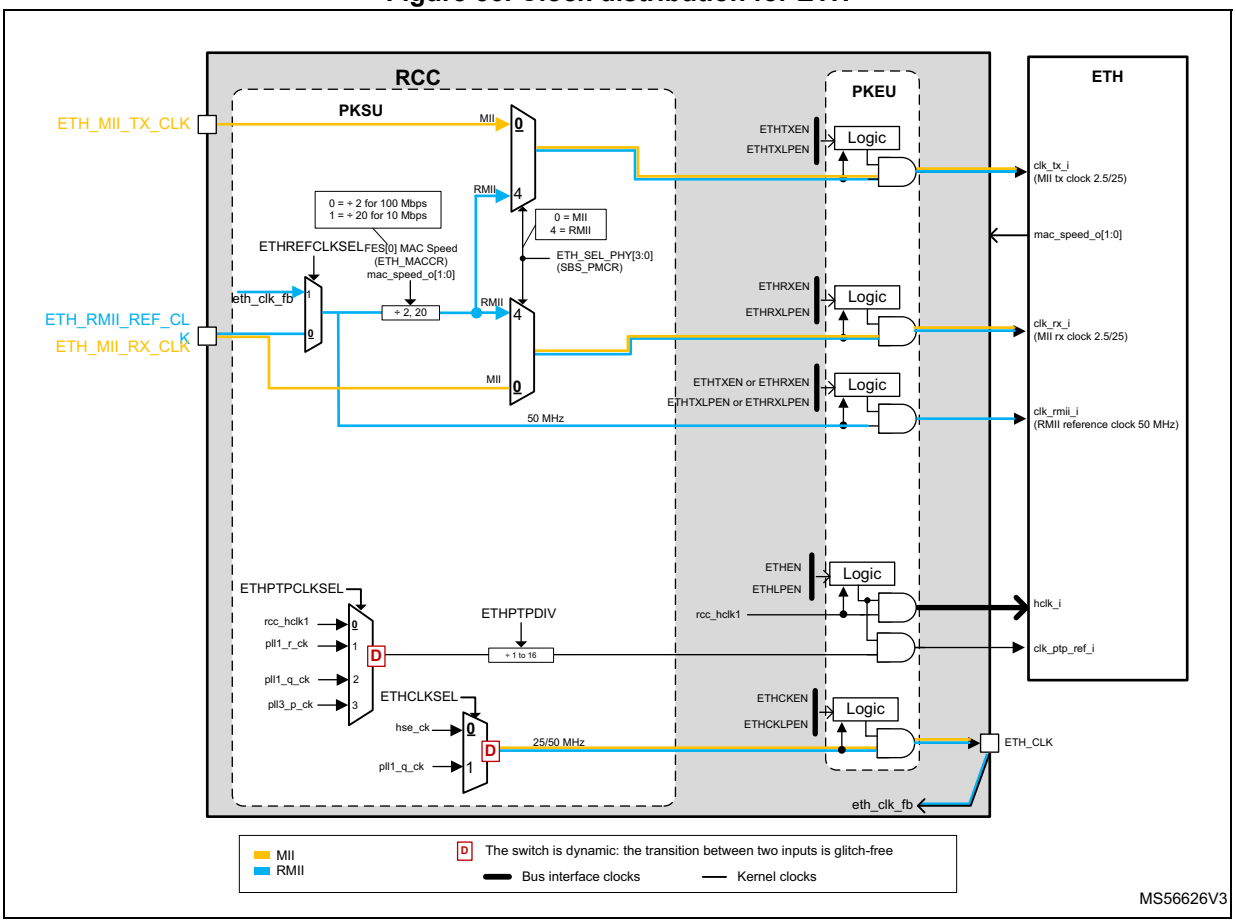
Clock distribution for ETH

The Ethernet clocks provided by the RCC are available on ETH_CLK pad. The application can select if the ETH_CLK is generated from the HSE clock or from the pll1_q_ck.

The RCC also provides the bus clock and the reference clock for the PTP function. The bus and PTP clocks generation are controlled via ETHEN and ETHLPEN bits.

The Ethernet transmit and receive clocks must be provided from an external Ethernet PHY.

Figure 56. Clock distribution for ETH



The signal ETH_SEL_PHY is provided by the SBS block and defines the interface type:

- In MII mode (orange path):
  - The transmit clock is received from the external PHY via the pad ETH_MII_TX_CLK.
  - The receive clock is received from the external PHY via the pad ETH_MII_RX_CLK.
  - The clock frequency is 2.5 (or 25) MHz for Ethernet at 10 (or 100) Mbps.
- In RMII mode (blue path):
  - The reference clock (50 MHz) can be selected between two sources, this selection is controlled via ETHREFCLKSEL.
  - The ETH_RMII_REF_CLK pad, if the reference clock is provided by the PHY

  - The ETH_CLK feedback clock (eth_clk_fb) if the RCC is providing the reference clock to the PHY.
- In RMII mode:
  - A clock must be provided to clk_rx_i and clk_tx_i inputs
  - The clock frequency at clk_rx_i and clk_tx_i inputs is 2.5 MHz (division by 20) for Ethernet at 10 Mbps, and 25 MHz (division by 2) for Ethernet at 100 Mbps.
  - The transmit and receive clock frequency can be adjusted dynamically to 2.5 or 25 MHz according to the signal mac_speed_o[0] (controlled by FES bit in ETH_MACCR register) provided by the ETH block.
  - The clock can be provided by RCC to be used by the external ETH PHY through ETH_CLK output. This clock can be selected between two sources, this selection is controlled via ETHCLKSEL.

RTC/AWU clock

The rtc_ck clock source can be one of the following:

- hse_1M_ck (hse_ck divided by a programmable prescaler)
- lse_ck
- lsi_ck clock

The source clock is selected by programming the RTCSEL[1:0] bits in the *RCC backup domain control register (RCC_BDCR)* and the RTCPRE[5:0] bits in the *RCC clock configuration register1 (RCC_CFGR1)*.

This selection cannot be modified without resetting the backup domain.

If the LSE is selected as RTC clock, the RTC works normally even if the backup or the V_{DD} supply disappears.

The LSE clock is in the backup domain, unlike the other oscillators. As a consequence:

- If LSE is selected as RTC clock, the RTC continues working even if the V_{DD} supply is switched OFF, provided the V_{BAT} supply is maintained.
- If LSI is selected as the RTC clock, the AWU state is not guaranteed if the V_{DD} supply is powered off.
- If the HSE clock is used as RTC clock, the RTC state is not guaranteed if the V_{DD} supply is powered off or if the V_{CORE} supply is powered off.

The rtc_ck clock is enabled through RTCEN bit located in the *RCC backup domain control register (RCC_BDCR)*.

The RTC bus interface clock (APB clock) is enabled through RTCAPBEN and RTCAPBLPEN bits located in RCC_APB3ENR/LPENR registers.

Note: To read the RTC calendar register when the APB clock frequency is less than seven times the RTC clock frequency ($F_{APB} < 7 \times F_{RTCLCK}$), the software must read the calendar time and date registers twice. The data are correct if the second read access to RTC_TR gives the same result than the first one. Otherwise a third read access must be performed.

Watchdog clocks

The RCC provides the clock for the two available watchdogs:

- The independent watchdog (IWDG) is connected to the LSI
- The window watchdog (WWDG) is connected to the APB clock.

If an independent watchdog is started by either hardware option or software access, the LSI is forced ON and cannot be disabled. After the LSI oscillator setup delay, the clock is provided to the IWDG.

The window watchdog clock (pclk1) can be enabled by setting the WWDGEN bit in the RCC_APB1ENR register. The software cannot stop WWDG down-counting by setting WWDGEN bit to 0.

The WWDG block is frozen when the MCU goes to Stop mode.

Clock distribution for ADF1 and MDF1

The ADF1 and MDF1 kernel clock source is selected by ADF1SEL[2:0] and MDF1SEL[2:0] in the *RCC kernel clock configuration register (RCC_CCIPR5)*.

The ADF and MDF can work in Stop mode.

Clock frequency measurement using TIMx

Most of the clock source generator frequencies can be measured by means of the input capture of TIMx.

- Calibrating the HSI or CSI with the LSE

  The primary purpose of having the LSE connected to a TIMx input capture is to be able to accurately measure the HSI or CSI. This requires to use the HSI or CSI as system clock source either directly or via PLL1. The number of system clock counts between consecutive edges of the LSE signal gives a measurement of the internal clock period. Taking advantage of the high precision of LSE crystals (typically a few tens of ppm) we can determine the internal clock frequency with the same resolution, and trim the source to compensate for manufacturing-process and/or temperature- and voltage-related frequency deviations.

  The basic concept consists in providing a relative measurement (such as the HSI/LSE ratio). The precision is therefore tightly linked to the ratio between the two clock sources. The higher the ratio, the more accurate the measurement.

  The HSI and CSI oscillators have dedicated user-accessible calibration bits for this purpose (see *RCC CSI calibration register (RCC_CSICFGR)*). When HSI or CSI is used via the PLLx, the system clock can also be fine-tuned by using the fractional divider of the PLLs.

- Calibrating the LSI with the HSI

  The LSI frequency can be measured: this is useful for applications that do not use a crystal. The ultra-low power LSI oscillator has a large manufacturing process deviation. The LSI clock frequency can be measured using the more precise HSI clock source. Using this measurement, a more accurate RTC time base timeouts (when LSI is used as the RTC clock source) and/or an IWDG timeout with an acceptable accuracy can be obtained.

11.4.13 RTC and TAMP clock

The RTCCLK clock source is used by RTC and TAMP, and can be either the HSE / 32, LSE or LSI clock. It is selected by programming the RTCSEL[1:0] bits in the *RCC backup domain control register (RCC_BDCR)*. This selection cannot be modified without resetting the backup domain. The system must always be configured so as to get a PCLK frequency greater than or equal to the RTCCLK frequency for a proper operation of the RTC. The TAMP does not require any kernel clock if only the backup registers are used, with tampers

in edge detection mode. All other tamper detection modes require a kernel clock (refer to *Section 58: Tamper and backup registers (TAMP)* for more details).

The LSE is in the backup domain, whereas the HSE and LSI clocks are not. Consequently:

- If LSE is selected as RTC and TAMP clock, these peripherals continue to work even if the V_{DD} supply is switched off, provided the V_{BAT} supply is maintained.
- If the HSE clock divided by a prescaler is used as the RTC or TAMP clock, the RTC state is not guaranteed if the V_{DD} supply is powered off or if the internal voltage regulator is powered off (removing power from the core domain). Depending on the TAMP configuration, this one can remain functional if used in a mode that does not need any kernel clock.
- If the LSI is used as the RTC or TAMP clock, the RTC state is not guaranteed if the V_{DD} supply is powered off. Depending on the TAMP configuration, this one can remain functional if used in a mode that does not need any kernel clock.

When the RTC and TAMP clock is LSE or LSI, the RTC remains clocked and functional under system reset.

11.4.14 Timer clock

The timer clock frequencies are automatically defined by hardware.

If the APB prescaler is 1, the frequencies are set to the APB domain frequency, otherwise, they are set to twice (×2) the APB domain frequency.

11.4.15 Watchdog clock

If the independent watchdog (IWDG) is started by either hardware option or software access, the LSI oscillator is forced on and cannot be disabled. After the LSI oscillator temporization, the LSI 32 kHz clock is provided to the IWDG.

11.4.16 Peripheral clock gating and autonomous mode

Peripheral clock gating in Run mode

Each peripheral clock can be enabled by the corresponding EN bit in the RCC_AHBxENR and RCC_APBxENR registers.

When the peripheral clock is not active, read or write accesses to the peripheral registers are not supported.

The enable bit has a synchronization mechanism to create a glitch-free clock for the peripheral. After the enable bit is set, the clock is active after two cycles of the peripheral bus clock.

Caution: Just after enabling the clock for a peripheral, the software must wait for these two clock cycles before accessing the peripheral registers.

Peripheral clock gating in Sleep mode

When a peripheral is enabled, its clock can be automatically gated off when the device is in Sleep mode, by clearing the peripheral LPEN bit in the RCC_AHBxLPENR and RCC_APBxLPENR registers. Both EN and LPEN bit of the peripheral must be set to keep the clock on in Sleep mode.

11.5 RCC security and privilege functional description

11.5.1 RCC TrustZone security protection modes

When the TrustZone security is activated by the TZEN option byte in the flash option byte configuration register, the RCC is able to secure RCC configuration and status bits from being modified by nonsecure accesses.

This is configured through the *RCC secure configuration register (RCC_SECCFGR)* to prevent nonsecure access to read or modify the following features:

- HSE, HSE-CSS, HSI, CSI, LSI, LSE, LSE-CSS, LSCO, HSI48 configuration and status bits
- PLL1, PLL2, PLL3, AHB and APB prescalers configuration and status bits
- system clock (SYSCLK) and source clock selection and status bits
- MCO clock output configuration and STOPWUCK and STOPKERWUCK bit
- reset flag RMVF configuration removed

If SPRIV is set in the *RCC privilege configuration register (RCC_PRIVCFGR)*, the RCC_SECCFGR register can be written only by secure and privileged access. If SPRIV is cleared in RCC_PRIVCFGR, RCC_SECCFGR can be written only by secure access, privileged or unprivileged.

RCC_SECCFGR can be read by secure, nonsecure, privileged and unprivileged access.

When a peripheral is configured as secure, its related clock, reset, clock source selection and clock enable during low-power modes control bits, are also secure in the RCC_AHBxENR, RCC_APBxENR, RCC_CCIPRx, RCC_CFGR1, and RCC_BDCR registers.

Note: When at least one feature in RTC or TAMP is secure, the RTCPRE[5:0] in RCC_CFGR1, RTCEN and RTCSEL[1:0] in RCC_BDCR register become secure.

A peripheral is secure when:

- For securable peripherals by TZSC (see*Section 5.4.3: TrustZone security controller (TZSC)*, the SEC security bit corresponding to this peripheral is set in the GTZC TZSC secure configuration registers.
- For TrustZone-aware peripherals, a security feature of this peripheral is enabled through its dedicated bits.

Table 108 summarizes the RCC secured bits following the security configuration bit in the RCC_SECCFGR register.

When one security configuration bit is set, some configuration and status bits are secured. The RCC registers may contain secure and nonsecure bits:

- Secure bits: read and write operations are only allowed by a secure access. Nonsecure read returns 0 and write accesses are ignored. No illegal access event is generated.
- Nonsecure bits: no restriction. Read and write operations are allowed by both secure and nonsecure accesses.
- A nonsecure write access to RCC_SECCFGR is ignored and generates an illegal access event. An illegal access interrupt is generated if the RCC illegal access interrupt is enabled in the GTZC TZIC registers. RCC_SECCFGR can be read by secure or nonsecure access.

When the TrustZone security is disabled (TZEN = 0xC3), all registers are nonsecure. RCC_SECCFGR write accesses are ignored.

Table 108. RCC security configuration summary

Configuration bit in RCC_SECCFGR	Secured bits	Corresponding register
HSISEC	HSION, HSIKERON, HSIRDY	RCC_CR
	HSICAL[11:0], HSITRIM[6:0]	RCC_HSICFGR
	HSIRDYIE	RCC_CIER
	HSIRDYIF	RCC_CIFR
	HSIRDYC	RCC_CICR
HSESEC	HSEON, HSERDY, HSEBYP, HSECSSON, HSEEXT	RCC_CR
	HSERDYIE, HSECSSF	RCC_CIER
	HSERDYIF, HSECSSF	RCC_CIFR
	HSERDYC, HSECSSC	RCC_CICR
CSISEC	CSISON, CSIKERON, CSISRDY	RCC_CR
	CSICAL[7:0], CSITRIM[5:0]	RCC_CSICFGR
	CSISRDYIE	RCC_CIER
	CSISRDYIF	RCC_CIFR
	CSISRDYIC	RCC_CICR
LSISEC	LSION, LSIRDY, LSCOSEL, LSCOEN	RCC_BDCR
	LSIRDYIE	RCC_CIER
	LSIRDYIF	RCC_CIFR
	LSIRDYC	RCC_CICR
LSESEC	LSECSSON, LSECSSD, LSEDRV[1:0], LSEBYP, LSERDY, LSEON, LSEEXT, LSCOSEL, LSCOEN	RCC_BDCR
	LSERDYIE	RCC_CIER
	LSERDYF	RCC_CIFR
	LSERDYC	RCC_CICR
SYSCLKSEC	SW[1:0], SWS[1:0], STOPWUCK, STOPKERWUCK, MCO1SEL[3:0], MCO1PRE[2:0], MCO2SEL[3:0], MCO2PRE[2:0]	RCC_CFGR1
	SYSTICKSEL[1:0]	RCC_CCIPR4
	VOS[1:0]	PWR_VOSR
	TIMPRE	RCC_CFGR1
PRESCSEC	HPRE[3:0], PPRE1[2:0], PPRE2[2:0], PPRE3[2:0]	RCC_CFGR2

Table 108. RCC security configuration summary (continued)

Configuration bit in RCC_SECCFGR	Secured bits	Corresponding register
PLL1SEC	PLL1SRC[1:0], PLL1RGE[1:0], PLL1FRACEN, PLL1M[3:0], PLL1VCOSEL, PLL1PEN, PLL1QEN, PLL1REN	RCC_PLL1CFGR
	PLL1N[8:0], PLL1P[6:0], PLL1Q[6:0], PLL1R[6:0]	RCC_PLL1DIVR
	PLL1FRACN[12:0]	RCC_PLL1FRACR
	PLL1RDY, PLL1ON	RCC_CR
	PLL1RDYIE	RCC_CIER
	PLL1RDYF	RCC_CIFR
	PLL1RDYC	RCC_CICR
PLL2SEC	PLL2SRC[1:0], PLL2RGE[1:0], PLL2FRACEN, PLL2M[3:0], PLL2PEN, PLL2QEN, PLL2REN, PLL2VCOSEL	RCC_PLL2CFGR
	PLL2N[8:0], PLL2P[6:0], PLL2Q[6:0], PLL2R[6:0]	RCC_PLL2DIVR
	PLL2FRACN[12:0]	RCC_PLL2FRACR
	PLL2RDY, PLL2ON	RCC_CR
	PLL2RDYIE	RCC_CIER
	PLL2RDYF	RCC_CIFR
	PLL2RDYC	RCC_CICR
PLL3SEC	PLL3SRC[1:0], PLL3RGE[1:0], PLL3FRACEN, PLL3M[3:0], PLL3PEN, PLL3QEN, PLL3REN, PLL3VCOSEL	RCC_PLL3CFGR
	PLL3N[8:0], PLL3P[6:0], PLL3Q[6:0], PLL3R[6:0]	RCC_PLL3DIVR
	PLL3FRACN[12:0]	RCC_PLL3FRACR
	PLL3RDY, PLL3ON	RCC_CR
	PLL3RDYIE	RCC_CIER
	PLL3RDYF	RCC_CIFR
	PLL3RDYC	RCC_CICR
HSI48SEC(1)	HSI48ON, HSI48RDY	RCC_CR
	HSI48CAL[9:0]	RCC_CRRCR
	HSI48RDYE	RCC_CIER
	HSI48RDYF	RCC_CIFR
	HSI48RDYC	RCC_CICR
CKPERSELSEC	CKPERSEL[1:0]	RCC_CCIPR5
RMVFSEC	RMVF	RCC_CSR

1. TRIM field of the HSI48 is located in CRS peripheral. Secure it using the CRSSEC bit in GTZC1 TZSC secure configuration register 1.

11.5.2 RCC privilege protection modes

By default, after reset, all RCC registers can be read or written with both privileged and unprivileged access, except *RCC privilege configuration register (RCC_PRIVCFGR)* that can be written with privileged access only. RCC_PRIVCFGR can be read by secure and nonsecure, privileged and unprivileged access.

The SPRIV bit in RCC_PRIVCFGR can be written with secure privileged access only. This bit configures the privileged access of all RCC secure functions (as defined by *RCC secure configuration register (RCC_SECCFGR)* or by the GTZC for securable peripherals, or by the peripheral itself in case of TrustZone-aware peripherals).

When the SPRIV bit is set in RCC_PRIVCFGR:

- Writing the RCC secure bits is possible only with privileged access, including RCC_SECCFGR.
- The RCC secure bits can be read only with privileged access except RCC_SECCFGR and RCC_PRIVCFGR that can be read by privileged or unprivileged access.
- An unprivileged access to a privileged RCC bit or register is discarded: the bits are read as zero and the write to these bits is ignored (RAZ/WI).

The NSPRIV bit in RCC_PRIVCFGR can be written with privileged access only, secure or nonsecure. This bit configures the privileged access of all RCC nonsecure functions (as defined by RCC_SECCFGR, or by the GTZC for securable peripherals, or by the peripheral itself in case of TrustZone-aware peripherals).

When the NSPRIV bit is set in RCC_PRIVCFGR:

- Writing the RCC nonsecure bits is possible only with privileged access.
- The RCC nonsecure bits can be read only with privileged access except RCC_PRIVCFGR that can be read by privileged or unprivileged access.
- An unprivileged access to a privileged RCC bit or register is discarded: the bits are read as zero and the write to these bits is ignored (RAZ/WI).

11.6 RCC low-power modes

- AHB and APB peripheral clocks, including DMA clock, can be disabled by software.
- Sleep mode stops the CPU clock. The memory interface clocks (flash memory, caches and all SRAM interfaces) can be stopped by software during Sleep mode. The AHB to APB bridge clocks are disabled by hardware during Sleep mode when all the clocks of the peripherals connected to them are disabled.
- Stop mode stops all the clocks in the core domain, and disables the PLLs, HSI, HSI48, CSI and HSE oscillators. However, HSI or CSI can be switched ON to generate a wake-up interrupt. LSI and LSE remain active in Stop mode.
- Standby mode stops all the clocks in the core domain and disable the PLLs, HSI, HSI48, CSI and HSE oscillators.

The CPU DeepSleep mode can be overridden for debugging by setting the DBG_STOP or DBG_STANDBY bit in the DBGMCU_CR register.

When exiting Stop mode, the system clock is either HSI or CSI, depending on the software configuration of STOPWUCK in the *RCC CPU domain clock configuration register 2 (RCC_CFGR2)*. The frequency (range and user trim) of the HSI is the one configured before entering Stop mode.

The other internal oscillator can be automatically woken up in addition to the one used by the system clock, to avoid waiting for the other oscillator wake-up time when the device is back in Run mode. This is done thanks to STOPKERWUCK in RCC_CFGR1.

When leaving the Standby mode, the system clock is HSI (32 MHz). The user trim is lost.

If a flash memory programming operation is ongoing, Stop or Standby mode entry is delayed until the flash memory interface access is finished. If an access to the APB domain is ongoing, Stop or Standby mode entry is delayed until the APB access is finished.

11.7 RCC interrupts

The following table summarizes the interrupt sources and the way to control them.

Table 109. Interrupt sources and control

Interrupt vector	Interrupt event flag	Description	Enable control bits	Interrupt clear method	Exit from Sleep mode	Exit from Stop and Standby modes
RCC	LSIRDYF	LSI ready	LSIRDYIE and LSISEC = 0	Set LSIRDYC to 1	Yes	No
	LSERDYF	LSE ready	LSERDYIE and LSESEC = 0	Set LSERDYC to 1	Yes	No
	HSIDRYF	HSI ready	HSIDRYIE and HSISEC = 0	Set HSIRDYC to 1	Yes	No
	HSERDYF	HSE ready	HSERDYIE and HSESEC = 0	Set HSERDYC to 1	Yes	No
	CSISRDYF	CSIS ready	CSISRDYIE and CSISEC = 0	Set CSISRDYC to 1	Yes	No
	HSI48RDYF	HSI48 ready	HSI48RDYIE and HSI48SEC = 0	Set HSI48RDYC to 1	Yes	No
	PLL1RDYF	PLL1 ready	PLL1RDYIE and PLL1SEC = 0	Set PLL1RDYC to 1	Yes	No
	PLL2RDYF	PLL2 ready	PLL2RDYIE and PLL2SEC = 0	Set PLL2RDYC to 1	Yes	No
	PLL3RDYF	PLL3 ready	PLL3RDYIE and PLL3SEC = 0	Set PLL3DYC to 1	Yes	No

Table 109. Interrupt sources and control (continued)

Interrupt vector	Interrupt event flag	Description	Enable control bits	Interrupt clear method	Exit from Sleep mode	Exit from Stop and Standby modes
RCC_S(1)	LSIRDYF	LSI ready	LSIRDYIE and LSISEC = 1	Set LSIRDYC to 1	Yes	No
	LSERDYF	LSE ready	LSERDYIE and LSESEC = 1	Set LSERDYC to 1	Yes	No
	HSIDRYF	HSI ready	HSIDRYIE and HSISEC = 1	Set HSIRDYC to 1	Yes	No
	HSERDYF	HSE ready	HSERDYIE and HSESEC = 1	Set HSERDYC to 1	Yes	No
	CSISRDYF	CSIS ready	CSISRDYIE and CSISEC = 1	Set CSISRDYC to 1	Yes	No
	HSI48RDYF	HSI48 ready	HSI48RDYIE and HSI48SEC = 1	Set HSI48RDYC to 1	Yes	No
	PLL1RDYF	PLL1 ready	PLL1RDYIE and PLL1SEC = 1	Set PLL1RDYC to 1	Yes	No
	PLL2RDYF	PLL2 ready	PLL2RDYIE and PLL2SEC = 1	Set PLL2RDYC to 1	Yes	No
	PLL3RDYF	PLL3 ready	PLL3RDYIE and PLL3SEC = 1	Set PLL3RDYC to 1	Yes	No
TAMP	ITAMP3F(2)	LSE CSS failure	LSECSSON and ITAMP3E(2) and ITAMP3IE(2)	Set CITAMP3F(2) to 1	Yes	Yes
NMI	HSECSSF	HSE CSS failure	(3)	Set HSECSSC to 1	Yes	No

1. The RCC secure interrupt vector is used only when TrustZone is enabled.
2. The LSE CSS failure event (LSECSSD) is connected to TAMP internal tamper 3. to get the interrupt associated to this event, the internal tamper 3 must be enabled, and the internal tamper 3 interrupt must be enabled. The ITAMP3F, ITAMP3E, ITAMP3IE, and CITAMP3F bits are in the TAMP peripheral.
3. It is not possible to mask this interrupt when the security system feature is enabled (HSECSSON = 1).

11.8 RCC registers

11.8.1 RCC clock control register (RCC_CR)

Address offset: 0x000

Reset value: 0x0000 002B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	PLL3 RDY	PLL3 ON	PLL2 RDY	PLL2 ON	PLL1 RDY	PLL1 ON	Res.	Res.	Res.	HSE EXT	HSE CSSON	HSE BYP	HSE RDY	HSE ON
		r	rw	r	rw	r	rw				rw	rs	rw	r	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	HSI48 RDY	HSI48 ON	Res.	CSIKER ON	CSI RDY	CSION	Res.	Res.	HSI DIVF	HSIDIV[1:0]		HSIKER ON	HSI RDY	HSION
		r	rw		rw	r	rw			r	rw	rw	rw	r	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **PLL3RDY:** PLL3 clock ready flag
Set by hardware to indicate that the PLL3 is locked.
0: PLL3 unlocked (default after reset)
1: PLL3 locked

Bit 28 **PLL3ON**: PLL3 enable
Set and cleared by software to enable PLL3.
Cleared by hardware when entering Stop or Standby mode.
0: PLL3 OFF (default after reset)
1: PLL3 ON

Bit 27 **PLL2RDY**: PLL2 clock ready flag
Set by hardware to indicate that the PLL is locked.
0: PLL2 unlocked
1: PLL2 locked

Bit 26 **PLL2ON**: PLL2 enable
Set and cleared by software to enable PLL2.
Cleared by hardware when entering Stop or Standby mode.
0: PLL2 OFF (default after reset)
1: PLL2 ON

Bit 25 **PLL1RDY**: PLL1 clock ready flag
Set by hardware to indicate that the PLL1 is locked.
0: PLL1 unlocked (default after reset)
1: PLL1 locked

Bit 24 **PLL1ON**: PLL1 enable
Set and cleared by software to enable PLL1.
Cleared by hardware when entering Stop or Standby mode. Note that the hardware prevents writing this bit to 0, if the PLL1 output is used as the system clock.
0: PLL1 OFF (default after reset)
1: PLL1 ON

Bits 23:21 Reserved, must be kept at reset value.

Bit 20 **HSEEXT**: external high speed clock type in Bypass mode

Set and reset by software to select the external clock type (analog or digital).
The external clock must be enabled with the HSEON bit to be used by the device. The HSEEXT bit can be written only if the HSE oscillator is disabled.
0: HSE in analog mode (default after reset)
1: HSE in digital mode

Bit 19 **HSECSSON**: HSE clock security system enable

Set by software to enable clock security system on HSE.
This bit is “set only” (disabled by a system reset or when the system enters in Standby mode). When HSECSSON is set, the clock detector is enabled by hardware when the HSE is ready and disabled by hardware if an oscillator failure is detected.
0: CSS on HSE OFF (clock detector OFF) (default after reset)
1: CSS on HSE ON (clock detector ON if the HSE oscillator is stable, OFF if not).

Bit 18 **HSEBYP**: HSE clock bypass

Set and cleared by software to bypass the oscillator with an external clock. The external clock must be enabled with the HSEON bit to be used by the device.
The HSEBYP bit can be written only if the HSE oscillator is disabled.
0: HSE oscillator not bypassed (default after reset)
1: HSE oscillator bypassed with an external clock

Bit 17 **HSERDY**: HSE clock ready flag

Set by hardware to indicate that the HSE oscillator is stable.
0: HSE clock is not ready (default after reset)
1: HSE clock is ready

Bit 16 **HSEON**: HSE clock enable

Set and cleared by software.
Cleared by hardware to stop the HSE when entering Stop or Standby mode.
This bit cannot be cleared if the HSE is used directly (via SW mux) as system clock, or if the HSE is selected as reference clock for PLL1 with PLL1 enabled (PLL1ON bit set to 1).
0: HSE is OFF (default after reset)
1: HSE is ON

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **HSI48RDY**: HSI48 clock ready flag

Set by hardware to indicate that the HSI48 oscillator is stable.
0: HSI48 clock is not ready (default after reset)
1: HSI48 clock is ready

Bit 12 **HSI48ON**: HSI48 clock enable

Set by software and cleared by software or by the hardware when the system enters to Stop or Standby mode.
0: HSI48 is OFF (default after reset)
1: HSI48 is ON

Bit 11 Reserved, must be kept at reset value.

Bit 10 **CSIKERON**: CSI clock enable in Stop mode

Set and reset by software to force the CSI to ON, even in Stop mode, to be quickly available as kernel clock for some peripherals. This bit has no effect on the value of CSION.
0: no effect on CSI (default after reset)
1: CSI is forced to ON even in Stop mode

Bit 9 **CSIRDY**: CSI clock ready flag

Set by hardware to indicate that the CSI oscillator is stable. This bit is activated only if the RC is enabled by CSION (it is not activated if the CSI is enabled by CSIKERON or by a peripheral request).

0: CSI clock is not ready (default after reset)

1: CSI clock is ready

Bit 8 **CSION**: CSI clock enable

Set and reset by software to enable/disable CSI clock for system and/or peripheral.

Set by hardware to force the CSI to ON when the system leaves Stop mode, if STOPWUCK = 1 or STOPKERWUCK = 1.

This bit cannot be cleared if the CSI is used directly (via SW mux) as system clock, or if the CSI is selected as reference clock for PLL1 with PLL1 enabled (PLL1ON bit set to 1).

0: CSI is OFF (default after reset)

1: CSI is ON

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **HSIDIVF**: HSI divider flag

Set and reset by hardware.

As a write operation to HSIDIV has not an immediate effect on the frequency, this flag indicates the current status of the HSI divider. HSIDIVF goes immediately to 0 when HSIDIV value is changed, and is set back to 1 when the output frequency matches the value programmed into HSIDIV.

0: new division ratio not yet propagated to hsi_ck, hsi_ker_ck (default after reset)

1: hsi_ck, hsi_ker_ck clock frequency reflects the new HSIDIV value (default register value when the clock setting is completed).

Bits 4:3 **HSIDIV[1:0]**: HSI clock divider

Set and reset by software.

These bits allow selecting a division ratio to configure the wanted HSI clock frequency. The HSIDIV cannot be changed if the HSI is selected as reference clock for at least one enabled PLL (PLLxON bit set to 1). In that case, the new HSIDIV value is ignored.

00: division by 1, hsi_ck, hsi_ker_ck = 64 MHz

01: division by 2, hsi_ck, hsi_ker_ck = 32 MHz (default after reset)

10: division by 4, hsi_ck, hsi_ker_ck = 16 MHz

11: division by 8, hsi_ck, hsi_ker_ck = 8 MHz

Bit 2 **HSIKERON**: HSI clock enable in Stop mode

Set and reset by software to force the HSI to ON, even in Stop mode, to be quickly available as kernel clock for peripherals. This bit has no effect on the value of HSION.

0: no effect on HSI (default after reset)

1: HSI is forced to ON even in Stop mode

Bit 1 **HSIRDY**: HSI clock ready flag

Set by hardware to indicate that the HSI oscillator is stable.

0: HSI clock is not ready

1: HSI clock is ready (default after reset)

Bit 0 **HSION**: HSI clock enable

Set and cleared by software.

Set by hardware to force the HSI to ON when the product leaves Stop mode, if STOPWUCK = 1 or STOPKERWUCK = 1.

Set by hardware to force the HSI to ON when the product leaves Standby mode or in case of a failure of the HSE which is used as the system clock source.

This bit cannot be cleared if the HSI is used directly (via SW mux) as system clock, or if the HSI is selected as reference clock for PLL1 with PLL1 enabled (PLL1ON bit set to 1).

0: HSI is OFF

1: HSI is ON (default after reset)

11.8.2 RCC HSI calibration register (RCC_HSICFGR)

Address offset: 0x010

Reset value: 0x0040 0XXX

Reset value depends on the flash memory option bytes setting.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSITRIM[6:0]						
									rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	HSICAL[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:16 **HSITRIM[6:0]**: HSI clock trimming

Set by software to adjust calibration.

HSITRIM field is added to the engineering option bytes loaded during reset phase (FLASH_HSI_OPT) to form the calibration trimming value.

HSICAL = HSITRIM + FLASH_HSI_OPT.

After a change of HSITRIM it takes one system clock cycle before the new HSITRIM value is updated

Note: The reset value of the field is 0x40.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **HSICAL[11:0]**: HSI clock calibration

Set by hardware by option byte loading during system reset. Adjusted by software through trimming bits HSITRIM.

This field represents the sum of engineering option byte calibration and HSITRIM bits values.

11.8.3 RCC clock recovery RC register (RCC_CRRCR)

Address offset: 0x014

Reset value: 0x0000 0XXX

Reset value depends on the flash memory option bytes setting.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	HSI48CAL[9:0]									
						r	r	r	r	r	r	r	r	r	r

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:0 **HSI48CAL[9:0]**: Internal RC 48 MHz clock calibration

Set by hardware by option-byte loading during system reset NRESET. Read-only.

11.8.4 RCC CSI calibration register (RCC_CSICFGR)

Address offset: 0x018

Reset value: 0x0020 0XXX

Reset value depends on the flash memory option bytes setting.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSITRIM[5:0]					
										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSICAL[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:16 **CSITRIM[5:0]**: CSI clock trimming

Set by software to adjust calibration.

CSITRIM field is added to the engineering option bytes loaded during reset phase (FLASH_CSI_OPT) to form the calibration trimming value.

CSICAL = CSITRIM + FLASH_CSI_OPT.

Note: The reset value of the field is 0x20.

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **CSICAL[7:0]**: CSI clock calibration

Set by hardware by option byte loading during system reset NRESET. Adjusted by software through trimming bits CSITRIM.

This field represents the sum of engineering option byte calibration value and CSITRIM bits value.

11.8.5 RCC clock configuration register1 (RCC_CFGR1)

Address offset: 0x01C

Reset value: 0x0000 0000

Access: 0 ≤ wait state ≤ 2; word, half-word and byte access

One or two wait states are inserted only if the access occurs during clock source switch.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MCO2SEL[2:0]			MCO2PRE[3:0]				MCO1SEL[2:0]			MCO1PRE[3:0]				Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TIM PRE	Res.	RTCPRE[5:0]						STOP KER WUCK	STOP WUCK	Res.	SWS[1:0]		Res.	SW[1:0]	
rw		rw	rw	rw	rw	rw	rw	rw	rw		r	r		rw	rw

Bits 31:29 **MCO2SEL[2:0]**: microcontroller clock output 2

Set and cleared by software. Clock source selection may generate glitches on MCO2.
It is highly recommended to configure these bits only after reset, before enabling the external oscillators and the PLLs.
000: system clock selected (sys_ck) (default after reset)
001: PLL2 oscillator clock selected (pll2_p_ck)
010: HSE clock selected (hse_ck)
011: PLL1 clock selected (pll1_p_ck)
100: CSI clock selected (csi_ck)
101: LSI clock selected (lsi_ck)
Others: reserved

Bits 28:25 **MCO2PRE[3:0]**: MCO2 prescaler

Set and cleared by software to configure the prescaler of the MCO2. Modification of this prescaler may generate glitches on MCO2. It is highly recommended to change this prescaler only after reset, before enabling the external oscillators and the PLLs.
0000: prescaler disabled (default after reset)
0001: division by 1 (bypass)
0010: division by 2
0011: division by 3
0100: division by 4
...
1111: division by 15

Bits 24:22 **MCO1SEL[2:0]**: Microcontroller clock output 1

Set and cleared by software. Clock source selection may generate glitches on MCO1.
It is highly recommended to configure these bits only after reset, before enabling the external oscillators and the PLLs.
000: HSI clock selected (hsi_ck) (default after reset)
001: LSE oscillator clock selected (lse_ck)
010: HSE clock selected (hse_ck)
011: PLL1 clock selected (pll1_q_ck)
100: HSI48 clock selected (hsi48_ck)
Others: reserved

Bits 21:18 **MCO1PRE[3:0]**: MCO1 prescaler

Set and cleared by software to configure the prescaler of the MCO1. Modification of this prescaler may generate glitches on MCO1. It is highly recommended to change this prescaler only after reset, before enabling the external oscillators and the PLLs.
0000: prescaler disabled (default after reset)
0001: division by 1 (bypass)
0010: division by 2
0011: division by 3
0100: division by 4
...
1111: division by 15

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 **TIMPRE**: timers clocks prescaler selection

This bit is set and reset by software to control the clock frequency of all the timers connected to APB1 and APB2 domains.
0: The timers kernel clock is equal to rcc_hclk1 if PPRE1 or PPRE2 corresponds to a division by 1 or 2, else it is equal to 2 x F_{rcc_pclk1} or 2 x F_{rcc_pclk2} (default after reset)
1: The timers kernel clock is equal to 2 x F_{rcc_pclk1} or 2 x F_{rcc_pclk2} if PPRE1 or PPRE2 corresponds to a division by 1, 2, or 4, else it is equal to 4 x F_{rcc_pclk1} or 4 x F_{rcc_pclk2}

Bit 14 Reserved, must be kept at reset value.

Bits 13:8 **RTCPRE[5:0]**: HSE division factor for RTC clock

Set and cleared by software to divide the HSE to generate a clock for RTC.
Caution: The software must set these bits correctly to ensure that the clock supplied to the RTC is lower than 1 MHz. These bits must be configured if needed before selecting the RTC clock source.
000000: no clock (default after reset)
000001: no clock
000010: HSE/2
000011: HSE/3
000100: HSE/4
...
111110: HSE/62
111111: HSE/63

Bit 7 **STOPKERWUCK**: kernel clock selection after a wake-up from system Stop

Set and reset by software to select the kernel wake-up clock from system Stop.
0: HSI selected as wake-up clock from system Stop (default after reset)
1: CSI selected as wake-up clock from system Stop

Bit 6 **STOPWUCK**: system clock selection after a wake-up from system Stop

Set and reset by software to select the system wake-up clock from system Stop.
The selected clock is also used as emergency clock for the clock security system (CSS) on HSE. 0: HSI selected as wake-up clock from system Stop (default after reset)
1: CSI selected as wake-up clock from system Stop

Caution: STOPWUCK must not be modified when CSS is enabled (by HSECSSON bit) and the system clock is HSE (SWS = 10) or a switch on HSE is requested (SW =10).

Bit 5 Reserved, must be kept at reset value.

Bits 4:3 **SWS[1:0]**: system clock switch status
Set and reset by hardware to indicate which clock source is used as system clock.
00: HSI used as system clock (hsi_ck) (default after reset)
01: CSI used as system clock (csi_ck)
10: HSE used as system clock (hse_ck)
11: PLL1 used as system clock (pll1_p_ck)

Bit 2 Reserved, must be kept at reset value.

Bits 1:0 **SW[1:0]**: system clock and trace clock switch
Set and reset by software to select system clock and trace clock sources (sys_ck).
Set by hardware to force the selection of the HSI or CSI (depending on STOPWUCK selection) when leaving a system Stop mode, and to force the selection of the HSI in case of failure of the HSE when used directly or indirectly as system clock
00: HSI selected as system clock (hsi_ck) (default after reset)
01: CSI selected as system clock (csi_ck)
10: HSE selected as system clock (hse_ck)
11: PLL1 selected as system clock (pll1_p_ck

11.8.6 RCC CPU domain clock configuration register 2 (RCC_CFGR2)

Address offset: 0x020

Reset value: 0x0000 0000

1 or 2 wait states are inserted only if the access occurs during clock source switch.

From 0 to 15 wait states are inserted if the access occurs when the APB or AHB prescalers values update is ongoing.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APB3 DIS	APB2 DIS	APB1 DIS	AHB4 DIS	Res.	AHB2 DIS	AHB1 DIS
									rw	rw	rw	rw		rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	PPRE3[2:0]			Res.	PPRE2[2:0]			Res.	PPRE1[2:0]			HPRE[3:0]			
	rw	rw	rw		rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **APB3DIS**: APB3 clock disable value.Set and cleared by software
This bit can be set to further reduce power consumption, when none of the APB3 peripherals are used and when their clocks are disabled in RCC_APB3ENR. When this bit is set, all the APB3 peripherals clocks are off.
0: APB3 clock enabled, distributed to peripherals according to their dedicated clock enable control bits
1: APB3 clock disabled

Bit 21 **APB2DIS**: APB2 clock disable value
This bit can be set to further reduce power consumption, when none of the APB2 peripherals are used and when their clocks are disabled in RCC_APB2ENR. When this bit is set, all the APB2 peripherals clocks are off.
0: APB2 clock enabled, distributed to peripherals according to their dedicated clock enable control bits
1: APB2 clock disabled

Bit 20 **APB1DIS**: APB1 clock disable value

This bit can be set to further reduce power consumption, when none of the APB1 peripherals (except IWDG) are used and when their clocks are disabled in RCC_APB1ENR. When this bit is set, all the APB1 peripherals clocks are off, except for IWDG.

0: APB1 clock enabled, distributed to peripherals according to their dedicated clock enable control bits

1: APB1 clock disabled

Bit 19 **AHB4DIS**: AHB4 clock disable

This bit can be set to further reduce power consumption, when none of the AHB4 peripherals from RCC_AHB4ENR are used and when their clocks are disabled in RCC_AHB4ENR. When this bit is set, all the AHB4 peripherals clocks from RCC_AHB4ENR are off.

0: AHB4 clock enabled, distributed to peripherals according to their dedicated clock enable control bits

1: AHB4 clock disabled

Bit 18 Reserved, must be kept at reset value.

Bit 17 **AHB2DIS**: AHB2 clock disable

This bit can be set to further reduce power consumption, when none of the AHB2 peripherals from RCC_AHB2ENR are used and when their clocks are disabled in RCC_AHB2ENR. When this bit is set, all the AHB2 peripherals clocks are off, except for SRAM2 and SRAM3.

0: AHB2 clock enabled, distributed to peripherals according to their dedicated clock enable control bits

1: AHB2 clock disabled

Bit 16 **AHB1DIS**: AHB1 clock disable

This bit can be set to further reduce power consumption, when none of the AHB1 peripherals from RCC_AHB1ENR are used and when their clocks are disabled in RCC_AHB1ENR. When this bit is set, all the AHB1 peripherals clocks are off, except for FLASH, BKPSRAM, ICACHE, DCACHE1 and SRAM1.

0: AHB1 clock enabled, distributed to peripherals according to their dedicated clock enable control bits

1: AHB1 clock disabled

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **PPRE3[2:0]**: APB low-speed prescaler (APB3)

Set and reset by software to control APB low-speed clocks division factor.

The clocks are divided with the new prescaler factor from 1 to 16 APB cycles after PPRE3 write.

0xx: rcc_pclk3 = rcc_hclk1

100: rcc_pclk3 = rcc_hclk1 / 2

101: rcc_pclk3 = rcc_hclk1 / 4

110: rcc_pclk3 = rcc_hclk1 / 8

111: rcc_pclk3 = rcc_hclk1 / 16

Bit 11 Reserved, must be kept at reset value.

Bits 10:8 **PPRE2[2:0]**: APB high-speed prescaler (APB2)

Set and reset by software to control APB high-speed clocks division factor.
The clocks are divided with the new prescaler factor from 1 to 16 APB cycles after PPRE2 write.
0xx: rcc_pclk2 = rcc_hclk1
100: rcc_pclk2 = rcc_hclk1 / 2
101: rcc_pclk2 = rcc_hclk1 / 4
110: rcc_pclk2 = rcc_hclk1 / 8
111: rcc_pclk2 = rcc_hclk1 / 16

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **PPRE1[2:0]**: APB low-speed prescaler (APB1)

Set and reset by software to control the division factor of rcc_pclk1.
The clock is divided by the new prescaler factor from 1 to 16 cycles of rcc_hclk after PPRE write.
0xx: rcc_pclk1 = rcc_hclk1 (default after reset)
100: rcc_pclk1 = rcc_hclk1 / 2
101: rcc_pclk1 = rcc_hclk1 / 4
110: rcc_pclk1 = rcc_hclk1 / 8
111: rcc_pclk1 = rcc_hclk1 / 16

Bits 3:0 **HPRE[3:0]**: AHB prescaler

Set and reset by software to control the division factor of rcc_hclk. Changing this division ratio has an impact on the frequency of all bus matrix clocks
0xxx: rcc_hclk = sys_ck (default after reset)
1000: rcc_hclk = sys_ck / 2
1001: rcc_hclk = sys_ck / 4
1010: rcc_hclk = sys_ck / 8
1011: rcc_hclk = sys_ck / 16
1100: rcc_hclk = sys_ck / 64
1101: rcc_hclk = sys_ck / 128
1110: rcc_hclk = sys_ck / 256
1111: rcc_hclk = sys_ck / 512

Caution: Be careful when using voltage scaling. Due to the propagation delay of the new division factor, after a prescaler factor change, and before lowering the V_{CORE} voltage, this register must be read to check that the new prescaler value has been taken into account. Depending upon the clock source frequency and the voltage range, the software application must program a correct value in HPRE to make sure that the system frequency does not exceed the maximum frequency.

11.8.7 RCC PLL clock source selection register (RCC_PLL1CFGR)

Address offset: 0x028

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLL1REN	PLL1QEN	PLL1PEN
													rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	PLL1M[5:0]						Res.	Res.	PLL1VCOSEL	PLL1FRACEN	PLL1RGE[1:0]		PLL1SRC[1:0]	
		rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **PLL1REN**: PLL1 DIVR divider output enable

Set and reset by software to enable the pll1_r_ck output of the PLL1.

To save power, when the pll1_r_ck output of the PLL1 is not used, the pll1_r_ck must be disabled. This bit can be written only when the PLL1 is disabled (PLL1ON = 0 and PLL1RDY = 0).

0: pll1_r_ck output disabled (default after reset)

1: pll1_r_ck output enabled

Bit 17 **PLL1QEN**: PLL1 DIVQ divider output enable

Set and reset by software to enable the pll1_q_ck output of the PLL1.

To save power, when the pll1_q_ck output of the PLL1 is not used, the pll1_q_ck must be disabled.

This bit can be written only when the PLL1 is disabled (PLL1ON = 0 and PLL1RDY = 0).

0: pll1_q_ck output disabled (default after reset)

1: pll1_q_ck output enabled

Bit 16 **PLL1PEN**: PLL1 DIVP divider output enable

Set and reset by software to enable the pll1_p_ck output of the PLL1.

This bit can be written only when the PLL1 is disabled (PLL1ON = 0 and PLL1RDY = 0).

To save power, when the pll1_p_ck output of the PLL1 is not used, the pll1_p_ck must be disabled.

0: pll1_p_ck output disabled (default after reset)

1: pll1_p_ck output enabled

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:8 **PLL1M[5:0]**: prescaler for PLL1

Set and cleared by software to configure the prescaler of the PLL1.

The hardware does not allow any modification of this prescaler when PLL1 is enabled (PLL1ON = 1 or PLL1RDY = 1).

To save power when PLL1 is not used, the value of PLL1M must be set to 0.

000000: prescaler disabled (default after reset)

000001: division by 1 (bypass)

000010: division by 2

000011: division by 3

...

100000: division by 32

...

111111: division by 63

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **PLL1VCOSEL**: PLL1 VCO selection

Set and reset by software to select the proper VCO frequency range used for PLL1. This bit must be written before enabling the PLL1.

0: wide VCO range: 128 to 560 MHz (default after reset)

1: medium VCO range: 150 to 420 MHz

Bit 4 **PLL1FRACEN**: PLL1 fractional latch enable

Set and reset by software to latch the content of FRACN1 into the sigma-delta modulator. To latch the FRACN1 value into the sigma-delta modulator, PLL1FRACEN must be set to 0, then set to 1. The transition 0 to 1 transfers the content of FRACN1 into the modulator.

Bits 3:2 **PLL1RGE[1:0]**: PLL1 input frequency range

Set and reset by software to select the proper reference frequency range used for PLL1. This bit must be written before enabling the PLL1.

00: PLL1 input (ref1_ck) clock range frequency between 1 and 2 MHz (default after reset)

01: PLL1 input (ref1_ck) clock range frequency between 2 and 4 MHz

10: PLL1 input (ref1_ck) clock range frequency between 4 and 8 MHz

11: PLL1 input (ref1_ck) clock range frequency between 8 and 16 MHz

Bits 1:0 **PLL1SRC[1:0]**: PLL1M and PLLs clock source selection

Set and reset by software to select the PLL clock source. These bits can be written only when all PLLs are disabled.

To save power, when no PLL is used, the value of PLL1SRC must be set to '00'.

00: no clock send to PLL1M divider and PLLs (default after reset).

01: HSI selected as PLL clock (hsi_ck)

10: CSI selected as PLL clock (csi_ck)

11: HSE selected as PLL clock (hse_ck)

11.8.8 RCC PLL clock source selection register (RCC_PLL2CFGR)

Address offset: 0x02C

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLL2REN	PLL2QEN	PLL2PEN
													rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	PLL2M[5:0]						Res.	Res.	PLL2VCOSEL	PLL2FRACEN	PLL2RGE[1:0]		PLL2SRC[1:0]	
		rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **PLL2REN**: PLL2 DIVR divider output enable

Set and reset by software to enable the pll2_r_ck output of the PLL2.

To save power, when the pll2_r_ck output of the PLL2 is not used, the pll2_r_ck must be disabled.

0: pll2_r_ck output disabled (default after reset)

1: pll2_r_ck output enabled

Bit 17 **PLL2QEN**: PLL2 DIVQ divider output enable
Set and reset by software to enable the pll2_q_ck output of the PLL2.
To save power, when the pll2_q_ck output of the PLL2 is not used, the pll2_q_ck must be disabled.
0: pll2_q_ck output disabled (default after reset)
1: pll2_q_ck output enabled

Bit 16 **PLL2PEN**: PLL2 DIVP divider output enable
Set and reset by software to enable the pll2_p_ck output of the PLL2.
To save power, when the pll2_p_ck output of the PLL2 is not used, the pll2_p_ck must be disabled.
0: pll2_p_ck output disabled (default after reset)
1: pll2_p_ck output enabled

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:8 **PLL2M[5:0]**: prescaler for PLL2
Set and cleared by software to configure the prescaler of the PLL2.
The hardware does not allow any modification of this prescaler when PLL2 is enabled (PLL2ON = 1 or PLL2RDY = 1).
To save power when PLL2 is not used, the value of PLL2M must be set to 0.
000000: prescaler disabled (default after reset)
000001: division by 1 (bypass)
000010: division by 2
000011: division by 3
...
100000: division by 32
...
111111: division by 63

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **PLL2VCOSEL**: PLL2 VCO selection
Set and reset by software to select the proper VCO frequency range used for PLL2.
This bit must be written before enabling the PLL2.
0: wide VCO range 128 to 560 MHz (default after reset)
1: medium VCO range 150 to 420 MHz

Bit 4 **PLL2FRACEN**: PLL2 fractional latch enable
Set and reset by software to enable the pll2_p_ck output of the PLL2.
To save power, when the pll2_p_ck output of the PLL2 is not used, the pll2_p_ck must be disabled.
0: pll2_p_ck output disabled (default after reset)
1: pll2_p_ck output enabled

Bits 3:2 **PLL2RGE[1:0]**: PLL2 input frequency range
Set and reset by software to select the proper reference frequency range used for PLL2.
These bits must be written before enabling the PLL2.
00: PLL2 input (ref2_ck) clock range frequency between 1 and 2 MHz (default after reset)
01: PLL2 input (ref2_ck) clock range frequency between 2 and 4 MHz
10: PLL2 input (ref2_ck) clock range frequency between 4 and 8 MHz
11: PLL2 input (ref2_ck) clock range frequency between 8 and 16 MHz

Bits 1:0 **PLL2SRC[1:0]**: PLL2M and PLLs clock source selection
Set and reset by software to select the PLL clock source.
These bits can be written only when all PLLs are disabled.
To save power, when no PLL is used, the value of PLL2SRC must be set to '00'.
00: no clock send to PLL2M divider and PLLs (default after reset)
01: HSI selected as PLL clock (hsi_ck)
10: CSI selected as PLL clock (csi_ck)
11: HSE selected as PLL clock (hse_ck)

11.8.9 RCC PLL clock source selection register (RCC_PLL3CFGR)

Address offset: 0x030

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLL3REN	PLL3QEN	PLL3PEN
													rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	PLL3M[5:0]						Res.	Res.	PLL3VCOSEL	PLL3FRACEN	PLL3RGE[1:0]		PLL3SRC[1:0]	
		rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **PLL3REN**: PLL3 DIVR divider output enable
Set and reset by software to enable the pll3_r_ck output of the PLL3.
To save power, when the pll3_r_ck output of the PLL3 is not used, the pll3_r_ck must be disabled.
0: pll3_r_ck output disabled (default after reset)
1: pll3_r_ck output enabled

Bit 17 **PLL3QEN**: PLL3 DIVQ divider output enable
Set and reset by software to enable the pll3_q_ck output of the PLL3.
To save power, when the pll3_q_ck output of the PLL3 is not used, the pll3_q_ck must be disabled.
0: pll3_q_ck output disabled (default after reset)
1: pll3_q_ck output enabled

Bit 16 **PLL3PEN**: PLL3 DIVP divider output enable
Set and reset by software to enable the pll3_p_ck output of the PLL3.
To save power, when the pll3_p_ck output of the PLL3 is not used, the pll3_p_ck must be disabled.
0: pll3_p_ck output disabled (default after reset)
1: pll3_p_ck output enabled

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:8 **PLL3M[5:0]**: prescaler for PLL3

Set and cleared by software to configure the prescaler of the PLL3.
The hardware does not allow any modification of this prescaler when PLL3 is enabled (PLL3ON = 1 or PLL3RDY = 1).
To save power when PLL3 is not used, the value of PLL3M must be set to 0.
000000: prescaler disabled (default after reset)
000001: division by 1 (bypass)
000010: division by 2
000011: division by 3
...
100000: division by 32
...
111111: division by 63

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **PLL3VCOSEL**: PLL3 VCO selection

Set and reset by software to select the proper VCO frequency range used for PLL3.
This bit must be written before enabling the PLL3.
0: wide VCO range 128 to 560 MHz (default after reset)
1: medium VCO range 150 to 420 MHz

Bit 4 **PLL3FRACEN**: PLL3 fractional latch enable

Set and reset by software to latch the content of FRACN3 into the sigma-delta modulator.
To latch the FRACN3 value into the sigma-delta modulator, PLL3FRACEN must be set to 0, then set to 1. The transition 0 to 1 transfers the content of FRACN3 into the modulator.

Bits 3:2 **PLL3RGE[1:0]**: PLL3 input frequency range

Set and reset by software to select the proper reference frequency range used for PLL3.
This bit must be written before enabling the PLL3.
00: PLL3 input (ref3_ck) clock range frequency between 1 and 2 MHz (default after reset)
01: PLL3 input (ref3_ck) clock range frequency between 2 and 4 MHz
10: PLL3 input (ref3_ck) clock range frequency between 4 and 8 MHz
11: PLL3 input (ref3_ck) clock range frequency between 8 and 16 MHz

Bits 1:0 **PLL3SRC[1:0]**: PLL3M and PLLs clock source selection

Set and reset by software to select the PLL clock source. These bits can be written only when all PLLs are disabled.
To save power, when no PLL is used, the value of PLL3SRC must be set to '00'.
00: no clock send to PLL3M divider and PLLs (default after reset)
01: HSI selected as PLL clock (hsi_ck)
10: CSI selected as PLL clock (csi_ck)
11: HSE selected as PLL clock (hse_ck)

11.8.10 RCC PLL1 dividers register (RCC_PLL1DIVR)

Address offset: 0x034

Reset value: 0x0101 0280

Access: no wait state, word, half-word and byte access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	PLL1R[6:0]							Res.	PLL1Q[6:0]						
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PLL1P[6:0]							PLL1N[8:0]								
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **PLL1R[6:0]**: PLL1 DIVR division factor

Set and reset by software to control the frequency of the pll1_r_ck clock.
These bits can be written only when the PLL1 is disabled (PLL1ON = 0 and PLL1RDY = 0).
0000000: pll1_r_ck = vco1_ck / 1
0000001: pll1_r_ck = vco1_ck / 2 (default after reset)
0000010: pll1_r_ck = vco1_ck / 3
0000011: pll1_r_ck = vco1_ck / 4
...
1111111: pll1_r_ck = vco1_ck / 128

Bit 23 Reserved, must be kept at reset value.

Bits 22:16 **PLL1Q[6:0]**: PLL1 DIVQ division factor

Set and reset by software to control the frequency of the pll1_q_ck clock.
These bits can be written only when the PLL1 is disabled (PLL1ON = 0 and PLL1RDY = 0).
0000000: pll1_q_ck = vco1_ck
0000001: pll1_q_ck = vco1_ck / 2 (default after reset)
0000010: pll1_q_ck = vco1_ck / 3
0000011: pll1_q_ck = vco1_ck / 4
...
1111111: pll1_q_ck = vco1_ck / 128

Bits 15:9 **PLL1P[6:0]**: PLL1 DIVP division factor

Set and reset by software to control the frequency of the pll1_p_ck clock.
These bits can be written only when the PLL1 is disabled (PLL1ON = 0 and PLL1RDY = 0).
Note that odd division factors are not allowed.
0000000: Not allowed
0000001: pll1_p_ck = vco1_ck / 2 (default after reset)
0000010: Not allowed
0000011: pll1_p_ck = vco1_ck / 4
...
1111111: pll1_p_ck = vco1_ck / 128

Bits 8:0 **PLL1N[8:0]**: Multiplication factor for PLL1VCO

Set and reset by software to control the multiplication factor of the VCO.
These bits can be written only when the PLL is disabled (PLL1ON = 0 and PLL1RDY = 0).
0x003: PLL1N = 4
0x004: PLL1N = 5
0x005: PLL1N = 6
...
0x080: PLL1N = 129 (default after reset)
...
0x1FF: PLL1N = 512
Others: reserved

11.8.11 RCC PLL1 fractional divider register (RCC_PLL1FRACR)

Address offset: 0x038

Reset value: 0x0000 0000

Access: no wait state; word and half-word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PLL1FRACN[12:0]													Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:3 **PLL1FRACN[12:0]**: fractional part of the multiplication factor for PLL1 VCO

Set and reset by software to control the fractional part of the multiplication factor of the VCO. These bits can be written at any time, allowing dynamic fine-tuning of the PLL1 VCO.

Caution: The software must set correctly these bits to ensure that the VCO output frequency is in the valid frequency range, that is:
- 128 to 560 MHz if PLL1VCOSEL = 0
- 150 to 420 MHz if PLL1VCOSEL = 1

VCO output frequency = F_{ref1_ck} x (PLL1N + (PLL1FRACN / 2^{13})), with
- PLL1N between 8 and 420
- PLL1FRACN between 0 and 2^{13} - 1
- The input frequency F_{ref1_ck} must be between 1 and 16 MHz.

To change the PLL1FRACN value on-the-fly even if the PLL is enabled, the application must proceed as follows:
- Set the bit PLL1FRACEN to 0.
- Write the new fractional value into PLL1FRACN.
- Set the bit PLL1FRACEN to 1.

Bits 2:0 Reserved, must be kept at reset value.

11.8.12 RCC PLL1 dividers register (RCC_PLL2DIVR)

Address offset: 0x03C

Reset value: 0x0101 0280

Access: no wait state, word, half-word and byte access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	PLL2R[6:0]							Res.	PLL2Q[6:0]						
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PLL2P[6:0]							PLL2N[8:0]								
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **PLL2R[6:0]**: PLL2 DIVR division factor
Set and reset by software to control the frequency of the pll2_r_ck clock.
These bits can be written only when the PLL1 is disabled (PLL2ON = 0 and PLL2RDY = 0).
0000000: pll2_r_ck = vco2_ck
0000001: pll2_r_ck = vco2_ck / 2 (default after reset)
0000010: pll2_r_ck = vco2_ck / 3
0000011: pll2_r_ck = vco2_ck / 4
...
1111111: pll2_r_ck = vco2_ck / 128

Bit 23 Reserved, must be kept at reset value.

Bits 22:16 **PLL2Q[6:0]**: PLL2 DIVQ division factor
Set and reset by software to control the frequency of the pll2_q_ck clock.
These bits can be written only when the PLL2 is disabled (PLL2ON = 0 and PLL2RDY = 0).
0000000: pll2_q_ck = vco2_ck
0000001: pll2_q_ck = vco2_ck / 2 (default after reset)
0000010: pll2_q_ck = vco2_ck / 3
0000011: pll2_q_ck = vco2_ck / 4
...
1111111: pll2_q_ck = vco2_ck / 128

Bits 15:9 **PLL2P[6:0]**: PLL2 DIVP division factor
Set and reset by software to control the frequency of the pll2_p_ck clock.
These bits can be written only when the PLL2 is disabled (PLL2ON = 0 and PLL2RDY = 0).
0000000: pll2_p_ck = vco2_ck
0000001: pll2_p_ck = vco2_ck / 2 (default after reset)
0000010: pll2_p_ck = vco2_ck / 3
0000011: pll2_p_ck = vco2_ck / 4
...
1111111: pll2_p_ck = vco2_ck / 128

Bits 8:0 **PLL2N[8:0]**: Multiplication factor for PLL2VCO
Set and reset by software to control the multiplication factor of the VCO.
These bits can be written only when the PLL is disabled (PLL2ON = 0 and PLL2RDY = 0).
0x003: PLL2N = 4
0x004: PLL2N = 5
0x005: PLL2N = 6
...
0x080: PLL2N = 129 (default after reset)
...
0x1FF: PLL2N = 512
Others: reserved

11.8.13 RCC PLL2 fractional divider register (RCC_PLL2FRACR)

Address offset: 0x040

Reset value: 0x0000 0000

Access: no wait state; word and half-word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PLL2FRACN[12:0]													Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:3 **PLL2FRACN[12:0]:** fractional part of the multiplication factor for PLL2 VCO

Set and reset by software to control the fractional part of the multiplication factor of the VCO. These bits can be written at any time, allowing dynamic fine-tuning of the PLL2 VCO.

Caution: The software must set correctly these bits to ensure that the VCO output frequency is between its valid frequency range, that is:
- 128 to 560 MHz if PLL2VCOSEL = 0
- 150 to 420 MHz if PLL2VCOSEL = 1

VCO output frequency = F_{ref2_ck} x (PLL2N + (PLL2FRACN / 2^{13})), with
- PLL2N between 8 and 420
- PLL2FRACN can be between 0 and 2^{13}- 1
- The input frequency F_{ref2_ck} must be between 1 and 16 MHz.

To change the PLL2FRACN value on-the-fly even if the PLL is enabled, the application must proceed as follows:
- Set the bit PLL2FRACEN to 0
- Write the new fractional value into PLL2FRACN
- Set the bit PLL2FRACEN to 1

Bits 2:0 Reserved, must be kept at reset value.

11.8.14 RCC PLL3 dividers register (RCC_PLL3DIVR)

Address offset: 0x044

Reset value: 0x0101 0280

Access: no wait state; word, half-word and byte access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	PLL3R[6:0]							Res.	PLL3Q[6:0]						
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PLL3P[6:0]							PLL3N[8:0]								
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **PLL3R[6:0]**: PLL3 DIVR division factor
Set and reset by software to control the frequency of the pll3_r_ck clock.
These bits can be written only when the PLL1 is disabled (PLL3ON = 0 and PLL3RDY = 0).
0000000: pll3_r_ck = vco3_ck
0000001: pll3_r_ck = vco3_ck / 2 (default after reset)
0000010: pll3_r_ck = vco3_ck / 3
0000011: pll3_r_ck = vco3_ck / 4
...
1111111: pll3_r_ck = vco3_ck / 128

Bit 23 Reserved, must be kept at reset value.

Bits 22:16 **PLL3Q[6:0]**: PLL3 DIVQ division factor
Set and reset by software to control the frequency of the pll3_q_ck clock.
These bits can be written only when the PLL3 is disabled (PLL3ON = 0 and PLL3RDY = 0).
0000000: pll3_q_ck = vco3_ck
0000001: pll3_q_ck = vco3_ck / 2 (default after reset)
0000010: pll3_q_ck = vco3_ck / 3
0000011: pll3_q_ck = vco3_ck / 4
...
1111111: pll3_q_ck = vco3_ck / 128

Bits 15:9 **PLL3P[6:0]**: PLL3 DIVP division factor
Set and reset by software to control the frequency of the pll3_p_ck clock.
These bits can be written only when the PLL3 is disabled (PLL3ON = 0 and PLL3RDY = 0).
0000000: pll3_p_ck = vco3_ck
0000001: pll3_p_ck = vco3_ck / 2 (default after reset)
0000010: pll3_p_ck = vco3_ck / 3
0000011: pll3_p_ck = vco3_ck / 4
...
1111111: pll3_p_ck = vco3_ck / 128

Bits 8:0 **PLL3N[8:0]**: Multiplication factor for PLL3VCO
Set and reset by software to control the multiplication factor of the VCO.
These bits can be written only when the PLL is disabled (PLL3ON = 0 and PLL3RDY = 0).
0x003: PLL3N = 4
0x004: PLL3N = 5
0x005: PLL3N = 6
...
0x080: PLL3N = 129 (default after reset)
...
0x1FF: PLL3N = 512
Others: reserved

11.8.15 RCC PLL3 fractional divider register (RCC_PLL3FRACR)

Address offset: 0x048

Reset value: 0x0000 0000

Access: no wait state; word and half-word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PLL3FRACN[12:0]													Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:3 **PLL3FRACN[12:0]**: Fractional part of the multiplication factor for PLL3 VCO

Set and reset by software to control the fractional part of the multiplication factor of the VCO. These bits can be written at any time, allowing dynamic fine-tuning of the PLL3 VCO.

Caution: The software must set correctly these bits to ensure that the VCO output frequency is between its valid frequency range, that is:
- 128 to 560 MHz if PLL3VCOSEL = 0
- 150 to 420 MHz if PLL3VCOSEL = 1

VCO output frequency = F_{ref3_ck} x (PLL3N + (PLL3FRACN / 2^{13})), with
- PLL3N between 8 and 420
- PLL3FRACN can be between 0 and 2^{13} - 1
- The input frequency F_{ref3_ck} must be between 1 and 16 MHz.

To change the PLL3FRACN value on-the-fly even if the PLL is enabled, the application must proceed as follows:
- Set the bit PLL3FRACEN to 0.
- Write the new fractional value into PLL3FRACN.
- Set the bit PLL3FRACEN to 1.

Bits 2:0 Reserved, must be kept at reset value.

11.8.16 RCC clock source interrupt enable register (RCC_CIER)

Address offset: 0x050

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLL3RDYIE	PLL2RDYIE	PLL1RDYIE	HSI48RDYIE	HSERDYIE	HSIRDYIE	CSIRDYIE	LSERDYIE	LSIRDYIE
							rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **PLL3RDYIE**: PLL3 ready interrupt enable

Set and reset by software to enable/disable interrupt caused by PLL3 lock.
0: PLL3 lock interrupt disabled (default after reset)
1: PLL3 lock interrupt enabled

Bit 7 **PLL2RDYIE**: PLL2 ready interrupt enable

Set and reset by software to enable/disable interrupt caused by PLL2 lock.
0: PLL2 lock interrupt disabled (default after reset)
1: PLL2 lock interrupt enabled

Bit 6 **PLL1RDYIE**: PLL1 ready interrupt enable
Set and reset by software to enable/disable interrupt caused by PLL1 lock.
0: PLL1 lock interrupt disabled (default after reset)
1: PLL1 lock interrupt enabled

Bit 5 **HSI48RDYIE:** HSI48 ready interrupt enable
Set and reset by software to enable/disable interrupt caused by the HSI48 oscillator stabilization.
0: HSI48 ready interrupt disabled (default after reset)
1: HSI48 ready interrupt enabled

Bit 4 **HSERDYIE**: HSE ready interrupt enable
Set and reset by software to enable/disable interrupt caused by the HSE oscillator stabilization.
0: HSE ready interrupt disabled (default after reset)
1: HSE ready interrupt enabled

Bit 3 **HSIRDYIE**: HSI ready interrupt enable
Set and reset by software to enable/disable interrupt caused by the HSI oscillator stabilization.
0: HSI ready interrupt disabled (default after reset)
1: HSI ready interrupt enabled

Bit 2 **CSIRDYIE**: CSI ready interrupt enable
Set and reset by software to enable/disable interrupt caused by the CSI oscillator stabilization.
0: CSI ready interrupt disabled (default after reset)
1: CSI ready interrupt enabled

Bit 1 **LSERDYIE**: LSE ready interrupt enable
Set and reset by software to enable/disable interrupt caused by the LSE oscillator stabilization.
0: LSE ready interrupt disabled (default after reset)
1: LSE ready interrupt enabled

Bit 0 **LSIRDYIE**: LSI ready interrupt enable
Set and reset by software to enable/disable interrupt caused by the LSI oscillator stabilization.
0: LSI ready interrupt disabled (default after reset)
1: LSI ready interrupt enabled

11.8.17 RCC clock source interrupt flag register (RCC_CIFR)

Address offset: 0x054

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	HSECSSF	Res.	PLL3RDYF	PLL2RDYF	PLL1RDYF	HSI48RDYF	HSERDYF	HSIRDYF	CSIRDYF	LSERDYF	LSIRDYF
					r		r	r	r	r	r	r	r	r	r

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **HSECSSF**: HSE clock security system interrupt flag
Reset by software by writing HSECSSC bit.
Set by hardware in case of HSE clock failure.
0: no clock security interrupt caused by HSE clock failure (default after reset)
1: clock security interrupt caused by HSE clock failure

Bit 9 Reserved, must be kept at reset value.

Bit 8 **PLL3RDYF**: PLL3 ready interrupt flag
Reset by software by writing PLL3RDYC bit.
Set by hardware when the PLL3 locks and PLL3RDYIE is set.
0: no clock ready interrupt caused by PLL3 lock (default after reset)
1: clock ready interrupt caused by PLL3 lock

Bit 7 **PLL2RDYF**: PLL2 ready interrupt flag
Reset by software by writing PLL2RDYC bit.
Set by hardware when the PLL2 locks and PLL2RDYIE is set.
0: no clock ready interrupt caused by PLL2 lock (default after reset)
1: clock ready interrupt caused by PLL2 lock

Bit 6 **PLL1RDYF**: PLL1 ready interrupt flag
Reset by software by writing PLL1RDYC bit.
Set by hardware when the PLL1 locks and PLL1RDYIE is set.
0: no clock ready interrupt caused by PLL1 lock (default after reset)
1: clock ready interrupt caused by PLL1 lock

Bit 5 **HSI48RDYF**: HSI48 ready interrupt flag
Reset by software by writing HSI48RDYC bit.
Set by hardware when the HSI48 clock becomes stable and HSI48RDYIE is set.
0: no clock ready interrupt caused by the HSI48 oscillator (default after reset)
1: clock ready interrupt caused by the HSI48 oscillator

Bit 4 **HSERDYF**: HSE ready interrupt flag
Reset by software by writing HSERDYC bit.
Set by hardware when the HSE clock becomes stable and HSERDYIE is set.
0: no clock ready interrupt caused by the HSE (default after reset)
1: clock ready interrupt caused by the HSE

Bit 3 **HSIRDYF**: HSI ready interrupt flag
Reset by software by writing HSIRDYC bit.
Set by hardware when the HSI clock becomes stable and HSIRDYIE is set.
0: no clock ready interrupt caused by the HSI (default after reset)
1: clock ready interrupt caused by the HSI

Bit 2 **CSIRDYF**: CSI ready interrupt flag
Reset by software by writing CSIRDYC bit.
Set by hardware when the CSI clock becomes stable and CSIRDYIE is set.
0: no clock ready interrupt caused by the CSI (default after reset)
1: clock ready interrupt caused by the CSI

Bit 1 **LSERDYF**: LSE ready interrupt flag
Reset by software by writing LSERDYC bit.
Set by hardware when the LSE clock becomes stable and LSERDYIE is set.
0: no clock ready interrupt caused by the LSE (default after reset)
1: clock ready interrupt caused by the LSE

Bit 0 **LSIRDYF**: LSI ready interrupt flag
Reset by software by writing LSIRDYC bit.
Set by hardware when the LSI clock becomes stable and LSIRDYIE is set.
0: no clock ready interrupt caused by the LSI (default after reset)
1: clock ready interrupt caused by the LSI

11.8.18 RCC clock source interrupt clear register (RCC_CICR)

Address offset: 0x058

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	HSECSSC	Res.	PLL3RDYC	PLL2RDYC	PLL1RDYC	HSI48RDYC	HSERDYC	HSIRDYC	CSIRDYC	LSERDYC	LSIRDYC
					rc_w1		rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **HSECSSC**: HSE clock security system interrupt clear
Set by software to clear HSECSSF.
Reset by hardware when clear done.
0: HSECSSF no effect (default after reset)
1: HSECSSF cleared

Bit 9 Reserved, must be kept at reset value.

Bit 8 **PLL3RDYC**: PLL3 ready interrupt clear
Set by software to clear PLL3RDYF.
Reset by hardware when clear done.
0: PLL3RDYF no effect (default after reset)
1: PLL3RDYF cleared

Bit 7 **PLL2RDYC**: PLL2 ready interrupt clear
Set by software to clear PLL2RDYF.
Reset by hardware when clear done.
0: PLL2RDYF no effect (default after reset)
1: PLL2RDYF cleared

Bit 6 **PLL1RDYC**: PLL1 ready interrupt clear
Set by software to clear PLL1RDYF.
Reset by hardware when clear done.
0: PLL1RDYF no effect (default after reset)
1: PLL1RDYF cleared

Bit 5 **HSI48RDYC**: HSI48 ready interrupt clear
Set by software to clear HSI48RDYF.
Reset by hardware when clear done.
0: HSI48RDYF no effect (default after reset)
1: HSI48RDYF cleared

Bit 4 **HSERDYC**: HSE ready interrupt clear
Set by software to clear HSERDYF.
Reset by hardware when clear done.
0: HSERDYF no effect (default after reset)
1: HSERDYF cleared

Bit 3 **HSIRDYC**: HSI ready interrupt clear
Set by software to clear HSIRDYF.
Reset by hardware when clear done.
0: HSIRDYF no effect (default after reset)
1: HSIRDYF cleared

Bit 2 **CSIRDYC**: HSI ready interrupt clear
Set by software to clear CSIRDYF.
Reset by hardware when clear done.
0: CSIRDYF no effect (default after reset)
1: CSIRDYF cleared

Bit 1 **LSERDYC**: LSE ready interrupt clear
Set by software to clear LSERDYF.
Reset by hardware when clear done.
0: LSERDYF no effect (default after reset)
1: LSERDYF cleared

Bit 0 **LSIRDYC**: LSI ready interrupt clear
Set by software to clear LSIRDYF.
Reset by hardware when clear done.
0: LSIRDYF no effect (default after reset)
1: LSIRDYF cleared

11.8.19 RCC AHB1 reset register (RCC_AHB1RSTR)

Address offset: 0x060

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JPEGRST	DMA2DRST	Res.	Res.	ETHRST	Res.	RAMCFGRST	MDF1RST
								rw	rw			rw		rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FMACRST	CORDICRST	Res.	CRCRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPDMA2RST	GPDMA1RST
rw	rw		rw											rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **JPEGRST**: JPEG reset
Set and reset by software.
0: does not reset JPEG (default after reset)
1: resets the JPEG

Bit 22 **DMA2DRST**: DMA2D reset
Set and reset by software.
0: does not reset DMA2D (default after reset)
1: resets the DMA2D

Bits 21:20 Reserved, must be kept at reset value.

Bit 19 **ETHRST**: ETH reset
Set and reset by software.
0: does not reset ETH (default after reset)
1: resets the ETH

Bit 18 Reserved, must be kept at reset value.

Bit 17 **RAMCFGRST**: RAMCFG reset
Set and reset by software.
0: does not reset RAMCFG (default after reset)
1: resets RAMCFG

Bit 16 **MDF1RST**: MDF1 reset
Set and reset by software.
0: does not reset MDF1 (default after reset)
1: resets MDF1

Bit 15 **FMACRST**: FMAC reset
Set and reset by software.
0: does not reset FMAC (default after reset)
1: resets FMAC

Bit 14 **CORDICRST**: CORDIC reset
Set and reset by software.
0: does not reset CORDIC (default after reset)
1: resets CORDIC

Bit 13 Reserved, must be kept at reset value.

Bit 12 **CRCRST**: CRC reset
Set and reset by software.
0: does not reset CRC (default after reset)
1: resets CRC

Bits 11:2 Reserved, must be kept at reset value.

Bit 1 **GPDMA2RST**: GPDMA2 reset
Set and reset by software.
0: does not reset GPDMA2 (default after reset)
1: resets GPDMA2

Bit 0 **GPDMA1RST**: GPDMA1 reset
Set and reset by software.
0: does not reset GPDMA1 (default after reset)
1: resets GPDMA1

11.8.20 RCC AHB2 peripheral reset register (RCC_AHB2RSTR)

Address offset: 0x064

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	GPIOKRST	ADF1RST	ADC3RST	Res.	Res.	CCBRST	SAESRST	PKARST	RNGRST	HASHRST	AESRST
					rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OTGFSRST	OTGHSRST	OTGPHYRST	DCMI_PSSIRST	DAC1RST	ADCRST	GPIOJRST	GPIOIRST	GPIOHRST	GPIOGRST	GPIOFRST	GPIOERST	GPIODRST	GPIOCRST	GPIOBRST	GPIOARST
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **GPIOKRST**: GPIOK reset
Set and reset by software.
0: does not reset the GPIOK (default after reset)
1: resets the GPIOK

Bit 25 **ADF1RST**: ADF1 reset
Set and reset by software.
0: does not reset ADF1 (default after reset)
1: resets ADF1

Bit 24 **ADC3RST**: ADC3 reset
Set and reset by software.
0: does not reset ADC3 (default after reset)
1: resets ADC3

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **CCBRST**: CCB reset
Set and reset by software.
0: does not reset CCB (default after reset)
1: resets CCB

Bit 20 **SAESRST**: SAES reset
Set and reset by software.
0: does not reset SAES (default after reset)
1: resets SAES

Bit 19 **PKARST**: PKA block reset
Set and reset by software.
0: does not reset PKA (default after reset)
1: resets PKA

Bit 18 **RNGRST**: RNG reset
Set and reset by software.
0: does not reset RNG (default after reset)
1: resets RNG

Bit 17 **HASHRST**: HASH reset
Set and reset by software.
0: does not reset HASH (default after reset)
1: resets HASH

Bit 16 **AESRST**: AES reset
Set and reset by software.
0: does not reset AES (default after reset)
1: resets AES

Bit 15 **OTGFSRST**: OTGFS reset
Set and reset by software.
0: does not reset OTGFS (default after reset)
1: resets OTGFS

Bit 14 **OTGHSRST**: OTGHS reset
Set and reset by software.
0: does not reset OTGHS (default after reset)
1: resets OTGHS

Bit 13 **OTGPHYRST**: OTGPHY reset
Set and reset by software.
0: does not reset the OTGPHY (default after reset)
1: resets the OTGPHY

Bit 12 **DCMI_PSSIRST**: Digital camera interface reset (DCMI or PSSI depending which one is active)
Set and reset by software.
0: does not reset the DCMI/PSSI (default after reset)
1: resets the DCMI/PSSI

Bit 11 **DAC1RST**: DAC1 reset
Set and reset by software.
0: does not reset DAC1 (default after reset)
1: resets DAC1

Bit 10 **ADCRST**: ADC1 and ADC2 reset
Set and reset by software.
0: does not reset ADC1 and ADC2 (default after reset)
1: resets ADC1 and ADC2

Bit 9 **GPIOJRST**: GPIOJ reset
Set and reset by software.
0: does not reset the GPIOJ (default after reset)
1: resets the GPIOJ

Bit 8 **GPIOIRST**: GPIOI reset
Set and reset by software.
0: does not reset the GPIOI (default after reset)
1: resets the GPIOI

Bit 7 **GPIOHRST**: GPIOH reset
Set and reset by software.
0: does not reset the GPIOH (default after reset)
1: resets the GPIOH

Bit 6 **GPIOGRST**: GPIOG reset
Set and reset by software.
0: does not reset the GPIOG (default after reset)
1: resets the GPIOG

Bit 5 **GPIOFRST**: GPIOF reset
Set and reset by software.
0: does not reset the GPIOF (default after reset)
1: resets the GPIOF

Bit 4 **GPIOERST**: GPIOE reset
Set and reset by software.
0: does not reset the GPIOE (default after reset)
1: resets the GPIOE

Bit 3 **GPIODRST**: GPIOD reset
Set and reset by software.
0: does not reset the GPIOD (default after reset)
1: resets the GPIOD

Bit 2 **GPIOCRST**: GPIOC reset
Set and reset by software.
0: does not reset the GPIOC (default after reset)
1: resets the GPIOC

Bit 1 **GPIOBRST**: GPIOB reset
Set and reset by software.
0: does not reset the GPIOB (default after reset)
1: resets the GPIOB

Bit 0 **GPIOARST**: GPIOA reset
Set and reset by software.
0: does not reset the GPIOA (default after reset)
1: resets the GPIOA

11.8.21 RCC AHB4 peripheral reset register (RCC_AHB4RSTR)

Address offset: 0x06C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCTOSPIMRST	OCTOSPI2RST	OCTOSPI1RST	Res.	Res.	Res.	FMCRST
									rw	rw	rw				rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	SDMMC2RST	SDMMC1RST	Res.	Res.	OTFDEC2RST	OTFDEC1RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.
			rw	rw			rw	rw							

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **OCTOSPIMRST**: OCTOSPIM reset
Set and reset by software.
0: does not reset OCTOSPIM (default after reset)
1: resets OCTOSPIM

Bit 21 **OCTOSPI2RST**: OCTOSPI2 reset
Set and reset by software.
0: does not reset OCTOSPI2 (default after reset)
1: resets OCTOSPI2

Bit 20 **OCTOSPI1RST**: OCTOSPI1 reset
Set and reset by software.
0: does not reset OCTOSPI1 (default after reset)
1: resets OCTOSPI1

Bits 19:17 Reserved, must be kept at reset value.

Bit 16 **FMCRST**: FMC reset
Set and reset by software.
0: does not reset FMC (default after reset)
1: resets FMC

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **SDMMC2RST**: SDMMC2 and SDMMC2 delay reset
Set and reset by software.
0: does not reset SDMMC2 and SDMMC2 delay (default after reset)
1: resets SDMMC2 and SDMMC2 delay

Bit 11 **SDMMC1RST**: SDMMC1 and SDMMC1 delay reset
Set and reset by software.
0: does not reset SDMMC1 and SDMMC1 delay (default after reset)
1: resets SDMMC1 and SDMMC1 delay

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **OTFDEC2RST**: OTFDEC2 reset
Set and reset by software.
0: does not reset OTFDEC2 (default after reset)
1: resets OTFDEC2

Bit 7 **OTFDEC1RST**: OTFDEC1 reset
Set and reset by software.
0: does not reset OTFDEC1 (default after reset)
1: resets OTFDEC1

Bits 6:0 Reserved, must be kept at reset value.

11.8.22 RCC APB1 peripheral low reset register (RCC_APB1LRSTR)

Address offset: 0x074

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UART8RST	UART7RST	Res.	CECRST	USART11RST	USART10RST	USART6RST	CRSRST	I3C1RST	I2C2RST	I2C1RST	UART5RST	UART4RST	USART3RST	USART2RST	COMPRST
rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI3RST	SPI2RST	OPAMPRST	Res.	Res.	Res.	Res.	TIM14RST	TIM13RST	TIM12RST	TIM7RST	TIM6RST	TIM5RST	TIM4RST	TIM3RST	TIM2RST
rw	rw	rw					rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UART8RST**: UART8 reset
Set and reset by software.
0: does not reset the UART8 (default after reset)
1: resets the UART8

Bit 30 **UART7RST**: UART7 reset
Set and reset by software.
0: does not reset the UART7 (default after reset)
1: resets the UART7

Bit 29 Reserved, must be kept at reset value.

Bit 28 **CECRST**: HDMI-CEC reset
Set and reset by software.
0: does not reset the HDMI-CEC (default after reset)
1: resets the HDMI-CEC

Bit 27 **USART11RST**: USART11 reset
Set and reset by software.
0: does not reset the USART11 (default after reset)
1: resets the USART11

Bit 26 **USART10RST**: USART10 reset
Set and reset by software.
0: does not reset the USART10 (default after reset)
1: resets the USART10

Bit 25 **USART6RST**: USART6 reset
Set and reset by software.
0: does not reset the USART6 (default after reset)
1: resets the USART6

Bit 24 **CRSRST**: CRS reset
Set and reset by software.
0: does not reset the CRS (default after reset)
1: resets the CRS

Bit 23 **I3C1RST**: I3C1 reset
Set and reset by software.
0: does not reset the I3C1 (default after reset)
1: resets the I3C1

Bit 22 **I2C2RST**: I2C2 block reset
Set and reset by software.
0: does not reset the I2C2 block (default after reset)
1: resets the I2C2 block

Bit 21 **I2C1RST**: I2C1 reset
Set and reset by software.
0: does not reset the I2C1 (default after reset)
1: resets the I2C1

Bit 20 **UART5RST**: UART5 reset
Set and reset by software.
0: does not reset the UART5 (default after reset)
1: resets the UART5

Bit 19 **UART4RST**: UART4 reset
Set and reset by software.
0: does not reset the UART4 (default after reset)
1: resets the UART4

Bit 18 **USART3RST**: USART3 reset
Set and reset by software.
0: does not reset the USART3 (default after reset)
1: resets the USART3

Bit 17 **USART2RST**: USART2 reset
Set and reset by software.
0: does not reset the USART2 (default after reset)
1: resets the USART2

Bit 16 **COMPRST**: COMP reset
Set and reset by software.
0: does not reset the COMP (default after reset)
1: resets the COMP

Bit 15 **SPI3RST**: SPI3 reset
Set and reset by software.
0: does not reset the SPI3 (default after reset)
1: resets the SPI3

Bit 14 **SPI2RST**: SPI2 reset
Set and reset by software.
0: does not reset the SPI2 (default after reset)
1: resets the SPI2

Bit 13 **OPAMPRST**: OPAMP reset
Set and reset by software.
0: does not reset the OPAMP (default after reset)
1: resets the OPAMP

Bits 12:9 Reserved, must be kept at reset value.

Bit 8 **TIM14RST**: TIM14 reset
Set and reset by software.
0: does not reset the TIM14 (default after reset)
1: resets the TIM14

Bit 7 **TIM13RST**: TIM13 reset
Set and reset by software.
0: does not reset the TIM13 (default after reset)
1: resets the TIM13

Bit 6 **TIM12RST**: TIM12 reset
Set and reset by software.
0: does not reset the TIM12 (default after reset)
1: resets the TIM12

Bit 5 **TIM7RST**: TIM7 reset
Set and reset by software.
0: does not reset the TIM7 (default after reset)
1: resets the TIM7

Bit 4 **TIM6RST**: TIM6 reset
Set and reset by software.
0: does not reset the TIM6 (default after reset)
1: resets the TIM6

Bit 3 **TIM5RST**: TIM5 reset
Set and reset by software.
0: does not reset the TIM5 (default after reset)
1: resets the TIM5

Bit 2 **TIM4RST**: TIM4 reset
Set and reset by software.
0: does not reset the TIM4 (default after reset)
1: resets the TIM4

Bit 1 **TIM3RST**: TIM3 reset
Set and reset by software.
0: does not reset the TIM3 (default after reset)
1: resets the TIM3

Bit 0 **TIM2RST**: TIM2 reset
Set and reset by software.
0: does not reset the TIM2 (default after reset)
1: resets the TIM2

11.8.23 RCC APB1 peripheral high reset register (RCC_APB1HRSTR)

Address offset: 0x078

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UCPD1RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.
								rw							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	FDCANRST	Res.	Res.	Res.	LPTIM2RST	Res.	DTSRST	Res.	UART12RST	UART9RST
						rw				rw		rw		rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **UCPD1RST**: UCPD1 reset
Set and reset by software.
0: does not reset the UCPD1 (default after reset)
1: resets the UCPD1

Bits 22:10 Reserved, must be kept at reset value.

Bit 9 **FDCANRST**: FDCAN1/2 reset
Set and reset by software.
0: does not reset the FDCAN1/2 (default after reset)
1: resets the FDCAN1/2

Bits 8:6 Reserved, must be kept at reset value.

Bit 5 **LPTIM2RST**: LPTIM2 reset
Set and reset by software.
0: does not reset the LPTIM2 (default after reset)
1: resets the LPTIM2

Bit 4 Reserved, must be kept at reset value.

Bit 3 **DTSRST**: DTS reset
Set and reset by software.
0: does not reset the DTS (default after reset)
1: resets the DTS

Bit 2 Reserved, must be kept at reset value.

Bit 1 **UART12RST**: UART12 reset
Set and reset by software.
0: does not reset the UART12 (default after reset)
1: resets the UART12

Bit 0 **UART9RST**: UART9 reset
Set and reset by software.
0: does not reset UART9 (default after reset)
1: resets UART9

11.8.24 RCC APB2 peripheral reset register (RCC_APB2RSTR)

Address offset: 0x07C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	GFXTIMRST	Res.	LTDCRST	Res.	Res.	Res.	Res.	SAI2RST	SAI1RST	SPI6RST	SPI4RST	TIM17RST	TIM16RST	TIM15RST
		rw		rw					rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	USART1RST	TIM8RST	SPI1RST	TIM1RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw	rw	rw	rw											

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **GFXTIMRST**: GFXTIM reset
Set and reset by software.
0: does not reset the GFXTIM (default after reset)
1: resets the GFXTIM

Bit 28 Reserved, must be kept at reset value.

Bit 27 **LTDCRST**: LTDC reset
Set and reset by software.
0: does not reset the LTDC (default after reset)
1: resets the LTDC

Bits 26:23 Reserved, must be kept at reset value.

Bit 22 **SAI2RST**: SAI2 reset
Set and reset by software.
0: does not reset the SAI2 (default after reset)
1: resets the SAI2

Bit 21 **SAI1RST**: SAI1 reset
Set and reset by software.
0: does not reset the SAI1 (default after reset)
1: resets the SAI1

Bit 20 **SPI6RST**: SPI6 reset
Set and reset by software.
0: does not reset the SPI6 (default after reset)
1: resets the SPI6

Bit 19 **SPI4RST**: SPI4 reset
Set and reset by software.
0: does not reset the SPI4 (default after reset)
1: resets the SPI4

Bit 18 **TIM17RST**: TIM17 reset
Set and reset by software.
0: does not reset the TIM17 (default after reset)
1: resets the TIM17

Bit 17 **TIM16RST**: TIM16 reset
Set and reset by software.
0: does not reset the TIM16 (default after reset)
1: resets the TIM16

Bit 16 **TIM15RST**: TIM15 reset
Set and reset by software.
0: does not reset the TIM15 (default after reset)
1: resets the TIM15

Bit 15 Reserved, must be kept at reset value.

Bit 14 **USART1RST**: USART1 reset
Set and reset by software.
0: does not reset the USART1 (default after reset)
1: resets the USART1

Bit 13 **TIM8RST**: TIM8 reset
Set and reset by software.
0: does not reset the TIM8 (default after reset)
1: resets the TIM8

Bit 12 **SPI1RST**: SPI1 reset
Set and reset by software.
0: does not reset the SPI1 (default after reset)
1: resets the SPI1

Bit 11 **TIM1RST**: TIM1 reset
Set and reset by software.
0: does not reset the TIM1 (default after reset)
1: resets the TIM1

Bits 10:0 Reserved, must be kept at reset value.

11.8.25 RCC APB3 peripheral reset register (RCC_APB3RSTR)

Address offset: 0x080

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLAY1RST	PLAY1POR	Res.	VREFRST	Res.	Res.	Res.	Res.
								rw	rw		rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LPTIM6RST	LPTIM5RST	LPTIM4RST	LPTIM3RST	LPTIM1RST	Res.	I3C2RST	I2C4RST	I2C3RST	LPUART1RST	SPI5RST	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw		rw	rw	rw	rw	rw					

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **PLAY1RST**: PLAY1 reset
Set and reset by software. This bit does not reset the user config registers and the matrix
0: does not reset the PLAY1 (default after reset)
1: resets the PLAY1

Bit 22 **PLAY1POR**: PLAY1 POR reset
Set and reset by software. This bit generates a global reset including the configuration registers and the matrix
0: does not reset the PLAY1 (default after reset)
1: resets the PLAY1

Bit 21 Reserved, must be kept at reset value.

Bit 20 **VREFRST**: VREFBUF reset
Set and reset by software.
0: does not reset the VREFBUF (default after reset)
1: resets the VREFBUF

Bits 19:16 Reserved, must be kept at reset value.

Bit 15 **LPTIM6RST**: LPTIM6 reset
Set and reset by software.
0: does not reset the LPTIM6 (default after reset)
1: resets the LPTIM6

Bit 14 **LPTIM5RST**: LPTIM5 reset
Set and reset by software.
0: does not reset the LPTIM5 (default after reset)
1: resets the LPTIM5

Bit 13 **LPTIM4RST**: LPTIM4 reset
Set and reset by software.
0: does not reset the LPTIM4 (default after reset)
1: resets the LPTIM4

Bit 12 **LPTIM3RST**: LPTIM3 reset
Set and reset by software.
0: does not reset the LPTIM3 (default after reset)
1: resets the LPTIM3

Bit 11 **LPTIM1RST**: LPTIM1 reset
Set and reset by software.
0: does not reset the LPTIM1 (default after reset)
1: resets the LPTIM1

Bit 10 Reserved, must be kept at reset value.

Bit 9 **I3C2RST**: I3C2 reset
Set and reset by software.
0: does not reset the I3C2 (default after reset)
1: resets the I3C2

Bit 8 **I2C4RST**: I2C4 reset
Set and reset by software.
0: does not reset the I2C4 (default after reset)
1: resets the I2C4

Bit 7 **I2C3RST**: I2C3 reset
Set and reset by software.
0: does not reset the I2C3 (default after reset)
1: resets the I2C3

Bit 6 **LPUART1RST**: LPUART1 reset
Set and reset by software.
0: does not reset the LPUART1 (default after reset)
1: resets the LPUART1

Bit 5 **SPI5RST**: SPI5 reset
Set and reset by software.
0: does not reset the SPI5 (default after reset)
1: resets the SPI5

Bits 4:0 Reserved, must be kept at reset value.

11.8.26 RCC AHB1 peripheral clock register (RCC_AHB1ENR)

Address offset: 0x088

Reset value: 0xD000 0100

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SRAM1EN	DCACHEEN	Res.	BKPRAMEN	Res.	Res.	Res.	TZSC1EN	JPEGEN	DMA2DEN	ETHRXEN	ETHTXEN	ETHEN	ETHCKEN	RAMCFGEN	MDF1EN
rw	rw		rw				rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FMACEN	CORDICEN	Res.	CRCEN	Res.	Res.	Res.	FLITFEN	Res.	Res.	Res.	Res.	Res.	Res.	GPDMA2EN	GPDMA1EN
rw	rw		rw				rw							rw	rw

Bit 31 **SRAM1EN**:SRAM1 clock enable
Set and reset by software.
0: SRAM1 clock disabled
1: SRAM1 clock enabled (default after reset)

Bit 30 **DCACHEEN**: DCACHE clock enable
Set and reset by software
0: DCACHE clock disabled
1: DCACHE clock enabled (default after reset)

Bit 29 Reserved, must be kept at reset value.

Bit 28 **BKPRAMEN**: BKPRAM clock enable
Set and reset by software.
0: BKPRAM clock disabled
1: BKPRAM clock enabled (default after reset)

Bits 27:25 Reserved, must be kept at reset value.

Bit 24 **TZSC1EN**: TZSC1 clock enable
Set and reset by software.
0: TZSC1 clock disabled (default after reset)
1: TZSC1 clock enabled

Bit 23 **JPEGEN**: JPEG clock enable
Set and reset by software.
0: JPEG clock disabled (default after reset)
1: JPEG clock enabled

Bit 22 **DMA2DEN**: DMA2D clock enable
Set and reset by software.
0: DMA2D clock disabled (default after reset)
1: DMA2D clock enabled

Bit 21 **ETHRXEN**: ETHRX clock enable
Set and reset by software.
0: ETHRX clock disabled (default after reset)
1: ETHRX clock enabled

Bit 20 **ETHTXEN**: ETHTX clock enable
Set and reset by software.
0: ETHTX clock disabled (default after reset)
1: ETHTX clock enabled

Bit 19 **ETHEN**: ETH clock enable
Set and reset by software.
0: ETH clock disabled (default after reset)
1: ETH clock enabled

Bit 18 **ETHCKEN**: ETH internal clock enable
Set and reset by software.
0: ETH internal clock disabled (default after reset)
1: ETH internal clock enabled

Bit 17 **RAMCFGEN**: RAMCFG clock enable
Set and reset by software.
0: RAMCFG clock disabled (default after reset)
1: RAMCFG clock enabled

Bit 16 **MDF1EN**: MDF1 clock enable
Set and reset by software.
0: MDF1 clock disabled (default after reset)
1: MDF1 clock enabled

Bit 15 **FMACEN**: FMAC clock enable
Set and reset by software.
0: FMAC clock disabled (default after reset)
1: FMAC clock enabled

Bit 14 **CORDICEN**: CORDIC clock enable
Set and reset by software.
0: CORDIC clock disabled (default after reset)
1: CORDIC clock enabled

Bit 13 Reserved, must be kept at reset value.

Bit 12 **CRCEN**: CRC clock enable
Set and reset by software.
0: CRC clock disabled (default after reset)
1: CRC clock enabled

Bits 11:9 Reserved, must be kept at reset value.

Bit 8 **FLITFEN**: Flash interface clock enable
Set and reset by software.
0: FLASH clock disabled
1: FLASH clock enabled (default after reset)

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **GPDMA2EN**: GPDMA2 clock enable
Set and reset by software.
0: GPDMA2 clock disabled (default after reset)
1: GPDMA2 clock enabled

Bit 0 **GPDMA1EN**: GPDMA1 clock enable
Set and reset by software.
0: GPDMA1 clock disabled (default after reset)
1: GPDMA1 clock enabled

11.8.27 RCC AHB2 peripheral clock register (RCC_AHB2ENR)

Address offset: 0x08C

Reset value: 0xF000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SRAM3EN	SRAM2EN	SRAM5EN	SRAM4EN	Res.	GPIOKEN	ADF1EN	ADC3EN	Res.	Res.	CCBEN	SAESEN	PKAEN	RNGEN	HASHEN	AESEN
rw	rw	rw	rw		rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OTGFSEN	OTGHSEN	OTGPHYEN	DCMI_PSSIEN	DAC1EN	ADCEN	GPIOJEN	GPIOIEN	GPIOHEN	GPIOGEN	GPIOFEN	GPIOEEN	GPIODEN	GPIOCEN	GPIOBEN	GPIOAEN
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **SRAM3EN**: SRAM3 clock enable
Set and reset by software.
0: SRAM3 clock disabled
1: SRAM3 clock enabled (default after reset)

Bit 30 **SRAM2EN**: SRAM2 clock enable
Set and reset by software.
0: SRAM2 clock disabled
1: SRAM2 clock enabled (default after reset)

Bit 29 **SRAM5EN**: SRAM5 clock enable
Set and reset by software.
0: SRAM5 clock disabled
1: SRAM5 clock enabled (default after reset)

Bit 28 **SRAM4EN**: SRAM4 clock enable
Set and reset by software.
0: SRAM4 clock disabled
1: SRAM4 clock enabled (default after reset)

Bit 27 Reserved, must be kept at reset value.

Bit 26 **GPIOKEN**: GPIOK clock enable
Set and reset by software.
0: GPIOK clock disabled (default after reset)
1: GPIOK clock enabled

Bit 25 **ADF1EN**: ADF1 clock enable
Set and reset by software.
0: ADF1 clock disabled
1: ADF1 clock enabled (default after reset)

Bit 24 **ADC3EN**: ADC3 clock enable
Set and reset by software.
0: ADC3 clock disabled (default after reset)
1: ADC3 clock enabled

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **CCBEN**: CCB clock enable
Set and reset by software.
0: CCB clock disabled (default after reset)
1: CCB clock enabled

Bit 20 **SAESEN**: SAES clock enable
Set and reset by software.
0: SAES clock disabled (default after reset)
1: SAES clock enabled

Bit 19 **PKAEN**: PKA clock enable
Set and reset by software.
0: PKA clock disabled (default after reset)
1: PKA clock enabled

Bit 18 **RNGEN**: RNG clock enable
Set and reset by software.
0: RNG clock disabled (default after reset)
1: RNG clock enabled

Bit 17 **HASHEN**: HASH clock enable
Set and reset by software.
0: HASH clock disabled (default after reset)
1: HASH clock enabled

Bit 16 **AESEN**: AES clock enable
Set and reset by software.
0: AES clock disabled (default after reset)
1: AES clock enabled

Bit 15 **OTGFSEN**: OTGFS clock enable
Set and reset by software.
0: OTGFS clock disabled (default after reset)
1: OTGFS clock enabled

Bit 14 **OTGHSEN**: OTGHS clock enable
Set and reset by software.
0: OTGHS clock disabled (default after reset)
1: OTGHS clock enabled

Bit 13 **OTGPHYEN**: OTGPHY clock enable
Set and reset by software.
0: OTGPHY clock disabled (default after reset)
1: OTGPHY clock enabled

Bit 12 **DCMI_PSSIEN**: digital camera interface clock enable (DCMI or PSSI, depending which interface is active)
Set and reset by software.
0: DCMI/PSSI clock disabled (default after reset)
1: DCMI/PSSI clock enabled

Bit 11 **DAC1EN**: DAC clock enable
Set and reset by software.
0: DAC clock disabled (default after reset)
1: DAC clock enabled

Bit 10 **ADCEN**: ADC1 and 2 peripherals clock enable
Set and reset by software.
0: ADC1 and 2 clock disabled (default after reset)
1: ADC1 and 2 clock enabled

Bit 9 **GPIOJEN**: GPIOJ clock enable
Set and reset by software.
0: GPIOJ clock disabled (default after reset)
1: GPIOJ clock enabled

Bit 8 **GPIOIEN**: GPIOI clock enable
Set and reset by software.
0: GPIOI clock disabled (default after reset)
1: GPIOI clock enabled

Bit 7 **GPIOHEN**: GPIOH clock enable
Set and reset by software.
0: GPIOH clock disabled (default after reset)
1: GPIOH clock enabled

Bit 6 **GPIOGEN**: GPIOG clock enable
Set and reset by software.
0: GPIOG clock disabled (default after reset)
1: GPIOG clock enabled

Bit 5 **GPIOFEN**: GPIOF clock enable
Set and reset by software.
0: GPIOF clock disabled (default after reset)
1: GPIOF clock enabled

Bit 4 **GPIOEEN**: GPIOE clock enable
Set and reset by software.
0: GPIOE clock disabled (default after reset)
1: GPIOE clock enabled

Bit 3 **GPIODEN**: GPIOD clock enable
Set and reset by software.
0: GPIOD clock disabled (default after reset)
1: GPIOD clock enabled

Bit 2 **GPIOCEN**: GPIOC clock enable
Set and reset by software.
0: GPIOC clock disabled (default after reset)
1: GPIOC clock enabled

Bit 1 **GPIOBEN**: GPIOB clock enable
Set and reset by software.
0: GPIOB clock disabled (default after reset)
1: GPIOB clock enabled

Bit 0 **GPIOAEN**: GPIOA clock enable
Set and reset by software.
0: GPIOA clock disabled (default after reset)
1: GPIOA clock enabled

11.8.28 RCC AHB4 peripheral clock register (RCC_AHB4ENR)

Address offset: 0x094

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCTOSPIMEN	OCTOSPI2EN	OCTOSPI1EN	Res.	Res.	Res.	FMCEN
									rw	rw	rw				rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	SDMMC2EN	SDMMC1EN	Res.	Res.	OTFDEC2EN	OTFDEC1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.
			rw	rw			rw	rw							

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **OCTOSPIMEN**: OCTOSPIM clock enable
Set and reset by software.
0: OCTOSPIM clock disabled (default after reset)
1: OCTOSPIM clock enabled

Bit 21 **OCTOSPI2EN**: OCTOSPI2 clock enable
Set and reset by software.
0: OCTOSPI2 clock disabled (default after reset)
1: OCTOSPI2 clock enabled

Bit 20 **OCTOSPI1EN**: OCTOSPI1 clock enable
Set and reset by software.
0: OCTOSPI1 clock disabled (default after reset)
1: OCTOSPI1 clock enabled

Bits 19:17 Reserved, must be kept at reset value.

Bit 16 **FMCEN**: FMC clock enable
Set and reset by software.
0: FMC clock disabled (default after reset)
1: FMC clock enabled

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **SDMMC2EN**: SDMMC2 and SDMMC2 delay peripheral clock enable
Set and reset by software.
0: SDMMC2 and SDMMC2 delay clock disabled (default after reset)
1: SDMMC2 and SDMMC2 delay clock enabled

Bit 11 **SDMMC1EN**: SDMMC1 and SDMMC1 delay peripheral clock enable reset
0: SDMMC1 and SDMMC1 delay clock disabled (default after reset)
1: SDMMC1 and SDMMC1 delay clock enabled

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **OTFDEC2EN**: OTFDEC2 clock enable
Set and reset by software.
0: OTFDEC2 clock disabled (default after reset)
1: OTFDEC2 clock enabled

Bit 7 **OTFDEC1EN**: OTFDEC1 clock enable
Set and reset by software.
0: OTFDEC1 clock disabled (default after reset)
1: OTFDEC1 clock enabled

Bits 6:0 Reserved, must be kept at reset value.

11.8.29 RCC APB1 peripheral clock register (RCC_APB1LENR)

Address offset: 0x09C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UART8EN	UART7EN	Res.	CECEN	USART11EN	USART10EN	USART6EN	CRSEN	I3C1EN	I2C2EN	I2C1EN	UART5EN	UART4EN	USART3EN	USART2EN	COMPEN
rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI3EN	SPI2EN	OPAMPEN	Res.	WWDGEN	Res.	Res.	TIM14EN	TIM13EN	TIM12EN	TIM7EN	TIM6EN	TIM5EN	TIM4EN	TIM3EN	TIM2EN
rw	rw	rw		rs			rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UART8EN**: UART8 clock enable
Set and reset by software.
0: UART8 clock disabled (default after reset)
1: UART8 clock enabled

Bit 30 **UART7EN**: UART7 clock enable
Set and reset by software.
0: UART7 clock disabled (default after reset)
1: UART7 clock enabled

Bit 29 Reserved, must be kept at reset value.

Bit 28 **CECEN**: HDMI-CEC clock enable
Set and reset by software.
0: HDMI-CEC clock disabled (default after reset)
1: HDMI-CEC clock enabled

Bit 27 **USART11EN**: USART11 clock enable
Set and reset by software.
0: USART11 clock disabled (default after reset)
1: USART11 clock enabled

Bit 26 **USART10EN**: USART10 clock enable
Set and reset by software.
0: USART10 clock disabled (default after reset)
1: USART10 clock enabled

Bit 25 **USART6EN**: USART6 clock enable
Set and reset by software.
0: USART6 clock disabled (default after reset)
1: USART6 clock enabled

Bit 24 **CRSEN**: CRS clock enable
Set and reset by software.
0: CRS clock disabled (default after reset)
1: CRS clock enabled

Bit 23 **I3C1EN**: I3C1 clock enable
Set and reset by software.
0: I3C1 clock disabled (default after reset)
1: I3C1 clock enabled

Bit 22 **I2C2EN**: I2C2 clock enable
Set and reset by software.
0: I2C2 clock disabled (default after reset)
1: I2C2 clock enabled

Bit 21 **I2C1EN**: I2C1 clock enable
Set and reset by software.
0: I2C1 clock disabled (default after reset)
1: I2C1 clock enabled

Bit 20 **UART5EN**: UART5 clock enable
Set and reset by software.
0: UART5 clock disabled (default after reset)
1: UART5 clock enabled

Bit 19 **UART4EN**: UART4 clock enable
Set and reset by software.
0: UART4 clock disabled (default after reset)
1: UART4 clock enabled

Bit 18 **USART3EN**: USART3 clock enable
Set and reset by software.
0: USART3 clock disabled (default after reset)
1: USART3 clock enabled

Bit 17 **USART2EN**: USART2 clock enable
Set and reset by software.
0: USART2 clock disabled (default after reset)
1: USART2 clock enabled

Bit 16 **COMPEN**: COMP clock enable
Set and reset by software.
0: COMP clock disabled (default after reset)
1: COMP clock enabled

Bit 15 **SPI3EN**: SPI3 clock enable
Set and reset by software.
0: SPI3 clock disabled (default after reset)
1: SPI3 clock enabled

Bit 14 **SPI2EN**: SPI2 clock enable
Set and reset by software.
0: SPI2 clock disabled (default after reset)
1: SPI2 clock enabled

Bit 13 **OPAMPEN**: OPAMP clock enable
Set and reset by software.
0: OPAMP clock disabled (default after reset)
1: OPAMP clock enabled

Bit 12 Reserved, must be kept at reset value.

Bit 11 **WWDGEN**: WWDG clock enable
Set by software and reset by hardware or after system reset.
0: WWDG clock disabled (default after reset)
1: WWDG clock enabled

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **TIM14EN**: TIM14 clock enable
Set and reset by software.
0: TIM14 clock disabled (default after reset)
1: TIM14 clock enabled

Bit 7 **TIM13EN**: TIM13 clock enable
Set and reset by software.
0: TIM13 clock disabled (default after reset)
1: TIM13 clock enabled

Bit 6 **TIM12EN**: TIM12 clock enable
Set and reset by software.
0: TIM12 clock disabled (default after reset)
1: TIM12 clock enabled

Bit 5 **TIM7EN**: TIM7 clock enable
Set and reset by software.
0: TIM7 clock disabled (default after reset)
1: TIM7 clock enabled

Bit 4 **TIM6EN**: TIM6 clock enable
Set and reset by software.
0: TIM6 clock disabled (default after reset)
1: TIM6 clock enabled

Bit 3 **TIM5EN**: TIM5 clock enable
Set and reset by software.
0: TIM5 clock disabled (default after reset)
1: TIM5 clock enabled

Bit 2 **TIM4EN**: TIM4 clock enable
Set and reset by software.
0: TIM4 clock disabled (default after reset)
1: TIM4 clock enabled

Bit 1 **TIM3EN**: TIM3 clock enable
Set and reset by software.
0: TIM3 clock disabled (default after reset)
1: TIM3 clock enabled

Bit 0 **TIM2EN**: TIM2 clock enable
Set and reset by software.
0: TIM2 clock disabled (default after reset)
1: TIM2 clock enabled

11.8.30 RCC APB1 peripheral clock register (RCC_APB1HENR)

Address offset: 0x0A0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UCPD1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.
								rw							

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	FDCANEN	Res.	Res.	Res.	LPTIM2EN	Res.	DTSEN	Res.	UART12EN	UART9EN
						rw				rw		rw		rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **UCPD1EN**: UCPD1 clock enable
Set and reset by software.
0: UCPD1 clock disabled (default after reset)
1: UCPD1 clock enabled

Bits 22:10 Reserved, must be kept at reset value.

Bit 9 **FDCANEN**: FDCAN1/2/3 clock enable
Set and reset by software.
0: FDCAN1/2/3 clock disabled (default after reset)
1: FDCAN1/2/3 clock enabled

Bits 8:6 Reserved, must be kept at reset value.

Bit 5 **LPTIM2EN**: LPTIM2 clock enable
Set and reset by software.
0: LPTIM2 disabled (default after reset)
1: LPTIM2 peripheral clock enabled

Bit 4 Reserved, must be kept at reset value.

Bit 3 **DTSEN**: DTS clock enable
Set and reset by software.
0: DTS clock disabled (default after reset)
1: DTS clock enabled

Bit 2 Reserved, must be kept at reset value.

Bit 1 **UART12EN**: UART12 clock enable
Set and reset by software.
0: UART12 clock disabled (default after reset)
1: UART12 clock enabled

Bit 0 **UART9EN**: UART9 clock enable
Set and reset by software.
0: UART9 clock disabled (default after reset)
1: UART9 clock enabled

11.8.31 RCC APB2 peripheral clock register (RCC_APB2ENR)

Address offset: 0x0A4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	GFXTIMEN	Res.	LTDCEN	Res.	Res.	Res.	Res.	SAI2EN	SAI1EN	SPI6EN	SPI4EN	TIM17EN	TIM16EN	TIM15EN
		rw		rw					rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	USART1EN	TIM8EN	SPI1EN	TIM1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw	rw	rw	rw											

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **GFXTIMEN:** GFXTIM clock enable
Set and reset by software.
0: GFXTIM clock disabled (default after reset)
1: GFXTIM clock enabled

Bit 28 Reserved, must be kept at reset value.

Bit 27 **LTDCEN**: LTDC clock enable
Set and cleared by software.
0: LTDC clock disabled
1: LTDC clock enabled

Bits 26:23 Reserved, must be kept at reset value.

Bit 22 **SAI2EN**: SAI2 clock enable
Set and cleared by software.
0: SAI2 clock disabled
1: SAI2 clock enabled

Bit 21 **SAI1EN**: SAI1 clock enable
Set and reset by software.
0: SAI1 clock disabled (default after reset)
1: SAI1 clock enabled

Bit 20 **SPI6EN**: SPI6 clock enable
Set and reset by software.
0: SPI6 clock disabled (default after reset)
1: SPI6 clock enabled

Bit 19 **SPI4EN**: SPI4 clock enable
Set and reset by software.
0: SPI4 clock disabled (default after reset)
1: SPI4 clock enabled

Bit 18 **TIM17EN**: TIM17 clock enable
Set and reset by software.
0: TIM17 clock disabled (default after reset)
1: TIM17 clock enabled

Bit 17 **TIM16EN**: TIM16 clock enable
Set and reset by software.
0: TIM16 clock disabled (default after reset)
1: TIM16 clock enabled

Bit 16 **TIM15EN**: TIM15 clock enable
Set and reset by software.
0: TIM15 clock disabled (default after reset)
1: TIM15 clock enabled

Bit 15 Reserved, must be kept at reset value.

Bit 14 **USART1EN**: USART1 clock enable
Set and reset by software.
0: USART1 clock disabled (default after reset)
1: USART1 clock enabled

Bit 13 **TIM8EN**: TIM8 clock enable
Set and reset by software.
0: TIM8 clock disabled (default after reset)
1: TIM8 clock enabled

Bit 12 **SPI1EN**: SPI1 clock enable
Set and reset by software.
0: SPI1 clock disabled (default after reset)
1: SPI1 clock enabled

Bit 11 **TIM1EN**: TIM1 clock enable
Set and reset by software.
0: TIM1 clock disabled (default after reset)
1: TIM1 clock enabled

Bits 10:0 Reserved, must be kept at reset value.

11.8.32 RCC APB3 peripheral clock register (RCC_APB3ENR)

Address offset: 0x0A8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLAY1EN	PLAY1APBEN	RTCAPBEN	VREFBUFEN	Res.	Res.	Res.	Res.
								rw	rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LPTIM6EN	LPTIM5EN	LPTIM4EN	LPTIM3EN	LPTIM1EN	Res.	I3C2EN	I2C4EN	I2C3EN	LPUART1EN	SPI5EN	Res.	Res.	Res.	SBSEN	Res.
rw	rw	rw	rw	rw		rw	rw	rw	rw	rw				rw	

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **PLAY1EN**: PLAY1 clock enable
Set and reset by software.
0: PLAY1 clock disabled (default after reset)
1: PLAY1 clock enabled

Bit 22 **PLAY1APBEN**: clock enable for PLAY1 configuration
Set and reset by software.
0: PLAY1 clock disabled (default after reset)
1: PLAY1 clock enabled

Bit 21 **RTCAPBEN**: RTC APB interface clock enable
Set and reset by software.
0: RTC APB interface clock disabled (default after reset)
1: RTC APB interface clock enabled

Bit 20 **VREFBUFEN**: VREFBUF clock enable
Set and reset by software.
0: VREFBUF clock disabled (default after reset)
1: VREFBUF clock enabled

Bits 19:16 Reserved, must be kept at reset value.

Bit 15 **LPTIM6EN**: LPTIM6 clock enable
Set and reset by software.
0: LPTIM6 clock disabled (default after reset)
1: LPTIM6 clock enabled

Bit 14 **LPTIM5EN**: LPTIM5 clock enable
Set and reset by software.
0: LPTIM5 clock disabled (default after reset)
1: LPTIM5 clock enabled

Bit 13 **LPTIM4EN**: LPTIM4 clock enable
Set and reset by software.
0: LPTIM4 clock disabled (default after reset)
1: LPTIM4 clock enabled

Bit 12 **LPTIM3EN**: LPTIM3 clock enable
Set and reset by software.
0: LPTIM3 clock disabled (default after reset)
1: LPTIM3 clock enabled

Bit 11 **LPTIM1EN**: LPTIM1 clock enable
Set and reset by software.
0: LPTIM1 clock disabled (default after reset)
1: LPTIM1 clock enabled

Bit 10 Reserved, must be kept at reset value.

Bit 9 **I3C2EN**: I3C2 clock enable
Set and reset by software.
0: I3C2 clock disabled (default after reset)
1: I3C2 clock enabled

Bit 8 **I2C4EN**: I2C4 clock enable
Set and reset by software.
0: I2C4 clock disabled (default after reset)
1: I2C4 clock enabled

Bit 7 **I2C3EN**: I2C3 clock enable
Set and reset by software.
0: I2C3 clock disabled (default after reset)
1: I2C3 clock enabled

Bit 6 **LPUART1EN**: LPUART1 clock enable
Set and reset by software.
0: LPUART1 clock disabled (default after reset)
1: LPUART1 clock enabled

Bit 5 **SPI5EN**: SPI5 clock enable
Set and reset by software.
0: SPI5 clock disabled (default after reset)
1: SPI5 clock enabled

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **SBSEN**: SBS clock enable
Set and reset by software.
0: SBS clock disabled (default after reset)
1: SBS clock enabled

Bit 0 Reserved, must be kept at reset value.

11.8.33 RCC AHB1 sleep clock register (RCC_AHB1LPENR)

Address offset: 0x0B0

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SRAM1LPEN	DCACHELPEN	ICACHELPEN	BKPRAMLPEN	Res.	Res.	Res.	TZSC1LPEN	JPEGLPEN	DMA2DLPEN	ETHRXLPEN	ETHTXLPEN	ETHLPEN	ETHCKLPEN	RAMCFGLPEN	MDF1LPEN
rw	rw	rw	rw				rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FMACLPEN	CORDICLPEN	Res.	CRCLPEN	Res.	Res.	Res.	FLITFLPEN	Res.	Res.	Res.	Res.	Res.	Res.	GPDMA2LPEN	GPDMA1LPEN
rw	rw		rw				rw							rw	rw

Bit 31 **SRAM1LPEN**: SRAM1 clock enable during Sleep mode
Set and reset by software
0: SRAM1 clock disabled during Sleep mode
1: SRAM1 clock enabled during Sleep mode (default after reset)

Bit 30 **DCACHELPEN**: DCACHE clock enable during Sleep mode
Set and reset by software
0: DCACHE clock disabled during Sleep mode
1: DCACHE clock enabled during Sleep mode (default after reset)

Bit 29 **ICACHELPEN**: ICACHE clock enable during Sleep mode
Set and reset by software.
0: ICACHE clock disabled during Sleep mode
1: ICACHE clock enabled during Sleep mode (default after reset)

Bit 28 **BKPRAMLPEN**: BKPRAM clock enable during Sleep mode
Set and reset by software.
0: BKPRAM clock disabled during Sleep mode
1: BKPRAM clock enabled during Sleep mode (default after reset)

Bits 27:25 Reserved, must be kept at reset value.

Bit 24 **TZSC1LPEN**: TZSC1 clock enable during Sleep mode
Set and reset by software.
0: TZSC1 clock disabled during Sleep mode
1: TZSC1 clock enabled during Sleep mode (default after reset)

Bit 23 **JPEGLPEN**: JPEG clock enable during Sleep mode
Set and reset by software.
0: JPEG clock disabled during Sleep mode
1: JPEG clock enabled during Sleep mode (default after reset)

Bit 22 **DMA2DLPEN**: DMA2D clock enable during Sleep mode
Set and reset by software.
0: DMA2D clock disabled during Sleep mode
1: DMA2D clock enabled during Sleep mode (default after reset)

Bit 21 **ETHRXLPEN**: ETHRX clock enable during Sleep mode
Set and reset by software.
0: ETHRX clock disabled during Sleep mode
1: ETHRX clock enabled during Sleep mode (default after reset)

Bit 20 **ETHTXLPEN**: ETHTX clock enable during Sleep mode
Set and reset by software.
0: ETHTX clock disabled during Sleep mode
1: ETHTX clock enabled during Sleep mode (default after reset)

Bit 19 **ETHLPEN**: ETH clock enable during Sleep mode
Set and reset by software.
0: ETH clock disabled during Sleep mode
1: ETH clock enabled during Sleep mode (default after reset)

Bit 18 **ETHCKLPEN**: ETH internal clock enable during Sleep mode
Set and reset by software.
0: ETH internal clock disabled during Sleep mode
1: ETH internal clock enabled during Sleep mode (default after reset)

Bit 17 **RAMCFGLPEN**: RAMCFG clock enable during Sleep mode
Set and reset by software.
0: RAMCFG clock disabled during Sleep mode
1: RAMCFG clock enabled during Sleep mode (default after reset)

Bit 16 **MDF1LPEN**: MDF1 clock enable during Sleep mode
Set and reset by software.
0: MDF1 clock disabled during Sleep mode
1: MDF1 clock enabled during Sleep mode (default after reset)

Bit 15 **FMACLPEN**: FMAC clock enable during Sleep mode
Set and reset by software.
0: FMAC clock disabled during Sleep mode
1: FMAC clock enabled during Sleep mode (default after reset)

Bit 14 **CORDICLPEN**: CORDIC clock enable during Sleep mode
Set and reset by software.
0: CORDIC clock disabled during Sleep mode
1: CORDIC clock enabled during Sleep mode (default after reset)

Bit 13 Reserved, must be kept at reset value.

Bit 12 **CRCLPEN**: CRC clock enable during Sleep mode
Set and reset by software.
0: CRC clock disabled during Sleep mode
1: CRC clock enabled during Sleep mode (default after reset)

Bits 11:9 Reserved, must be kept at reset value.

Bit 8 **FLITFLPEN**: Flash interface (FLITF) clock enable during Sleep mode
Set and reset by software.
0: FLITF clock disabled during Sleep mode
1: FLITF clock enabled during Sleep mode (default after reset)

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **GPDMA2LPEN**: GPDMA2 clock enable during Sleep mode
Set and reset by software.
0: GPDMA2 clock disabled during Sleep mode
1: GPDMA2 clock enabled during Sleep mode (default after reset)

Bit 0 **GPDMA1LPEN**: GPDMA1 clock enable during Sleep mode
Set and reset by software.
0: GPDMA1 clock disabled during Sleep mode
1: GPDMA1 clock enabled during Sleep mode (default after reset)

11.8.34 RCC AHB2 sleep clock register (RCC_AHB2LPENR)

Address offset: 0x0B4

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SRAM3 LPEN	SRAM2 LPEN	SRAM5 LPEN	SRAM4 LPEN	Res.	GPIOK LPEN	ADF1L PEN	ADC3L PEN	Res.	Res.	CCBLP EN	SAESL PEN	PKALP EN	RNGLP EN	HASHL PEN	AESLP EN
rw	rw	rw	rw		rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OTGFS LPEN	OTGH SLPEN	OTGP HYLPE N	DCMI_ PSSILP EN	DAC1L PEN	ADCLP EN	GPIOJ LPEN	GPIOIL PEN	GPIOH LPEN	GPIOG LPEN	GPIOF LPEN	GPIOE LPEN	GPIOD LPEN	GPIOC LPEN	GPIOB LPEN	GPIOA LPEN
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **SRAM3LPEN**: SRAM3 clock enable during Sleep mode
Set and reset by software.
0: SRAM3 clock disabled during Sleep mode
1: SRAM3 clock enabled during Sleep mode (default after reset)

Bit 30 **SRAM2LPEN**: SRAM2 clock enable during Sleep mode
Set and reset by software.
0: SRAM2 clock disabled during Sleep mode
1: SRAM2 clock enabled during Sleep mode (default after reset)

Bit 29 **SRAM5LPEN**: SRAM5 clock enable during Sleep mode
Set and reset by software.
0: SRAM5 clock disabled during Sleep mode
1: SRAM5 clock enabled during Sleep mode (default after reset)

Bit 28 **SRAM4LPEN**: SRAM4 clock enable during Sleep mode
Set and reset by software.
0: SRAM4 clock disabled during Sleep mode
1: SRAM4 clock enabled during Sleep mode (default after reset)

Bit 27 Reserved, must be kept at reset value.

Bit 26 **GPIOKLPEN**: GPIOK clock enable during Sleep mode
Set and reset by software.
0: GPIOK clock disabled during Sleep mode
1: GPIOK clock enabled during Sleep mode (default after reset)

Bit 25 **ADF1LPEN**: ADF1 clock enable during Sleep mode
Set and reset by software.
0: ADF1 clock disabled during Sleep mode
1: ADF1 clock enabled during Sleep mode (default after reset)

Bit 24 **ADC3LPEN**: ADC3 clock enable during Sleep mode
Set and reset by software.
0: ADC3 clock disabled during Sleep mode
1: ADC3 clock enabled during Sleep mode (default after reset)

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **CCBLPEN**: CCB clock enable during Sleep mode
Set and reset by software.
0: CCB clock disabled during Sleep mode
1: CCB clock enabled during Sleep mode (default after reset)

Bit 20 **SAESLPEN**: SAES clock enable during Sleep mode
Set and reset by software.
0: SAES clock disabled during Sleep mode
1: SAES clock enabled during Sleep mode (default after reset)

Bit 19 **PKALPEN**: PKA clock enable during Sleep mode
Set and reset by software.
0: PKA clock disabled during Sleep mode
1: PKA clock enabled during Sleep mode (default after reset)

Bit 18 **RNGLPEN**: RNG clock enable during Sleep mode
Set and reset by software.
0: RNG clock disabled during Sleep mode
1: RNG clock enabled during Sleep mode (default after reset)

Bit 17 **HASHLPEN**: HASH clock enable during Sleep mode
Set and reset by software.
0: HASH clock disabled during Sleep mode
1: HASH clock enabled during Sleep mode (default after reset)

Bit 16 **AESLPEN**: AES clock enable during Sleep mode
Set and reset by software.
0: AES clock disabled during Sleep mode
1: AES clock enabled during Sleep mode (default after reset)

Bit 15 **OTGFSLPEN**: OTGFS clock enable during Sleep mode
Set and reset by software.
0: OTGFS clock disabled during Sleep mode
1: OTGFS clock enabled during Sleep mode (default after reset)

Bit 14 **OTGHSLPEN**: OTGHS clock enable during Sleep mode
Set and reset by software.
0: OTGHS clock disabled during Sleep mode
1: OTGHS clock enabled during Sleep mode (default after reset)

Bit 13 **OTGPHYLPEN**: OTGPHY clock enable during Sleep mode
Set and reset by software.
0: OTGPHY clock disabled during Sleep mode
1: OTGPHY clock enabled during Sleep mode (default after reset)

Bit 12 **DCMI_PSSILPEN**: Digital camera interface clock enable during Sleep mode (DCMI or PSSI, depending which interface is active)
Set and reset by software.
0: DCMI/PSSI clock disabled during Sleep mode
1: DCMI/PSSI clock enabled during Sleep mode (default after reset)

Bit 11 **DAC1LPEN**: DAC clock enable during Sleep mode
Set and reset by software.
0: DAC clock disabled during Sleep mode
1: DAC clock enabled during Sleep mode (default after reset)

Bit 10 **ADCLPEN**: ADC1/2 clock enable during Sleep mode
Set and reset by software.
0: ADC1/2 clock disabled during Sleep mode
1: ADC1/2 clock enabled during Sleep mode (default after reset)

Bit 9 **GPIOJLPEN**: GPIOJ clock enable during Sleep mode
Set and reset by software.
0: GPIOJ clock disabled during Sleep mode
1: GPIOJ clock enabled during Sleep mode (default after reset)

Bit 8 **GPIOILPEN**: GPIOI clock enable during Sleep mode
Set and reset by software.
0: GPIOI clock disabled during Sleep mode
1: GPIOI clock enabled during Sleep mode (default after reset)

Bit 7 **GPIOHLPEN**: GPIOH clock enable during Sleep mode
Set and reset by software.
0: GPIOH clock disabled during Sleep mode
1: GPIOH clock enabled during Sleep mode (default after reset)

Bit 6 **GPIOGLPEN**: GPIOG clock enable during Sleep mode
Set and reset by software.
0: GPIOG clock disabled during Sleep mode
1: GPIOG clock enabled during Sleep mode (default after reset)

Bit 5 **GPIOFLPEN**: GPIOF clock enable during Sleep mode
Set and reset by software.
0: GPIOF clock disabled during Sleep mode
1: GPIOF clock enabled during Sleep mode (default after reset)

Bit 4 **GPIOELPEN**: GPIOE clock enable during Sleep mode
Set and reset by software.
0: GPIOE clock disabled during Sleep mode
1: GPIOE clock enabled during Sleep mode (default after reset)

Bit 3 **GPIODLPEN**: GPIOD clock enable during Sleep mode
Set and reset by software.
0: GPIOD clock disabled during Sleep mode
1: GPIOD clock enabled during Sleep mode (default after reset)

Bit 2 **GPIOCLPEN**: GPIOC clock enable during Sleep mode
Set and reset by software.
0: GPIOC clock disabled during Sleep mode
1: GPIOC clock enabled during Sleep mode (default after reset)

Bit 1 **GPIOBLPEN**: GPIOB clock enable during Sleep mode
Set and reset by software.
0: GPIOB clock disabled during Sleep mode
1: GPIOB clock enabled during Sleep mode (default after reset)

Bit 0 **GPIOALPEN**: GPIOA clock enable during Sleep mode
Set and reset by software.
0: GPIOA clock disabled during Sleep mode
1: GPIOA clock enabled during Sleep mode (default after reset)

11.8.35 RCC AHB4 sleep clock register (RCC_AHB4LPENR)

Address offset: 0x0BC

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCTOSPIMLPEN	OCTOSPI2LPEN	OCTOSPI1LPEN	Res.	Res.	Res.	FMCLPEN
									rw	rw	rw				rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	SDMMC2LPEN	SDMMC1LPEN	Res.	Res.	OTFDEC2LPEN	OTFDEC1LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.
			rw	rw			rw	rw							

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **OCTOSPIMLPEN**: OCTOSPIM clock enable during Sleep mode
Set and reset by software.
0: OCTOSPIM clock disabled during Sleep mode
1: OCTOSPIM clock enabled during Sleep mode (default after reset)

Bit 21 **OCTOSPI2LPEN**: OCTOSPI2 clock enable during Sleep mode
Set and reset by software.
0: OCTOSPI2 clock disabled during Sleep mode
1: OCTOSPI2 clock enabled during Sleep mode (default after reset)

Bit 20 **OCTOSPI1LPEN**: OCTOSPI1 clock enable during Sleep mode
Set and reset by software.
0: OCTOSPI1 clock disabled during Sleep mode
1: OCTOSPI1 clock enabled during Sleep mode (default after reset)

Bits 19:17 Reserved, must be kept at reset value.

Bit 16 **FMCLPEN**: FMC clock enable during Sleep mode
Set and reset by software.
0: FMC clock disabled during Sleep mode
1: FMC clock enabled during Sleep mode (default after reset)

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **SDMMC2LPEN**: SDMMC2 and SDMMC2 delay clock enable during Sleep mode
Set and reset by software.
0: SDMMC2 and SDMMC2 delay clock disabled during Sleep mode
1: SDMMC2 and SDMMC2 delay clock enabled during Sleep mode (default after reset)

Bit 11 **SDMMC1LPEN**: SDMMC1 and SDMMC1 delay clock enable during Sleep mode
Set and reset by software
0: SDMMC1 and SDMMC1 delay clock disabled during Sleep mode
1: SDMMC1 and SDMMC1 delay clock enabled during Sleep mode (default after reset)

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **OTFDEC2LPEN**: OTFDEC2 clock enable during Sleep mode
Set and reset by software.
0: OTFDEC2 clock disabled during Sleep mode
1: OTFDEC2 clock enabled during Sleep mode (default after reset)

Bit 7 **OTFDEC1LPEN**: OTFDEC1 clock enable during Sleep mode
Set and reset by software.
0: OTFDEC1 clock disabled during Sleep mode
1: OTFDEC1 clock enabled during Sleep mode (default after reset)

Bits 6:0 Reserved, must be kept at reset value.

11.8.36 RCC APB1 sleep clock register (RCC_APB1LLPENR)

Address offset: 0x0C4

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UART8 LPEN	UART7 LPEN	Res.	CECLP EN	USART 11LPE N	USART 10LPE N	USART 6LPEN	CRSLP EN	I3C1LP EN	I2C2LP EN	I2C1LP EN	UART5 LPEN	UART4 LPEN	USART 3LPEN	USART 2LPEN	COMP LPEN
rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI3LP EN	SPI2LP EN	OPAMP LPEN	Res.	WWDG LPEN	Res.	Res.	TIM14L PEN	TIM13L PEN	TIM12L PEN	TIM7LP EN	TIM6LP EN	TIM5LP EN	TIM4LP EN	TIM3LP EN	TIM2LP EN
rw	rw	rw		rw			rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UART8LPEN**: UART8 clock enable during Sleep mode
Set and reset by software.
0: UART8 clock disabled during Sleep mode
1: UART8 clock enabled during Sleep mode (default after reset)

Bit 30 **UART7LPEN**: UART7 clock enable during Sleep mode
Set and reset by software.
0: UART7 clock disabled during Sleep mode
1: UART7 clock enabled during Sleep mode (default after reset)

Bit 29 Reserved, must be kept at reset value.

Bit 28 **CECLPEN**: HDMI-CEC clock enable during Sleep mode
Set and reset by software.
0: HDMI-CEC clock disabled during Sleep mode
1: HDMI-CEC clock enabled during Sleep mode (default after reset)

Bit 27 **USART11LPEN**: USART11 clock enable during Sleep mode
Set and reset by software.
0: USART11 clock disabled during Sleep mode
1: USART11 clock enabled during Sleep mode (default after reset)

Bit 26 **USART10LPEN**: USART10 clock enable during Sleep mode
Set and reset by software.
0: USART10 clock disabled during Sleep mode
1: USART10 clock enabled during Sleep mode (default after reset)

Bit 25 **USART6LPEN**: USART6 clock enable during Sleep mode
Set and reset by software.
0: USART6 clock disabled during Sleep mode
1: USART6 clock enabled during Sleep mode (default after reset)

Bit 24 **CRSLPEN**: CRS clock enable during Sleep mode
Set and reset by software.
0: CRS clock disabled during Sleep mode
1: CRS clock enabled during Sleep mode (default after reset)

Bit 23 **I3C1LPEN**: I3C1 clock enable during Sleep mode
Set and reset by software.
0: I3C1 clock disabled during Sleep mode
1: I3C1 clock enabled during Sleep mode (default after reset)

Bit 22 **I2C2LPEN**: I2C2 clock enable during Sleep mode
Set and reset by software.
0: I2C2 clock disabled during Sleep mode
1: I2C2 clock enabled during Sleep mode (default after reset)

Bit 21 **I2C1LPEN**: I2C1 clock enable during Sleep mode
Set and reset by software.
0: I2C1 clock disabled during Sleep mode
1: I2C1 clock enabled during Sleep mode (default after reset)

Bit 20 **UART5LPEN**: UART5 clock enable during Sleep mode
Set and reset by software.
0: UART5 clock disabled during Sleep mode
1: UART5 clock enabled during Sleep mode (default after reset)

Bit 19 **UART4LPEN**: UART4 clock enable during Sleep mode
Set and reset by software.
0: UART4 clock disabled during Sleep mode
1: UART4 clock enabled during Sleep mode (default after reset)

Bit 18 **USART3LPEN**: USART3 clock enable during Sleep mode
Set and reset by software.
0: USART3 clock disabled during Sleep mode
1: USART3 clock enabled during Sleep mode (default after reset)

Bit 17 **USART2LPEN**: USART2 clock enable during Sleep mode
Set and reset by software.
0: USART2 clock disabled during Sleep mode
1: USART2 clock enabled during Sleep mode (default after reset)

Bit 16 **COMPLPEN**: COMP clock enable during Sleep mode
Set and reset by software.
0: COMP clock disabled during Sleep mode
1: COMP clock enabled during Sleep mode (default after reset)

Bit 15 **SPI3LPEN**: SPI3 clock enable during Sleep mode
Set and reset by software.
0: SPI3 clock disabled during Sleep mode
1: SPI3 clock enabled during Sleep mode (default after reset)

Bit 14 **SPI2LPEN**: SPI2 clock enable during Sleep mode
Set and reset by software.
0: SPI2 clock disabled during Sleep mode
1: SPI2 clock enabled during Sleep mode (default after reset)

Bit 13 **OPAMPLPEN**: OPAMP clock enable during Sleep mode
Set and reset by software.
0: OPAMP clock disabled during Sleep mode
1: OPAMP clock enabled during Sleep mode (default after reset)

Bit 12 Reserved, must be kept at reset value.

Bit 11 **WWDGLPEN**: WWDG clock enable during Sleep mode
Set and reset by software.This bit can also be set by hardware with WWDG_SW option bit.
0: WWDG clock disabled during Sleep mode
1: WWDG clock enabled during Sleep mode (default after reset)

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **TIM14LPEN**: TIM14 clock enable during Sleep mode
Set and reset by software.
0: TIM14 clock disabled during Sleep mode
1: TIM14 clock enabled during Sleep mode (default after reset)

Bit 7 **TIM13LPEN**: TIM13 clock enable during Sleep mode
Set and reset by software.
0: TIM13 clock disabled during Sleep mode
1: TIM13 clock enabled during Sleep mode (default after reset)

Bit 6 **TIM12LPEN**: TIM12 clock enable during Sleep mode
Set and reset by software.
0: TIM12 clock disabled during Sleep mode
1: TIM12 clock enabled during Sleep mode (default after reset)

Bit 5 **TIM7LPEN**: TIM7 clock enable during Sleep mode
Set and reset by software.
0: TIM7 clock disabled during Sleep mode
1: TIM7 clock enabled during Sleep mode (default after reset)

Bit 4 **TIM6LPEN**: TIM6 clock enable during Sleep mode
Set and reset by software.
0: TIM6 clock disabled during Sleep mode
1: TIM6 clock enabled during Sleep mode (default after reset)

Bit 3 **TIM5LPEN**: TIM5 clock enable during Sleep mode
Set and reset by software.
0: TIM5 clock disabled during Sleep mode
1: TIM5 clock enabled during Sleep mode (default after reset)

Bit 2 **TIM4LPEN**: TIM4 clock enable during Sleep mode
Set and reset by software.
0: TIM4 clock disabled during Sleep mode
1: TIM4 clock enabled during Sleep mode (default after reset)

Bit 1 **TIM3LPEN**: TIM3 clock enable during Sleep mode
Set and reset by software.
0: TIM3 clock disabled during Sleep mode
1: TIM3 clock enabled during Sleep mode (default after reset)

Bit 0 **TIM2LPEN**: TIM2 clock enable during Sleep mode
Set and reset by software.
0: TIM2 clock disabled during Sleep mode
1: TIM2 clock enabled during Sleep mode (default after reset)

11.8.37 RCC APB1 sleep clock register (RCC_APB1HLPENR)

Address offset: 0x0C8

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UCPD1 LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.
								rw							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	FDCAN LPEN	Res.	Res.	Res.	LPTIM2 LPEN	Res.	DTSLP EN	Res.	UART1 2LPEN	UART9 LPEN
						rw				rw		rw		rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **UCPD1LPEN**: UCPD1 clock enable during Sleep mode
Set and reset by software.
0: UCPD1 clock disabled during Sleep mode
1: UCPD1 clock enabled during Sleep mode (default after reset)

Bits 22:10 Reserved, must be kept at reset value.

Bit 9 **FDCANLPEN**: FDCAN1/2/3 clock enable during Sleep mode
Set and reset by software.
0: FDCAN1/2/3 clock disabled during Sleep mode
1: FDCAN1/2/3 clock enabled during Sleep mode (default after reset)

Bits 8:6 Reserved, must be kept at reset value.

Bit 5 **LPTIM2LPEN**: LPTIM2 clock enable during Sleep mode
Set and reset by software.
0: LPTIM2 clock disabled during Sleep mode
1: LPTIM2 clock enabled during Sleep mode (default after reset)

Bit 4 Reserved, must be kept at reset value.

Bit 3 **DTSLPEN**: DTS clock enable during Sleep mode
Set and reset by software.
0: DTS clock disabled during Sleep mode
1: DTS clock enabled during Sleep mode (default after reset)

Bit 2 Reserved, must be kept at reset value.

Bit 1 **UART12LPEN**: UART12 clock enable during Sleep mode
Set and reset by software.
0: UART12 clock disabled during Sleep mode
1: UART12 clock enabled during Sleep mode (default after reset)

Bit 0 **UART9LPEN**: UART9 clock enable during Sleep mode
Set and reset by software.
0: UART9 clock disabled during Sleep mode
1: UART9 clock enabled during Sleep mode (default after reset)

11.8.38 RCC APB2 sleep clock register (RCC_APB2LPENR)

Address offset: 0x0CC

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	GFXTIMLPEN	Res.	LTDCLPEN	Res.	Res.	Res.	Res.	SAI2LPEN	SAI1LPEN	SPI6LPEN	SPI4LPEN	TIM17LPEN	TIM16LPEN	TIM15LPEN
		rw		rw					rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	USART1LPEN	TIM8LPEN	SPI1LPEN	TIM1LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw	rw	rw	rw											

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **GFXTIMLPEN**: GFXTIM clock enable during Sleep mode
Set and reset by software.
0: GFXTIM clock disabled during Sleep mode
1: GFXTIM clock enabled during Sleep mode (default after reset)

Bit 28 Reserved, must be kept at reset value.

Bit 27 **LTDCLPEN**: LTDC clock enable during Sleep mode
Set and reset by software.
0: LTDC clock disabled during Sleep mode
1: LTDC clock enabled during Sleep mode (default after reset)

Bits 26:23 Reserved, must be kept at reset value.

Bit 22 **SAI2LPEN**: SAI2 clock enable during Sleep mode
Set and reset by software.
0: SAI2 clock disabled during Sleep mode
1: SAI2 clock enabled during Sleep mode (default after reset)

Bit 21 **SAI1LPEN**: SAI1 clock enable during Sleep mode
Set and reset by software.
0: SAI1 clock disabled during Sleep mode
1: SAI1 clock enabled during Sleep mode (default after reset)

Bit 20 **SPI6LPEN**: SPI6 clock enable during Sleep mode
Set and reset by software.
0: SPI6 clock disabled during Sleep mode
1: SPI6 clock enabled during Sleep mode (default after reset)

Bit 19 **SPI4LPEN**: SPI4 clock enable during Sleep mode
Set and reset by software.
0: SPI4 clock disabled during Sleep mode
1: SPI4 clock enabled during Sleep mode (default after reset)

Bit 18 **TIM17LPEN**: TIM17 clock enable during Sleep mode
Set and reset by software.
0: TIM17 clock disabled during Sleep mode
1: TIM17 clock enabled during Sleep mode (default after reset)

Bit 17 **TIM16LPEN**: TIM16 clock enable during Sleep mode
Set and reset by software.
0: TIM16 clock disabled during Sleep mode
1: TIM16 clock enabled during Sleep mode (default after reset)

Bit 16 **TIM15LPEN**: TIM15 clock enable during Sleep mode
Set and reset by software.
0: TIM15 clock disabled during Sleep mode
1: TIM15 clock enabled during Sleep mode (default after reset)

Bit 15 Reserved, must be kept at reset value.

Bit 14 **USART1LPEN**: USART1 clock enable during Sleep mode
Set and reset by software.
0: USART1 clock disabled during Sleep mode
1: USART1 clock enabled during Sleep mode (default after reset)

Bit 13 **TIM8LPEN**: TIM8 clock enable during Sleep mode
Set and reset by software.
0: TIM8 clock disabled during Sleep mode
1: TIM8 clock enabled during Sleep mode (default after reset)

Bit 12 **SPI1LPEN**: SPI1 clock enable during Sleep mode
Set and reset by software.
0: SPI1 clock disabled during Sleep mode
1: SPI1 clock enabled during Sleep mode (default after reset)

Bit 11 **TIM1LPEN**: TIM1 clock enable during Sleep mode
Set and reset by software.
0: TIM1 clock disabled during Sleep mode
1: TIM1 clock enabled during Sleep mode (default after reset)

Bits 10:0 Reserved, must be kept at reset value.

11.8.39 RCC APB3 sleep clock register (RCC_APB3LPENR)

Address offset: 0x0D0

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLAY1LPEN	Res.	RTCAPBLPEN	VREFLPEN	Res.	Res.	Res.	Res.
								rw		rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LPTIM6LPEN	LPTIM5LPEN	LPTIM4LPEN	LPTIM3LPEN	LPTIM1LPEN	Res.	I3C2LPEN	I2C4LPEN	I2C3LPEN	LPUART1LPEN	SPI5LPEN	Res.	Res.	Res.	SBSLPEN	Res.
rw	rw	rw	rw	rw		rw	rw	rw	rw	rw				rw	

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **PLAY1LPEN**: PLAY1 clock enable during Sleep mode
Set and reset by software.
0: PLAY1 clock disabled during Sleep mode
1: PLAY1 clock enabled during Sleep mode (default after reset)

Bit 22 Reserved, must be kept at reset value.

Bit 21 **RTCAPBLPEN**: RTC APB interface clock enable during Sleep mode
Set and reset by software.
0: RTC APB interface clock disabled during Sleep mode
1: RTC APB interface clock enabled during Sleep mode (default after reset)

Bit 20 **VREFLPEN**: VREFBUF clock enable during Sleep mode
Set and reset by software.
0: VREFBUF clock disabled during Sleep mode
1: VREFBUF clock enabled during Sleep mode (default after reset)

Bits 19:16 Reserved, must be kept at reset value.

Bit 15 **LPTIM6LPEN**: LPTIM6 clock enable during Sleep mode
Set and reset by software.
0: LPTIM6 clock disabled during Sleep mode
1: LPTIM6 clock enabled during Sleep mode (default after reset)

Bit 14 **LPTIM5LPEN**: LPTIM5 clock enable during Sleep mode
Set and reset by software.
0: LPTIM5 clock disabled during Sleep mode
1: LPTIM5 clock enabled during Sleep mode (default after reset)

Bit 13 **LPTIM4LPEN**: LPTIM4 clock enable during Sleep mode
Set and reset by software.
0: LPTIM4 clock disabled during Sleep mode
1: LPTIM4 clock enabled during Sleep mode (default after reset)

Bit 12 **LPTIM3LPEN**: LPTIM3 clock enable during Sleep mode
Set and reset by software.
0: LPTIM3 clock disabled during Sleep mode
1: LPTIM3 clock enabled during Sleep mode (default after reset)

Bit 11 **LPTIM1LPEN**: LPTIM1 clock enable during Sleep mode
Set and reset by software.
0: LPTIM1 clock disabled during Sleep mode
1: LPTIM1 clock enabled during Sleep mode (default after reset)

Bit 10 Reserved, must be kept at reset value.

Bit 9 **I3C2LPEN**: I3C2 clock enable during Sleep mode
Set and reset by software.
0: I3C2 clock disabled during Sleep mode
1: I3C2 clock enabled during Sleep mode (default after reset)

Bit 8 **I2C4LPEN**: I2C4 clock enable during Sleep mode
Set and reset by software.
0: I2C4 clock disabled during Sleep mode
1: I2C4 clock enabled during Sleep mode (default after reset)

Bit 7 **I2C3LPEN**: I2C3 clock enable during Sleep mode
Set and reset by software.
0: I2C3 clock disabled during Sleep mode
1: I2C3 clock enabled during Sleep mode (default after reset)

Bit 6 **LPUART1LPEN**: LPUART1 clock enable during Sleep mode
Set and reset by software.
0: LPUART1 clock disabled during Sleep mode
1: LPUART1 clock enabled during Sleep mode (default after reset)

Bit 5 **SPI5LPEN**: SPI5 clock enable during Sleep mode
Set and reset by software.
0: SPI5 clock disabled during Sleep mode
1: SPI5 clock enabled during Sleep mode (default after reset)

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **SBSLPEN**: SBS clock enable during Sleep mode
Set and reset by software.
0: SBS clock disabled during Sleep mode
1: SBS clock enabled during Sleep mode (default after reset)

Bit 0 Reserved, must be kept at reset value.

11.8.40 RCC kernel clock configuration register (RCC_CCIPR1)

Address offset: 0x0D8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TIMICSEL	Res.	USART10SEL[2:0]			UART9SEL[2:0]			UART8SEL[2:0]			UART7SEL[2:0]			USART6SEL[2:1]	
rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USART6SEL[0]	UART5SEL[2:0]			UART4SEL[2:0]			USART3SEL[2:0]			USART2SEL[2:0]			USART1SEL[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **TIMICSEL**: TIM12, TIM15, and LPTIM2 input capture source selection
Set and reset by software.
0: No internal clock available for timers input capture (default after reset)
1: hsi_ker_ck/1024, hsi_ker_ck/8, and csi_ker_ck/128 selected for timers input capture

Bit 30 Reserved, must be kept at reset value.

Bits 29:27 **USART10SEL[2:0]**: USART10 kernel clock source selection
000: rcc_pclk1 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 26:24 **UART9SEL[2:0]**: UART9 kernel clock source selection
000: rcc_pclk1 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 23:21 **UART8SEL[2:0]**: UART8 kernel clock source selection
000: rcc_pclk1 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 20:18 **UART7SEL[2:0]**: UART7 kernel clock source selection
000: rcc_pclk1 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 17:15 **USART6SEL[2:0]**: USART6 kernel clock source selection
000: rcc_pclk1 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 14:12 **UART5SEL[2:0]**: UART5 kernel clock source selection
000: rcc_pclk1 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 11:9 **UART4SEL[2:0]**: UART4 kernel clock source selection
000: rcc_pclk1 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 8:6 **USART3SEL[2:0]**: USART3 kernel clock source selection
Set and reset by software.
000: rcc_pclk1 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 5:3 **USART2SEL[2:0]**: USART2 kernel clock source selection
Set and reset by software.
000: rcc_pclk1 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 2:0 **USART1SEL[2:0]**: USART1 kernel clock source selection
Set and reset by software.
000: rcc_pclk2 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

11.8.41 RCC kernel clock configuration register (RCC_CCIPR2)

Address offset: 0x0DC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	LPTIM6SEL[2:0]			Res.	LPTIM5SEL[2:0]			Res.	LPTIM4SEL[2:0]			Res.	LPTIM3SEL[2:0]		
	rw	rw	rw		rw	rw	rw		rw	rw	rw		rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	LPTIM2SEL[2:0]			Res.	LPTIM1SEL[2:0]			Res.	UART12SEL[2:0]			Res.	USART11SEL[2:0]		
	rw	rw	rw		rw	rw	rw		rw	rw	rw		rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:28 **LPTIM6SEL[2:0]**: LPTIM6 kernel clock source selection
000: rcc_pclk3 selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_r_ck selected as kernel clock
011: lse_ker_ck selected as kernel clock
100: lsi_ker_ck selected as kernel clock
101: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bit 27 Reserved, must be kept at reset value.

Bits 26:24 **LPTIM5SEL[2:0]**: LPTIM5 kernel clock source selection
000: rcc_pclk3 selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_r_ck selected as kernel clock
011: lse_ker_ck selected as kernel clock
100: lsi_ker_ck selected as kernel clock
101: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bit 23 Reserved, must be kept at reset value.

Bits 22:20 **LPTIM4SEL[2:0]**: LPTIM4 kernel clock source selection
000: rcc_pclk3 selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_r_ck selected as kernel clock
011: lse_ker_ck selected as kernel clock
100: lsi_ker_ck selected as kernel clock
101: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **LPTIM3SEL[2:0]**: LPTIM3 kernel clock source selection
000: rcc_pclk3 selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_r_ck selected as kernel clock
011: lse_ker_ck selected as kernel clock
100: lsi_ker_ck selected as kernel clock
101: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **LPTIM2SEL[2:0]**: LPTIM2 kernel clock source selection
000: rcc_pclk1 selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_r_ck selected as kernel clock
011: lse_ker_ck selected as kernel clock
100: lsi_ker_ck selected as kernel clock
101: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bit 11 Reserved, must be kept at reset value.

Bits 10:8 **LPTIM1SEL[2:0]**: LPTIM1 kernel clock source selection
000: rcc_pclk3 selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_r_ck selected as kernel clock
011: lse_ker_ck selected as kernel clock
100: lsi_ker_ck selected as kernel clock
101: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **UART12SEL[2:0]**: UART12 kernel clock source selection
Set and reset by software.
000: rcc_pclk1 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **USART11SEL[2:0]**: USART11 kernel clock source selection
Set and reset by software.
000: rcc_pclk1 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

11.8.42 RCC kernel clock configuration register (RCC_CCIPR3)

Address offset: 0x0E0
Reset value: 0x0010 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PLAY1 SEL[2:0]			Res.	Res.	LPUART1 SEL[2:0]			PLAY1 DIV[3:0]				Res.	Res.	SPI6 SEL[2:1]	
rw	rw	rw			rw	rw	rw	rw	rw	rw	rw			rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI6 SEL[0]	SPI5 SEL[2:0]			SPI4 SEL[2:0]			SPI3 SEL[2:0]			SPI2 SEL[2:0]			SPI1 SEL[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 **PLAY1SEL[2:0]**: PLAY1 kernel clock source selection
000: rcc_pclk3 selected as kernel clock
001: pll2_p_ck selected as kernel clock
010: pll3_r_ck selected as kernel clock
011: lse_ker_ck selected as kernel clock
100: lsi_ker_ck selected as kernel clock
101: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 28:27 Reserved, must be kept at reset value.

Bits 26:24 **LPUART1SEL[2:0]**: LPUART1 kernel clock source selection
000: rcc_pclk3 s elected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: lse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 23:20 **PLAY1DIV[3:0]**: PLAY1 kernel clock division ratio
2^N divider with N = 0 to N = 15
0000: N=0, PLAY1DIV_1
0001: N=1, PLAY1DIV_2
0010: N=2, PLAY1DIV_4
0011: N=3, PLAY1DIV_8
...
1111: N=15, PLAY1DIV_32768

Bits 19:18 Reserved, must be kept at reset value.

Bits 17:15 **SPI6SEL[2:0]**: SPI6 kernel clock source selection
000: rcc_pclk2 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: hse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 14:12 **SPI5SEL[2:0]**: SPI5 kernel clock source selection
000: rcc_pclk3 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: hse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 11:9 **SPI4SEL[2:0]**: SPI4 kernel clock source selection
000: rcc_pclk2 selected as kernel clock (default after reset)
001: pll2_q_ck selected as kernel clock
010: pll3_q_ck selected as kernel clock
011: hsi_ker_ck selected as kernel clock
100: csi_ker_ck selected as kernel clock
101: hse_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 8:6 **SPI3SEL[2:0]**: SPI3 kernel clock source selection
Set and reset by software.
000: pll1_q_ck selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_p_ck selected as kernel clock
011: AUDIOCLK selected as kernel clock
100: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 5:3 **SPI2SEL[2:0]**: SPI2 kernel clock source selection
Set and reset by software.
000: pll1_q_ck selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_p_ck selected as kernel clock
011: AUDIOCLK selected as kernel clock
100: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 2:0 **SPI1SEL[2:0]**: SPI1 kernel clock source selection
Set and reset by software.
000: pll1_q_ck selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_p_ck selected as kernel clock
011: AUDIOCLK selected as kernel clock
100: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

11.8.43 RCC kernel clock configuration register (RCC_CCIPR4)

Address offset: 0x0E4

Reset value: 0xA000 A000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ETHPTPDIV[3:0]				I3C2SEL[1:0]		I3C1SEL[1:0]		I2C4SEL[1:0]		I2C3SEL[1:0]		I2C2SEL[1:0]		I2C1SEL[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OTGPHYREFCKSEL[3:0]				OTGHSSEL[1:0]		OTGP DCTRL	ETHCL KSEL	SDMM C2SEL	SDMM C1SEL	OTGFSSEL[1:0]		SYSTICKSEL [1:0]		OCTOSPI1SEL [1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 **ETHPTPDIV[3:0]**: Ethernet PTP clock division
This fields selects the division factor of the PTP clock.
0000: divided by 1 (default after reset)
0001: divided by 2
...
1110: divided by 15
1111: divided by 16

Bits 27:26 **I3C2SEL[1:0]**: I3C2 kernel clock source selection
00: rcc_pclk3 selected as kernel clock (default after reset)
01: pll3_r_ck selected as kernel clock
10: hsi_ker_ck selected as kernel clock
11: csi_ker_ck selected as kernel clock

Bits 25:24 **I3C1SEL[1:0]**: I3C1 kernel clock source selection
00: rcc_pclk1 selected as kernel clock (default after reset)
01: pll3_r_ck selected as kernel clock
10: hsi_ker_ck selected as kernel clock
11: csi_ker_ck selected as kernel clock

Bits 23:22 **I2C4SEL[1:0]**: I2C4 kernel clock source selection
00: rcc_pclk3 selected as kernel clock (default after reset)
01: pll3_r_ck selected as kernel clock
10: hsi_ker_ck selected as kernel clock
11: csi_ker_ck selected as kernel clock

Bits 21:20 **I2C3SEL[1:0]**: I2C3 kernel clock source selection
00: rcc_pclk3 selected as kernel clock (default after reset)
01: pll3_r_ck selected as kernel clock
10: hsi_ker_ck selected as kernel clock
11: csi_ker_ck selected as kernel clock

Bits 19:18 **I2C2SEL[1:0]**: I2C2 kernel clock source selection
00: rcc_pclk1 selected as kernel clock (default after reset)
01: pll3_r_ck selected as kernel clock
10: hsi_ker_ck selected as kernel clock
11: csi_ker_ck selected as kernel clock

Bits 17:16 **I2C1SEL[1:0]**: I2C1 kernel clock source selection
00: rcc_pclk1 selected as kernel clock (default after reset)
01: pll3_r_ck selected as kernel clock
10: hsi_ker_ck selected as kernel clock
11: csi_ker_ck selected as kernel clock

Bits 15:12 **OTGPHYREFCKSEL[3:0]**: OTG_HS PHY kernel clock frequency selection
Set and reset by software.
This field is used to indicate to the OTG_HS PHY the frequency of the reference kernel clock provided to it.
0011: The kernel clock frequency is 16 MHz
1000: The kernel clock frequency is 19.2 MHz
1001: The kernel clock frequency is 20 MHz
1010: The kernel clock frequency is 24 MHz (default after reset)
1110: The kernel clock frequency is 26 MHz
1011: The kernel clock frequency is 32 MHz
Others: reserved

Bits 11:10 **OTGHSSEL[1:0]**: OTG_HS PHY kernel clock source selection
00: hse_ck selected as kernel clock (default after reset)
01: pll3_q_ck selected as kernel clock
10: hse_ck / 2 selected as kernel clock
11: pll1_q_ck / 2 selected as kernel clock

Bit 9 **OTGPDCTRL**: OTG_HS PHY common block power-down control
Set and reset by software.
0: In SUSPEND, PHY state machine, bias, and OTG_HS PHY PLL remain powered (default after reset).
1: In SUSPEND, PHY state machine, bias, and OTG_HS PHY PLL are powered down.

Bit 8 **ETHCLKSEL**: ETH clock selection
This bit selects the reference clock of the PAD ETH_CLK
0: hse_ck (default after reset)
1: pll1_q_ck

Bit 7 **SDMMC2SEL**: SDMMC2 kernel clock source selection
0: pll1_q_ck selected as kernel clock (default after reset)
1: pll2_r_ck selected as kernel clock

Bit 6 **SDMMC1SEL**: SDMMC1 kernel clock source selection
0: pll1_q_ck selected as kernel clock (default after reset)
1: pll2_r_ck selected as kernel clock

Bits 5:4 **OTGFSSEL[1:0]**: OTG_FS kernel clock source selection
00: hsi48_ck selected as kernel clock (default after reset)
01: pll1_q_ck is selected as kernel clock
10: pll3_q_ck selected as kernel clock
11: clk48mohci selected as kernel clock

Bits 3:2 **SYSTICKSEL[1:0]**: SYSTICK clock source selection
00: rcc_hclk/8 selected as clock source (default after reset)
01: lsi_ker_ck selected as clock source
10: lse_ck selected as clock source
11: reserved, the kernel clock is disabled

*Note: rcc_hclk frequency must be four times higher than lsi_ker_ck/lse_ck, that is, period (LSI/LSE) ≥ 4 * period (HCLK).*

Bits 1:0 **OCTOSPI1SEL[1:0]**: OCTOSPI1 kernel clock source selection
Set and reset by software.
00: rcc_hclk4 selected as kernel clock (default after reset)
01: pll1_q_ck selected as kernel clock
10: pll2_r_ck selected as kernel clock
11: per_ck selected as kernel clock

11.8.44 RCC kernel clock configuration register (RCC_CCIPR5)

Address offset: 0x0E8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CKPERSEL[1:0]		MDF1SEL[2:0]			ADF1SEL[2:0]			ETHREFCLKSEL	LTDCSEL	SAI2SEL[2:0]			SAI1SEL[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	OCTOSPI2SEL[1:0]		ETHPTPCLKSEL[1:0]		FDCANSEL[1:0]		CECSEL[1:0]		RNGSEL[1:0]		DACSEL	ADCDACSEL[2:0]		
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 **CKPERSEL[1:0]**: per_ck clock source selection
00: hsi_ker_ck selected as kernel clock (default after reset)
01: csi_ker_ck selected as kernel clock
10: hse_ck selected as kernel clock
11: reserved, the per_ck clock is disabled

Bits 29:27 **MDF1SEL[2:0]**: MDF1 kernel clock source selection
000: pll1_q_ck selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_p_ck selected as kernel clock
011: AUDIOCLK selected as kernel clock
100: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 26:24 **ADF1SEL[2:0]**: ADF1 kernel clock source selection
000: pll1_q_ck selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_p_ck selected as kernel clock
011: AUDIOCLK selected as kernel clock
100: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bit 23 **ETHREFCLKSEL**: ETH RMII reference kernel clock source selection
This bit selects the reference clock of the ETH for RMII mode. It must be set to 0 in any other mode than RMII.
0: ETH_RMII_REF_CLK (default after reset)
1: eth_clk_fb

Bit 22 **LTDCSEL**: LTDC kernel source selection
This bit is used to select the LTDC kernel clock source.
0: pll3_r_ck selected as kernel clock (default after reset)
1: pll2_r_ck selected as kernel clock

Bits 21:19 **SAI2SEL[2:0]**: SAI2 kernel clock source selection
000: pll1_q_ck selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_p_ck selected as kernel clock
011: AUDIOCLK selected as kernel clock
100: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 18:16 **SAI1SEL[2:0**]: SAI1 kernel clock source selection
000: pll1_q_ck selected as kernel clock (default after reset)
001: pll2_p_ck selected as kernel clock
010: pll3_p_ck selected as kernel clock
011: AUDIOCLK selected as kernel clock
100: per_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:12 **OCTOSPI2SEL[1:0**]: OCTOSPI2 kernel clock source selection
Set and reset by software.
00: rcc_hclk4 selected as kernel clock (default after reset)
01: pll1_q_ck selected as kernel clock
10: pll2_r_ck selected as kernel clock
11: per_ck selected as kernel clock

Bits 11:10 **ETHPTPCLKSEL[1:0]**: ETH PTP kernel clock source selection
Set and reset by software.
00: rcc_hclk1 selected as kernel clock (default after reset)
01: pll1_r_ck selected as kernel clock
10: pll1_q_ck selected as kernel clock
11: pll3_p_ckselected as kernel clock

Bits 9:8 **FDCANSEL[1:0]**: FDCAN1, FDCAN2, and FDCAN3 kernel clock source selection
00: hse_ck selected as kernel clock (default after reset)
01: pll1_q_ck selected as kernel clock
10: pll2_q_ck selected as kernel clock
11: reserved, the kernel clock is disabled

Bits 7:6 **CECSEL[1:0]**: HDMI_CEC kernel clock source selection
00: lse_ck selected as kernel clock (default after reset)
01: lsi_ker_ck selected as kernel clock
10: csi_ker_ck/122 selected as kernel clock
11: reserved, the kernel clock is disabled

Bits 5:4 **RNGSEL[1:0]**: RNG kernel clock source selection
00: hsi48_ck selected as kernel clock (default after reset)
01: pll1_q_ck selected as kernel clock
10: lse_ck selected as kernel clock
11: lsi_ker_ck selected as kernel clock

Bit 3 **DACSEL**: DAC sample and hold clock
0: dac_hold_ck selected as kernel clock (default after reset)
1: dac_hold_ck selected as kernel clock

Bits 2:0 **ADCDACSEL[2:0]**: ADC and DAC kernel clock source selection
000: rcc_hclk selected as kernel clock (default after reset)
001: sys_ck selected as kernel clock
010: pll2_r_ck selected as kernel clock
011: hse_ck selected as kernel clock
100: hsi_ker_ck selected as kernel clock
101: csi_ker_ck selected as kernel clock
Others: reserved, the kernel clock is disabled

11.8.45 RCC backup domain control register (RCC_BDCR)

Address offset: 0x0F0

Reset value: 0x0000 0088

Reset by backup domain reset.

Access: 0 ≤ wait state ≤ 3, word, half-word and byte access.

Wait states are inserted in case of successive accesses to this register.

Note: After a system reset, this register is write-protected (except bits 27:26). To modify the backup domain bits, the DBP bit in the PWR backup domain control register (PWR_DBPCR) must be set to 1. All bits (except bits 27:24 and bit 16) are reset only after a backup domain reset (see Section 11.3.3). Other resets do not have effect on these bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	LSI RDY	LSI ON	LSCO SEL	LSCO EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VSW RST
				r	rw	rw	rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RTC EN	Res.	Res.	Res.	Res.	Res.	RTCSEL[1:0]		LSE EXT	LSEC SSD	LSEC SSON	LSEDRV[1:0]		LSE BYP	LSE RDY	LSE ON
rw						rw	rw	rw	r	rw	rw	rw	rw	rw	r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **LSIRDY**: LSI oscillator ready

Set and cleared by hardware to indicate when the LSI oscillator is stable. After the LSION bit is cleared, LSIRDY goes low after three internal low-speed oscillator clock cycles.
This bit is set when the LSI is used by IWDG or RTC, even if LSION = 0.
0: LSI oscillator not ready
1: LSI oscillator ready

Bit 26 **LSION**: LSI oscillator enable

Set and cleared by software.
0: LSI oscillator off
1: LSI oscillator on

Bit 25 **LSCOSEL**: Low-speed clock output selection

Set and cleared by software.
0: LSI clock selected
1: LSE clock selected

Bit 24 **LSCOEN**: Low-speed clock output (LSCO) enable

Set and cleared by software.
0: LSCO output disabled
1: LSCO output enabled

Bits 23:17 Reserved, must be kept at reset value.

Bit 16 **VSWRST**: VSwitch domain software reset

Set and reset by software.
0: reset not activated (default after backup domain reset)
1: resets the entire VSW domain

Bit 15 **RTCEN**: RTC clock enable

Set and reset by software.
0: rtc_ck disabled (default after backup domain reset)
1: rtc_ck enabled

Bits 14:10 Reserved, must be kept at reset value.

Bits 9:8 **RTCSEL[1:0]**:RTC clock source selection

Set by software to select the clock source for the RTC.
These bits can be written only one time (except in case of failure detection on LSE).
These bits must be written before LSECSSON is enabled.
The VSWRST bit can be used to reset them, then it can be written one time again.
If HSE is selected as RTC clock, this clock is lost when the system is in Stop mode or in case of a pin reset (NRST).
00: no clock (default after backup domain reset)
01: LSE selected as RTC clock
10: LSI selected as RTC clock
11: HSE divided by RTCPRE value selected as RTC clock

Bit 7 **LSEEXT**: Low-speed external clock in bypass mode

This bit must be kept at its reset value.
0: Reserved
1: LSE in digital mode (default after backup domain reset

Bit 6 **LSECSSD**: LSE clock security system failure detection

Set by hardware to indicate when a failure has been detected by the clock security system on the external 32 kHz oscillator.
0: no failure detected on 32 kHz oscillator (default after backup domain reset)
1: failure detected on 32 kHz oscillator

Bit 5 **LSECSSON**: LSE clock security system enable

Set by software to enable the clock security system on 32 kHz oscillator.
LSECSSON must be enabled after LSE is enabled (LSEON enabled) and ready (LSERDY set by hardware) and after RTCSEL is selected.
Once enabled, this bit cannot be disabled, except after a LSE failure detection (LSECSSD = 1). In that case the software must disable LSECSSON.
0: CSS on 32 kHz oscillator OFF (default after backup domain reset)
1: CSS on 32 kHz oscillator ON

Bits 4:3 **LSEDRV[1:0]**: LSE oscillator driving capability

Set by software to select the driving capability of the LSE oscillator.
These bit can be written only if LSE oscillator is disabled (LSEON = 0 and LSERDY = 0).
00: Reserved
01: medium-low drive
10: medium-high drive
11: highest drive

Bit 2 **LSEBYP**: LSE oscillator bypass

Set and reset by software to bypass oscillator in debug mode. This bit must not be written when the LSE is enabled (by LSEON) or ready (LSERDY = 1)
0: LSE oscillator not bypassed (default after backup domain reset)
1: LSE oscillator bypassed

Bit 1 **LSERDY**: LSE oscillator ready

Set and reset by hardware to indicate when the LSE is stable.
This bit needs 6 cycles of lse_ck clock to fall down after LSEON has been set to 0.
0: LSE oscillator not ready (default after backup domain reset)
1: LSE oscillator ready

Bit 0 **LSEON**: LSE oscillator enabled
Set and reset by software.
0: LSE oscillator OFF (default after backup domain reset)
1: LSE oscillator ON

11.8.46 RCC reset status register (RCC_RSR)

Address offset: 0x0F4

Reset value: 0x0C00 0000

Reset by power-on reset only.

Access: 0 ≤ wait state ≤ 3, word, half-word and byte access.

Wait states are inserted in case of successive accesses to this register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LPWR RSTF	WWDG RSTF	IWDG RSTF	SFT RSTF	BOR RSTF	PIN RSTF	Res.	Res.	RMVF	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw			rw							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bit 31 **LPWRRSTF**: Low-power reset flag
Set by hardware when a reset occurs due to stop or standby mode entry, whereas the corresponding NRST_STOP, NRST_STBY option bit is cleared.
Cleared by writing to the RMVF bit.
0: no illegal low-power mode reset occurred
1: illegal low-power mode reset occurred

Bit 30 **WWDGRSTF**: Window watchdog reset flag
Reset by software by writing the RMVF bit.
Set by hardware when a window watchdog reset occurs.
0: no window watchdog reset occurred (default after power-on reset)
1: window watchdog reset occurred

Bit 29 **IWDGRSTF**: Independent watchdog reset flag
Reset by software by writing the RMVF bit.
Set by hardware when an independent watchdog reset occurs.
0: no independent watchdog reset occurred (default after power-on reset)
1: independent watchdog reset occurred

Bit 28 **SFTRSTF**: System reset from CPU reset flag
Reset by software by writing the RMVF bit.
Set by hardware when the system reset is due to CPU.The CPU can generate a system reset by writing SYSRESETREQ bit of AIRCR register of the core Cortex-M33.
0: no CPU software reset occurred (default after power-on reset)
1: a system reset has been generated by the CPU

Bit 27 **BORRSTF**: BOR reset flag
Reset by software by writing the RMVF bit.
Set by hardware when a BOR reset occurs (pwr_bor_rst).
0: no BOR reset occurred
1: BOR reset occurred (default after power-on reset)

Bit 26 **PINRSTF**: Pin reset flag (NRST)
Reset by software by writing the RMVF bit.
Set by hardware when a reset from pin occurs.
0: no reset from pin occurred
1: reset from pin occurred (default after power-on reset)

Bits 25:24 Reserved, must be kept at reset value.

Bit 23 **RMVF**: Remove reset flag
Set and reset by software to reset the value of the reset flags.
0: reset of the reset flags not activated (default after power-on reset)
1: resets the value of the reset flags

Bits 22:0 Reserved, must be kept at reset value.

11.8.47 RCC secure configuration register (RCC_SECCFGR)

Address offset: 0x110

Reset value: 0x0000 0000

Access: no wait state; word, half-word and byte access

When the system is secure (TZEN = 0xB4), this register can be written only by a secure privileged access if SPRIV = 1, and by a secure privileged or unprivileged access if SPRIV = 0. A nonsecure write access generates an illegal access event and data is not written. This register can be read by secure or nonsecure, privilege or unprivileged access. When the system is not secure (TZEN = 0xC3), this register is read as 0 and the register write is ignored.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CKPERSELSEC	RMVFSEC	HSI48SEC	Res.	PLL3SEC	PLL2SEC	PLL1SEC	PRESCSEC	SYSCLKSEC	LSESEC	LSISEC	CSISEC	HSESEC	HSISEC
		rw	rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **CKPERSELSEC**: per_ck selection security
Set and reset by software.
0: Nonsecure
1: Secure

Bit 12 **RMVFSEC**: Remove reset flag security
Set and reset by software.
0: Nonsecure
1: Secure

Bit 11 **HSI48SEC**: HSI48 clock configuration and status bits security
Set and reset by software.
0: Nonsecure
1: Secure

Bit 10 Reserved, must be kept at reset value.

Bit 9 **PLL3SEC**: PLL3 clock configuration and status bits security
Set and reset by software.
0: Nonsecure
1: Secure

Bit 8 **PLL2SEC**: PLL2 clock configuration and status bits security
Set and reset by software.
0: Nonsecure
1: Secure

Bit 7 **PLL1SEC**: PLL1 clock configuration and status bits security
Set and reset by software.
0: Nonsecure
1: Secure

Bit 6 **PRESCSEC**: AHBx/APBx prescaler configuration bits security
Set and reset by software.
0: Nonsecure
1: Secure

Bit 5 **SYSCLKSEC**: SYSCLK clock selection, STOPWUCK bit, clock output on MCO configuration security
Set and reset by software.
0: Nonsecure
1: Secure

Bit 4 **LSESEC**: LSE clock configuration and status bits security
Set and reset by software.
0: Nonsecure
1: Secure

Bit 3 **LSISEC**: LSI clock configuration and status bits security
Set and reset by software.
0: Nonsecure
1: Secure

Bit 2 **CSISEC**: CSI clock configuration and status bits security
Set and reset by software.
0: Nonsecure
1: Secure

Bit 1 **HSESEC**: HSE clock configuration bits, status bits and HSE_CSS security
Set and reset by software.
0: Nonsecure
1: Secure

Bit 0 **HSISEC**: HSI clock configuration and status bits security
Set and reset by software.
0: Nonsecure
1: Secure

11.8.48 RCC privilege configuration register (RCC_PRIVCFGR)

Address offset: 0x114

Reset value: 0x0000 0000

Access: no wait state; word, half-word and byte access

This register can be written only by a privileged access. It can be read by privileged or unprivileged access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NSPRIV	SPRIV
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **NSPRIV**: RCC nonsecure functions privilege configuration

Set and reset by software. This bit can be written only by privileged access, secure or nonsecure.

0: Read and write to RCC nonsecure functions can be done by privileged or unprivileged access.

1: Read and write to RCC nonsecure functions can be done by privileged access only

Bit 0 **SPRIV**: RCC secure functions privilege configuration

Set and reset by software. This bit can be written only by a secure privileged access.

0: Read and write to RCC secure functions can be done by privileged or unprivileged access.

1: Read and write to RCC secure functions can be done by privileged access only

11.8.49 RCC register map

Table 110. RCC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	RCC_CR	Res.	Res.	PLL3RDY	PLL3ON	PLL2RDY	PLL2ON	PLL1RDY	PLL1ON	Res.	Res.	Res.	HSEEXT	HSECSSON	HSEBYP	HSERDY	HSEON	Res.	Res.	HSI48RDY	HSI48ON	Res.	CSIKERON	CSIRDY	CSION	Res.	Res.	HSIDIVF	HSIDIV[1:0]		HSIKERON	HSIRDY	HSION
	Reset value			0	0	0	0	0	0				0	0	0	0	0			0	0		0	0	0			1	0	1	0	1	1
0x004-0x008	Reserved	Reserved																															
0x010	RCC_HSICFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSITRIM[6:0]							Res.	Res.	Res.	Res.	HSICAL[11:0]											
	Reset value										1	0	0	0	0	0	0					X	X	X	X	X	X	X	X	X	X	X	X
0x014	RCC_CRRCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSI48CAL[9:0]									
	Reset value																							X	X	X	X	X	X	X	X	X	X
0x018	RCC_CSICFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSITRIM[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSICAL[7:0]							
	Reset value											1	0	0	0	0	0									X	X	X	X	X	X	X	X

Table 110. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x01C	RCC_CFGR1	MCO2SEL [2:0]			MCO2PRE [3:0]				MCO1SEL [2:0]			MCO1PRE [3:0]				Res.	Res.	TIMPRE	Res.	RTCPRE[5:0]						STOPKERWUCK	STOPWUCK	Res.	SWS[1:0]		Res.	SW[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0		0	0	0	0	0	0	0	0		0	0		0	0
0x020	RCC_CFGR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APB3DIS	APB2DIS	APB1DIS	AHB4DIS	Res.	AHB2DIS	AHB1DIS	Res.	PPRE3 [2:0]			Res.	PPRE2 [2:0]			Res.	PPRE1 [2:0]			HPRE [3:0]			
	Reset value										0	0	0	0		0	0		0	0	0		0	0	0		0	0	0	0	0	0	0	0
0x024	Reserved	Reserved																															
0x028	RCC_PLL1CFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLL1REN	PLL1QEN	PLL1PEN	Res.	Res.	PLL1M[5:0]						Res.	Res.	PLL1VCOSEL	PLL1FRACEN	PLL1RGE [1:0]		PLL1SRC [1:0]	
	Reset value														0	0	0			0	0	0	0	0	0			0	0	0	0	0	0
0x02C	RCC_PLL2CFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLL2REN	PLL2QEN	PLL2PEN	Res.	Res.	PLL2M[5:0]						Res.	Res.	PLL2VCOSEL	PLL2FRACEN	PLL2RGE [1:0]		PLL2SRC [1:0]	
	Reset value														0	0	0			0	0	0	0	0	0			0	0	0	0	0	0
0x030	RCC_PLL3CFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLL3REN	PLL3QEN	PLL3PEN	Res.	Res.	PLL3M[5:0]						Res.	Res.	PLL3VCOSEL	PLL3FRACEN	PLL3RGE [1:0]		PLL3SRC [1:0]	
	Reset value														0	0	0			0	0	0	0	0	0			0	0	0	0	0	0
0x034	RCC_PLL1DIVR	Res.	PLL1R[6:0]							Res.	PLL1Q[6:0]							PLL1P[6:0]								PLL1N[8:0]							
	Reset value		0	0	0	0	0	0	1		0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
0x038	RCC_PLL1FRACR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLL1FRACN[12:0]													Res.	Res.	Res.
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x03C	RCC_PLL2DIVR	Res.	PLL2R[6:0]							Res.	PLL2Q[6:0]							PLL2P[6:0]								PLL2N[8:0]							
	Reset value		0	0	0	0	0	0	1		0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
0x040	RCC_PLL2FRACR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLL2FRACN[12:0]													Res.	Res.	Res.
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x044	RCC_PLL3DIVR	Res.	PLL3R[6:0]							Res.	PLL3Q[6:0]							PLL3P[6:0]								PLL3N[8:0]							
	Reset value		0	0	0	0	0	0	1		0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
0x048	RCC_PLL3FRACR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLL3FRACN[12:0]													Res.	Res.	Res.
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x04C	Reserved	Reserved																															

Table 110. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x050	RCC_CIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLL3RDYIE	PLL2RDYIE	PLL1RDYIE	HSI48RDYIE	HSERDYIE	HSIRDYIE	CSIRDYIE	LSERDYIE	LSIRDYIE
	Reset value																								0	0	0	0	0	0	0	0	0
0x054	RCC_CIFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSECSSF	Res.	PLL3RDYF	PLL2RDYF	PLL1RDYF	HSI48RDYF	HSERDYF	HSIRDYF	CSIRDYF	LSERDYF	LSIRDYF
	Reset value																						0		0	0	0	0	0	0	0	0	0
0x058	RCC_CICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSECSSC	Res.	PLL3RDYC	PLL2RDYC	PLL1RDYC	HSI48RDYC	HSERDYC	HSIRDYC	CSIRDYC	LSERDYC	LSIRDYC
	Reset value																						0		0	0	0	0	0	0	0	0	0
0x05C	Reserved	Reserved																															
0x060	RCC_AHB1RSTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JPEGRST	DMA2DRST	Res.	Res.	ETHRST	Res.	RAMCFGRST	MDF1RST	FMACRST	CORDICRST	Res.	CRCRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPDMA2RST	GPDMA1RST
	Reset value									0	0			0		0	0	0	0		0											0	0
0x064	RCC_AHB2RSTR	Res.	Res.	Res.	Res.	Res.	GPIOKRST	ADF1RST	ADC3RST	Res.	Res.	CCBRST	SAESRST	PKARST	RNGRST	HASHRST	AESRST	OTGFSRST	OTGHSRST	OTGPHYRST	DCMI_PSSIRST	DAC1RST	ADCRST	GPIOJRST	GPIOIRST	GPIOHRST	GPIOGRST	GPIOFRST	GPIOERST	GPIODRST	GPIOCRST	GPIOBRST	GPIOARST
	Reset value						0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x068	Reserved	Reserved																															
0x06C	RCC_AHB4RSTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCTOSPIMRST	OCTOSPI2RST	OCTOSPI1RST	Res.	Res.	Res.	FMCRST	Res.	Res.	Res.	SDMMC2RST	SDMMC1RST	Res.	Res.	OTFDEC2RST	OTFDEC1RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value										0	0	0				0				0	0			0	0							
0x070	Reserved	Reserved																															
0x074	RCC_APB1LRSTR	UART8RST	UART7RST	Res.	CECRST	USART11	USART10RST	USART6RST	CRSRST	I3C1RST	I2C2RST	I2C1RST	UART5RST	UART4RST	USART3RST	USART2RST	COMPRST	SPI3RST	SPI2RST	OPAMPRST	Res.	Res.	Res.	Res.	TIM14RST	TIM13RST	TIM12RST	TIM7RST	TIM6RST	TIM5RST	TIM4RST	TIM3RST	TIM2RST
	Reset value	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0
0x078	RCC_APB1HRSTR	Res.		Res.	Res.	Res.	Res.	Res.	Res.	UCPD1RST		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FDCANRST			LPTIM2RST		DTSRST		UART12RST	UART9RST
	Reset value									0														0			0		0		0	0

Table 110. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x07C	RCC_APB2RSTR	Res.	Res.	GFXTIMRST	Res.	LTDCRST	Res.	Res.	Res.	Res.	SAI2RST	SAI1RST	SPI6RST	SPI4RST	TIM17RST	TIM16RST	TIM15RST	Res.	USART1RST	TIM8RST	SPI1RST	TIM1RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value			0		0					0	0	0	0	0	0	0		0	0	0	0											
0x080	RCC_APB3RSTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLAY1RST	PLAY1POR	Res.	VREFRST	Res.	Res.	Res.	Res.	LPTIM6RST	LPTIM5RST	LPTIM4RST	LPTIM3RST	LPTIM1RST	Res.	I3C2RST	I2C4RST	I2C3RST	LPUART1RST	SPI5RST	Res.	Res.	Res.	Res.	Res.
	Reset value									0	0		0					0	0	0	0	0		0	0	0	0	0					
0x084	Reserved	Reserved																															
0x088	RCC_AHB1ENR	SRAM1EN	DCACHEEN	Res.	BKPRAMEN	Res.	Res.	Res.	TZSC1EN	JPEGEN	DMA2DEN	ETHRXEN	ETHTXEN	ETHEN	ETHCKEN	RAMCFGEN	MDF1CEN	FMACEN	CORDICEN	Res.	CRCEN	Res.	Res.	Res.	FLITFEN	Res.	Res.	Res.	Res.	Res.	Res.	GPDMA2EN	GPDMA1EN
	Reset value	1	1		1				0	0	0	0	0	0	0	0	0	0	0		0			1							0	0
0x08C	RCC_AHB2ENR	SRAM3EN	SRAM2EN	SRAM5EN	SRAM4EN	Res.	GPIOKEN	ADF1EN	ADC3EN	Res.	Res.	CCBEN	SAESEN	PKAEN	RNGEN	HASHEN	AESEN	OTGFSEN	OTGHSEN	OTGPHYEN	DCMI_PSSIEN	DAC1EN	ADCEN	GPIOJEN	GPIOIEN	GPIOHEN	GPIOGEN	GPIOFEN	GPIOEEN	GPIODEN	GPIOCEN	GPIOBEN	GPIOAEN
	Reset value	1	1	1	1		0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x090	Reserved	Reserved																															
0x094	RCC_AHB4ENR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCTOSPIMEN	OCTOSPI2EN	OCTOSPI1EN	Res.	Res.	Res.	FMCEN	Res.	Res.	Res.	SDMMC2EN	SDMMC1EN	Res.	Res.	OTFDEC2EN	OTFDEC1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value										0	0	0				0					0			0	0							
0x098	Reserved	Reserved																															
0x09C	RCC_APB1LENR	UART8EN	UART7EN	Res.	CECEN	USART11	USART10EN	USART6EN	CRSEN	I3C1EN	I2C2EN	I2C1EN	UART5EN	UART4EN	USART3EN	USART2EN	COMPEN	SPI3EN	SPI2EN	OPAMPEN	Res.	WWDGEN	Res.	Res.	TIM14EN	TIM13EN	TIM12EN	TIM7EN	TIM6EN	TIM5EN	TIM4EN	TIM3EN	TIM2EN
	Reset value	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0			0	0	0	0	0	0	0	0	0
0x0A0	RCC_APB1HENR	Res.		Res.	Res.	Res.	Res.	Res.	Res.	UCPD1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FDCANEN	Res.	Res.	Res.	LPTIM2EN	Res.	DTSEN	Res.	UART12EN	UART9EN
	Reset value									0														0				0		0		0	0
0x0A4	RCC_APB2ENR	Res.	Res.	GFXTIMEN	Res.	LTDCEN	Res.	Res.	Res.	Res.	SAI2EN	SAI1EN	SPI6EN	SPI4EN	TIM17EN	TIM16EN	TIM15EN	Res.	USART1EN	TIM8EN	SPI1EN	TIM1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value			0		0			0		0	0	0	0	0	0	0		0	0	0	0											
0x0A8	RCC_APB3ENR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLAY1EN	PLAY1APBEN	RTCAPBEN	VREFEN	Res.	Res.	Res.	Res.	LPTIM6EN	LPTIM5EN	LPTIM4EN	LPTIM3EN	LPTIM1EN	Res.	I3C2EN	I2C4EN	I2C3EN	LPUART1EN	SPI5EN	Res.	Res.	Res.	SBSEN	Res.
	Reset value									0	0	0	0					0	0	0	0	0		0	0	0	0	0				0	

Table 110. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0AC	Reserved	Reserved																															
0x0B0	RCC_AHB1LPENR	SRAM1LPEN	DCACHELPEN	ICACHELPEN	BKPRAMLPEN	Res.	Res.	Res.	TZSC1LPEN	JPEGLPEN	DMA2DLPEN	ETHRXLPEN	ETHTXLPEN	ETHLPEN	ETHCKLPEN	RAMCFGLPEN	MDF1LPEN	FMACLPEN	CORDICLPEN	Res.	CRCLPEN	Res.	Res.	Res.	FLITFLPEN	Res.	Res.	Res.	Res.	Res.	Res.	GPDMA2LPEN	GPDMA1LPEN
	Reset value	1	1	1	1				1	1	1	1	1	1	1	1	1	1	1		1				1							1	1
0x0B4	RCC_AHB2LPENR	SRAM3LPEN	SRAM2LPEN	SRAM5LPEN	SRAM4LPEN	Res.	GPIOKLPEN	ADF1LPEN	ADC3LPEN	Res.	Res.	CCBLPEN	SAESLPEN	PKALPEN	RNGLPEN	HASHLPEN	AESLPEN	OTGFSLPEN	OTGHSLPEN	OTGPHYLPEN	DCMI_PSSILPEN	DAC1LPEN	ADCLPEN	GPIOJLPEN	GPIOILPEN	GPIOHLPEN	GPIOGLPEN	GPIOFLPEN	GPIOELPEN	GPIODLPEN	GPIOCLPEN	GPIOBLPEN	GPIOALPEN
	Reset value	1	1	1	1		1	1	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0BC	RCC_AHB4LPENR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCTOSPIMLPEN	OCTOSPI2LPEN	OCTOSPI1LPEN	Res.	Res.	Res.	FMCLPEN	Res.	Res.	Res.	SDMMC2LPEN	SDMMC1LPEN	Res.	Res.	OTFDEC2LPEN	OTFDEC1LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value										1	1	1				1				1	1			1	1							
0x0C0	Reserved	Reserved																															
0x0C4	RCC_APB1LLPENR	UART8LPEN	UART7LPEN	Res.	CECLPEN	USART11LPEN	USART10LPEN	USART6LPEN	CRSLPEN	I3C1LPEN	I2C2LPEN	I2C1LPEN	UART5LPEN	UART4LPEN	USART3LPEN	USART2LPEN	COMPLPEN	SPI3LPEN	SPI2LPEN	OPAMPLPEN	Res.	WWDGLPEN	Res.	Res.	TIM14LPEN	TIM13LPEN	TIM12LPEN	TIM7LPEN	TIM6LPEN	TIM5LPEN	TIM4LPEN	TIM3LPEN	TIM2LPEN
	Reset value	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1			1	1	1	1	1	1	1	1	1
0x0C8	RCC_APB1HLPENR	Res.		Res.	Res.	Res.	Res.	Res.	Res.	UCPD1LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FDCANLPEN	Res.	Res.	Res.	LPTIM2LPEN	Res.	DTSLPEN	Res.	UART12LPEN	UART9LPEN
	Reset value									1														1				1		1		1	1
0x0CC	RCC_APB2LPENR	Res.	Res.	GFXTIMLPEN	Res.	LTDCLPEN	Res.	Res.	Res.	Res.	SAI2LPEN	SAI1LPEN	SPI6LPEN	SPI4LPEN	TIM17LPEN	TIM16LPEN	TIM15LPEN	Res.	USART1LPEN	TIM8LPEN	SPI1LPEN	TIM1LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value			1		1					1	1	1	1	1	1	1		1	1	1	1											
0x0D0	RCC_APB3LPENR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLAY1LPEN	Res.	RTCAPBLPEN	VREFLPEN	Res.	Res.	Res.	Res.	LPTIM6LPEN	LPTIM5LPEN	LPTIM4LPEN	LPTIM3LPEN	LPTIM1LPEN	Res.	I3C2LPEN	I2C4LPEN	I2C3LPEN	LPUART1LPEN	SPI5LPEN	Res.	Res.	Res.	SBSLPEN	Res.
	Reset value									1		1	1					1	1	1	1	1		1	1	1	1	1				1	
0x0D4	Reserved	Reserved																															
0x0D8	RCC_CCIPR1	TIMICSEL	Res.	USART10SEL [2:0]			UART9SEL [2:0]			UART8SEL [2:0]			UART7SEL [2:0]			USART6SEL [2:0]			UART5SEL [2:0]			UART4SEL [2:0]			USART3SEL [2:0]			USART2SEL [2:0]			USART1SEL [2:0]		
	Reset value	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 110. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0DC	RCC_CCIPR2	Res.	LPTIM6SEL [2:0]			Res.	LPTIM5SEL [2:0]			Res.	LPTIM4SEL [2:0]			Res.	LPTIM3SEL [2:0]			Res.	LPTIM2SEL [2:0]			Res.	LPTIM1SEL [2:0]			Res.	UART12SEL [2:0]			Res.	USART11SEL [2:0]		
	Reset value		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0
0x0E0	RCC_CCIPR3	PLAY1 SEL [2:0]			Res.	Res.	LPUART 1SEL [2:0]			PLAY1 DIV [3:0]				Res.	Res.	SPI6 SEL [2:0]			SPI5 SEL [2:0]			SPI4 SEL [2:0]			SPI3 SEL [2:0]			SPI2 SEL [2:0]			SPI1 SEL [2:0]		
	Reset value	0	0	0			0	0	0	0	0	0	1			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0E4	RCC_CCIPR4	ETHPTPDIV [3:0]				I3C2SEL [1:0]	I3C1SEL [1:0]			I2C4SL [1:0]	I2C3SEL [1:0]			I2C2SEL [1:0]	I2C1SEL [1:0]			OTGPHYREFCKSEL [3:0]				OTGHSSEL [1:0]		OTGPDCTRL	ETHCLKSEL	SDMMC2SEL	SDMMC1SEL	OTGFSSEL [1:0]		SYSTICKSEL [1:0]		OCTOSPI [1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0E8	RCC_CCIPR5	CKPERSEL [1:0]		MDF1SEL [2:0]			ADF1SEL [2:0]			ETHREFCLKSEL	LTDCSEL	SAI2SEL [2:0]			SAI1SEL [2:0]			Res.	Res.	OCTOSPI2SEL [1:0]		ETHPTPCLKSEL [1:0]		FDCANSEL [1:0]		CECSEL [1:0]		RNGSEL [1:0]		DACSEL		ADCDACSEL [2:0]		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0EC	Reserved	Reserved																															
0x0F0	RCC_BDCR	Res.	Res.	Res.	Res.	LSIRDY	LSION	LSCOSEL	LSCOEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VSWRST	RTCEN	Res.	Res.	Res.	Res.	Res.	RTCSEL [1:0]		LSEEXT	LSECSSD	LSECSSON	LSEDRV [1:0]		LSEBYP	LSERDY	LSEON
	Reset value					0	0	0	0								0	0						0	0	1	0	0	0	1	0	0	0
0x0F4	RCC_RSR	LPWRRSTF	WWDGRSTF	IWDGRSTF	SFTRSTF	BORRSTF	PINRSTF	Res.	Res.	RMVF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	1	1			0																							
0x0F8-0x10C	Reserved	Reserved																															
0x110	RCC_SECCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CKPERSELSEC	RMVFSEC	HSI48SEC	Res.	PLL3SEC	PLL2SEC	PLL1SEC	PRESCSEC	SYSCLKSEC	LSESEC	LSISEC	CSISEC	HSESEC	HSISEC
	Reset value																			0	0	0		0	0	0	0	0	0	0	0	0	0
0x114	RCC_PRIVCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NSPRIV	SPRI
	Reset value																															0	0

Refer to *Section 2.3.1* for the register boundary addresses.

12 Clock recovery system (CRS)

12.1 CRS introduction

The clock recovery system (CRS) is an advanced digital controller acting on the internal fine-granularity trimmable RC oscillator HSI48. The CRS provides powerful means to evaluate the oscillator output frequency, based on comparison with a selectable synchronization signal. The CRS can perform automatic trimming adjustments based on the measured frequency error value, while keeping the possibility of a manual trimming.

The CRS is ideally suited to provide a precise clock to the USB peripheral. In this case, the synchronization signal can be derived from the start-of-frame (SOF) packet signalization on the USB bus, sent by a USB host at 1 ms intervals.

The synchronization signal can also be derived from alternative synchronization or generated by the user software.

12.2 CRS main features

- Selectable synchronization source with programmable prescaler and polarity (see *Section 12.4.2: CRS internal signals*)
- Possibility to generate synchronization pulses by software
- Automatic oscillator trimming capability with no need of CPU action
- Manual control option for faster startup convergence
- 16-bit frequency error counter with automatic error value capture and reload
- Programmable limit for automatic frequency error value evaluation and status reporting
- Maskable interrupts/events:
  - Expected synchronization (ESYNC)
  - Synchronization OK (SYNCOK)
  - Synchronization warning (SYNCWARN)
  - Synchronization or trimming error (ERR)

12.3 CRS implementation

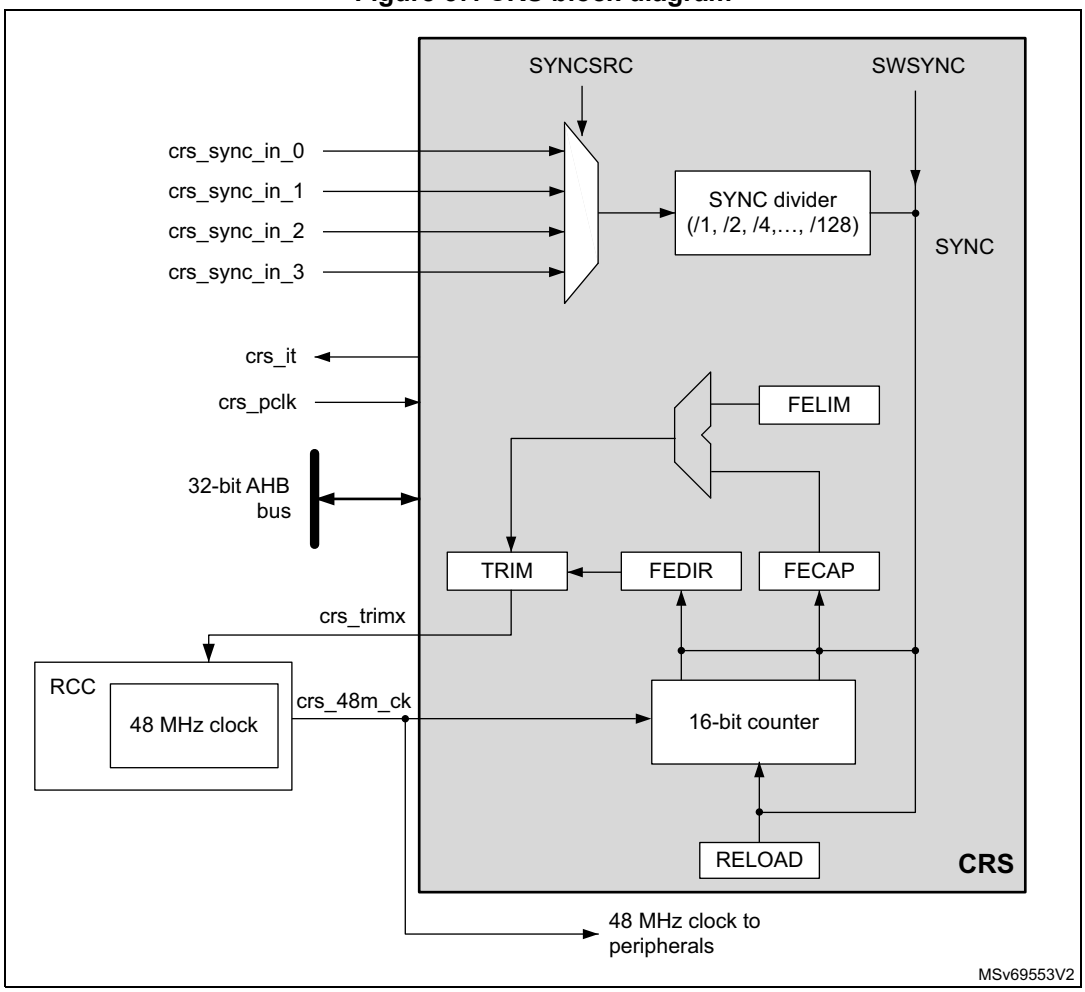
Table 111. CRS features

Feature	CRS
TRIM width	6 bits

12.4 CRS functional description

12.4.1 CRS block diagram

Figure 57. CRS block diagram



12.4.2 CRS internal signals

Below the list of CRS internal signals.

Table 112. CRS internal input/output signals

Internal signal name	Signal type	Description
crs_it	Digital output	CRS interrupt
crs_pclk	Digital input	AHB bus clock
crs_48m_ck	Digital input	HSI48 48 MHz clock
crs_trim[0:5]	Digital output	HSI48 oscillator smooth trimming value

Table 112. CRS internal input/output signals (continued)

Internal signal name	Signal type	Description
crs_sync_in_0	Digital input	SYNC signal source
crs_sync_in_1		
crs_sync_in_2		
crs_sync_in_3		

Table 113. CRS interconnection

Internal signal name	Description
crs_sync_in_0	GPIO AF selected as SYNC signal source
crs_sync_in_1	LSE selected as SYNC signal source
crs_sync_in_2	OTG_FS_SOF (SOF from OTG FS) selected as SYNC signal source (default)
crs_sync_in_3	OTG_HS_SOF (SOF from OTG HS) selected as SYNC signal source

12.4.3 Synchronization input

The CRS synchronization source (crs_sync_in_x) can be selected through SYNCSRC[1:0] bitfield of CRS_CFGR register (refer to *Section 12.4.2: CRS internal signals* for the possible sources). For a better robustness of the crs_sync_in_x input, a simple digital filter (2 out of 3 majority votes, sampled by the 48 MHz clock) is implemented to filter out glitches. In addition, the source signal has a configurable polarity (selected through SYNCPOL bit of CRS_CFGR). The signal can then be divided by a programmable binary prescaler to obtain a synchronization signal in a suitable frequency range (usually around 1 kHz).

For more information on the CRS synchronization source configuration, refer to CRS_CFGR register.

It is also possible to generate a synchronization event by software, by setting the SWSYNC bit in the CRS_CR register.

For more information on the CRS synchronization source configuration, refer to *CRS configuration register (CRS_CFGR)*.

It is also possible to generate a synchronization event by software, by setting the SWSYNC bit in the CRS_CR register.

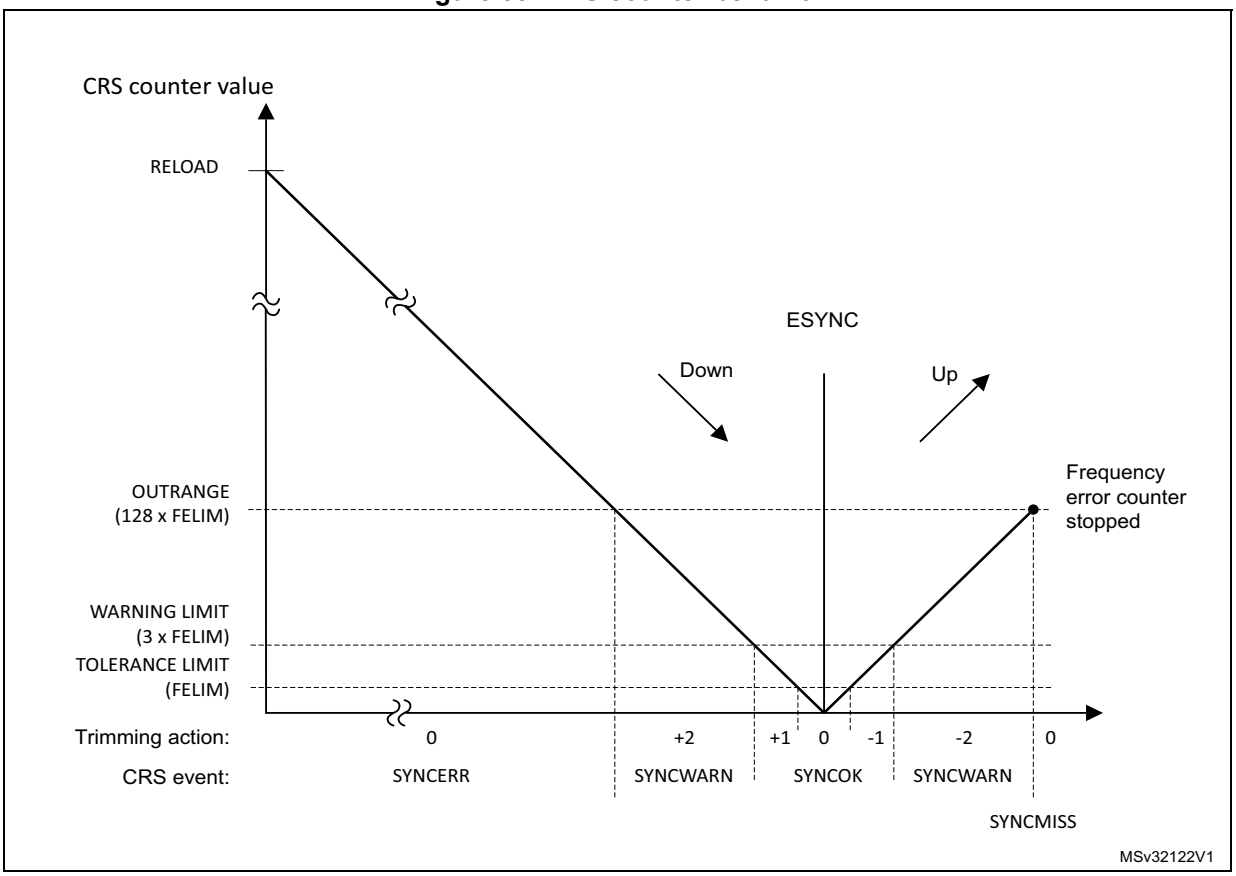
12.4.4 Frequency error measurement

The frequency error counter is a 16-bit down/up counter, reloaded with the RELOAD value on each SYNC event. It starts counting down until it reaches the zero value, where the ESYNC (expected synchronization) event is generated. Then it starts counting up to the OUTRANGE limit, where it eventually stops (if no SYNC event is received), and generates a SYNCMISS event. The OUTRANGE limit is defined as the frequency error limit (FELIM field of the CRS_CFGR register) multiplied by 128.

When the SYNC event is detected, the actual value of the frequency error counter and its counting direction are stored in the FECAP (frequency error capture) field and in the FEDIR (frequency error direction) bit of the CRS_ISR register. When the SYNC event is detected

during the down-counting phase (before reaching the zero value), it means that the actual frequency is lower than the target (the TRIM value must be incremented). When it is detected during the up-counting phase, it means that the actual frequency is higher (the TRIM value must be decremented).

Figure 58. CRS counter behavior



12.4.5 Frequency error evaluation and automatic trimming

The measured frequency error is evaluated by comparing its value with a set of limits:

- TOLERANCE LIMIT, given directly in the FELIM field of the CRS_CFGR register
- WARNING LIMIT, defined as 3 × FELIM value
- OUTRANGE (error limit), defined as 128 × FELIM value

The result of this comparison is used to generate the status indication and also to control the automatic trimming, which is enabled by setting the AUTOTRIMEN bit in the CRS_CR register:

- When the frequency error is below the tolerance limit, it means that the actual trimming value in the TRIM field is the optimal one, hence no trimming action is needed.
  - SYNCOK status indicated
  - TRIM value not changed in AUTOTRIM mode
- When the frequency error is below the warning limit but above or equal to the tolerance limit, it means that some trimming action is necessary but that adjustment by one trimming step is enough to reach the optimal TRIM value.

  - SYNCOK status indicated
  - TRIM value adjusted by one trimming step in AUTOTRIM mode
- When the frequency error is above or equal to the warning limit but below the error limit, a stronger trimming action is necessary, and there is a risk that the optimal TRIM value is not reached for the next period.
  - SYNCWARN status indicated
  - TRIM value adjusted by two trimming steps in AUTOTRIM mode
- When the frequency error is above or equal to the error limit, the frequency is out of the trimming range. This can also happen when the SYNC input is not clean, or when some SYNC pulse is missing (for example when one USB SOF is corrupted).
  - SYNCERR or SYNCMISS status indicated
  - TRIM value not changed in AUTOTRIM mode

Note: If the actual value of the TRIM field is close to its limits and the automatic trimming can force it to overflow or underflow, the TRIM value is set to the limit, and the TRIMOVF status is indicated.

In AUTOTRIM mode (AUTOTRIMEN bit set in the CRS_CR register), the TRIM field of CRS_CR is adjusted by hardware and is read-only.

12.4.6 CRS initialization and configuration

RELOAD value

The RELOAD value must be selected according to the ratio between the target frequency and the frequency of the synchronization source after prescaling. This value is decreased by 1, to reach the expected synchronization on the zero value. The formula is the following:

$$RELOAD = (f_{TARGET} / f_{SYNC}) - 1$$

The reset value of the RELOAD field corresponds to a target frequency of 48 MHz and a synchronization signal frequency of 1 kHz (SOF signal from USB).

FELIM value

The selection of the FELIM value is closely coupled with the HSI48 oscillator characteristics and its typical trimming step size. The optimal value corresponds to half of the trimming step size, expressed as a number of oscillator clock ticks. The following formula can be used:

$$FELIM = (f_{TARGET} / f_{SYNC}) * STEP[\%] / 100\% / 2$$

The result must be always rounded up to the nearest integer value to obtain the best trimming response. If frequent trimming actions are not needed in the application, the hysteresis can be increased by slightly increasing the FELIM value.

The reset value of the FELIM field corresponds to $(f_{TARGET} / f_{SYNC}) = 48000$, and to a typical trimming step size of 0.14%.

Note: The trimming step size depends upon the product, check the datasheet for accurate setting.

Caution: There is no hardware protection from a wrong configuration of the RELOAD and FELIM fields, this can lead to an erratic trimming response. The expected operational mode requires proper setup of the RELOAD value (according to the synchronization source frequency), which is also greater than 128 * FELIM value (OUTRANGE limit).

12.5 CRS in low-power modes

Table 114. Effect of low-power modes on CRS

Mode	Description
Sleep	No effect. CRS interrupts cause the device to exit the Sleep mode.
Stop	CRS registers are frozen. The CRS stops operating until the Stop mode is exited and the HSI48 oscillator is restarted.
Standby	The peripheral is powered down and must be reinitialized after exiting Standby mode.
Shutdown	The peripheral is powered down and must be reinitialized after exiting Shutdown mode.

12.6 CRS interrupts

Table 115. Interrupt control bits

Interrupt event	Event flag	Enable control bit	Clear flag bit
Expected synchronization	ESYNCF	ESYNCIE	ESYNCC
Synchronization OK	SYNCOKF	SYNCOKIE	SYNCOKC
Synchronization warning	SYNCWARNF	SYNCWARNIE	SYNCWARNC
Synchronization or trimming error (TRIMOVF, SYNCMISS, SYNCERR)	ERRF	ERRIE	ERRC

12.7 CRS registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed only by words (32-bit).

12.7.1 CRS control register (CRS_CR)

Address offset: 0x00

Reset value: 0x0000 2000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	TRIM[5:0]						SW SYNC	AUTO TRIMEN	CEN	Res.	ESYNC IE	ERR IE	SYNC WARNIE	SYNC OKIE
		rw	rw	rw	rw	rw	rw	rt_w1	rw	rw		rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bits 13:8 **TRIM[5:0]**: HSI48 oscillator smooth trimming

These bits provide a user-programmable trimming value to the HSI48 oscillator. They can be programmed to adjust to variations in voltage and temperature that influence the oscillator frequency.

The default value of the HSI48 oscillator smooth trimming is 32, for a complete TRIM range of 64 steps.

The trimming step is specified in the product datasheet. A higher TRIM value corresponds to a higher output frequency.

When the AUTOTRIMEN bit is set, this field is controlled by hardware and is read-only.

Bit 7 **SWSYNC**: Generate software SYNC event

This bit is set by software in order to generate a software SYNC event. It is automatically cleared by hardware.

0: No action

1: A software SYNC event is generated.

Bit 6 **AUTOTRIMEN**: Automatic trimming enable

This bit enables the automatic hardware adjustment of TRIM bits according to the measured frequency error between two SYNC events. If this bit is set, the TRIM bits are read-only. The TRIM value can be adjusted by hardware by one or two steps at a time, depending on the measured frequency error value. Refer to *Section 12.4.5* for more details.

0: Automatic trimming disabled, TRIM bits can be adjusted by the user.

1: Automatic trimming enabled, TRIM bits are read-only and under hardware control.

Bit 5 **CEN**: Frequency error counter enable

This bit enables the oscillator clock for the frequency error counter.

0: Frequency error counter disabled

1: Frequency error counter enabled

When this bit is set, the CRS_CFGR register is write-protected and cannot be modified.

Bit 4 Reserved, must be kept at reset value.

Bit 3 **ESYNCIE**: Expected SYNC interrupt enable

0: Expected SYNC (ESYNCF) interrupt disabled

1: Expected SYNC (ESYNCF) interrupt enabled

Bit 2 **ERRIE**: Synchronization or trimming error interrupt enable

0: Synchronization or trimming error (ERRF) interrupt disabled

1: Synchronization or trimming error (ERRF) interrupt enabled

Bit 1 **SYNCWARNIE**: SYNC warning interrupt enable

0: SYNC warning (SYNCWARNF) interrupt disabled

1: SYNC warning (SYNCWARNF) interrupt enabled

Bit 0 **SYNCOKIE**: SYNC event OK interrupt enable

0: SYNC event OK (SYNCOKF) interrupt disabled

1: SYNC event OK (SYNCOKF) interrupt enabled

12.7.2 CRS configuration register (CRS_CFGR)

This register can be written only when the frequency error counter is disabled (the CEN bit is cleared in CRS_CR). When the counter is enabled, this register is write-protected.

Address offset: 0x04

Reset value: 0x2022 BB7F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SYNCPOL	Res.	SYNCSRC[1:0]		Res.	SYNCDIV[2:0]			FELIM[7:0]							
rw		rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RELOAD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **SYNCPOL**: SYNC polarity selection

This bit is set and cleared by software to select the input polarity for the SYNC signal source.

0: SYNC active on rising edge (default)

1: SYNC active on falling edge

Bit 30 Reserved, must be kept at reset value.

Bits 29:28 **SYNCSRC[1:0]**: SYNC signal source selection

These bits are set and cleared by software to select the SYNC signal source (see *Section 12.4.2: CRS internal signals*).

00: crs_sync_in_0 selected as SYNC signal source

01: crs_sync_in_1 selected as SYNC signal source

10: crs_sync_in_2 selected as SYNC signal source

11: crs_sync_in_3 selected as SYNC signal source

Note: When using USB LPM (link power management) and the device is in Sleep mode, the periodic USB SOF is not generated by the host. No SYNC signal is therefore provided to the CRS to calibrate the 48 MHz clock on the run. To guarantee the required clock precision after waking up from Sleep mode, the LSE clock or the SYNC pin must be used as SYNC signal.

Bit 27 Reserved, must be kept at reset value.

Bits 26:24 **SYNCDIV[2:0]**: SYNC divider

These bits are set and cleared by software to control the division factor of the SYNC signal.

000: SYNC not divided (default)

001: SYNC divided by 2

010: SYNC divided by 4

011: SYNC divided by 8

100: SYNC divided by 16

101: SYNC divided by 32

110: SYNC divided by 64

111: SYNC divided by 128

Bits 23:16 **FELIM[7:0]**: Frequency error limit

FELIM contains the value to be used to evaluate the captured frequency error value latched in the FECAP[15:0] bits of the CRS_ISR register. Refer to *Section 12.4.5* for more details about FECAP evaluation.

Bits 15:0 **RELOAD[15:0]**: Counter reload value

RELOAD is the value to be loaded in the frequency error counter with each SYNC event. Refer to *Section 12.4.4* for more details about counter behavior.

12.7.3 CRS interrupt and status register (CRS_ISR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FECAP[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FEDIR	Res.	Res.	Res.	Res.	TRIM OVF	SYNC MISS	SYNC ERR	Res.	Res.	Res.	Res.	ESYNCF	ERRF	SYNC WARNF	SYNC OKF
r					r	r	r					r	r	r	r

Bits 31:16 **FECAP[15:0]**: Frequency error capture

FECAP is the frequency error counter value latched in the time of the last SYNC event. Refer to *Section 12.4.5* for more details about FECAP usage.

Bit 15 **FEDIR**: Frequency error direction

FEDIR is the counting direction of the frequency error counter latched in the time of the last SYNC event. It shows whether the actual frequency is below or above the target.

0: Up-counting direction, the actual frequency is above the target

1: Down-counting direction, the actual frequency is below the target

Bits 14:11 Reserved, must be kept at reset value.

Bit 10 **TRIMOVF**: Trimming overflow or underflow

This flag is set by hardware when the automatic trimming tries to over- or under-flow the TRIM value. An interrupt is generated if the ERRIE bit is set in the CRS_CR register. It is cleared by software by setting the ERRC bit in the CRS_ICR register.

0: No trimming error signaled

1: Trimming error signaled

Bit 9 **SYNCMISS**: SYNC missed

This flag is set by hardware when the frequency error counter reaches value FELIM * 128 and no SYNC is detected, meaning either that a SYNC pulse was missed, or the frequency error is too big (internal frequency too high) to be compensated by adjusting the TRIM value, hence some other action must be taken. At this point, the frequency error counter is stopped (waiting for a next SYNC), and an interrupt is generated if the ERRIE bit is set in the CRS_CR register. It is cleared by software by setting the ERRC bit in the CRS_ICR register.

0: No SYNC missed error signaled

1: SYNC missed error signaled

Bit 8 **SYNCERR**: SYNC error

This flag is set by hardware when the SYNC pulse arrives before the ESYNC event and the measured frequency error is greater than or equal to FELIM * 128. This means that the frequency error is too big (internal frequency too low) to be compensated by adjusting the TRIM value, and that some other action has to be taken. An interrupt is generated if the ERRIE bit is set in the CRS_CR register. It is cleared by software by setting the ERRC bit in the CRS_ICR register.

0: No SYNC error signaled

1: SYNC error signaled

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **ESYNCF**: Expected SYNC flag

This flag is set by hardware when the frequency error counter reached a zero value. An interrupt is generated if the ESYNCIE bit is set in the CRS_CR register. It is cleared by software by setting the ESYNCC bit in the CRS_ICR register.

0: No expected SYNC signaled

1: Expected SYNC signaled

Bit 2 **ERRF**: Error flag

This flag is set by hardware in case of any synchronization or trimming error. It is the logical OR of the TRIMOVF, SYNCMISS and SYNCERR bits. An interrupt is generated if the ERRIE bit is set in the CRS_CR register. It is cleared by software in reaction to setting the ERRC bit in the CRS_ICR register, which clears the TRIMOVF, SYNCMISS and SYNCERR bits.

0: No synchronization or trimming error signaled

1: Synchronization or trimming error signaled

Bit 1 **SYNCWARNF**: SYNC warning flag

This flag is set by hardware when the measured frequency error is greater than or equal to FELIM * 3, but smaller than FELIM * 128. This means that to compensate the frequency error, the TRIM value must be adjusted by two steps or more. An interrupt is generated if the SYNCWARNIE bit is set in the CRS_CR register. It is cleared by software by setting the SYNCWARNC bit in the CRS_ICR register.

0: No SYNC warning signaled

1: SYNC warning signaled

Bit 0 **SYNCOKF**: SYNC event OK flag

This flag is set by hardware when the measured frequency error is smaller than FELIM * 3. This means that either no adjustment of the TRIM value is needed or that an adjustment by one trimming step is enough to compensate the frequency error. An interrupt is generated if the SYNCOKIE bit is set in the CRS_CR register. It is cleared by software by setting the SYNCOKC bit in the CRS_ICR register.

0: No SYNC event OK signaled

1: SYNC event OK signaled

12.7.4 CRS interrupt flag clear register (CRS_ICR)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ESYNCC	ERRC	SYNC WARNC	SYNC OKC
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **ESYNCC**: Expected SYNC clear flag
Writing 1 to this bit clears the ESYNCF flag in the CRS_ISR register.

Bit 2 **ERRC**: Error clear flag
Writing 1 to this bit clears TRIMOVF, SYNCMISS, and SYNCERR bits and consequently also the ERRF flag in the CRS_ISR register.

Bit 1 **SYNCWARNC**: SYNC warning clear flag
Writing 1 to this bit clears the SYNCWARNF flag in the CRS_ISR register.

Bit 0 **SYNCOKC**: SYNC event OK clear flag
Writing 1 to this bit clears the SYNCOKF flag in the CRS_ISR register.

12.7.5 CRS register map

Table 116. CRS register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	CRS_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIM[5:0]						SWSYNC	AUTOTRIMEN	CEN	Res.	ESYNCIE	ERRIE	SYNCWARNIE	SYNCOKIE
	Reset value	0x0000 2000																															
0x04	CRS_CFGR	SYNCPOL	Res.	SYNCSRC[1:0]		Res.	SYNCDIV[2:0]			FELIM[7:0]								RELOAD[15:0]															
	Reset value	0		1	0		0	0	0	0	0	1	0	0	0	1	0	1	0	1	1	1	0	1	1	0	1	1	1	1	1	1	1
0x08	CRS_ISR	FECAP[15:0]																FEDIR	Res.	Res.	Res.	Res.	TRIMOVF	SYNCMISS	SYNCERR	Res.	Res.	Res.	Res.	ESYNCF	ERRF	SYNCWARNF	SYNCOKF
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0					0	0	0	0
0x0C	CRS_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ESYNCC	ERRC	SYNCWARNC	SYNCOKC
	Reset value																													0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

13 General-purpose I/Os (GPIO)

13.1 Introduction

Each general-purpose I/O port has four 32-bit configuration registers (GPIOx_MODER, GPIOx_OTYPER, GPIOx_OSPEEDR and GPIOx_PUPDR), two 32-bit data registers (GPIOx_IDR and GPIOx_ODR), a 16-bit reset register (GPIOx_BRR), and a 32-bit set/reset register (GPIOx_BSRR).

In addition, all GPIOs have a 32-bit locking register (GPIOx_LCKR), two 32-bit alternate function selection registers (GPIOx_AFRH and GPIOx_AFRL), a secure configuration register (GPIOx_SECCFGR), and a high-speed low-voltage register (GPIOx_HSLVR).

13.2 GPIO main features

- Output states: push-pull or open drain + pull-up/down
- Output data from output data register (GPIOx_ODR) or peripheral (alternate function output)
- Speed selection for each I/O
- Input states: floating, pull-up/down, analog
- Input data to input data register (GPIOx_IDR) or peripheral (alternate function input)
- Bit set and reset register (GPIOx_BSRR) for bit-wise write access to GPIOx_ODR
- Lock mechanism (GPIOx_LCKR) provided to freeze the I/O port configurations
- Analog function
- Alternate function selection registers
- Fast toggle capable of changing every two clock cycles
- Highly flexible pin multiplexing allows the use of I/O pins as GPIOs or as one of several peripheral functions
- TrustZone security support (each I/O pin of the GPIO port can be individually configured as secure)
- I/Os state retention during Standby mode

13.3 GPIO functional description

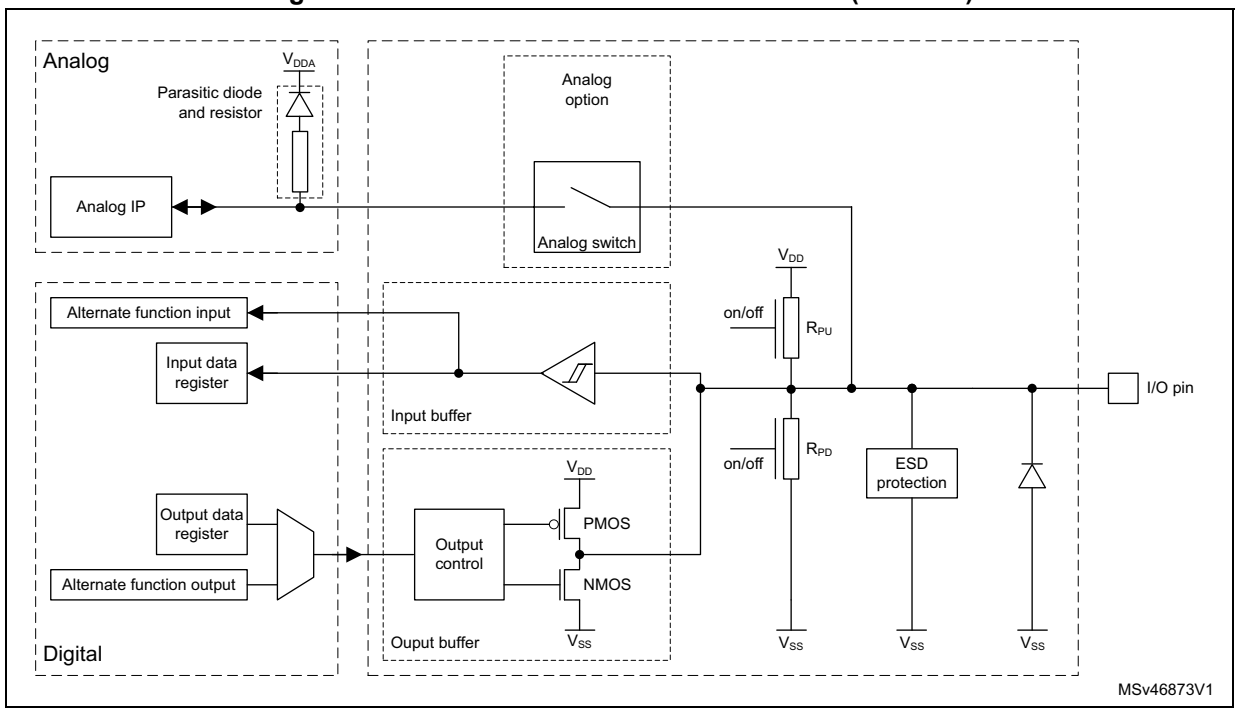
Subject to the specific hardware characteristics of each I/O port listed in the datasheet, each port bit of the general-purpose I/O (GPIO) ports can be individually configured by software in several modes:

- Input floating
- Input pull-up
- Input-pull-down
- Analog
- Output open-drain with pull-up or pull-down capability
- Output push-pull with pull-up or pull-down capability
- Alternate function push-pull with pull-up or pull-down capability
- Alternate function open-drain with pull-up or pull-down capability

Each I/O port bit is freely programmable, however the I/O port registers must be accessed as 32-bit words, half-words, or bytes. The GPIOx_BSRR and GPIOx_BRR registers allow atomic read/modify accesses to any of the GPIOx_ODR registers. In this way, there is no risk of an IRQ occurring between the read and the modify access.

The figure below shows the basic structure of a 3- or 5-V tolerant GPIO (TT or FT). *Table 117* gives the possible port bit configurations.

Figure 59. Structure of 3- or 5-V tolerant GPIO (TT or FT)



Note: On a TT GPIO, the analog switch is not present, it is replaced by a direct connection. The analog bloc parasitic circuitry does not allow 5-V tolerance.

Table 117. Port bit configuration(1)

MODE(i)[1:0]	OTYPE(i)	OSPEED(i)[1:0]	PUPD(i)[1:0]		I/O configuration	
01	0	SPEED[1:0]	0	0	GP output	PP
	0		0	1	GP output	PP + PU
	0		1	0	GP output	PP + PD
	0		1	1	Reserved	
	1		0	0	GP output	OD
	1		0	1	GP output	OD + PU
	1		1	0	GP output	OD + PD
	1		1	1	Reserved (GP output OD)	

Table 117. Port bit configuration[1] (continued)

MODE(i)[1:0]	OTYPE(i)	OSPEED(i)[1:0]		PUPD(i)[1:0]		I/O configuration	
10	0	SPEED[1:0]		0	0	AF	PP
	0			0	1	AF	PP + PU
	0			1	0	AF	PP + PD
	0			1	1	Reserved	
	1			0	0	AF	OD
	1			0	1	AF	OD + PU
	1			1	0	AF	OD + PD
	1			1	1	Reserved	
00	x	x	x	0	0	Input	Floating
	x	x	x	0	1	Input	PU
	x	x	x	1	0	Input	PD
	x	x	x	1	1	Reserved (input floating)	
11	x	x	x	0	0	Input/output	Analog
	x	x	x	0	1	Reserved	
	x	x	x	1	0	Input/output	Analog, PD
	x	x	x	1	1	Reserved	

1. GP = general-purpose, PP = push-pull, PU = pull-up, PD = pull-down, OD = open-drain, AF = alternate function.

13.3.1 General-purpose I/O (GPIO)

During and just after reset, the alternate functions are not active and most of the I/O ports are configured in analog mode.

The debug pins are in AF pull-up/pull-down after reset:

- PA15: JTDI in pull-up
- PA14: JTCK/SWCLK in pull-down
- PA13: JTMS/SWDIO in pull-up
- PB4: NJTRST in pull-up
- PB3: JTDO/TRACESWO in floating state no pull-up/pull-down

BOOT0 is in input mode during the reset until at least the end of the option byte loading phase (see *Section 13.3.15*).

When the pin is configured as output, the value written to the output data register (GPIOx_ODR) is output on the I/O pin. It is possible to use the output driver in push-pull mode or open-drain mode (only the low level is driven, the high level is high-Z).

The input data register (GPIOx_IDR) captures the data present on the I/O pin at every AHB clock cycle.

All GPIO pins have weak internal pull-up and pull-down resistors, which can be activated or not, depending upon the value in the GPIOx_PUPDR register.

13.3.2 I/O pin alternate function multiplexer and mapping

The device I/O pins are connected to on-board peripherals/modules through a multiplexer that allows only one peripheral alternate function (AF) connected to an I/O pin at a time. In this way, there is no conflict between peripherals available on the same I/O pin.

Each I/O pin has a multiplexer with up to 16 alternate function inputs (AF0 to AF15) that can be configured through the GPIOx_AFRL (for pin 0 to 7) and GPIOx_AFRH (for pin 8 to 15) registers:

- After reset, the multiplexer selection is alternate function 0 (AF0). The I/Os are configured in alternate function mode through the GPIOx_MODER register.
- The specific alternate function assignments for each pin are detailed in the device datasheet.

In addition to this flexible I/O multiplexing architecture, each peripheral has alternate functions mapped onto different I/O pins to optimize the number of peripherals available in smaller packages.

To use an I/O in a given configuration, the user must proceed as follows:

- **Debug function**: after each device reset these pins are assigned as alternate function pins immediately usable by the debugger host.
- **GPIO**: configure the desired I/O as output, input, or analog in the GPIOx_MODER register.
- **Peripheral alternate function**:
  - Connect the I/O to the desired AFx in one of the GPIOx_AFRL or GPIOx_AFRH register.
  - Select the type, pull-up/pull-down, and output speed via the GPIOx_OTYPER, GPIOx_PUPDR and GPIOx_OSPEEDR registers respectively.
  - Configure the desired I/O as an alternate function in the GPIOx_MODER register.
- **Cortex®-M33 alternate function (EVENTOUT)**
  - The Cortex®-M33 output EVENTOUT signal can be output as alternate function on I/O pin. An event can be signaled through the configured pin after executing SEV instruction
  - EVENTOUT signal can be used internally as a trigger for some peripherals (see *Section Table 125.: Peripherals interconnect matrix*)
- **Additional functions:**
  - For the ADC and DAC, configure the desired I/O in analog mode in the GPIOx_MODER register and configure the required function in the ADC and DAC registers.
  - For the additional functions like RTC, WKUPx, and oscillators, configure the required functions in the related RTC, PWR, and RCC registers. These functions have priority over the configuration in the standard GPIO registers.

Refer to the “Alternate function mapping” table in the device datasheet for the detailed mapping of the alternate function I/O pins.

13.3.3 I/O port control registers

Each of the GPIO ports has four 32-bit memory-mapped control registers (GPIOx_MODER, GPIOx_OTYPER, GPIOx_OSPEEDR, GPIOx_PUPDR) to configure up to 16 I/Os.

- GPIOx_MODER is used to select the I/O mode (input, output, AF, analog).
- GPIOx_OTYPER and GPIOx_OSPEEDR are used to select the output type (push-pull or open-drain) and speed.
- GPIOx_PUPDR is used to select the pull-up/pull-down whatever the I/O direction.

13.3.4 I/O port data registers

Each GPIO has two 16-bit memory-mapped data registers: input and output data registers (*GPIO port input data register (GPIOx_IDR) (x = A to K)* and *GPIO port output data register (GPIOx_ODR) (x = A to K)*).

GPIOx_ODR stores the data to be output, it is read/write accessible. The data entered through the I/Os are stored into the input data register (GPIOx_IDR), a read-only register.

13.3.5 I/O data bitwise handling

The bit set reset register (GPIOx_BSRR) is a 32-bit register that allows the application to set and reset each individual bit in the output data register (GPIOx_ODR). The bit set reset register has twice the size of GPIOx_ODR.

To each bit in GPIOx_ODR, correspond two control bits in GPIOx_BSRR: BS(i) and BR(i). When written to 1, BS(i) sets the corresponding ODR(i) bit. When written to 1, BR(i) resets the ODR(i) corresponding bit.

Writing any bit to 0 in GPIOx_BSRR does not have any effect on the corresponding bit in GPIOx_ODR. If there is an attempt to both set and reset a bit in GPIOx_BSRR, the set action takes priority.

Using the GPIOx_BSRR register to change the values of individual bits in GPIOx_ODR is a “one-shot” effect that does not lock the GPIOx_ODR bits. The GPIOx_ODR bits can always be accessed directly. The GPIOx_BSRR register provides a way of performing atomic bitwise handling.

There is no need for the software to disable interrupts when programming the GPIOx_ODR at bit level: one or more bits can be modified in a single atomic AHB write access.

13.3.6 GPIO locking mechanism

The GPIO control registers can be frozen by applying a specific write sequence to the GPIOx_LCKR register. The frozen registers are GPIOx_MODER, GPIOx_OTYPER, GPIOx_OSPEEDR, GPIOx_PUPDR, GPIOx_AFRL, GPIOx_AFRH and GPIOx_HSLVR.

To write the GPIOx_LCKR register, a specific write/read sequence must be applied. When the right LOCK sequence is applied to the bit 16 in this register, the value of LCKR[15:0] is used to lock the configuration of the I/Os (during the write sequence the LCKR[15:0] value must be the same). When the LOCK sequence is applied to a port bit, the value of the port bit can no longer be modified until the next MCU reset or peripheral reset. Each GPIOx_LCKR bit freezes the corresponding bit in the control registers (GPIOx_MODER, GPIOx_OTYPER, GPIOx_OSPEEDR, GPIOx_PUPDR, GPIOx_AFRL and GPIOx_AFRH.

The LOCK sequence can be performed only using a word (32-bit long) access to the GPIOx_LCKR register, because GPIOx_LCKR bit 16 must be set at the same time as the [15:0] bits.

13.3.7 I/O alternate function input/output

Two registers are provided to select one of the alternate function inputs/outputs available for each I/O. With these registers, the user can connect an alternate function to some other pin as required by the application.

This means that some peripheral functions are multiplexed on each GPIO using the GPIOx_AFRL and GPIOx_AFRH alternate function registers. The application can thus select any one of the possible functions for each I/O. The AF selection signal being common to the alternate function input and alternate function output, a single channel is selected for the alternate function input/output of a given I/O.

To know which functions are multiplexed on each GPIO pin, refer to the device datasheet.

13.3.8 External interrupt/wakeup lines

All ports have external interrupt capability. To use external interrupt lines, the port can be configured in input, output, or alternate function mode (the port must not be configured in analog mode). Refer to *Section 20: Extended interrupts and event controller (EXTI)*.

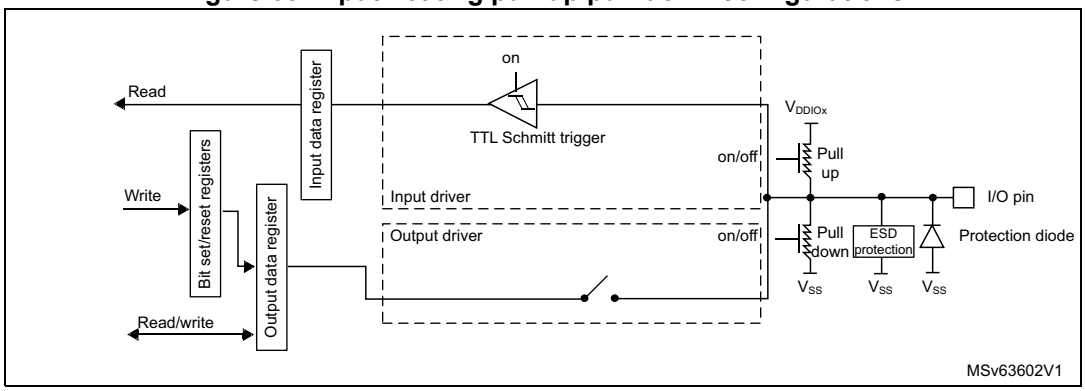
13.3.9 Input configuration

When the I/O port is programmed as input:

- The output buffer is disabled.
- The Schmitt trigger input is activated.
- The pull-up and pull-down resistors are activated depending on the value in the GPIOx_PUPDR register.
- The data present on the I/O pin are sampled into the input data register every AHB clock cycle.
- A read access to the input data register provides the I/O state.

The figure below shows the input configuration of the I/O port bit.

Figure 60. Input floating/pull-up/pull-down configurations



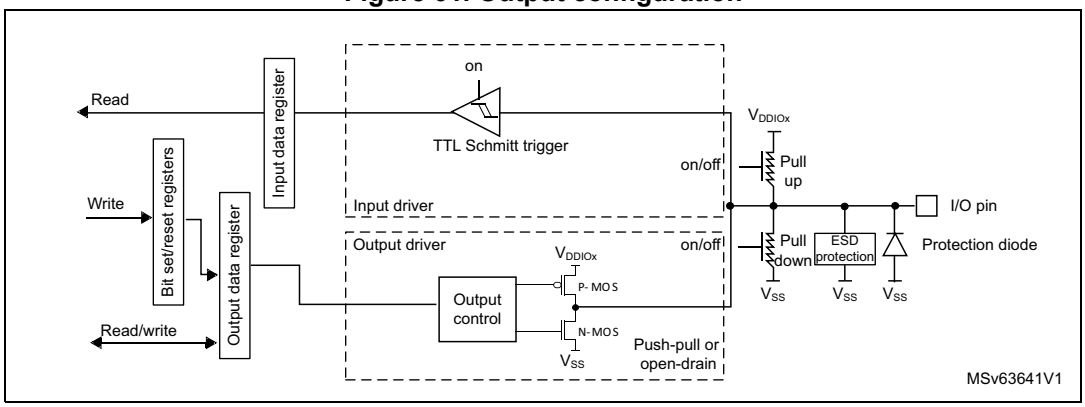
13.3.10 Output configuration

When the I/O port is programmed as output:

- The output buffer is enabled:
  - Open-drain mode: a 0 in the output register activates the N-MOS whereas a 1 in the output register leaves the port in high-Z (the P-MOS is never activated).
  - Push-pull mode: a 0 in the output register activates the N-MOS whereas a 1 in the output register activates the P-MOS.
- The Schmitt trigger input is activated.
- The pull-up and pull-down resistors are activated depending on the value in the GPIOx_PUPDR register.
- The data present on the I/O pin are sampled into the input data register every AHB clock cycle.
- A read access to the input data register gets the I/O state.
- A read access to the output data register gets the last written value.

The figure below shows the output configuration of the I/O port bit.

Figure 61. Output configuration



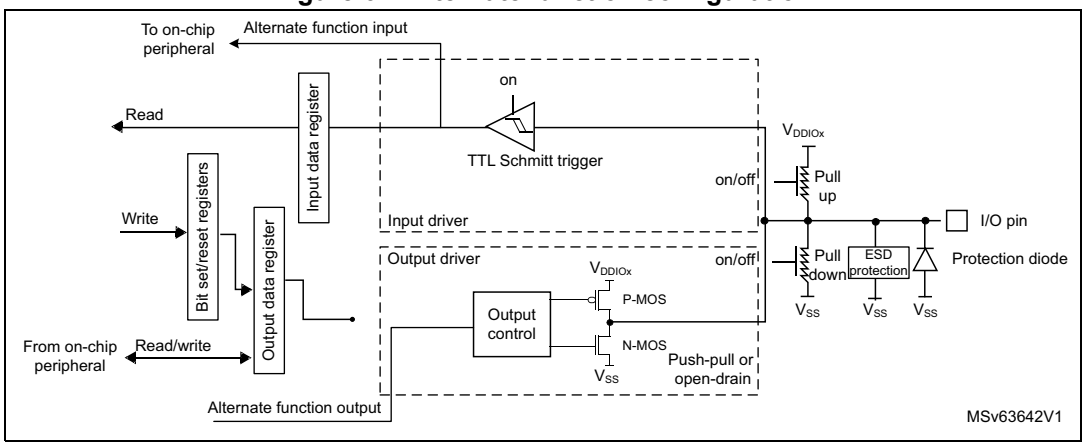
13.3.11 Alternate function configuration

When the I/O port is programmed as an alternate function:

- The output buffer can be configured in open-drain or push-pull mode.
- The output buffer is driven by the signals coming from the peripheral (transmitter enable and data).
- The Schmitt trigger input is activated.
- The weak pull-up and pull-down resistors are activated or not depending on the value in the GPIOx_PUPDR register.
- The data present on the I/O pin are sampled into the input data register every AHB clock cycle.
- A read access to the input data register gets the I/O state.

The figure below shows the alternate function configuration of the I/O port bit.

Figure 62. Alternate function configuration



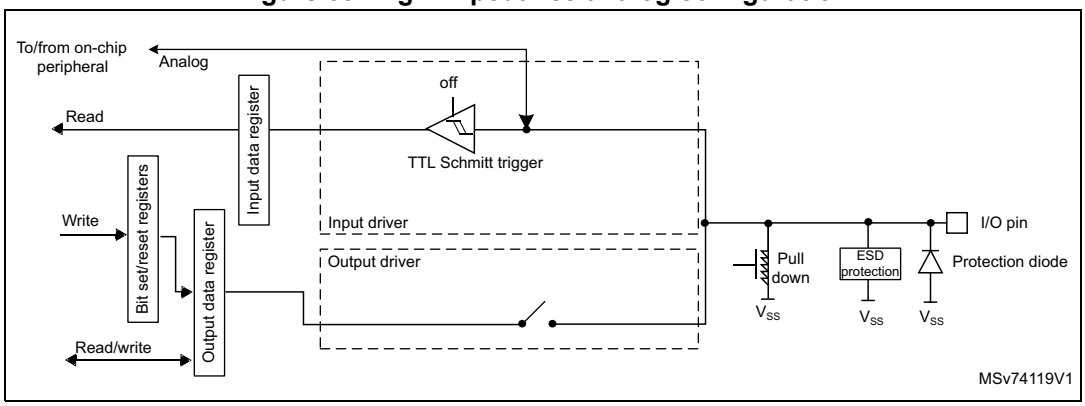
13.3.12 Analog configuration

When the I/O port is programmed as an analog configuration:

- The output buffer is disabled.
- The Schmitt trigger input is deactivated, providing zero consumption for every analog value of the I/O pin. The output of the Schmitt trigger is forced to a constant value (0).
- The weak pull-up is disabled by hardware. The weak pull-down is configurable.
- Read access to the input data register gets the value 0.

The figure below shows the high-Z, analog-input configuration of the I/O port bits.

Figure 63. High-impedance analog configuration



13.3.13 Using the HSE or LSE oscillator pins as GPIOs

When the HSE or LSE oscillator is switched off (default state after reset), the related oscillator pins can be used as normal GPIOs.

When the HSE or LSE oscillator is switched on (by setting the HSEON or LSEON bit in the RCC_CSR register), the oscillator takes control of its associated pins and the GPIO configuration of these pins has no effect.

When the oscillator is configured in a user external clock mode, only the pin is reserved for clock input, and the OSC_OUT or OSC32_OUT pin can still be used as a normal GPIO.

13.3.14 Using the GPIO pins in the RTC supply domain

The PC13/PC14/PC15/PI8 GPIO functionality is lost when the core supply domain is powered off (when the device enters Standby mode). In this case, if their GPIO configuration is not bypassed by the RTC configuration, these pins are set in an analog input mode.

For details about I/O control by the RTC, refer to *Section 57: Real-time clock (RTC)*.

13.3.15 I/Os state retention during standby mode

In the Standby mode, the I/Os are by default in a floating state.

If the IORETEN bit in the PWR_IORETR register is set, the I/Os state is sampled during standby entry. The state of I/Os is applied to the pin via pull-up and pull-down resistors. The pull-up and pull-down resistors remains applied after Standby wake-up until the IORETEN bit in the PWR_IORETR register is cleared by software.

13.3.16 TrustZone security

The TrustZone security is activated by the TZEN option byte in the FLASH option byte register. When the TrustZone is active (TZEN = 0xB4), each I/O pin of the GPIO port can be individually configured as secure through the GPIOx_SECCFGR register.

When the selected I/O pin is configured as secure, its corresponding configuration bits for alternate function, mode selection, I/O data are secure against a nonsecure access. In case of nonsecure access, these bits are RAZ/WI.

The I/Os with peripherals functions are also conditioned by the peripheral security configuration (see *Section 5: Global TrustZone® controller (GTZC)*, for more details):

- For peripherals for which the I/O pin selection is done through alternate functions registers: if the peripheral is configured as secure, it cannot be connected to a nonsecure I/O pin. If this is not respected, the input data to the secure peripheral is forced to 0 (the I/O input pin value is ignored) and the output pin value is forced to 0, thus avoiding any secure information leak through nonsecure I/Os.
- For I/Os with analog switches, directly controlled by peripherals (such as the ADC for instance): If the I/O is secure, the I/O analog switch cannot be controlled by a nonsecure peripheral. If this is not respected, the switch remains open. This prevents the redirection of secure data to a nonsecure peripheral or I/O through the analog path. Refer to *Section 3: System security*, for more details.
- Some of the paths between I/Os “additional functions” and peripherals are not blocked if the I/O is secure and the peripheral is nonsecure. Therefore, it is recommended to configure those peripherals as secure even when not used by the application. Refer to *Section 3: System security*, for the list of concerned peripherals. When the path has a security control, it follows the same rule as I/O selection through alternate functions.

Refer to the device pins definition table in the datasheet for more information about peripheral alternate functions and additional functions mapping.

After reset, all GPIO ports are secure.

The table below gives a summary of the I/O port-secured bits following the security configuration bit in the GPIO_SECCFGR register. When the I/O bit port is configured as secure:

- Secured bits: read and write operations are only allowed by a secure access. nonsecure-read or write accesses on secured bits are RAZ/WI. There is no illegal access event generated.
- Nonsecure bits: no restriction. Read and write operations are allowed by both secure and nonsecure accesses.

When the TrustZone security is disabled (TZEN = 0xC3 in FLASH_OPTSR2 register), all registers bits are nonsecure. The GPIOx_SECCFGR register is RAZ/WI.

Table 118. GPIO secured bits

Secure configuration bit	Secured bit	Register name	nonsecure access on secure bits
SECy = 1 in GPIOx_SECCFGR(1)	MODEy[1:0]	GPIOx_MODER	RAZ/WI
	OTy	GPIOx_OTYPER	
	OSPEEDy[1:0]	GPIOx_OSPEEDR	
	PUPDy[1:0]	GPIOx_PUPDR	
	IDy	GPIOx_IDR	
	ODy	GPIOx_ODR	
	BSy and BRy	GPIOx_BSRR	
	LCKy	GPIOx_LCKR	
	BRy	GPIOx_BRR	
	AFSELy[3:0]	GPIOx_AFRH	
		GPIOx_AFRL	
	HSLVy	GPIOx_HSLVR	

1. The number of GPIOx ports varies depending on packages. Refer to the product datasheet for availability of a particular port.

13.3.17 Privileged and unprivileged modes

All GPIO registers can be read and written by privileged and unprivileged accesses, whatever the security state (secure or nonsecure).

13.3.18 High-speed low-voltage mode (HSLV)

Some I/Os have the capability to increase their maximum speed at low voltage by configuring them in HSLV mode. The I/O HSLV bit controls whether the I/O output speed is optimized to operate at 3.3 V (default setting) or at 1.8 V (HSLV = 1).

Caution: The I/O HSLV configuration bit must not be set if the I/O supply (V_{DD} or V_{DDIO2}) is above 2.7 V. Setting it while the voltage is higher than 2.7 V can damage the device. The I/O HSLV bit can be set only when the corresponding option bit is activated (IO_VDD_HSLV or IO_VDDIO2_HSLV depending on the I/O supply, refer to *Section 7.4: FLASH option bytes*). There is no hardware protection associated to this feature so it is recommended to use it only as a static configuration for fixed I/O supply.

Caution: HSLVy bits in GPIOx_HLSVR must be programmed with the same value within the following pairs: PB4/PB5, PG7/PG8. Each of these pairs can be used as differential clock for the OCTOSPIs.

13.3.19 I/O compensation cell

The I/O commutation slew rate (tfall / trise) can be adapted by software depending on process, voltage and temperature conditions, to reduce the I/O noise on the power supply. Refer to *Section 14: System configuration, boot, and security (SBS)* for more details.

13.4 GPIO registers

This section gives a detailed description of the GPIO registers.

The peripheral registers can be written in word, half-word, or byte mode. The number of GPIOx ports varies depending on packages. Refer to the product datasheet for availability of a particular port.

13.4.1 GPIO port mode register (GPIOx_MODER) (x = A to K)

Address offset: 0x00

Reset value: 0xABFF FFFF (for port A)

Reset value: 0xFFFF FEBF (for port B)

Reset value: 0xFFFF FFFF (for the other ports)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MODE15[1:0]		MODE14[1:0]		MODE13[1:0]		MODE12[1:0]		MODE11[1:0]		MODE10[1:0]		MODE9[1:0]		MODE8[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MODE7[1:0]		MODE6[1:0]		MODE5[1:0]		MODE4[1:0]		MODE3[1:0]		MODE2[1:0]		MODE1[1:0]		MODE0[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MODEy[1:0]:** Port x configuration I/O pin y (y = 15 to 0)

These bits are written by software to configure the I/O mode.

00: Input mode

01: General purpose output mode

10: Alternate function mode

11: Analog mode (reset state)

Note: The bitfield is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.2 GPIO port output type register (GPIOx_OTYPER) (x = A to K)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OT15	OT14	OT13	OT12	OT11	OT10	OT9	OT8	OT7	OT6	OT5	OT4	OT3	OT2	OT1	OT0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **OTy:** Port x configuration I/O pin y (y = 15 to 0)

These bits are written by software to configure the I/O output type.

0: Output push-pull (reset state)

1: Output open-drain

Note: The bit is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.3 GPIO port output speed register (GPIOx_OSPEEDR) (x = A to K)

Address offset: 0x08

Reset value: 0x0C00 0000 (for port A)

Reset value: 0x0000 00C0 (for port B)

Reset value: 0x0000 0000 (for the other ports)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OSPEED15[1:0]		OSPEED14[1:0]		OSPEED13[1:0]		OSPEED12[1:0]		OSPEED11[1:0]		OSPEED10[1:0]		OSPEED9[1:0]		OSPEED8[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OSPEED7[1:0]		OSPEED6[1:0]		OSPEED5[1:0]		OSPEED4[1:0]		OSPEED3[1:0]		OSPEED2[1:0]		OSPEED1[1:0]		OSPEED0[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **OSPEEDy[1:0]**: Port x configuration I/O pin y (y = 15 to 0)

These bits are written by software to configure the I/O output speed.

00: Low speed

01: Medium speed

10: High speed

11: Very-high speed

Note: Refer to the device datasheet for the frequency specifications, the power supply, and the load conditions for each speed.

The bitfield is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.4 GPIO port pull-up/pull-down register (GPIOx_PUPDR) (x = A to K)

Address offset: 0x0C

Reset value: 0x6400 0000 (for port A)

Reset value: 0x0000 0100 (for port B)

Reset value: 0x0000 0000 (for the other ports)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PUPD15[1:0]		PUPD14[1:0]		PUPD13[1:0]		PUPD12[1:0]		PUPD11[1:0]		PUPD10[1:0]		PUPD9[1:0]		PUPD8[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PUPD7[1:0]		PUPD6[1:0]		PUPD5[1:0]		PUPD4[1:0]		PUPD3[1:0]		PUPD2[1:0]		PUPD1[1:0]		PUPD0[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PUPDy[1:0]:** Port x configuration I/O pin y (y = 15 to 0)

These bits are written by software to configure the I/O pull-up or pull-down

00: No pull-up, pull-down

01: Pull-up

10: Pull-down

11: Reserved

Note: The bitfield is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.5 GPIO port input data register (GPIOx_IDR) (x = A to K)

Address offset: 0x10

Reset value: 0x0000 XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ID15	ID14	ID13	ID12	ID11	ID10	ID9	ID8	ID7	ID6	ID5	ID4	ID3	ID2	ID1	ID0
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **IDy:** Port x input data I/O pin y (y = 15 to 0)

These bits are read-only. They contain the input value of the corresponding I/O port.

Note: The bit is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.6 GPIO port output data register (GPIOx_ODR) (x = A to K)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OD15	OD14	OD13	OD12	OD11	OD10	OD9	OD8	OD7	OD6	OD5	OD4	OD3	OD2	OD1	OD0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **ODy:** Port output data I/O pin y (y = 15 to 0)

These bits can be read and written by software.

Note: For atomic bit set/reset, the OD bits can be individually set and/or reset by writing to the GPIOx_BSRR or GPIOx_BRR registers (x = A to I).

The bit is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.7 GPIO port bit set/reset register (GPIOx_BSRR) (x = A to K)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BR15	BR14	BR13	BR12	BR11	BR10	BR9	BR8	BR7	BR6	BR5	BR4	BR3	BR2	BR1	BR0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BS15	BS14	BS13	BS12	BS11	BS10	BS9	BS8	BS7	BS6	BS5	BS4	BS3	BS2	BS1	BS0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 **BRy:** Port x reset I/O pin y (y = 15 to 0)

These bits are write-only. A read to these bits returns the value 0x0000.

0: No action on the corresponding ODy bit

1: Resets the corresponding ODy bit

Note: If both BSy and BRy are set, BSy has priority.

The bit is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

Bits 15:0 **BSy:** Port x set I/O pin y (y = 15 to 0)

These bits are write-only. A read to these bits returns the value 0x0000.

0: No action on the corresponding ODy bit

1: Sets the corresponding ODy bit

Note: The bit is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.8 GPIO port configuration lock register (GPIOx_LCKR) (x = A to K)

Address offset: 0x1C

Reset value: 0x0000 0000

This register is used to lock the configuration of the port bits when a correct write sequence is applied to bit 16 (LCKK). The value of bits [15:0] is used to lock the configuration of the GPIO. During the write sequence, the value of LCKR[15:0] must not change. When the LOCK sequence has been applied on a port bit, the value of this port bit can no longer be modified until the next MCU reset or peripheral reset.

Note: A specific write sequence is used to write to the GPIOx_LCKR register. Only word access (32-bit long) is allowed during this locking sequence.

Each bit freezes a specific configuration register (control and alternate function registers).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LCKK
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LCK15	LCK14	LCK13	LCK12	LCK11	LCK10	LCK9	LCK8	LCK7	LCK6	LCK5	LCK4	LCK3	LCK2	LCK1	LCK0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **LCKK:** Lock key

This bit can be read any time. It can only be modified using the lock key write sequence.

0: Port configuration lock key not active

1: Port configuration lock key active. The GPIOx_LCKR register is locked until the next MCU reset or peripheral reset.

- LOCK key write sequence:

WR LCKR[16] = 1 + LCKR[15:0]

WR LCKR[16] = 0 + LCKR[15:0]

WR LCKR[16] = 1 + LCKR[15:0]

- LOCK key read

RD LCKR[16] = 1 (this read operation is optional but it confirms that the lock is active)

Note: During the LOCK key write sequence, the value of LCK[15:0] must not change.

Any error in the lock sequence aborts the LOCK.

After the first LOCK sequence on any bit of the port, any read access on the LCKK bit returns 1 until the next MCU reset or peripheral reset.

Bits 15:0 **LCKy:** Port x lock I/O pin y (y = 15 to 0)

These bits are read/write but can only be written when the LCKK bit is 0

0: Port configuration not locked

1: Port configuration locked

Note: The bit is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.9 GPIO alternate function low register (GPIOx_AFRL) (x = A to K)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AFSEL7[3:0]				AFSEL6[3:0]				AFSEL5[3:0]				AFSEL4[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AFSEL3[3:0]				AFSEL2[3:0]				AFSEL1[3:0]				AFSEL0[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **AFSELy[3:0]:** Alternate function selection for port x I/O pin y (y = 7 to 0)
These bits are written by software to configure alternate function I/Os.
0000: AF0
0001: AF1
0010: AF2
0011: AF3
0100: AF4
0101: AF5
0110: AF6
0111: AF7
1000: AF8
1001: AF9
1010: AF10
1011: AF11
1100: AF12
1101: AF13
1110: AF14
1111: AF15

Note: The bitfield is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.10 GPIO alternate function high register (GPIOx_AFRH) (x = A to K)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AFSEL15[3:0]				AFSEL14[3:0]				AFSEL13[3:0]				AFSEL12[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AFSEL11[3:0]				AFSEL10[3:0]				AFSEL9[3:0]				AFSEL8[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **AFSELy[3:0]:** Alternate function selection for port x I/O pin y (y = 15 to 8)
These bits are written by software to configure alternate function I/Os.
0000: AF0
0001: AF1
0010: AF2
0011: AF3
0100: AF4
0101: AF5
0110: AF6
0111: AF7
1000: AF8
1001: AF9
1010: AF10
1011: AF11
1100: AF12
1101: AF13
1110: AF14
1111: AF15

Note: The bitfield is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.11 GPIO port bit reset register (GPIOx_BRR) (x = A to K)

Address offset: 0x28

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BR15	BR14	BR13	BR12	BR11	BR10	BR9	BR8	BR7	BR6	BR5	BR4	BR3	BR2	BR1	BR0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **BRy:** Port x reset IO pin y (y = 15 to 0)
These bits are write-only. A read to these bits returns the value 0x0000.
0: No action on the corresponding ODy bit
1: Reset the corresponding ODy bit

Note: The bit is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.12 GPIO high-speed low-voltage register (GPIOx_HSLVR) (x = A to K)

Address offset: 0x2C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HSLV15	HSLV14	HSLV13	HSLV12	HSLV11	HSLV10	HSLV9	HSLV8	HSLV7	HSLV6	HSLV5	HSLV4	HSLV3	HSLV2	HSLV1	HSLV0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **HSLVy:** Port x high-speed low-voltage configuration (y = 15 to 0)

These bits are written by software to optimize the I/O speed when the I/O supply is low. Each bit is active only if the corresponding IO_VDD_HSLV/IO_VDDIO2_HSLV user option bit is set. It must be used only if the I/O supply voltage is below 2.7 V.

Setting these bits when the I/O supply (VDD or VDDIO2) is higher than 2.7 V may be destructive.

0: I/O speed optimization disabled

1: I/O speed optimization enabled

Note: Not all I/Os support the HSLV mode. Refer to the I/O structure in the corresponding datasheet for the list of I/Os supporting this feature. Other I/Os HSLV configuration must be kept at reset value.

The bit is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.13 GPIO secure configuration register (GPIOx_SECCFGR) (x = A to K)

Address offset: 0x30

Reset value: 0x0000 FFFF (for ports A to K)

When the system is secure (TZEN = 0xB4), this register provides write access security and can be written only by a secure access. It is used to configure a selected I/O as secure. A nonsecure write access to this register is discarded.

When the system is not secure (TZEN = 0xC3), this register is RAZ/WI.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEC15	SEC14	SEC13	SEC12	SEC11	SEC10	SEC9	SEC8	SEC7	SEC6	SEC5	SEC4	SEC3	SEC2	SEC1	SEC0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **SECy**: I/O pin of Port x secure bit enable y (y = 15 to 0)

These bits are written by software to enable or disable the I/O port pin security.

0: The I/O pin is nonsecure

1: The I/O pin is secure. Refer to *Table 118* for all corresponding secured bits.

Note: The bit is reserved and must be kept to reset value when the corresponding I/O is not available on the selected package.

13.4.14 GPIO register map

Table 119. GPIO register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	GPIOx_MODER (x = A to K)	MODE15[1:0]		MODE14[1:0]		MODE13[1:0]		MODE12[1:0]		MODE11[1:0]		MODE10[1:0]		MODE9[1:0]		MODE8[1:0]		MODE7[1:0]		MODE6[1:0]		MODE5[1:0]		MODE4[1:0]		MODE3[1:0]		MODE2[1:0]		MODE1[1:0]		MODE0[1:0]	
	Reset value for port A	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Reset value for port B	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1
	Reset value for others	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x04	GPIOx_OTYPER (x = A to K)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OT15	OT14	OT13	OT12	OT11	OT10	OT9	OT8	OT7	OT6	OT5	OT4	OT3	OT2	OT1	OT0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	GPIOx_OSPEEDR (x = A to K)	OSPEED15[1:0]		OSPEED14[1:0]		OSPEED13[1:0]		OSPEED12[1:0]		OSPEED11[1:0]		OSPEED10[1:0]		OSPEED9[1:0]		OSPEED8[1:0]		OSPEED7[1:0]		OSPEED6[1:0]		OSPEED5[1:0]		OSPEED4[1:0]		OSPEED3[1:0]		OSPEED2[1:0]		OSPEED1[1:0]		OSPEED0[1:0]	
	Reset value for port A	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Reset value for port B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
	Reset value for others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	GPIOx_PUPDR (x = A to K)	PUPD15[1:0]		PUPD14[1:0]		PUPD13[1:0]		PUPD12[1:0]		PUPD11[1:0]		PUPD10[1:0]		PUPD9[1:0]		PUPD8[1:0]		PUPD7[1:0]		PUPD6[1:0]		PUPD5[1:0]		PUPD4[1:0]		PUPD3[1:0]		PUPD2[1:0]		PUPD1[1:0]		PUPD0[1:0]	
	Reset value for port A	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Reset value for port B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	Reset value for others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	GPIOx_IDR (x = A to K)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ID15	ID14	ID13	ID12	ID11	ID10	ID9	ID8	ID7	ID6	ID5	ID4	ID3	ID2	ID1	ID0
	Reset value																	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x14	GPIOx_ODR (x = A to K)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OD15	OD14	OD13	OD12	OD11	OD10	OD9	OD8	OD7	OD6	OD5	OD4	OD3	OD2	OD1	OD0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	GPIOx_BSRR (x = A to K)	BR15	BR14	BR13	BR12	BR11	BR10	BR9	BR8	BR7	BR6	BR5	BR4	BR3	BR2	BR1	BR0	BS15	BS14	BS13	BS12	BS11	BS10	BS9	BS8	BS7	BS6	BS5	BS4	BS3	BS2	BS1	BS0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	GPIOx_LCKR (x = A to K)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LCKK	LCK15	LCK14	LCK13	LCK12	LCK11	LCK10	LCK9	LCK8	LCK7	LCK6	LCK5	LCK4	LCK3	LCK2	LCK1	LCK0
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	GPIOx_AFRL (x = A to K)	AFSEL7[3:0]				AFSEL6[3:0]				AFSEL5[3:0]				AFSEL4[3:0]				AFSEL3[3:0]				AFSEL2[3:0]				AFSEL1[3:0]				AFSEL0[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x24	GPIOx_AFRH (x = A to K)	AFSEL15[3:0]				AFSEL14[3:0]				AFSEL13[3:0]				AFSEL12[3:0]				AFSEL11[3:0]				AFSEL10[3:0]				AFSEL9[3:0]				AFSEL8[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 119. GPIO register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x28	GPIOx_BRR (x = A to K)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BR15	BR14	BR13	BR12	BR11	BR10	BR9	BR8	BR7	BR6	BR5	BR4	BR3	BR2	BR1	BR0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	GPIOx_HSLVR (x = A to K)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSLV15	HSLV14	HSLV13	HSLV12	HSLV11	HSLV10	HSLV9	HSLV8	HSLV7	HSLV6	HSLV5	HSLV4	HSLV3	HSLV2	HSLV1	HSLV0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x30	GPIOx_SECCFGR (x = A to K)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEC15	SEC14	SEC13	SEC12	SEC11	SEC10	SEC9	SEC8	SEC7	SEC6	SEC5	SEC4	SEC3	SEC2	SEC1	SEC0
	Reset value																	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Refer to *Section 2.3* for the register boundary addresses.

14 System configuration, boot, and security (SBS)

14.1 SBS introduction

The STM32H5E4/5F4 and STM32H5E5/5F5 devices feature a set of configuration registers located in the SBS. On top of various device configurations, this SBS peripheral controls key boot and security features, including debug control and secure storage control.

14.2 SBS main features

- System configuration
  - Manage safety features
  - Enable/disable the FMP (fast mode plus) high-drive capability of some I/Os
  - Manage the I/O compensation cell
  - Configure register security access
  - Configuration for Cortex-M33 FPU interrupts
  - Selection and configuration of the Ethernet PHY interface
  - Configure the OTG_HS PHY (only for STM32H5E5x/F5x)
- Boot control
  - Upon system reset, configure the Cortex-M33 boot address and the temporal isolation level depending on the current configuration such as PRODUCT_STATE (sbs_product_state), BOOT_UBE (sbs_irot_select), or TZEN (sbs_tzen).
  - Manage the temporal isolation feature implemented thanks to the hide protect level (HDPL) monotonic counter
- Debug control
  - Control the opening of the device debug interface, ensuring the sequencing of events that guarantee the device security
- Hardware secure storage control
  - Control the secure storage selections: OBK-HDPL selection (selects the area of secure storage of the flash memory and selects the corresponding DHUK in SAES), EPOCH selection
- Security status
  - SRAM and caches erase status

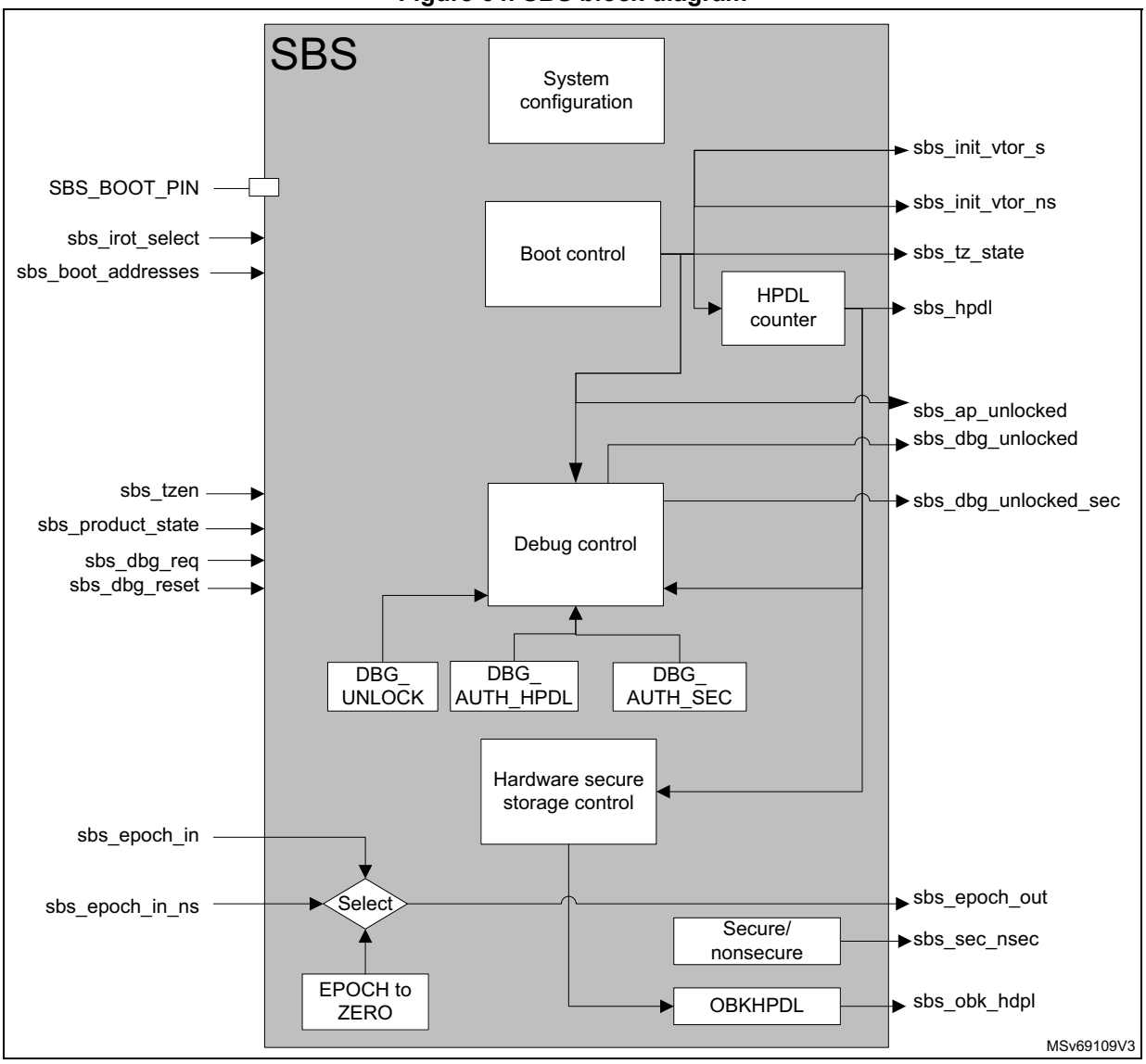
14.3 SBS functional description

14.3.1 SBS block diagram

The figure below shows the SBS block diagram, including the four main functions:

- System configuration
- Boot control
- Debug control
- Hardware secure storage control

Figure 64. SBS block diagram



14.3.2 SBS signals

The table below details the user relevant internal signals that interface the SBS.

Table 120. SBS internal input/output signals

Signal name	Type	Description
BOOT0	Input	Select booting on user flash memory or Bootloader when TrustZone is disabled (TZEN = 0xC3), or on RSS when TrustZone is enabled (TZEN = 0xB4).
sbs_irot_select		Signal based on BOOT_UBE option byte to select the iROT between ST-iROT and user flash memory (OEM-iROT)
sbs_tzen		Signal based on TZEN option byte to activate/deactivate the TrustZone
sbs_boot_addresses		List of addresses defined by the flash memory: – NSBOOTADD: nonsecure boot address – SECBOOTADD: secure boot address
sbs_product_state		Signal based on PRODUCT_STATE option byte to activate the different security mechanisms depending on the product use. Expected values are described in *Section 7: Embedded flash memory (FLASH)*.
sbs_dbg_req		Launch the debug authentication protocol when booting.
sbs_init_vtor_s	Output	Vector address for Cortex-M33 secure entry point
sbs_init_vtor_ns		Vector address for Cortex-M33 nonsecure entry point
sbs_tz_state		Inform the Cortex-M33 on the secure state of the core.
sbs_hdpl		HDPL (temporal isolation level, ID of the boot level, used to isolate boot levels) This signal reflects a monotonic counter that can be incremented from 0 to 3, and that is reset to zero only on software reset or POR.
sbs_ap_unlocked		Control the Cortex-M33 access port.
sbs_dbg_unlocked		Unlock the debug (when set to 1) for the Cortex-M33 nonsecure part.
sbs_dbg_unlocked_sec		Unlock the debug (when set to 1) for the Cortex-M33 secure part.
sbs_dbg_reset	Input	This signal is used to control the reset of the debug authentication configuration to be done with a system reset or a power-on reset. The configuration is done through the DBGMCU using the DCRT bitfield of DBGMCU_CR register.
sbs_obk_hdpl	Output	Select secure storage domain (OBK-HDPL) for current HDPL, or greater ones (to allow provisioning).
sbs_epoch_out		EPOCH counters (NS_EPOCH and SEC_EPOCH, inputs from flash memory) are used to manage the REPLAY protection.
sbs_sec_nsec		Reflect secure/nonsecure selection for the secure storage.

14.3.3 SBS reset and clocks

The SBS configuration port is clocked by the AHB bus clock. There is a general reset and a debug configuration reset controlled in DBGMCU.

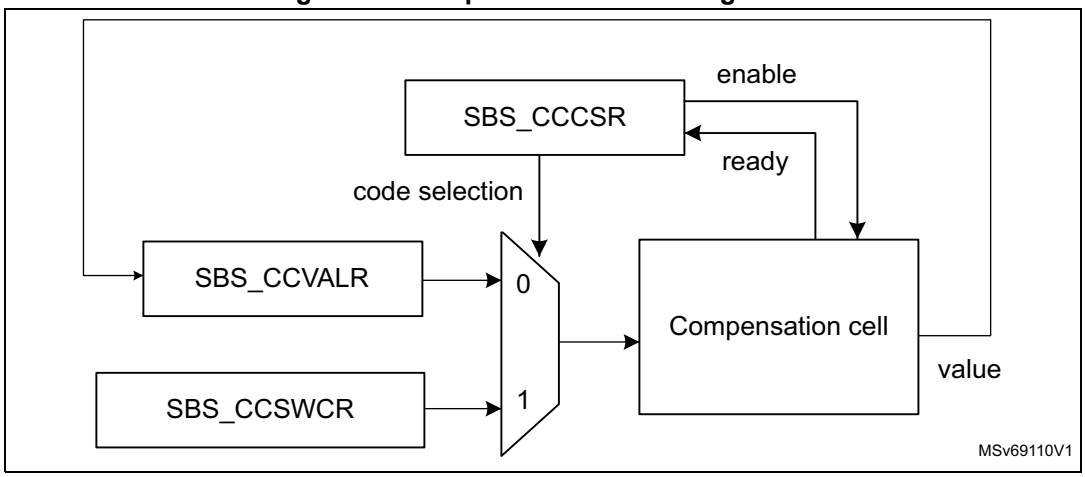
14.3.4 SBS system configuration

SBS I/O compensation cell management

The I/O compensation cell generates an 8-bit value for the I/O buffer (4 bits for N-MOS and 4 bits for P-MOS), that depends on PVT operating conditions (process, voltage, temperature). These bits are used to control the output impedance in the I/O buffer, and the slew rate of the I/O commutation (the t_{fall} and t_{rise} time), to reduce the I/O noise on the power supply.

As shown in the figure below, the compensation cell is split in two blocks: one block to provide an optimal code for the current PVT, and one block to drive the block controlled by the software.

Figure 65. Compensation cell management



The compensation cell value can be read when the READY flag is set in SBS_CCCSR. With CODESEL in SBS_CCCSR, the application can select the value to apply between two options: the code from the cell or the code from SBS_CCSWCR.

Two compensation cells are embedded in STM32H5E4/5F4 and STM32H5E5/5F5 devices:

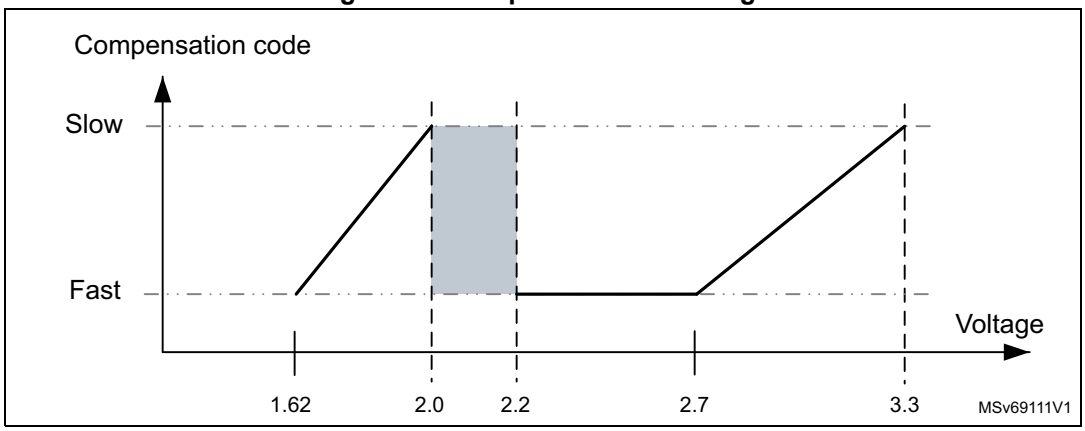
- One for the I/Os supplied by V_{DDIO} power rail
- One for the I/Os supplied by V_{DDIO2} power rail

By default, the compensation cells are disabled, and a fixed code is applied to all the I/Os.

Note: The compensation cell can be used only when 2.7 V ≤ V_{DDIOx} ≤ 3.6 V or 1.62 V ≤ V_{DDIOx} ≤ 2 V (see Figure 66).

Note: The compensation cell can be used only when the CSI oscillator is enabled, see Section 11: Reset and clock control (RCC) for more details on the CSI oscillator.

Figure 66. Compensation cell usage



Configuring the OTG_HS PHY (only for STM32H5E5x/F5x)

To use the OTG_HS PHY, the following configuration steps are required before the configuration of the OTG_HS:

1. Activate clocks in RCC clock gating registers for OTG_HS, and OTG_HS PHY.
2. Configure desired clock settings for OTG_HS PHY using the OTGPHYREFCKSEL[15:12] bitfield in RCC_CCIPR4.
3. Adjust the disconnect threshold by writing 0b010 to COMPDISTUNE bitfield and the squelch threshold by writing 0b000 to SQRXTUNE bitfield in SBS_OTGHSPHYTUNER2.
4. Enable the OTG_HS PHY by setting OTGHSEN in PWR_USBSCR.

SBS TrustZone security and privilege

- SBS TrustZone® security

  When the TrustZone® security is activated, the SBS is able to protect secure registers from being modified by nonsecure accesses.

  The TrustZone® security is activated by the TZEN option byte in FLASH_OPTSR2_PRG.

  A nonsecure read/write access to a secured register is RAZ/WI and generates an illegal access event. An illegal access interrupt is generated if the SBS illegal access event is enabled in the GTZC.

- Privileged/unprivileged mode

  The SBS registers can be read and written by privileged and unprivileged accesses except SBS registers for CPU configuration:

  – SBS_CSLCKR, SBS_FPUIMR and SBS_CNSLCKR
  – FPUSEC in SBS_SECCFGR

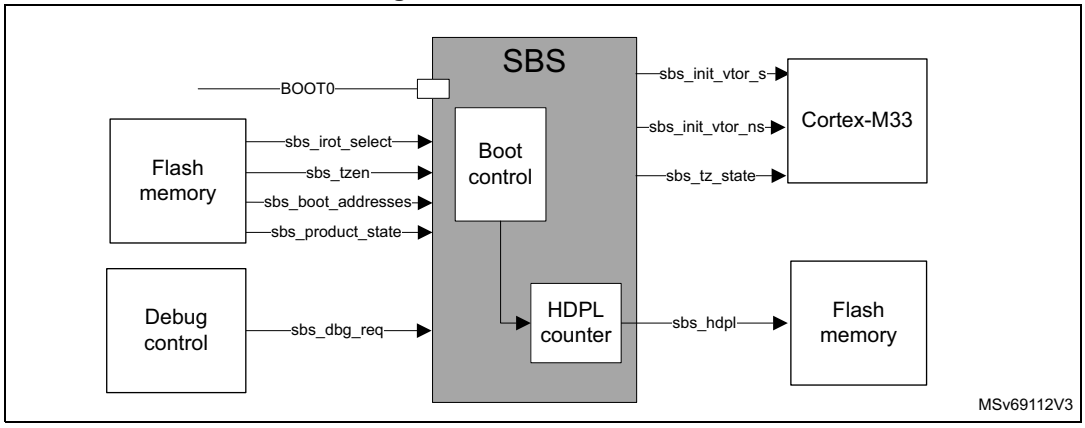
  An unprivileged access to a privileged register is RAZ/WI.

14.3.5 SBS boot control

The SBS can be used to control the boot entry points considering the product settings. The main boot control actions are listed below:

- Run the product with or without TrustZone enabled.
- Select between ST-iROT or OEM-iROT.
- Boot when launching a debug authentication sequence.
- Select boot between the bootloader or the user flash memory boot.
- Initialize the HDPL boot value.

Figure 67. SBS boot control



The boot configurations are selected considering the product settings:

- BOOT0: to select booting on user flash memory or RSS (root secure services)
- BOOT_UBE option byte to select the iROT between ST-iROT and OEM-iROT
- TZEN option byte to activate/deactivate the Trust Zone
- sbs_boot_addresses: list of addresses defined by the flash memory:
  - NSBOOTADD: nonsecure boot address
  - SECBOOTADD: secure boot address
- PRODUCT_STATE: option byte to activate the different security mechanisms depending on the product use. Expected values are described in *Section 7: Embedded flash memory (FLASH)*.
- sbs_dbg_req: used to launch the debug authentication protocol when booting

The boot control logic sets the following data:

- sbs_init_vtor_s: vector address for Cortex-M33 secure entry point
- sbs_init_vtor_ns: vector address for Cortex-M33 nonsecure entry point
- sbs_tz_state (secure/nonsecure): informs the Cortex-M33 on the secure state of the core.
- HDPL (see the description below)

SBS HDPL (temporal isolation level) management

The HDPL is a monotonic counter incremented during the boot stages. The HDPL is reset to its default value only after a power-on or a system reset. This default value (0 or 1) depends on the device life cycle, as defined in boot logic.

The STM32H5E4/5F4 and STM32H5E5/5F5 devices use HDPL information to automatically isolate the code and its associated secrets (like keys) during the boot process. Incrementing HPDL ensures that private code and data for one boot stage cannot be directly accessible from later boot stages.

The HDPL is used by the user flash memory see *Section 7: Embedded flash memory (FLASH)*, for more details. The HDPL can take values from 0 to 3. When reaching the value 3, HDPL keeps this value until reset. The current HDPL value is readable in the HDPL bitfield in SBS_HDPLSR.

To increment the HDPL by one, the application must write 0x6A to INCR_HDPL in SBS_HDPLCR. After such increment, and before doing any subsequent action, the user must check that the HDPL has effectively been incremented reading SBS_HDPLSR.

Table 121. HDPL encoded values

HDPL	Code
0	0xB4
1	0x51
2	0x8A
3	0x6F
	All other values

Table 122. SBS boot logic

Inputs						Outputs			
sbs_product_state	**sbs_dbg_req**	**sbs_tzen**	**sbs_irotselect**	**BOOT0**	**sbs_boot_addresses**	**sbs_init_vtor_s**	**sbs_init_vtor_ns**	**sbs_hdpl**	**sbs_tz_state**
Any except Locked	1	x	x	x	BOOT_DBG_AUTH_ADD	BOOT_DBG_AUTH_ADD	x	1	Secure
Open	0	0	x	0	NSBOOTADD	x	NSBOOTADD	1	Nonsecure
	0	0	x	1	BOOT_ST_RSS_ADD	BOOT_ST_RSS_ADD	x	0	Secure
	0	1	x	0	SECBOOTADD	SECBOOTADD	x	1	secure
	0	1	x	1	BOOT_ST_RSS_ADD	BOOT_ST_RSS_ADD	x	0	Secure
Provisioning	0	x	x	x	BOOT_ST_RSS_ADD	BOOT_ST_RSS_ADD	x	0	Secure

Table 122. SBS boot logic (continued)

Inputs						Outputs			
sbs_product_state	sbs_dbg_req	sbs_tzen	sbs_irotselect	BOOT0	sbs_boot_addresses	sbs_init_vtor_s	sbs_init_vtor_ns	sbs_hdpl	sbs_tz_state
iROT-Provisioned	0	0	x	x	NSBOOTADD	x	NSBOOTADD	1	Nonsecure
	0	1	0	x	BOOT_ST_iROT_ADD	BOOT_ST_iROT_ADD	x	1	Secure
	0	1	1	x	SECBOOTADD	x	SECBOOTADD	1	Secure
TZ-Closed	-	1	0	x	BOOT_ST_iROT_ADD	BOOT_ST_iROT_ADD	x	1	Secure
	-	1	1	x	SECBOOTADD	x	SECBOOT ADD	1	Secure
Closed	0	0	x	x	NSBOOTADD	x	NSBOOT ADD	1	Nonsecure
	0	1	0	x	BOOT_ST_iROT_ADD	BOOT_ST_iROT_ADD	x	1	Secure
	0	1	1	x	SECBOOTADD	x	SECBOOT ADD	1	Secure
Locked	0	0	x	x	NSBOOTADD	x	NSBOOT ADD	1	Nonsecure
	0	1	0	x	BOOT_ST_iROT_ADD	BOOT_ST_iROT_ADD	x	1	Secure
	0	1	1	x	SECBOOTADD	x	SECBOOTADD	1	Secure
Regression	0	0	x	x	BOOT_DBG_AUTH_ADD	BOOT_DBG_AUTH_ADD	x	0	Secure
	0	1	x	x	BOOT_DBG_AUTH_ADD	BOOT_DBG_AUTH_ADD	x	0	Secure
NS-Regression	0	1	x	x	BOOT_DBG_AUTH_ADD	BOOT_DBG_AUTH_ADD	x	0	Secure

14.3.6 SBS debug control

The SBS debug control is used to manage debug opening, taking care of the product context (PRODUCT_STATE, TZEN, HDPL) on register settings, or through a debug authentication control.

When the debug is forbidden, the mailbox access port, Cortex-M33 access port, and CPU debug interface are locked. In this situation, the debugger cannot access the CPU and no effective debug can be done. Refer to the *Section 71: Debug support (DBG)* for more details.

Authenticated debug sequence

1. The external host requests to launch the debug authentication protocol, via the DBGMCU access port mailbox. The rest of the device is kept under reset.
2. SBS selects the STMicroelectronics RSS-DA (debug authentication library) boot address, and requests the CPU to be released from reset.
3. The CPU running the RSS-DA library executes the debug authentication protocol in the system flash memory. If the device is closed, the access port mailbox is closed until RSS-DA acknowledges the authentication sequence start request.
4. The authentication method depends on TrustZone activation:
   – When TrustZone is activated (TZEN = 0xB4), the authentication method is based on certificates. As soon as a debug certificate chain is fully verified by the device, if the certificate concerns a debug permission, the RSS-DA programs the debug opening of the Cortex-M33. Alternatively, the certificate can authorize partial or full regression, allowing debug on a regressed part.
   – When TrustZone is disabled (TZEN = 0xC3), the authentication method is based on a password. This method only allows the full regression of the product to be controlled.
5. Above reopenings are effective only when HDPL in SBS_HDPLSR has a value equal or superior to the value programmed in DBG_AUTH_HDPL in SBS_DBGCR. In case of authentication failure, the user is informed through the host interface.

*Note: The debug authentication library in system flash memory is available only when HDPL = 0 or 1 in SBS_*HDPL*SR. Only this library can perform the steps 3 and 4 described above.*

Debug reset

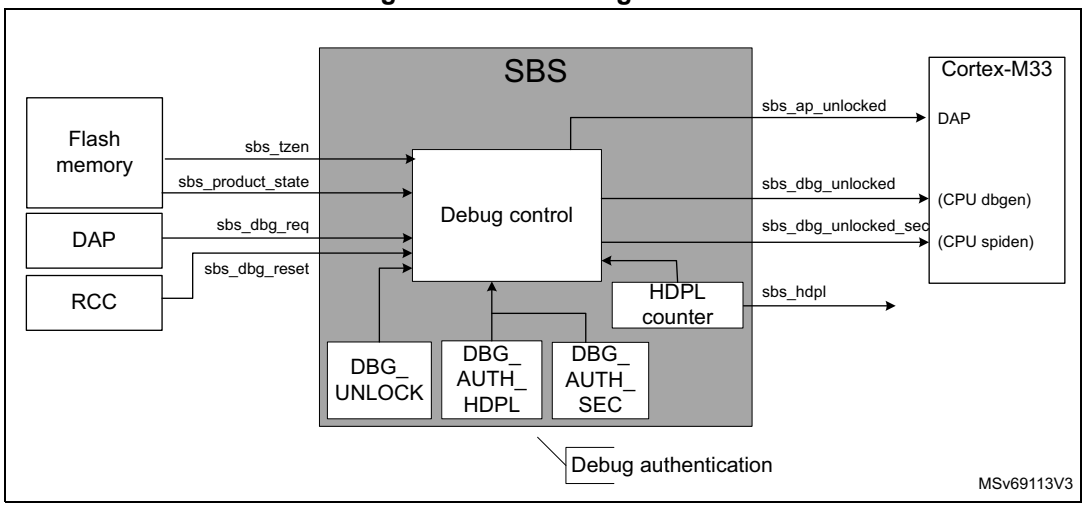
The debug opening can have the configuration to be reset by system or power-on reset, depending on a DBGMCU register field.

Debug locking

The debug configuration can be locked thanks to DBGCFG_LOCK in SBS_DBGLOCKR. SBS_DBGCR is then no longer writable.

When DBGCFG_LOCK is set to 1, it can be reset only by system or power-on reset. The configuration is done through the DBGMCU using the DCRT field of DBGMCU_CR.

Figure 68. SBS debug control



Inputs used to control the debug opening:

- sbs_dbg_req: input signal that a host requests to launch the debug authentication protocol. When this signal is set, the boot address is set to launch the debug authentication library.
- sbs_tzen: inform on the selected platform configuration related to TrustZone activation. When the TZEN value is set to zero (0xC3), the platform does not support TrustZone and the simplified life cycle is proposed. See *Section 7: Embedded flash memory (FLASH)* for more details.
- sbs_product_state: provide the current PRODUCT_STATE (from flash memory). See *Section 7: Embedded flash memory (FLASH)* for more details.
- sbs_dbg_reset: reset information coming from the RCC, and reset SBS_DBGCR if this register is configured to be reset.

Configuration

- DBG_UNLOCK in SBS_DBGCR: debug unlock when DBG_AUTH_HDPL is reached
- AP_UNLOCK in SBS_DBGCR: access port unlock
- DBG_AUTH_HDPL in SBS_DBGCR: authenticated debug temporal isolation level. Define the HDPL value from which the debug can be opened. Value can only be from 1 to 3.
- DBG_AUTH_SEC in SBS_DBGCR: specify if the debug reopening is for nonsecure only or for both secure and nonsecure.
- DBGC_LOCK in SBS_DBGLOCKR: lock the current debug configuration (released only by a reset).

Outputs

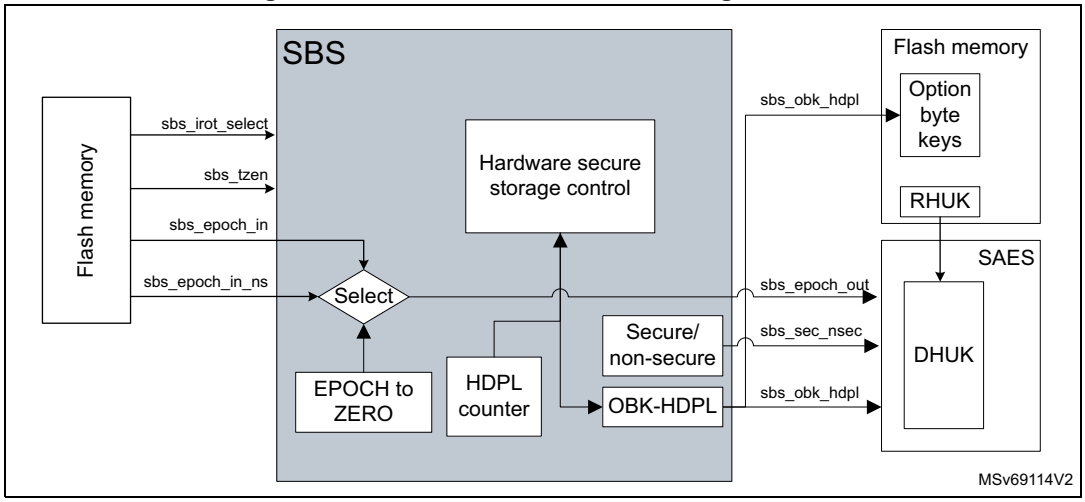
- sbs_ap_unlocked: signal controlling the Cortex-M33 access port
  - 1: 0xB4
  - 0: all other codes
- sbs_dbg_unlocked: unlock the debug (when set to 1) for the Cortex-M33 nonsecure.
  - 1: 0xB4
  - 0: all other codes
- sbs_dbg_unlocked_sec: unlock the debug (when set to 1) for the Cortex-M33 secure.
  - 1: 0xB4
  - 0: all other codes

14.3.7 SBS hardware secure storage control

This feature ensures the isolation of keys and data related to ROT (root-of-trust) when re-opening the debug (when product in the field).

This includes a dedicated area called OB-Keys in the flash memory (see *Section 7: Embedded flash memory (FLASH)* for more details), and the key derivation (DHUK) mechanism protecting data using a hardware key different for the identified domains.

Figure 69. SBS hardware secure storage control



- sbs_obk_hdpl: select a secure storage context for current HDPL, or greater ones (to allow provisioning). This signal is set thanks to the SBS_NEXTHDPLCR register. This information is used by the flash memory to select the right area, and by the SAES when processing the derived key to generate a key derived related to the HDPL context.
- sbs_epoch_out: EPOCH counters are used to manage the REPLAY protection. These counters are incremented when regressions are done. Injecting the EPOCH in the DHUK (in the SAES) ensures that all information encrypted with the DHUK cannot be replayed after a regression.
- sbs_sec_nsec: apply a different protection DHUK for secure and nonsecure assets.

All keys encrypted using the SAES/DHUK inherit of the RHUK property: unique per device.

All data encrypted thanks to the SAES using the DHUK are specific to a combination of [sbs_obk_hdpl + sbs_epoch_out + sbs_sec_nsec].

Inputs used to control the hardware secure storage control

sbs_epoch_in and sbs_epoch_in_ns: 24-bit values coming from the flash memory and representing regression counters respectively for secure and nonsecure.

Configuration

- NEXTHDPL in SBS_NEXTHDPLCR: access to next HDPL secure storage areas.
- EPOCH_SEL in SBS_EPOCHSELCR: select the EPOCH source related to the secure storage under control (SEC_EPOCH, NS_EPOCH, or FORCED_To_Zero).

Table 123. OBK-HDPL logic

<table>
<tr><th rowspan="2">HDPL[7:0] in SBS_HDPLSR</th><th colspan="4">NEXTHDPL[1:0]</th></tr>
<tr><th>0x0</th><th>0x1</th><th>0x2</th><th>0x3</th></tr>
<tr><td>0 (0xB4)</td><td>0xB4</td><td>0x51</td><td>0x8A</td><td rowspan="5">0x6F</td></tr>
<tr><td>1 (0x51)</td><td>0x51</td><td>0x8A</td><td rowspan="4">0x6F</td></tr>
<tr><td>2 (0x8A)</td><td>0x8A</td><td rowspan="3">0x6F</td></tr>
<tr><td>3 (0x6F)</td><td rowspan="2">0x6F</td></tr>
<tr><td>Other</td></tr>
</table>

14.4 SBS interrupts

SBS does not support interrupts.

14.5 SBS registers

14.5.1 SBS temporal isolation control register (SBS_HDPLCR)

Address offset: 0x010

Reset value: 0x0000 00B4

Reset: system reset

Register security: no restriction

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INCR_HDPL[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **INCR_HDPL[7:0]**: Increment HDPL value
0xB4: No increment
0x6A: Recommended value to increment HDPL level by one
Other: All other values allow a HDPL level increment.

14.5.2 SBS temporal isolation status register (SBS_HDPLSR)

Address offset: 0x014

Reset value: 0xXXXX XXXX

The reset value depends on the boot case: booting with HDPL0 for ST code, or HDPL1 for all other cases. See *Table 122* for more details.

Reset: system reset

Register security: no restriction

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDPL[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **HDPL[7:0]**: Temporal isolation level
This bitfield returns the current temporal isolation level.
0xB4: HDPL0, RSS
0x51: HDPL1, iRoT
0x8A: HDPL2, uRoT
0x6F: HDPL3, application (secure/nonsecure)

14.5.3 SBS next HDPL control register (SBS_NEXTHDPLCR)

Address offset: 0x018

Reset value: 0x0000 0000

Reset: system reset

Register security: no restriction

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NEXTHDPL[1:0]	
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bits 1:0 **NEXTHDPL[1:0]**: Index to point to a higher HDPL than the current one
Index to add to the current HDPL to point (through OBK-HDPL) to the next secure storage areas (OBK-HDPL = HDPL + NEXTHDPL). See *Table 123: OBK-HDPL logic* for more details.

14.5.4 SBS debug control register (SBS_DBGCR)

Address offset: 0x020

Reset value: 0x0000 0000

Reset: debug reset (system reset or power-on reset)

Register security: HDPL0/1, RAZ/WI otherwise

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DBG_AUTH_SEC[7:0]								DBG_AUTH_HDPL[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DBG_UNLOCK[7:0]								AP_UNLOCK[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **DBG_AUTH_SEC[7:0]**: Control debug opening secure/nonsecure
Write 0xB4 to this bitfield to open debug for secure. All other values are only open nonsecure.

Bits 23:16 **DBG_AUTH_HDPL[7:0]**: Authenticated debug temporal isolation level
Writing to this bitfield defines at which HDPL the authenticated debug opens.
0x51: HDPL1
0x8A: HDPL2
0x6F: HDPL3

Bits 15:8 **DBG_UNLOCK[7:0]**: Debug unlock when DBG_AUTH_HDPL is reached
Write 0xB4 to this bitfield to open the debug when HDPL in SBS_HDPLSR equals to DBG_AUTH_HDPL in this register.

Bits 7:0 **AP_UNLOCK[7:0]**: Access port unlock
Write 0xB4 to this bitfield to open the device access port.

14.5.5 SBS debug lock register (SBS_DBGLOCKR)

Address offset: 0x024

Reset value: 0x0000 00B4

Reset: debug reset (system reset or power-on reset)

Register security: HDPL0/1, RAZ/WI otherwise

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBGCFG_LOCK[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **DBGCFG_LOCK[7:0]**: Debug configuration lock
Reading this bitfield returns 0x6A if the bitfield value is different from 0xB4.
0xC3 is the recommended value to lock the debug configuration using this bitfield.
0xB4: Writes to SBS_DBGCR allowed (default)
Other: Writes to SBS_DBGCR ignored

14.5.6 SBS RSS command register (SBS_RSSCMDR)

Address offset: 0x034

Reset value: 0x0000 0000

Reset: power-on reset

Register security: always secure (RAZ/WI if nonsecure)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RSSCMD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **RSSCMD[15:0]**: RSS command
The application can use this bitfield to pass on a command to the RSS, executed at the next reset.
When RSSCMD ≠ 0 and PRODUCT_STATE is in Open, then the system always boots on RSS whatever is the boot pin value.

14.5.7 SBS EPOCH selection control register (SBS_EPOCHSELCR)

Address offset: 0x0A0

Reset value: 0x0000 0000

Reset: system reset

Register security: Secure when TZ_STATE = 1 (RAZ, WI in nonsecure access). Nonsecure protection when TZ_STATE = 0. This register is protected by privileged whatever is TZ_STATE, RAZ/WI if unprivileged access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EPOCH_SEL[1:0]	
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bits 1:0 **EPOCH_SEL[1:0]**: Select EPOCH value to be sent to the SAES
00: NS_EPOCH (nonsecure) counter input selected
01: SEC_EPOCH counter input selected
1x: EPOCH forced to zero

14.5.8 SBS security mode configuration control register (SBS_SECCFGR)

Address offset: 0x0C0

Reset value: 0x0000 0000

Reset: system reset

Register security: always secure. RAZ/WI if nonsecure transaction and TZ_STATE = 1. RAZ/WI if TZ_STATE = 0.

This register is programmed by secure software if the user wants functions configurable through system registers to be secure or not.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FPUSEC	Res.	CLASSBSEC	SBSSEC
												rw		rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **FPUSEC**: FPU security enable
0: SBS_FPUIMP register accessible through secure or nonsecure transaction
1: SBS_FPUIMP register accessible only through secure transaction
Note: This bit can be written only through privileged transaction.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CLASSBSEC**: ClassB security enable
0: SBS_CFGR2 register accessible through secure or nonsecure transaction
1: SBS_CFGR2 register accessible only through secure transaction

Bit 0 **SBSSEC**: SBS clock control, memory-erase status register and compensation cell register security enable
0: SBS_MESR, SBS_CCCSR, SBS_CCVALR, SBS_CCSWCR registers accessible through secure or nonsecure transaction
1: SBS_MESR, SBS_CCCSR, SBS_CCVALR, SBS_CCSWCR registers accessible only through secure transaction

14.5.9 SBS product mode and configuration register (SBS_PMCR)

Address offset: 0x100

Reset value: 0x4000 0000

Reset: system reset

Register security:

- When TrustZone is activated (TZEN = 0xB4):
  - depending on I/O PBx_SEC_EN secure input for PBx_FMP configuration bits
  - depending on Ethernet ETH_SEC_EN secure input for ETH_SEL_PHY, ETHTXLPI, ETHPDACK, and ETHINTPOL configuration bits
- When TrustZone is disabled (TZEN = 0xC3), there is no access restriction.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	ETHTXLPI	ETHPDACK	ETHINTPOL	ETH_SEL_PHY[3:0]				Res.	PB9_FMP	PB8_FMP	PB7_FMP	PB6_FMP
				r	r	rw	rw	rw	rw	rw		rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **ETHTXLPI**: ETH TxLPI status

This bit is set and reset by hardware.

When set, this bit indicates that the MAC has entered Tx LPI mode

Bit 26 **ETHPDACK**: ETH power-down acknowledge

This bit is set and reset by hardware.

When set, this bit indicates that the Ethernet controller has complete its power-down sequence and its clocks can be stopped.

0: ETH functional / power-down sequence not yet completed

1: ETH power-down sequence completed

Bit 25 **ETHINTPOL**: ETH external PHY interrupt polarity configuration

0: active high

1: active low

Bits 24:21 **ETH_SEL_PHY[3:0]**: Ethernet PHY interface selection

0000: GMII or MII

0001: reserved

0100: RMII

Other: reserved

Bit 20 Reserved, must be kept at reset value.

Bit 19 **PB9_FMP**: Fast-mode Plus driving capability activation on PB9

This bit can be read and written only with secure access if PB9 is secure in GPIOB. This bit enables the Fm+ driving mode for PB9 when PB9 is not used by I2C peripheral. This can be used to drive a LED for instance.

0: PB9 pin operates in standard mode.

1: Fm+ mode is enabled on PB9 pin and the speed control is bypassed.

Bit 18 **PB8_FMP**: Fast-mode Plus driving capability activation on PB8

This bit can be read and written only with secure access if PB8 is secure in GPIOB. This bit enables the Fm+ driving mode for PB8 when PB8 is not used by I2C peripheral. This can be used to drive a LED for instance.

0: PB8 pin operates in standard mode.

1: Fm+ mode is enabled on PB8 pin and the speed control is bypassed.

Bit 17 **PB7_FMP**: Fast-mode Plus driving capability activation on PB7

This bit can be read and written only with secure access if PB7 is secure in GPIOB. This bit enables the Fm+ driving mode for PB7 when PB7 is not used by I2C peripheral. This can be used to drive a LED for instance.

0: PB7 pin operates in standard mode.

1: Fm+ mode is enabled on PB7 pin and the speed control is bypassed.

Bit 16 **PB6_FMP**: Fast-mode Plus driving capability activation on PB6

This bit can be read and written only with secure access if PB6 is secure in GPIOB. This bit enables the Fm+ driving mode for PB6 when PB6 is not used by I2C peripheral. This can be used to drive a LED for instance.

0: PB6 pin operates in standard mode.

1: Fm+ mode is enabled on PB6 pin and the speed control is bypassed.

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 Reserved, must be kept at reset value.

14.5.10 SBS FPU interrupt mask register (SBS_FPUIMR)

Address offset: 0x104

Reset value: 0x0000 001F

Reset: system reset

Register security: depends on FPUSEC in SBS_SECCFGR

This register is accessible only through a privileged transaction.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FPU_IE[5:0]					
										rw	rw	rw	rw	rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:0 **FPU_IE[5:0]**: FPU interrupt enable

Set and cleared by software to enable the Cortex-M33 FPU interrupts

FPU_IE[5]: inexact interrupt enable (interrupt disabled at reset)

FPU_IE[4]: input abnormal interrupt enable

FPU_IE[3]: overflow interrupt enable

FPU_IE[2]: underflow interrupt enable

FPU_IE[1]: divide-by-zero interrupt enable

FPU_IE[0]: invalid operation interrupt enable

14.5.11 SBS memory erase status register (SBS_MESR)

Address offset: 0x108

Reset value: 0x0000 000X (bit 0 is not affected by system reset)

Register security: depends on SBSSEC in SBS_SECCFGR

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IPMEE
															rc_w1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MCLR
															rc_w1

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **IPMEE**: ICACHE erase status

This bit is set by hardware when ICACHE and PKA RAMs erase is completed after potential tamper detection or a product state regression (refer to *Section 58: Tamper and backup registers (TAMP)* for more details).

This bit is cleared by software by writing 1 to it.

0: ICACHE and PKA RAM erase ongoing

1: ICACHE and PKA SRAM erase done

Bits 15:1 Reserved, must be kept at reset value.

Bit 0 **MCLR**: device memories erase status

This bit is set by hardware when SRAM2, BKPSRAM, ICACHE, DCACHE and PKA RAMs erase is completed after power-on reset or tamper detection or product state regression (refer to *Section 58: Tamper and backup registers (TAMP)*).

This bit is not reset by system reset and is cleared by software by writing 1 to it.

0: memory erase ongoing if not yet cleared by software

1: Memory erase done

14.5.12 SBS compensation cell for I/Os control and status register (SBS_CCCSR)

Address offset: 0x110

Reset value: 0x0000 0000

Reset: system reset

Register security: depends on SBSSEC in SBS_SECCFGR

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	RDY2	RDY1	Res.	Res.	Res.	Res.	CS2	EN2	CS1	EN1
						r	r					rw	rw	rw	rw

Bits 31:10 Reserved, must be kept at reset value.

Bit 9 **RDY2**: VDDIO2 compensation cell ready flag
This bit provides the status of the VDDIO2 compensation cell.
0: VDDIO2 compensation cell not ready
1: VDDIO2 compensation cell ready (code value provided by the cell can be used)

Bit 8 **RDY1**: VDDIO compensation cell ready flag
This bit provides the status of the compensation cell.
0: VDDIO compensation cell not ready
1: VDDIO compensation cell ready (code value provided by the cell can be used)

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **CS2**: code selection for VDDIO2 power rail (reset value set to 1)
This bit selects the code to be applied for the I/O compensation cell.
0: Code from the cell (available in SBS_CCVR)
1: Code from SBS_CCCR

Bit 2 **EN2**: enable compensation cell for VDDIO2 power rail
This bit enables the I/O compensation cell.
0: I/O compensation cell disabled
1: I/O compensation cell enabled

Bit 1 **CS1**: code selection for VDDIO power rail (reset value set to 1)
This bit selects the code to be applied for the I/O compensation cell.
0: Code from the cell (available in the SBS_CCVR)
1: Code from SBS_CCCR

Bit 0 **EN**1: enable compensation cell for VDDIO power rail
This bit enables the I/O compensation cell.
0: I/O compensation cell disabled
1: I/O compensation cell enabled

14.5.13 SBS compensation cell for I/Os value register (SBS_CCVALR)

Address offset: 0x114

Reset value: 0x0000 0088

Reset: system reset

Register security: depends on SBSSEC in SBS_SECCFGR

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
APSRC2[3:0]				ANSRC2[3:0]				APSRC1[3:0]				ANSRC1[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **APSRC2[3:0]**: compensation value for the PMOS transistor
This value is provided by the cell and must be interpreted by the processor to compensate the slew rate in the functional range.

Bits 11:8 **ANSRC2[3:0]**: Compensation value for the NMOS transistor
This value is provided by the cell and must be interpreted by the processor to compensate the slew rate in the functional range.

Bits 7:4 **APSRC1[3:0]**: compensation value for the PMOS transistor
This value is provided by the cell and must be interpreted by the processor to compensate the slew rate in the functional range.

Bits 3:0 **ANSRC1[3:0]**: compensation value for the NMOS transistor
This value is provided by the cell and must be interpreted by the processor to compensate the slew rate in the functional range.

14.5.14 SBS compensation cell for I/Os software code register (SBS_CCSWCR)

Address offset: 0x118

Reset value: 0x0000 7878

Reset: system reset

Register security: depends on SBSSEC in SBS_SECCFGR

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SW_APSRC2[3:0]				SW_ANSRC2[3:0]				SW_APSRC1[3:0]				SW_ANSRC1[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **SW_APSRC2[3:0]**: PMOS compensation code for the V_{DDIO} power rails
This bitfield is written by software to define an I/O compensation cell code for PMOS transistors of the VDDIO power rail. This code is applied to the I/O when CS2 is set in SBS_CCSR.

Bits 11:8 **SW_ANSRC2[3:0]**: NMOS compensation code for VDDIO power rails
This bitfield is written by software to define an I/O compensation cell code for NMOS transistors of the VDD power rail. This code is applied to the I/O when CS2 is set in SBS_CCSR.

Bits 7:4 **SW_APSRC1[3:0]**: PMOS compensation code for the VDD power rails
This bitfield is written by software to define an I/O compensation cell code for PMOS transistors of the VDDIO power rail. This code is applied to the I/O when CS1 is set in SBS_CCSR.

Bits 3:0 **SW_ANSRC1[3:0]**: NMOS compensation code for VDD power rails
This bitfield is written by software to define an I/O compensation cell code for NMOS transistors of the VDD power rail. This code is applied to the I/O when CS1 is set in SBS_CCSR.

14.5.15 SBS Class B register (SBS_CFGR2)

Address offset: 0x120

Reset value: 0x0000 0000

Reset: system reset

Register security: depends on CLASSBSEC in SBS_SECCFGR

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCL	PVDL	SEL	CLL
												rs	rs	rs	rs

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **ECCL**: ECC lock

This bit is set and cleared by software. It can be used to enable and lock the flash memory double ECC error with break input of TIM1/8/15/6/17.

0: double ECC error flag disconnected to timer break inputs

1: double ECC error flag connected to timer break inputs

Bit 2 **PVDL**: PVD lock

This bit is set by software and cleared only by a system reset. It can be used to enable and lock the PVD connection with TIM1/8/15/16/17 break inputs.

0: PVD interrupt disconnected from timer break inputs. PVD_EN and PVD_SEL[2:0] in the PWR registers are read/write.

1: PVD interrupt is connected to timer break inputs. PVD_EN and PVD_SEL[2:0] in the PWR registers are read only

Bit 1 **SEL**: SRAM ECC error lock

This bit is set by software and cleared only by a system reset. It can be used to enable and lock the SRAM double ECC error signal with break input of TIM1/8/15/16/17.

0: SRAM double ECC error flag disconnected from timer break inputs

1: SRAM double ECC error flag connected to timer break inputs

Bit 0 **CLL**: core lockup lock

This bit is set by software and cleared only by a system reset. It can be used to enable and lock the lockup (HardFault) output of Cortex-M33 with TIM1/8/15/16/17 break inputs.

0: lockup output disconnected from timer break inputs

1: lockup output connected to timer break inputs

14.5.16 SBS CPU nonsecure lock register (SBS_CNSLCKR)

Address offset: 0x144

Reset value: 0x0000 0000

Reset: system reset

Register security: This register can be read and written by privileged access only. Unprivileged access is RAZ/WI.

This register is used to lock the configuration of the nonsecure MPU and VTOR_NS registers of the Cortex-M33.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKNSMPU	LOCKNSVTOR
														rs	rs

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **LOCKNSMPU**: Nonsecure MPU register lock

This bit is set by software and cleared only by a system reset. When set, this bit disables write access to nonsecure MPU_CTRL_NS, MPU_RNR_NS and MPU_RBAR_NS registers.

0: Nonsecure MPU registers write enabled

1: Nonsecure MPU registers write disabled

Bit 0 **LOCKNSVTOR**: VTOR_NS register lock

This bit is set by software and cleared only by a system reset.

0: VTOR_NS register write enabled

1: VTOR_NS register write disabled

14.5.17 SBS CPU secure lock register (SBS_CSLCKR)

Address offset: 0x148

Reset value: 0x0000 0000

Reset: system reset

Register security: This register can be written only when the access is secure/privilege.

A nonsecure read/write access is RAZ/WI and generates an illegal access event. When the system is not secure (TZ_STATE = 0), this register is RAZ/WI.

This register is used to lock the configuration of PRIS and BFHFNMINS in the AIRCR, SAU, secure MPU and VTOR_S registers of the Cortex-M33.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKSAU	LOCKSMPU	LOCKSVTAIRCR
													rs	rs	rs

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **LOCKSAU**: SAU registers lock

This bit is set by software and cleared only by a system reset. When set, this bit disables write access to SAU_CTRL, SAU_RNR, SAU_RBAR and SAU_RLAR registers.

0: SAU registers write enabled

1: SAU registers write disabled

Bit 1 **LOCKSMPU**: secure MPU registers lock

This bit is set by software and cleared only by a system reset. When set, this bit disables write access to secure MPU_CTRL, MPU_RNR and MPU_RBAR registers.

0: Secure MPU registers writes enabled

1: Secure MPU registers writes disabled

Bit 0 **LOCKSVTAIRCR**: VTOR_S and AIRCR register lock

This bit is set by software and cleared only by a system reset. When set, this bit disables write access to VTOR_S register, PRIS and BFHFNMINS bits in the AIRCR register.

0: VTOR_S register PRIS and BFHFNMINS bits in the AIRCR register write enabled

1: VTOR_S register PRIS and BFHFNMINS bits in the AIRCR register write disabled

14.5.18 SBS flift ECC NMI mask register (SBS_ECCNMIR)

Address offset: 0x14C

Reset value: 0x0000 0000

Reset: system reset

Register security: secure access only when TZ_STATE = 1 (RAZ/WI in nonsecure access). No security protection if TZ_STATE = 0. This register is accessible only through a privilege transaction.

This register sets up the expected behavior on NMI regarding double ECC errors from the flash memory.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCNMI_MASK_EN
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **ECCNMI_MASK_EN**: NMI behavior setup when a double ECC error occurs on flitf data part
0: NMI generated if a double ECC error in the flitf data part
1: NMI not generated if a double ECC error in the flitf data part

14.5.19 SBS OTG_HS PHY tune register 2 (SBS_OTGHSPHYTUNER2)

Address offset: 0x154

Reset value: 0xX1CD 06B1

Reset: system reset

Register security: secure access only when TZ_STATE = 1 RAZ/WI in access). No security protection if TZ_STATE = 0.

This register is accessible only through a privileged transaction.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TXPREEMPAMPTUNE[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	SQRXTUNE[2:0]			Res.	COMPDISTUNE[2:0]		
	rw	rw							rw	rw	rw		rw	rw	rw

Bits 31:15 Reserved, must be kept at reset value.

Bits 14:13 **TXPREEMPAMPTUNE[1:0]**: High-speed (HS) transmitter preemphasis current control
11: HS transmitter preemphasis circuit sources 3x preemphasis current
10: HS transmitter preemphasis circuit sources 2x preemphasis current
01: HS transmitter preemphasis circuit sources 1x preemphasis current
00: HS transmitter preemphasis circuit disabled

Bits 12:7 Reserved, must be kept at reset value.

Bits 6:4 **SQRXTUNE[2:0]**: Squelch threshold adjustment
This bitfield adjusts the voltage level for the threshold used to detect valid high-speed data.
000: +15% (recommended value)
011: 0% (default value)
Others: Reserved

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **COMPDISTUNE[2:0]**: Disconnect threshold adjustment
This bitfield adjusts the voltage level for the threshold used to detect a disconnect event at the host.
010: +5.9% (recommended value)
001: 0% (default value)
Others: Reserved

14.5.20 SBS register map

Table 124. SBS register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x010	SBS_HDPLCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INCR_HDPL[7:0]							
	Reset value																									1	0	1	1	0	1	0	0
0x014	SBS_HDPLSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDPL[7:0]							
	Reset value																									x	x	x	x	x	x	x	x
0x018	SBS_ NEXTHDPLCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NEXTHDPL[1:0]	
	Reset value																															0	0
0x020	SBS_DBGCR	DBG_AUTH_SEC[7:0]								DBG_AUTH_HDPL[7:0]								DBG_UNLOCK[7:0]								AP_UNLOCK[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	SBS_DBGLOCKR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBGCFG_LOCK[7:0]							
	Reset value																									1	0	1	1	0	1	0	0
0x028-0x030	Reserved	Reserved																															
0x034	SBS_RSSCMDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RSSCMD[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x038-0x09C	Reserved	Reserved																															
0x0A0	SBS_ EPOCHSELCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EPOCJ_SEL[1:0]	
	Reset value																															0	0

Table 124. SBS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0A4-0x0BC	Reserved	Reserved																															
0x0C0	SBS_SECCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FPUSEC	Res.	CLASSBSEC	SBSSEC
	Reset value																													0		0	0
0x0C4-0x0FC	Reserved	Reserved																															
0x100	SBS_PMCR	Res.	Res.	Res.	Res.	ETHTXLPI	ETHPDACK	ETHINTPOL	ETH_SEL_PHY [2:0]				Res.	PB9_FMP	PB8_FMP	PB7_FMP	PB6_FMP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0	0	0	0	0	0		0	0	0	0																
0x104	SBS_FPUIMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FPU_IE[5:0]					
	Reset value																											1	1	1	1	1	1
0x108	SBS_MESR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IPMEE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MCLR
	Reset value																0																X
0x110	SBS_CCCSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDY2	RDY1	Res.	Res.	Res.	Res.	CS2	EN2	CS1	EN1
	Reset value																							0	0					0	0	0	0
0x114	SBS_CCVALR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APSRC2 [3:0]				ANSRC2 [3:0]				APSRC1 [3:0]				ANSRC1 [3:0]			
	Reset value																	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
0x118	SBS_CCSWCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SW_APSRC2 [3:0]				SW_ANSRC2 [3:0]				SW_APSRC1 [3:0]				SW_ANSRC1 [3:0]			
	Reset value																	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0
0x120	SBS_CFGR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCL	PVDL	SEL	CLL
	Reset value																													0	0	0	0
0x124-0x140	Reserved	Reserved																															
0x144	SBS_CNSLCKR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKNSMPU	LOCKNSVTOR
	Reset value																															0	0
0x148	SBS_CSLCKR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKSAU	LOCKSMPU	LOCKSVTAIRCR
	Reset value																														0	0	0

Table 124. SBS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x14C	SBS_ECCNMIR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCNMI_MASK_EN
	Reset value																																0
0x154	SBS_ OTGHSPHYTUNER2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXPREEMPAMPTUNE[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	SQRXTUNE[2:0]			Res.	COMPDISTUNE]		
	Reset value																		0	0							0	1	1		0	0	1

Refer to *Section 2.3* for the register boundary addresses.

15 Peripherals interconnect matrix

15.1 Interconnect matrix introduction

Several peripherals have direct connections between them, enabling autonomous communication and/or synchronization: this approach saves CPU resources and power supply consumption. In addition, these hardware connections remove software latency and help the design of the predictable system.

Depending on peripherals, these interconnections can operate in Run, Sleep, and Stop modes.

15.2 Connection summary

Table 125. Peripherals interconnect matrix

Source	Destination																												
	TIM1	TIM8	TIM2	TIM3	TIM4	TIM5	TIM6	TIM7	TIM12	TIM13	TIM14	TIM15	TIM16	TIM17	LPTIM1	LPTIM2	LPTIM3/4/5/6	ADC1/2	ADC3	MDF1	ADF1	COMP1	COMP2	DAC1/2	GPDMA1/2	TAMP	RTC	PLAY1	DTS	AES/SAES	ETHERNET
TIM1	-	1	1	1	1	1	-	-	1	-	-	1	-	-	-	-	-	2	2	17	-	18	18	4	-	-	-	-	-	-	-
TIM8	1	-	1	1	1	1	-	-	1	-	-	1	-	-	-	-	-	2	2	17	-	-	18	4	-	-	-	-	-	-	-
TIM2	1	1	-	1	1	1	-	-	1	-	-	1	-	-	-	-	-	2	2	-	-	18	18	4	10	-	-	24	-	-	21
TIM3	1	1	1	-	1	1	-	-	1	-	-	1	-	-	-	-	-	2	2	17	-	18	18	4	-	-	-	24	-	-	21
TIM4	1	1	1	1	-	1	-	-	1	-	-	1	-	-	-	-	-	2	2	17	-	-	-	4	-	-	-	-	-	-	-
TIM5	1	1	1	1	1	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-
TIM6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2	17	-	-	-	4	-	-	-	-	-	-	-
TIM7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17	-	-	-	4	-	-	-	-	-	-	-
TIM12	1	1	1	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	4	10	-	-	-	-	-	-
TIM13	1	1	1	1	1	1	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TIM14	1	1	1	1	1	1	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TIM15	1	1	1	1	1	1	-	-	1	-	-	-	-	-	-	-	-	2	2	17	-	-	18	4	10	-	-	-	-	-	-
TIM16	1	1	1	1	1	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TIM17	1	1	1	1	1	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LPTIM1/2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2	17	-	18	-	4	10	-	-	24	25	-	-
LPTIM3/4/5/6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	25	-	-
ADC1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23	-	-	-	-	-	-	-	3	-	-	-
ADC2	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23	-	-	-	-	-	13	-	3	-	-	-
ADC3	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23	-	-	-	-	-	-	-	-	-	-
MDF1	15	15	-	-	-	-	-	-	-	-	-	15	15	15	-	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-
ADF1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-
COMP1	16	16	16	16	16	16	-	-	16	16	16	16	16	16	6	6	6	-	-	-	-	-	-	4	10	-	-	24	-	-	-
COMP2	16	16	16	16	16	16	-	-	16	16	16	16	16	16	6	6	6	-	-	-	-	-	-	4	10	-	-	24	-	-	-
GPDMA1/2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	6	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
EXTI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	6	2	2	-	17	-	-	4	10	-	-	-	25	-	-

Table 125. Peripherals interconnect matrix (continued)

Source	Destination																													
	TIM1	TIM8	TIM2	TIM3	TIM4	TIM5	TIM6	TIM7	TIM12	TIM13	TIM14	TIM15	TIM16	TIM17	LPTIM1	LPTIM2	LPTIM3/4/5/6	ADC1/2	ADC3	MDF1	ADF1	COMP1	COMP2	DAC1/2	GPDMA1/2	TAMP	RTC	PLAY1	DTS	AES/SAES	ETHERNET
RTC wake-up	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
RTC alarm	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	6	-	-	-	-	-	-	-	10	-	-	-	-	-	-
TAMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	6	-	-	-	-	-	-	-	10	-	14	-	-	26	-
HSE	-	-	-	-	-	-	-	-	-	-	-	-	5	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LSE	-	-	5	-	-	-	-	-	-	-	-	5	5	-	5	-	-	-	-	-	-	-	-	12	-	-	-	-	-	-	-
CSS in LSE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	-	-	-	-	-
CSI	-	-	-	-	-	-	-	-	5	-	-	5	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HSI	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LSI	-	-	-	-	-	-	-	-	-	-	-	-	5	-	5	-	-	-	-	-	-	-	-	12	-	-	-	-	-	-	-
MCO1	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	24	-	-	-
MCO2	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	-	-	-
VCORE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	11	-	-	-	-	-	-	-	-	-	-	-	-
VREFINT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	11	-	-	-	-	-	-	-	-	-	-	-	-
Vsensor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	11	-	-	-	-	-	-	-	-	-	-	-	-
VBAT8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	11	-	-	-	-	-	-	-	-	-	-	-	-
VBAT / temperature monitor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	-	-	-	-	-
System errors	8	8	-	-	-	-	-	-	-	-	-	8	8	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OTG_HS	-	-	19	-	-	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OTG_FS	-	-	19	-	-	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
System flash memory	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	-
I3C1/2	-	-	-	-	-	-	-	-	-	9	9	-	-	-	-	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
USART1/2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	-	-	-
SPI1/2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	-	-	-
AES/SAES	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	-
DMA2D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
GFXTIM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
JPEG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
Ethernet	-	-	20	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PLAY1	22	22	22	22	-	-	-	-	-	-	-	-	-	-	6	6	-	2	2	-	-	-	-	4	10	-	-	24	25	-	-
EVENTOUT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	10	-	-	24	-	-	-

15.3 Interconnection details

15.3.1 Master to slave interconnection for timers

From timer (TIM1/2/3/4/5/8/12/13/14/15/16/17) to timer (TIM1/2/3/4/5/8/12/15).

Purpose

Some timers are linked together internally for synchronization or chaining.

When one timer is configured in master mode, it can reset, start, stop, or clock the counter of another timer configured in slave mode.

A description of the features is provided in *Section 50.4.23: Timer synchronization*.

The synchronization modes are detailed in:

- *Section 49.3.30* for advanced-control timers TIM1/8
- *Section 50.4.22* for general-purpose timers TIM2/3/4/5
- *Section 52* for the general-purpose timers TIM12/13/14
- *Section 53.4.23* for the general-purpose timer TIM15

Triggering signals

The output (from master) is on signal TIMx_TRGO (and TIMx_TRGO2 for TIM1/8) following a configurable timer event. It can be also from signals tim16_oc1 and tim17_oc1 in the case of TIM16/17. The input (to slave) is on the signal TIMx_ITR0/1/2/3.

The possible master/slave connections are given in:

- *Table 515: Internal trigger connection* for advanced-control timers TIM1/8
- *Table 539: TIMx internal trigger connection* for general-purpose timers TIM2/3/4/5
- *Table 561: TIMx internal trigger connection* for the general-purpose timers TIM12/13/14
- *Table 570: TIM internal input/output signals* for the general-purpose timer TIM15

Active power mode

Timers are optionally active in Run and Sleep modes. The effects of low-power modes on TIMx are given in:

- *Table 528: Effect of low-power modes on TIM1/TIM8*
- *Table 547: Effect of low-power modes on TIM2/TIM3/TIM4/TIM5*
- *Table 563: Effect of low-power modes on TIM12/TIM13/TIM14*
- *Table 580: Effect of low-power modes on TIM15/TIM16/TIM17*

15.3.2 Triggers to ADCs

From EXTI, timers (TIM1/2/3/4/6/8/15), LP timers (LPTIM1/2), and PLAY1 to ADC1/ADC2/ADC3.

Purpose

A conversion (or a sequence of conversions) can be triggered either by software or by an external event (such as timer capture or input pins). For ADC12, if the EXTEN[1:0] (for a regular conversion) or JEXTEN[1:0] bits (for an injected conversion) are different from 0b00, external events can trigger a conversion with the selected polarity.

More details in:

- *Section 30.4.18: Conversion on external trigger and trigger polarity (EXTSEL, EXTEN,JEXTSEL, JEXTEN)*
- EXTEN[1:0] defined in *ADC configuration register (ADC_CFGR)*
- JEXTEN[1:0] defined in *ADC injected sequence register (ADC_JSQR)*

General-purpose timers (TIM2/3/4), basic timer (TIM6), advanced-control timers (TIM1/8), and general-purpose timer (TIM15) can be used to generate the ADC triggering event through the timer outputs tim_oc and tim_trgo.

Low-power timers (LPTIM1/2) can be used to generate the ADC triggering event through the LPTIM channels, in addition to the EXTI on channels 11 and 15.

PLAY1 can be used to generate the ADC triggering event through the PLAY1 outputs 7 and 9.

Triggering signals

For ADC1/ADC2/ADC3, the input triggering signals and the description of the interconnection between ADC1/ADC2/ADC3 and timers are given in:

- adc_ext_trg: *Table 290: ADC interconnection*
- adc_jext_trg: *Table 290: ADC interconnection*
- *Section 30.4.18: Conversion on external trigger and trigger polarity (EXTSEL, EXTEN,JEXTSEL, JEXTEN)*
- *Section 30.4.25: Timing diagrams example (single/continuous modes, hardware/software triggers)*

Active power mode

This interconnection is active in Run and Sleep modes for all ADCs. The timers are active only in Run and Sleep modes. The effects of low-power modes are given in:

- *Table 528: Effect of low-power modes on TIM1/TIM8*
- *Table 547: Effect of low-power modes on TIM2/TIM3/TIM4/TIM5*
- *Table 580: Effect of low-power modes on TIM15/TIM16/TIM17*
- *Table 586: STM32H5E4/5F4 and STM32H5E5/5F5 LPTIM features*
- *Table 601: Effect of low-power modes on the LPTIM*

15.3.3 ADC analog watchdogs as triggers to timers and PLAY1

From ADC1/ADC2/ADC3 to TIM1/8.

From ADC1/ADC2 to PLAY1.

Purpose

The internal analog watchdog output signals coming from ADC1/ADC2/ADC3 are connected to on-chip timers, and PLAY1. ADC1/ADC2/ADC3 can provide trigger events through analog watchdog signals to advanced-control timers (TIM1/8) to reset, start, stop, or clock the counter, and as input to PLAY1.

Settings description of the ADC analog watchdog and timer trigger, are provided in:

- *Section 49.3.6: External trigger input* for TIM1/8

- *Table 516: Interconnect to the tim_etr input multiplexer* for the internal ADC1/ADC2 sources connected to the TIM1/8 (tim_etr) input multiplexer
- *Section 24* for the ADC1/ADC2/ADC3/ADC_AWDy_OUT signal output generation

Triggering signals

The output (from ADC) is on the ADCn_AWDx_OUT signals, with n being the ADC instance and x = 1, 2, 3 (three watchdogs per ADC). The input (to timer) is on signal TIMx_ETR (external trigger).

The inputs (to PLAY1) are on signal PLAY1_IN[15:0].

Active power mode

ADC1/ADC2/ADC3 are active in Run and Sleep modes.

15.3.4 Triggers to DAC

From timers (TIM1/2/4/5/6/7/8/15), low-power timers (LPTIM1/2), COMP1/2, and EXTI to DAC.

Purpose

General-purpose timers (TIM2/4/5/15), basic timers (TIM6/7), advanced-control timers (TIM1/8), LP timers (LPTIM1/2) output channels (lptim1_ch1 and lptim2_ch1), comparators (COMP1/2) output channels (comp1_out and comp2_out), and EXTI can be used as a triggering event to start a DAC conversion.

Triggering signals

The output (from timer) on the TIMx_TRGO signal and from LP timers are directly connected to corresponding DAC inputs.

The selection of input triggers on the DAC is provided in:

- *Table 314: DAC interconnection*
- *Section 32.4.8: DAC trigger selection*

Active power mode

This interconnect is active in Run, Sleep, and Stop modes.

15.3.5 Clock sources to timers

From HSE, LSE, LSI, HSI, and MCO to timers (TIM2/12/15/16/17) and LP timers (LPTIM1/2).

Purpose

A timer input or counter can receive different clock sources, and can be used, for example, to calibrate the internal oscillator on a reference clock.

External clocks (HSE, LSE), internal clocks (LSI, CSI, HSI), and microcontroller output clock (MCO) can be used as input to timers:

- LSE, HSI, and CSI are assigned to general purpose timer TIM2 as external input signals. LSE can be selected as a counter clock provided by an external clock source

in mode1 (tim_ti1_in) and mode2 (external trigger input tim_etr_in). Inputs assignment and clock selection description are detailed in:

  - *Section 50.4.5: Clock selection* for TIM2
  - External clock mode1: *Table 559: Interconnect to the tim_ti1 input multiplexer* for TIM12, tim_ti1_in4 (HSI), and tim_ti1_in5 (CSI)
  - External clock mode2: *Table 539: TIMx internal trigger connection* for tim_etr3 (LSE)

- LSE, LSI, CSI, and HSE are assigned to general purpose timers TIM15/16/17 as external input signals. LSE/LSI/CSI/HSE can be selected as a counter clock provided by an external clock source in mode1 (tim_ti1 or tim_ti2 signals). Inputs assignment and clock selection description are detailed in:
  - *Section 53.4.6: Clock selection* for TIM15/16/17. External clock mode1: external input pin (tim_ti1 or tim_ti2, if available)
  - *Table 559: Interconnect to the tim_ti1 input multiplexer*, tim_ti1_in1 (LSI-TIM16), tim_ti1_in2 (LSE-TIM16/HSE-TIM17), tim_ti1_in4 (LSE- TIM15), and tim_ti1_in5 (CSI-TIM15)
- Microcontroller output clock (MCO): MCO1 is connected as external input to general-purpose timer TIM17, MCO2 is connected as external input to general-purpose timer TIM15.
  - *Table 571: Interconnect to the tim_ti1 input multiplexer* for TIM15/TIM16/TIM17
- LSI and LSE can be selected as input capture 2 to LPTIM1 as described in *Table 595: LPTIM1 input capture 2 connections*.
- HSI/1024, CSI/128, and HSI/8 can be selected as input capture 2 to LPTIM2 as described in *Table 596: LPTIM2 input capture 2 connections*.

Triggering signals

lptim_ic2_mux1 LPTIM input capture selection can be set in the LPTIM configuration register 2 (LPTIM_CFGR2). For timers, the internal clock signal can be selected as a counter clock provided by an external clock source in mode1 (tim_ti1_in) and mode2 (external trigger input tim_etr_in).

Active power mode

This feature is available under Run and Sleep modes.

15.3.6 Triggers to low-power timers

From EXTI, TAMP, PLAY1, comparators (COMP1/2), GPDMA1, CPU (EVENTOUT), and RTC alarm to LP timers (LPTIM1/2/3/4/5/6).

Purpose

LPTIM1/2/3/4/5/6 counters can be started either by software, or after the detection of an active edge on one of the eight trigger inputs (see *Section 54.4.7: Trigger multiplexer*).

RTC alarm, TAMP input detection, COMP1_OUT, GPDMA transfer complete and CPU EVENTOUT can be used as a trigger to start LPTIM counters (LPTIM1/2).

Triggering signals

This trigger feature is described in *Section 54.4.7: Trigger multiplexer* and in the following sections. The input selection is described in *Table 591: LPTIM1/2/3/4/5/6 external trigger connections*.

Active power mode

This interconnection is active in Run, Sleep, and Stop modes.

15.3.7 RTC wake-up as input to timers

From RTC to timer (TIM16).

Purpose

RTC wake-up interrupt can be used as input to general-purpose timer (TIM16) channel 1.

Triggering signals

The RTC wake-up signal is connected to the tim_ti1_in3 signal as described in *Table 571: Interconnect to the tim_ti1 input multiplexer* for TIM16.

Active power mode

This interconnection is active down to Stop mode. Timers are not active but the count is performed at wake-up.

15.3.8 System errors as break signals to timers

From system errors to timers (TIM1/8/15/16/17).

Purpose

CSS, CPU lockup, SRAM2/3 ECC double errors, FLASH ECC double-error detection, and PVD can generate system errors in the form of timer break toward timers (TIM1/8/15/16/17).

The purpose of the break function is to protect power switches driven by PWM signals generated by the timers.

Triggering signals

The possible sources of break are described in:

- *Section 49.3.18: Using the break function* for TIM1/8
- *Section 53.4.15: Using the break function* for TIM15/16/17
- *Section Table 519.: System break interconnect* for TIM1/8
- *Section Table 575.: System break interconnect* for TIM15/16/17

Active power mode

Timers are optionally active in Run and Sleep modes. The effects of low-power modes on TIMx are given in:

- *Table 528: Effect of low-power modes on TIM1/TIM8*
- *Table 547: Effect of low-power modes on TIM2/TIM3/TIM4/TIM5*
- *Table 580: Effect of low-power modes on TIM15/TIM16/TIM17*

15.3.9 I3C as trigger to timers

From I3C1/2 to timers (TIM13/14) and LP timers (LPTIM5/6).

Purpose

I3Cx_IBIackTi can be used as input for LPTIM5/6 and TIM13/14

Triggering signals

- The outputs from triggers are directly connected to peripheral trigger inputs.
- The selection of input triggers is detailed in:
- *Table 535: Interconnect to the tim_ti1 input multiplexer*
- *Table 540: Interconnect to the tim_etr input multiplexer*

Active power mode

These interconnections remain active in Run and Sleep modes.

15.3.10 Triggers to GPDMA1/2

From EXTI, RTC (alarm/wake-up), TAMP, timers (TIM2/12/15), LP timers (LPTIM1/2/3/4/5/6), comparators (COMP1/2), DMA2D, GFXTIM, JPEG, PLAY1, EVENTOUT, and GPDMA1 transfer complete (gpdma1_chx_tc, gpdma2_chx_tcf) to GPDMA1/2.

Purpose

A GPDMA trigger can be assigned to GPDMA channel x. A programmed GPDMA transfer can be triggered by a rising/falling edge of a selected input trigger event. The trigger mode can also be programmed to condition the LLI link transfer. More details are given in the sections below:

- *Section 16.3.7: GPDMA triggers*
- *Section 16.4.12: GPDMA triggered transfer*
- *GPDMA channel x transfer register 2 (GPDMA_CxTR2)* for more details on:
  - Trigger selection TRIGSEL[5:0] field
  - Trigger mode (LLI) defined by TRIGM[1:0]
  - Trigger polarity as defined by TRIGPOL[1:0]

Triggering signals

GPDMA trigger mapping is specified in *Table 128: Programmed GPDMA1/2 request*, according to GPDMA_CxTR2.TRIGSEL[5:0].

Active power mode

This interconnection remains functional in Sleep mode.

Refer to:

- *Section 16.6: GPDMA in low-power modes*

15.3.11 Internal analog signals to analog peripherals

From internal analog source to ADC (ADC1/2/3).

Purpose

The internal reference voltage (V_{REFINT}), the internal temperature sensor (V_{SENSE}), the internal digital core voltage (V_{DDCORE}), and the V_{BAT} monitoring channel are connected to the ADC (ADC1/2/3) input channels.

This is according to:

- *Section 30.2: ADC main features*
- *Section 30.4.11: Channel selection (ADC_SQRy, ADC_JSQR)*

15.3.12 Clock source for the DAC sample and hold mode

From LSI/LSE to DAC1.

Purpose

DAC1 can run in Stop mode. The sample and hold block and its associated registers use the LSI or LSE clock source (dac_hold_ck) in Stop mode.

Table 313: DAC internal input/output signals: dac_hold_ck, input, DAC low-power clock used in sample and hold mode

Active power mode

This feature remains available in Run, Sleep, and Stop modes.

15.3.13 Internal tamper sources

From internal peripherals, clocks, or monitoring, to tamper.

Purpose

To detect any abnormal activity or tentative to corrupt the device, embedded tampers alert the system of undesired events. Different actions can be taken as a consequence.

The list of tamper sources can be found in *Table 627: TAMP interconnection*.

Active power mode

This interconnection is active in all power modes if the tamper source is activated.

15.3.14 Output from tamper to RTC

From TAMP to RTC.

Purpose

The RTC can timestamp a tamper event to retrieve the history of the detection. The RTC can also control GPIOs, and set a signal based on tamp or alarm status outside the MCU.

Refer to *Section 57.3.3: GPIOs controlled by the RTC and TAMP* for more details.

Active power mode

This interconnection remains active in all power modes.

15.3.15 Timer break from MDF1

From MDF1 to advanced-control timer (TIM1/8) and general-purpose timer (TIM15/16/17)

Purpose

The MDF features an out-off limit detector (OLD) and a short circuit detector (SCD) functions. When a short-circuit or open-circuit errors (such as over current or over voltage) is detected, an interrupt event or/and a break signal can be generated to TIM1/8/15/16/17.

Triggering signals

The mdf1_break[0:3] output signals are connected to the break1 and break2 inputs signals of TIM1/8 and TIM15/16/17.

The following tables give the assignment of break signals:

- *Table 345: MDF break connections*
- *Table 574: Timer break interconnect*
- *Table 518: Timer break2 interconnect*

Active power mode

This interconnection is active under Run and Sleep modes. Refer to:

- *Section 36.4.13: Data transfer to memory*
- *Table 356: Effect of low-power modes on MDF*

15.3.16 Comparators as inputs, trigger, or break signals to timers1

From comparators to timers (TIM1/2/3/4/5/8/12/13/14/15/16/17)

Purpose

The comparators (COMP1/2) output values can be connected to timers (TIM1/2/3/4/5/8/12/13/14/15/16/17) input captures, TIMx_ETR, or timer break signals. The connection to ETR is described in *Section 49.3.6: External trigger input*.

Comparators (COMP1/2) output values can also generate break input signals for timers (such as TIM1 or TIM8). The sources for the break (tim_brk) channel are one of the following:

- External: connected to one of the TIMx_BKIN pin (as per selection done in the AFIO controller) with polarity selection and optional digital filtering
- Internal: coming from comparators, tim_brk_cmpx input (refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals* for product specific implementation).

Triggering signals

The tim_etr and tim_brk signals connected TIM1/8 (coming from COMP1/2) are given in:

- tim_etr: external trigger internal input bus

These inputs can be used as trigger, external clock or for hardware cycle-by-cycle pulse width control.

- tim_brk (*Table 517: Timer break interconnect* and *Table 518: Timer break2 interconnect*)
- *Section 49.3.6: External trigger input*
- *Section 49.3.18: Using the break function*

For TIM2/3/4/5, the sources connected to the tim_ti[1:4] input multiplexers coming from comparators and some other peripherals, are given in:

- *Table 535: Interconnect to the tim_ti1 input multiplexer*
- *Table 536: Interconnect to the tim_ti2 input multiplexer*
- *Table 537: Interconnect to the tim_ti3 input multiplexer*
- *Table 538: Interconnect to the tim_ti4 input multiplexer*
- *Table 540: Interconnect to the tim_etr input multiplexer*

For TIM12/13/14, the sources connected to timers coming from comparators and other peripherals, are given in:

- *Table 559: Interconnect to the tim_ti1 input multiplexer*
- *Table 560: Interconnect to the tim_ti2 input multiplexer*

For TIM15/16/17, the sources connected to timers coming from comparators and other peripherals are given in:

- *Table 571: Interconnect to the tim_ti1 input multiplexer*
- *Table 572: Interconnect to the tim_ti2 input multiplexer*
- *Table 574: Timer break interconnect*
- *Table 583: TIM15 register map and reset values*

Signals Active power mode

Run, Sleep, and wake-up capability in Stop 0, Stop 1, and Stop 2 modes for trigger sources.

Input and break remain active in the same low-power modes as timers activity, on Run and Sleep modes

15.3.17 Triggers on MDF1 or ADF1

From EXTI, ADF1, timers (TIM1/3/4/6/7/8/15), and LP timer (LPTIM1) to MDF1

From EXTI, TIM15, and MDF1 to ADF1

Purpose

General-purpose timers (TIM3/4/15), basic timers (TIM6/7), advanced-control timers (TIM1/8), low-power timer (LPTIM1), EXTI (EXTI11/15), and ADF1 can be used to generate a triggering event on the MDF1 module and start an A/C conversion.

In addition, EXTI15, TIM, and MDF1 can trigger ADF1.

Triggering signals

The mdf_trgi[13:0] trigger inputs are the triggering input signals. The MDF and ADF trigger inputs connections are detailed in:

- *Table 344: MDF trigger connections*
- *Table 365: ADF trigger connections*

Signals Active power mode

This interconnection remains active down to Stop 0 and Stop 1 modes for MDF1, and Stop 0, Stop 1, and Stop 2 modes for ADF1, assuming the trigger source remains active.

15.3.18 Blanking sources to comparators

From timers (TIM1/2/3/8/15) and LP timers (LPTIM1/2) to comparators (COMP1/2)

Purpose

Advanced-control timers (TIM1/8) =, general-purpose timers (TIM2/3/15) and LP timers (LPTIM1/2) can be used as blanking window input to COMP1/2.

The blanking function is described in *Table 35.3.7: Comparator output blanking function*.

The blanking sources are given in:

- COMP1 control and status register,
- COMP2 control and status register,

Triggering signals

Timer output signal TIMx_Ocx are the inputs to the blanking source of COMP1/2.

LP timer output signal lptimx_ch2 are the input to the blanking source of COMP1.

Signals Active power mode

This feature is available under Run and Sleep modes.

15.3.19 OTG_FS/OTG_HS SOF as trigger to timers

From OTG_FS/OTG_HS SOF to TIM2/TIM5

Purpose

The OTG_FS/OTG_HS SOF (start-of-frame) can generate a trigger to the general-purpose timers TIM2 and TIM5. The OTG_FS/OTG_HS connection to TIM2/TIM5 is described in *Table 539: TIMx internal trigger connection*.

Triggering signals

The tim_etr13 and tim_etr14 internal signals are generated by the OTG_FS/OTG_HS SOF.

Active power mode

This interconnection is active in Run and Sleep modes.

15.3.20 Ethernet as trigger to timers

From Ethernet to TIM2/TIM3

Purpose

To synchronize the system clock with the network, internal connections are available between timers and PTP to check for clock drifts.

Triggering signals

The outputs (from the timer) are directly connected to Ethernet PTP trigger inputs. More details are given below:

- *Section 69.3: Ethernet pins and internal signals*
- *Table 535: Interconnect to the tim_ti1 input multiplexer*
- *Table 540: Interconnect to the tim_etr input multiplexer*

Active power mode

These interconnections remain active in Run and Sleep modes.

15.3.21 Timers as trigger to Ethernet

From timers (TIM2/TIM3) to Ethernet.

Purpose

General-purpose timers TIM2/TIM3 can generate a trigger to Ethernet.

Triggering signals

The TIM2/TIM3 timers can generate a trigger to Ethernet to store a snapshot of the system time.

The event is considered to be the rising edge of the eth_ptp_trgx signal.

Active power mode

This interconnection is active in Run and Sleep modes.

15.3.22 PLAY1 as input to timers

From PLAY1 to TIM1/TIM2/TIM3/TIM8

Purpose

The PLAY1 outputs can be connected to the advanced-control timers (TIM1/8) and general purpose timers (TIM2/3).

Triggering signals

Timer input signals of the timers are connected to the output signals of the PLAY1 play1_out[3:0].

More details for connections are given in the following tables:

- *Table 195: PLAY logic array input n signal selection*
- *Table 511: Interconnect to the tim_ti1 input multiplexer*
- *Table 517: Timer break interconnect*

Active power mode

These interconnections remain active in Run and Sleep modes.

15.3.23 ADC data filtering by the MDF1/ADF1

From ADC1/ADC2 to MDF1

From ADC3 to ADF1

Purpose

The MDF1/ADF1 allows the connection of up to three ADCs to the filter path.

For each filter, the DATSRC[1:0] field in the MDF digital filter configuration register x (MDF_DFLTxCICR) is used to select either data from the ADCs in:

- *Section 30.4.4: ADC connectivity*
- *Table 346: MDF ADC data connections*
- *Table 290: ADC interconnection*
- *Section 36.5: MDF low-power modes*

Active power mode

This feature remains available down to Sleep mode.

15.3.24 Inputs to PLAY1

From timers (TIM2/3), LP timers (LPTIM1/2), MCO1/2, comparators (COMP1/2), USART1/2, SPI1/2, and CPU to PLAY1.

Purpose

General purpose timers (TIM2/TIM3), LP timers (LPTIM1/LPTIM2), MCO1/2, comparators (COMP1/COMP2), USART1/2, SPI1/2, and CPU are connected to PLAY1 inputs.

Triggering signals

The PLAY1 inputs play1_in[15:0] are connected to PLAY1, timers (TIM2/3), LP timers (LPTIM1/2), MCO1/2, comparators (COMP1/2), USART1/2, SPI1/2 and CPU.

The input connections are detailed in *Table 195: PLAY logic array input n signal selection*.

Active power mode

This feature is available under Run and Sleep modes. It is also available under Stop mode for the LP timers (LPTIM1/LPTIM2), the comparators (COMP1/COMP2), USART1/2, SPI1/2 except General purpose timers (TIM2/TIM3), MCO and CPU.

15.3.25 Triggers to DTS

From EXTI, LP timers (LPTIM1/LPTIM2) and PLAY1 to DTS.

Purpose

A temperature measurement can be triggered either by software, by LP timers, by PLAY1, or by an external event

Triggering signals

The input triggering signals and the description of the interconnection between DTS, PLAY1 and LP timers, are given in *Table 307: Trigger configuration*.

15.3.26 Encryption keys to AES/SAES

From TAMP backup registers, system flash memory to and in between SAES and AES.

Purpose

The encryption mechanism requires a hardware key that must be stored in a protected nonvolatile memory. Different approaches are implemented to load them in a nonreadable way. Tamper backup registers or system flash memory can be used to store respectively BHK or RHUK, and to implement a dedicated bus to pass it to the SAES.

Refer to *Section 45.4.14: SAES operation with wrapped keys* for more details.

The AES encryption mechanism (faster than the SAES) can benefit from the sharing key of the SAES. Refer to *Section 45.4.15: SAES operation with shared keys* for more details.

Active power mode

AES and SAES are operating under Run and Sleep modes.

16 General purpose direct memory access controller (GPDMA)

16.1 GPDMA introduction

The general purpose direct memory access (GPDMA) controller is a bus master and system peripheral.

The GPDMA is used to perform programmable data transfers between memory-mapped peripherals and/or memories via linked-lists, upon the control of an off-loaded CPU.

16.2 GPDMA main features

- Dual bidirectional AHB master
- Memory-mapped data transfers from a source to a destination:
  - Peripheral-to-memory
  - Memory-to-peripheral
  - Memory-to-memory
  - Peripheral-to-peripheral

  Transfer arbitration based on a 4-grade programmed priority at channel level:
  - One high-priority traffic class, for time-sensitive channels (queue 3)
  - Three low-priority traffic classes, with a weighted round-robin allocation for non time-sensitive channels (queues 0, 1, 2)
- Per channel event generation, on any of the following events: transfer complete, half-transfer complete, data transfer error, user setting error, link transfer error, completed suspension, and trigger overrun
- Per channel interrupt generation, with separately programmed interrupt enable per event
- 12 concurrent GPDMA channels:
  - Per channel FIFO for queuing source and destination transfers (see *Section 16.3.2*)
  - Intra-channel GPDMA transfers chaining via programmable linked-list into memory, supporting two execution modes: run-to-completion and link step mode
  - Intra-channel and inter-channel GPDMA transfers chaining via programmable GPDMA input triggers connection to GPDMA task completion events
- Per linked-list item within a channel:
  - Separately programmed source and destination transfers
  - Programmable data handling between source and destination: byte-based reordering, packing or unpacking, padding or truncation, sign extension and left/right realignment
  - Programmable number of data bytes to be transferred from the source, defining the block level
  - Linear source and destination addressing: either fixed or contiguously incremented addressing, programmed at a block level, between successive burst transfers

  - 2D source and destination addressing: programmable signed address offsets between successive burst transfers (non-contiguous addressing within a block, combined with programmable signed address offsets between successive blocks, at a second 2D/repeated block level, for a reduced set of channels (see *Section 16.3.2*)
  - Support for scatter-gather (multi-buffer transfers), data interleaving and deinterleaving via 2D addressing
  - Programmable GPDMA request and trigger selection
  - Programmable GPDMA half-transfer and transfer complete events generation
  - Pointer to the next linked-list item and its data structure in memory, with automatic update of the GPDMA linked-list control registers
  - Channel abort and restart
- Debug:
  - Channel suspend and resume support
  - Channel status reporting, including FIFO level, and event flags
- TrustZone support:
  - Support for secure and nonsecure GPDMA transfers, independently at a first channel level, and independently at a source/destination and link sublevels
  - Secure and nonsecure interrupts reporting, resulting from any of the respectively secure and nonsecure channels
  - TrustZone-aware AHB slave port, protecting any GPDMA secure resource (register, register field) from a nonsecure access
- Privileged/unprivileged support:
  - Support for privileged and unprivileged GPDMA transfers, independently at a channel level
  - Privileged-aware AHB slave port

16.3 GPDMA implementation

16.3.1 GPDMA instances

There are two instances of the GPDMA in the devices, named as GPDMA1 and GPDMA2.

Each GPDMA instance has the same channel-based implementation and is connected to the same requests and triggers, as detailed in the following sub-sections.

16.3.2 GPDMA channels

A given GPDMA channel x is implemented with the following features and intended usage. To make the best use of the GPDMA performances, the table below lists some general recommendations, allowing the user to select and allocate a channel, given its implemented FIFO size and the requested GPDMA transfer.

Table 126. GPDMA1/2 channel implementation

Channel x	Hardware parameters		Features
	dma_fifo_size[x]	dma_addressing[x]	
x = 0 to 7	2	0	Channel x (x = 0 to 7) is implemented with: – a FIFO of 8 bytes, 2 words – fixed/contiguously incremented addressing These channels must be typically allocated for GPDMA transfers between an APB or AHB peripheral and SRAM.
x = 8 to 9	4	0	Channel x (x = 8 to 9) is implemented with: – a FIFO of 32 bytes, 8 words – fixed/contiguously incremented addressing – These channels may be used for GPDMA transfers between a demanding AHB peripheral and SRAM, or for transfers from/to external memories.
x = 10 to 11	4	1	Channel x (x = 10 to 11) is implemented with: – a FIFO of 32 bytes, 8 words – 2D addressing These channels may be used for GPDMA transfers between a demanding AHB peripheral and SRAM, or for transfers from/to external memories.

16.3.3 GPDMA in low-power modes

The GPDMA wake-up feature is implemented in the device low-power modes as per the table below.

Table 127. GPDMA1/2 wake-up in low-power modes

Feature	Low-power modes
Wake-up	GPDMA1/2 in Sleep mode

16.3.4 GPDMA requests

A GPDMA request from a peripheral can be assigned to a GPDMA channel x, via REQSEL[7:0] in GPDMA_CxTR2, provided that SWREQ = 0.

The GPDMA requests mapping is specified in the table below.

Table 128. Programmed GPDMA1/2 request

GPDMA_CxTR2.REQSEL[7:0]	Selected GPDMA request
0	adc1_dma
1	adc2_dma
2	dac1_ch1_dma
3	dac1_ch2_dma
4	tim6_upd_dma

Table 128. Programmed GPDMA1/2 request (continued)

GPDMA_CxTR2.REQSEL[7:0]	Selected GPDMA request
5	tim7_upd_dma
6	spi1_rx_dma
7	spi1_tx_dma
8	spi2_rx_dma
9	spi2_tx_dma
10	spi3_rx_dma
11	spi3_tx_dma
12	i2c1_rx_dma
13	i2c1_tx_dma
14	Reserved
15	i2c2_rx_dma
16	i2c2_tx_dma
17	Reserved
18	i2c3_rx_dma
19	i2c3_tx_dma
20	Reserved
21	usart1_rx_dma
22	usart1_tx_dma
23	usart2_rx_dma
24	usart2_tx_dma
25	usart3_rx_dma
26	usart3_tx_dma
27	uart4_rx_dma
28	uart4_tx_dma
29	uart5_rx_dma
30	uart5_tx_dma
31	usart6_rx_dma
32	usart6_tx_dma
33	uart7_rx_dma
34	uart7_tx_dma
35	uart8_rx_dma
36	uart8_tx_dma
37	uart9_rx_dma
38	uart9_tx_dma
39	uart10_rx_dma

Table 128. Programmed GPDMA1/2 request (continued)

GPDMA_CxTR2.REQSEL[7:0]	Selected GPDMA request
40	uart10_tx_dma
41	uart11_rx_dma
42	uart11_tx_dma
43	uart12_rx_dma
44	uart12_tx_dma
45	lpuart1_rx_dma
46	lpuart1_tx_dma
47	spi4_rx_dma
48	spi4_tx_dma
49	spi5_rx_dma
50	spi5_tx_dma
51	spi6_rx_dma
52	spi6_tx_dma
53	sai1_a_dma
54	sai1_b_dma
55	sai2_a_dma
56	sai2_b_dma
57	ospi1_dma
58	tim1_cc1_dma
59	tim1_cc2_dma
60	tim1_cc3_dma
61	tim1_cc4_dma
62	tim1_upd_dma
63	tim1_trg_dma
64	tim1_com_dma
65	tim8_cc1_dma
66	tim8_cc2_dma
67	tim8_cc3_dma
68	tim8_cc4_dma
69	tim8_upd_dma
70	tim8_tig_dma
71	tim8_com_dma
72	tim2_cc1_dma
73	tim2_cc2_dma
74	tim2_cc3_dma

Table 128. Programmed GPDMA1/2 request (continued)

GPDMA_CxTR2.REQSEL[7:0]	Selected GPDMA request
75	tim2_cc4_dma
76	tim2_upd_dma
77	tim3_cc1_dma
78	tim3_cc2_dma
79	tim3_cc3_dma
80	tim3_cc4_dma
81	tim3_upd_dma
82	tim3_trg_dma
83	tim4_cc1_dma
84	tim4_cc2_dma
85	tim4_cc3_dma
86	tim4_cc4_dma
87	tim4_upd_dma
88	tim5_cc1_dma
89	tim5_cc2_dma
90	tim5_cc3_dma
91	tim5_cc4_dma
92	tim5_upd_dma
93	tim5_trg_dma
94	tim15_cc1_dma
95	tim15_upd_dma
96	tim15_trg_dma
97	tim15_com_dma
98	tim16_cc1_dma
99	tim16_upd_dma
100	tim17_cc1_dma
101	tim17_upd_dma
102	lptim1_ic1_dma
103	lptim1_ic2_dma
104	lptim1_ue_dma
105	lptim2_ic1_dma
106	lptim2_ic2_dma
107	lptim2_ue_dma
108	dcmi_dma or pssi_dma(1)
109	aes_out_dma

Table 128. Programmed GPDMA1/2 request (continued)

GPDMA_CxTR2.REQSEL[7:0]	Selected GPDMA request
110	aes_in_dma
111	hash_in_dma
112	ucpd1_rx_dma
113	ucpd1_tx_dma
114	cordic_read_dma
115	cordic_write_dma
116	fmac_read_dma
117	fmac_write_dma
118	saes_out_dma
119	saes_in_dma
120	i3c1_rx_dma
121	i3c1_tx_dma
122	i3c1_tc_dma
123	i3c1_rs_dma
124	i2c4_rx_dma
125	i2c4_tx_dma
126	Reserved
127	lptim3_ic1_dma
128	lptim3_ic2_dma
129	lptim3_ue_dma
130	lptim5_ic1_dma
131	lptim5_ic2_dma
132	lptim5_ue_dma
133	lptim6_ic1_dma
134	lptim6_ic2_dma
135	lptim6_ue_dma
136	i3c2_rx_dma
137	i3c2_tx_dma
138	i3c2_tc_dma
139	i3c2_rs_dma
140	jpeg_rx_dma
141	jpeg_tx_dma
142	adc3_dma
143	ospi2_dma
144	mdf1_flt0_dma

Table 128. Programmed GPDMA1/2 request (continued)

GPDMA_CxTR2.REQSEL[7:0]	Selected GPDMA request
145	mdf1_flt1_dma
146	mdf1_flt2_dma
147	mdf1_flt3_dma
148	mdf1_flt4_dma
149	mdf1_flt5_dma
150	adf1_flt0_dma

1. Depends on which exclusive function is used.

16.3.5 GPDMA block requests

Some GPDMA requests must be programmed as a block request, and not as a burst request. Then BREQ in GPDMA_CxTR2 must be set for a correct GPDMA execution of the requested peripheral transfer at the hardware level.

Table 129. Programmed GPDMA1/2 request as a block request

GPDMA block requests
lptim1_ue_dma
lptim2_ue_dma
lptim3_ue_dma
lptim5_ue_dma
lptim6_ue_dma

16.3.6 GPDMA channels with peripheral early termination

A GPDMA channel, if implemented with this feature, can support the early termination of the data transfer from the peripheral which does also support this feature.

Table 130. GPDMA1/2 channel with peripheral early termination

GPDMA channel x with peripheral early termination
x = 0, x = 1 and x = 11

This GPDMA support is activated when the channel x is programmed with GPDMA_CxTR2.PFREQ = 1. Then, the peripheral itself can initiate and request a data transfer completion, before the GPDMA has transferred the whole block (see *Section 16.4.14* for more details).

Table 131. Programmed GPDMA1/2 request with peripheral early termination

Programmed GPDMA channel x request with peripheral early termination
i3c1_rx_dma

Table 131. Programmed GPDMA1/2 request with peripheral early termination

Programmed GPDMA channel x request with peripheral early termination
i3c2_rx_dma
jpeg_tx_dma

16.3.7 GPDMA triggers

A GPDMA trigger can be assigned to a GPDMA channel x, via TRIGSEL[6:0] in GPDMA_CxTR2, provided that TRIGPOL[1:0] defines a rising or a falling edge of the selected trigger (TRIGPOL[1:0] = 01 or TRIGPOL[1:0] = 10).

Table 132. Programmed GPDMA1/2 trigger

GPDMA_CxTR2.TRIGSEL[5:0]	Selected GPDMA trigger
0	exti0
1	exti1
2	exti2
3	exti3
4	exti4
5	exti5
6	exti6
7	exti7
8	tamp_trg1
9	tamp_trg2
10	tamp_trg3
11	lptim1_ch1
12	lptim1_ch2
13	lptim2_ch1
14	lptim2_ch2
15	rtc_alra_trg
16	rtc_alrb_trg
17	rtc_wut_trg
18	gpdma1_ch0_tc
19	gpdma1_ch1_tc
20	gpdma1_ch2_tc
21	gpdma1_ch3_tc
22	gpdma1_ch4_tc
23	gpdma1_ch5_tc
24	gpdma1_ch6_tc
25	gpdma1_ch7_tc

Table 132. Programmed GPDMA1/2 trigger (continued)

GPDMA_CxTR2.TRIGSEL[5:0]	Selected GPDMA trigger
26	gpdma2_ch0_tc
27	gpdma2_ch1_tc
28	gpdma2_ch2_tc
29	gpdma2_ch3_tc
30	gpdma2_ch4_tc
31	gpdma2_ch5_tc
32	gpdma2_ch6_tc
33	gpdma2_ch7_tc
34	tim2_trgo
35	tim15_trgo
36	tim12_trgo
37	lptim3_ch1
38	lptim3_ch2
39	lptim4_ait
40	lptim5_ch1
41	lptim5_ch2
42	lptim6_ch1
43	lptim6_ch2
44	comp1_out
45	eventout
46	comp2_out
47	dma2d_tc
48	dma2d_ctc
49	dma2d_tw
50	dma2d_gpflags0
51	dma2d_gpflags1
52	dma2d_gpflags2
53	dma2d_gpflags3
54	jpeg_ift_trg
55	jpeg_ifnf_trg
56	jpeg_oft_trg
57	jpeg_ofne_trg
58	jpeg_eoc_trg
59	gfxtim_ev1
60	gfxtim_ev2

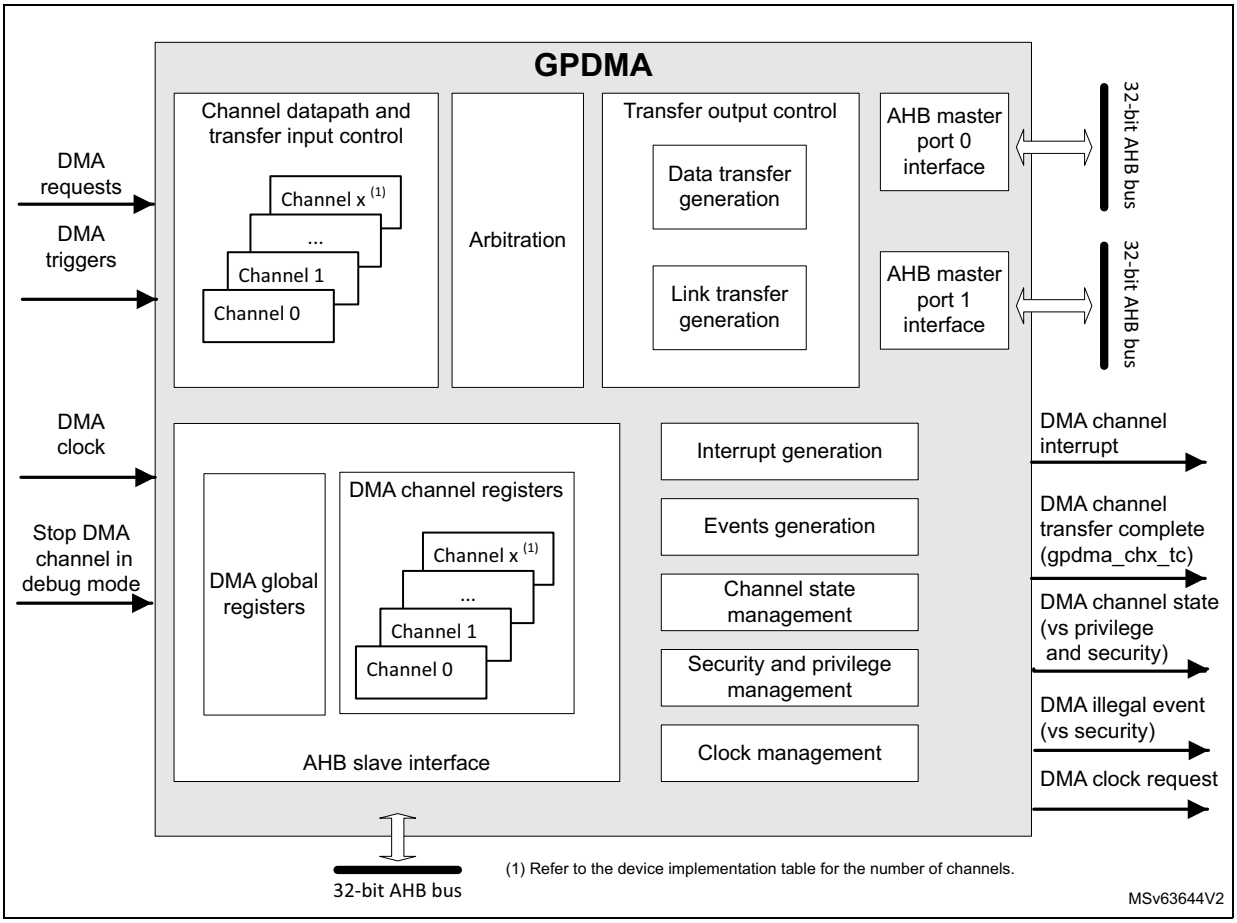
Table 132. Programmed GPDMA1/2 trigger (continued)

GPDMA_CxTR2.TRIGSEL[5:0]	Selected GPDMA trigger
61	gfxtim_ev3
62	gfxtim_ev4
63	lcd_ctrl_scanline
64	gpdma1_ch8_tc
65	gpdma1_ch9_tc
66	gpdma1_ch10_tc
67	gpdma1_ch11_tc
68	gpdma2_ch8_tc
69	gpdma2_ch9_tc
70	gpdma2_ch10_tc
71	gpdma2_ch11_tc
72	play1_out15

16.4 GPDMA functional description

16.4.1 GPDMA block diagram

Figure 70. GPDMA block diagram



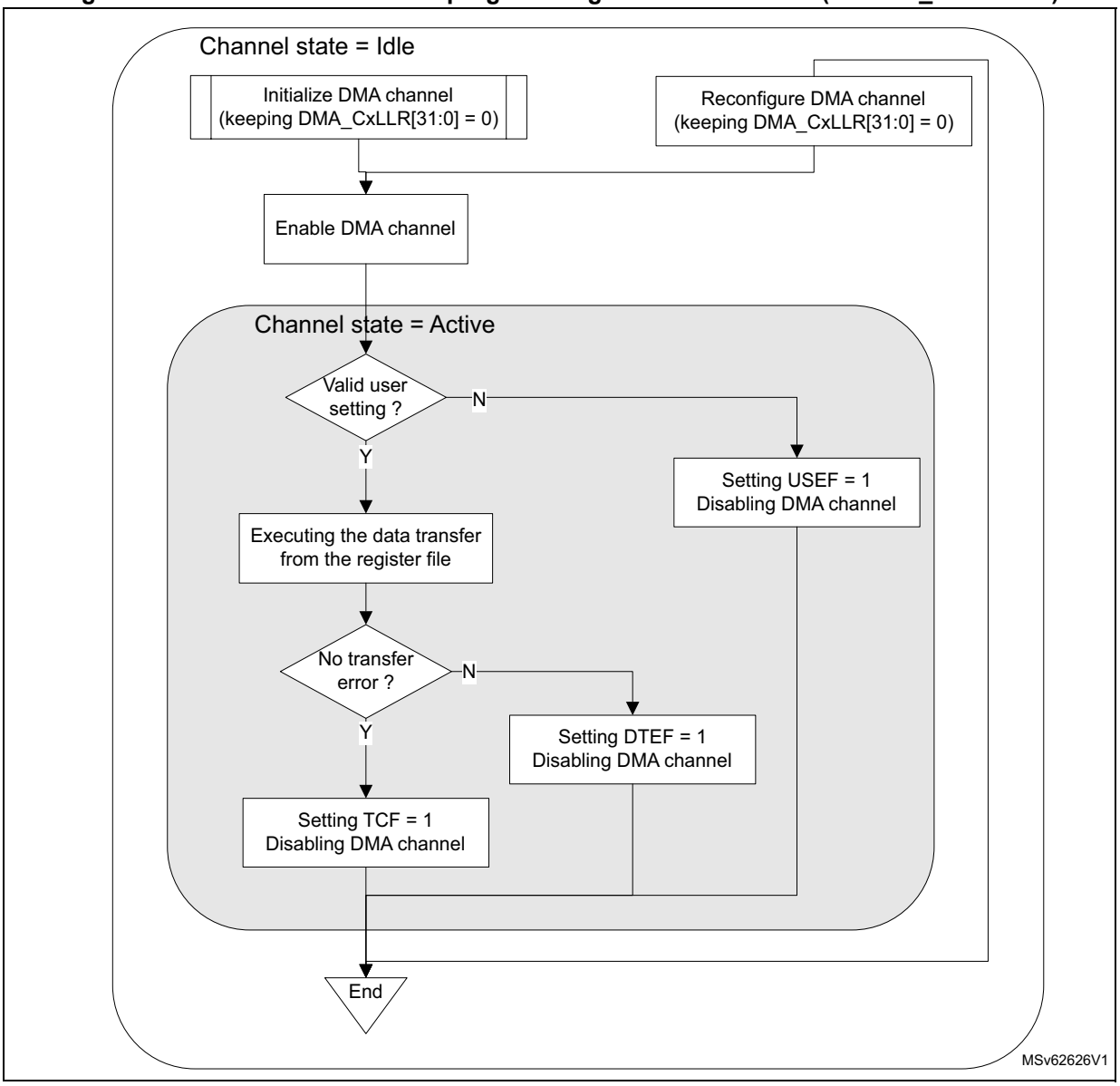
16.4.2 GPDMA channel state and direct programming without any linked-list

After a GPDMA reset, a GPDMA channel x is in idle state. When the software writes 1 in GPDMA_CxCR.EN, the channel takes into account the value of the different channel configuration registers (GPDMA_CxXXX), switches to the active/non-idle state and starts to execute the corresponding requested data transfers.

After enabling/starting a GPDMA channel transfer by writing 1 in GPDMA_CxCR.EN, a GPDMA channel interrupt on a complete transfer notifies the software that the GPDMA channel is back in idle state (EN is then deasserted by hardware) and that the channel is ready to be reconfigured then enabled again.

Figure 71 illustrates this GPDMA direct programming without any linked-list (GPDMA_CxLLR = 0).

Figure 71. GPDMA channel direct programming without linked-list (GPDMA_CxLLR = 0)



16.4.3 GPDMA channel suspend and resume

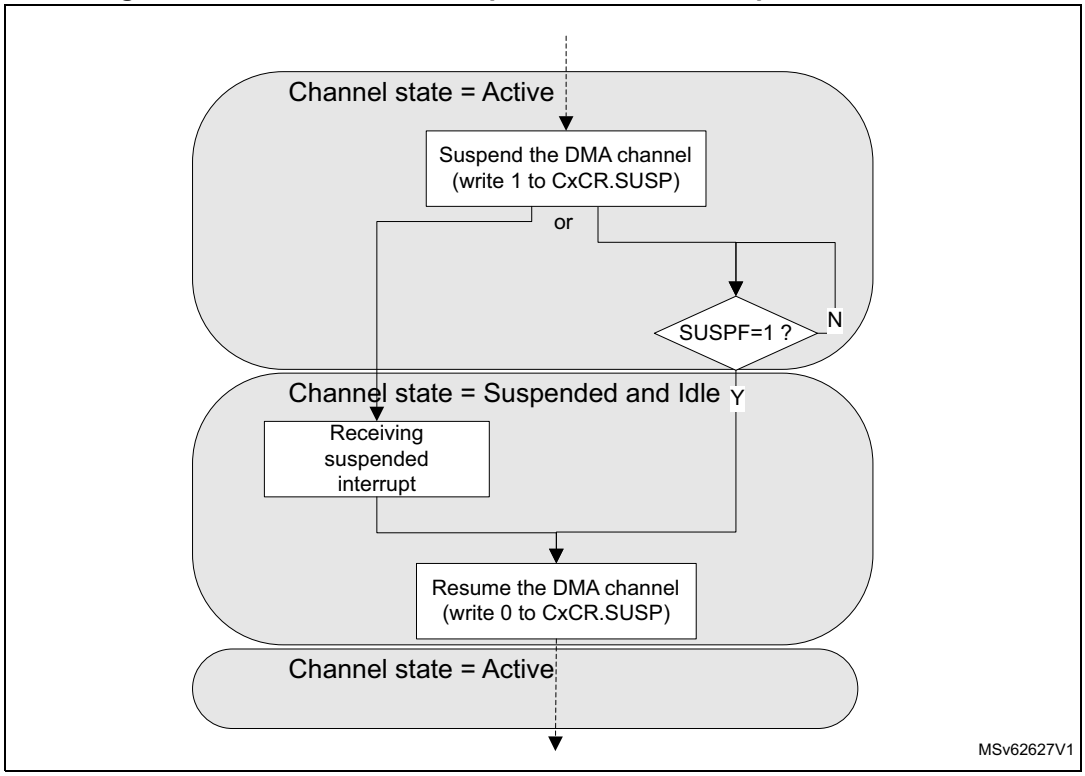
The software can suspend on its own a channel still active, with the following sequence:

1. The software writes 1 into the GPDMA_CxCR.SUSP bit.
2. The software polls the suspended flag GPDMA_CxSR.SUSPF until SUSPF = 1, or waits for an interrupt previously enabled by writing 1 to GPDMA_CxCR.SUSPIE. Wait for the channel to be effectively in suspended state means wait for the completion of any ongoing GPDMA transfer over its master ports. Then the software can observe, in a steady state, any read register or register field that is hardware modifiable.

Note: An ongoing GPDMA transfer can be a data transfer (a source/destination burst transfer) or a link transfer for the internal update of the linked-list register file from the next linked-list item.

3. The software safely resumes the suspended channel by writing 0 to GPDMA_CxCR.SUSP.

Figure 72. GPDMA channel suspend and resume sequence



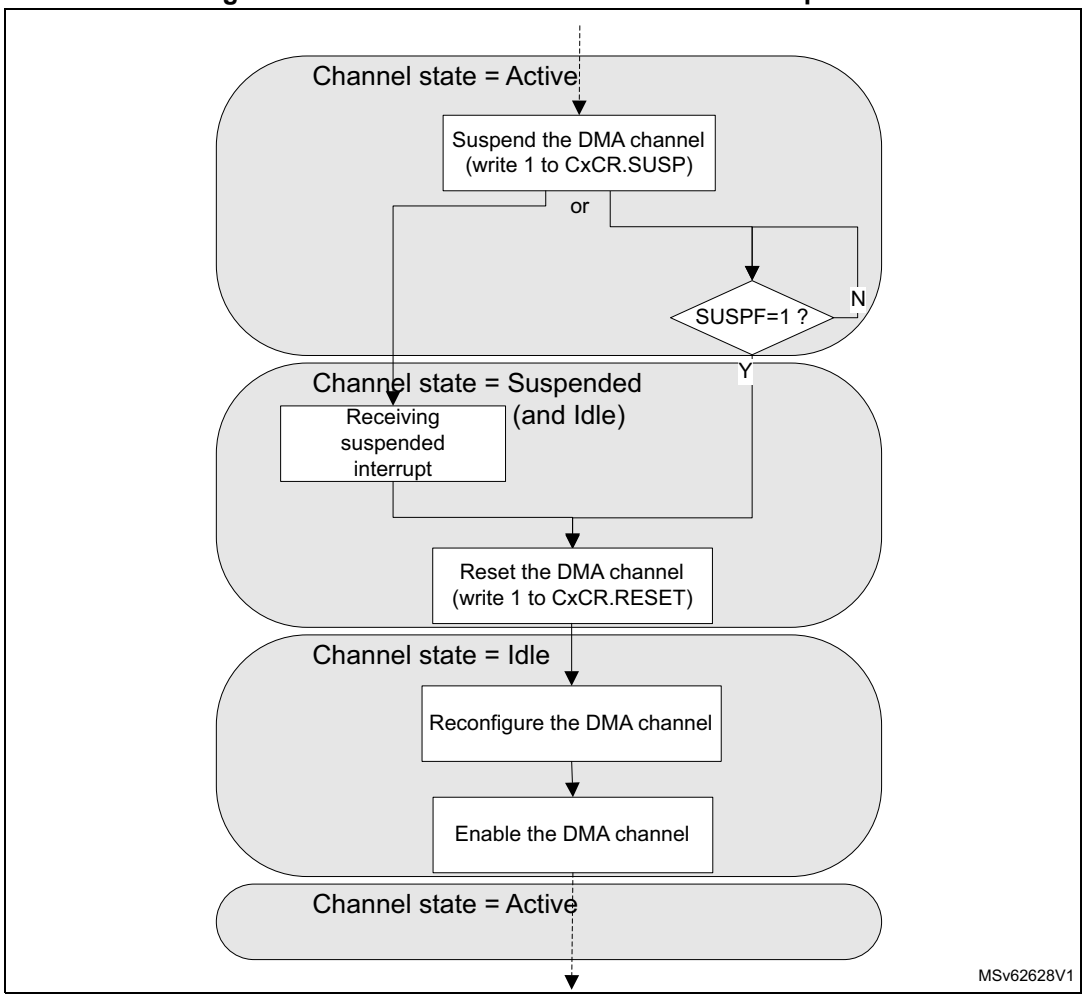
Note: A suspend and resume sequence does not impact the GPDMA_CxCR.EN bit. Suspending a channel (transfer) does not suspend a started trigger detection.

16.4.4 GPDMA channel abort and restart

Alternatively, like for aborting a continuous GPDMA transfer with a circular buffering or a double buffering, the software can abort, on its own, a still active channel with the following sequence:

1. The software writes 1 into the GPDMA_CxCR.SUSP bit.
2. The software polls suspended flag GPDMA_CxSR.SUSPF until SUSPF = 1, or waits for an interrupt previously enabled by writing 1 to GPDMA_CxCR.SUSPIE. Wait for the channel to be effectively in suspended state means wait for the completion of any ongoing GPDMA transfer over its master port.
3. The software resets the channel by writing 1 to GPDMA_CxCR.RESET. This causes the reset of the FIFO, the reset of the channel internal state, the reset of the GPDMA_CxCR.EN bit, and the reset of the GPDMA_CxCR.SUSP bit.
4. The software safely reconfigures the channel. The software must reprogram the hardware-modified GPDMA_CxBR1, GPDMA_CxSAR, and GPDMA_CxDAR registers.
5. In order to restart the aborted then reprogrammed channel, the software enables it again by writing 1 to the GPDMA_CxCR.EN bit.

Figure 73. GPDMA channel abort and restart sequence



16.4.5 GPDMA linked-list data structure

Alternatively to the direct programming mode, a channel can be programmed by a list of transfers, known as a list of linked-list items (LLI). Each LLI is defined by its data structure.

The base address in memory of the data structure of a next LLI_{n+1} of a channel x is the sum of the following:

- the link base address of the channel x (in GPDMA_CxLBAR)
- the link address offset (LA[15:2] field in GPDMA_CxLLR). The linked-list register GPDMA_CxLLR is the updated result from the data structure of the previous LLIn of the channel x.

The data structure for each LLI may be specific.

A linked-list data structure is addressed following the value of the following UT1, UT2, UB1, USA, UDA, UT3 and UB2 if present, and ULL bits in GPDMA_CxLLR.

In linked-list mode, each GPDMA linked-list register (GPDMA_CxTR1, GPDMA_CxTR2, GPDMA_CxBR1, GPDMA_CxSAR, GPDMA_CxDAR, GPDMA_CxTR3 and GPDMA_CxBR2 if present, and GPDMA_CxLLR) is conditionally and automatically updated from the next linked-list data structure in the memory, following the current value of the

GPDMA_CxLLR register that was conditionally updated from the linked-list data structure of the previous LLI.

Caution: The user must program the pointer to the next linked-list data structure (GPDMA_CxLLR[15:0]) not to exceed the 64-Kbyte addressable space defined by the link base address register (GPDMA_CxLBAR). The complete linked-list data structure must be included in the 64-Kbyte addressable space.

Static linked-list data structure

For example, when the update bits (UT1, UT2, UB1, USA, UDA, plus UB2 and UT3 if present, and ULL) in GPDMA_CxLLR are all asserted, the linked-list data structure in the memory is maximal with:

- channel x (x = 0 to 9) contiguous 32-bit locations, including GPDMA_CxTR1, GPDMA_CxTR2, GPDMA_CxBR1, GPDMA_CxSAR, GPDMA_CxDAR and GPDMA_CxLLR (see *Figure 74*) and including the first linked-list register file (LLI_0) and the next LLIs (such as LLI_1, LLI_2) in the memory
- channel x (x = 10 to 11), contiguous 32-bit locations, including GPDMA_CxTR1, GPDMA_CxTR2, GPDMA_CxBR1, GPDMA_CxSAR, GPDMA_CxDAR, GPDMA_CxTR3, GPDMA_CxBR2 and GPDMA_CxLLR, (see *Figure 75*), and including the first linked-list register file (LLI_0) and the next LLIs (such as LLI_1, LLI_2) in the memory

Figure 74. Static linked-list data structure (all Uxx = 1) of a linear addressing channel x

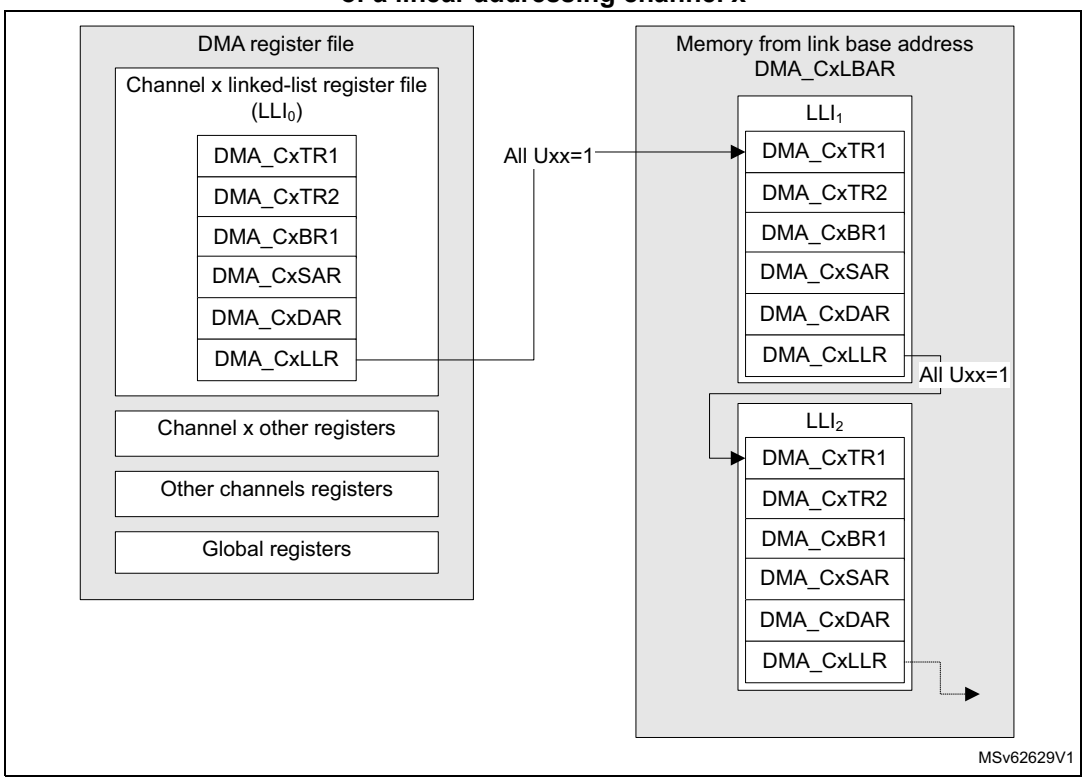
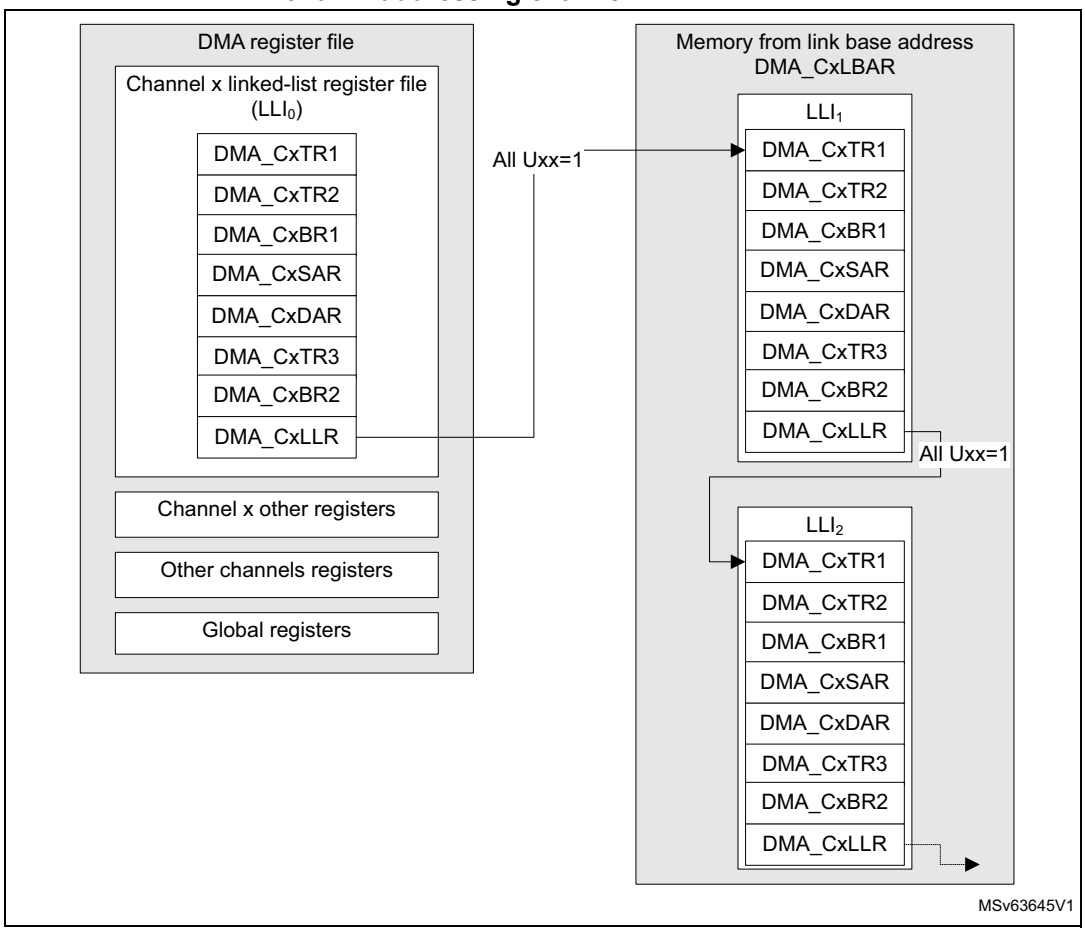


Figure 75. Static linked-list data structure (all Uxx = 1) of a 2D addressing channel x



Dynamic linked-list data structure

Alternatively, the memory organization for the full list of LLIs can be compacted with specific data structure for each LLI.

If UT1 = 0 and UT2 = 1, the link address offset of the register GPDMA_CxLLR is pointing to the updated value of the GPDMA_CxTR2 instead of the GPDMA_CxTR1 which is not to be modified (see *Figure 76*).

Example: if UT1 = UB1 = USA = 0 and if UT3 = UB2 = 0, when channel x is with 2D addressing, and if UT2 = UDA = ULL = 1, the next LLI does not contain an (updated) value for GPDMA_CxTR1, nor GPDMA_CxBR1, nor GPDMA_CxSAR, nor GPDMA_CxTR3, nor GPDMA_CxBR2 when channel x is with 2D addressing. The next LLI contains an updated value for GPDMA_CxTR2, GPDMA_CxDAR, and GPDMA_CxLLR, as shown in *Figure 77*.

Figure 76. GPDMA dynamic linked-list data structure of a linear addressing channel x

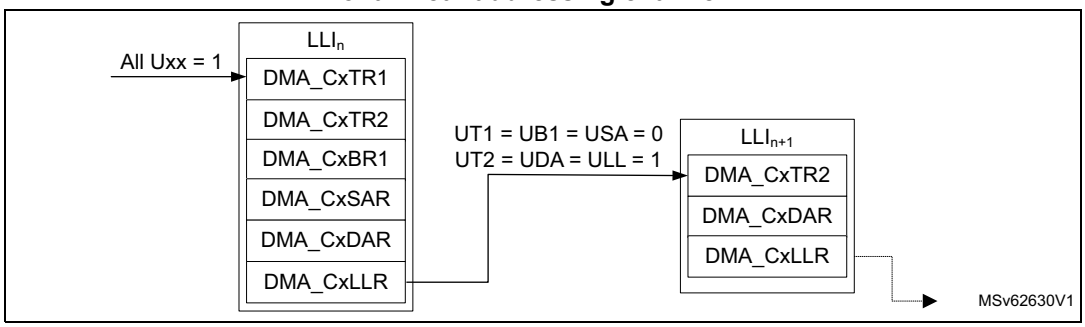
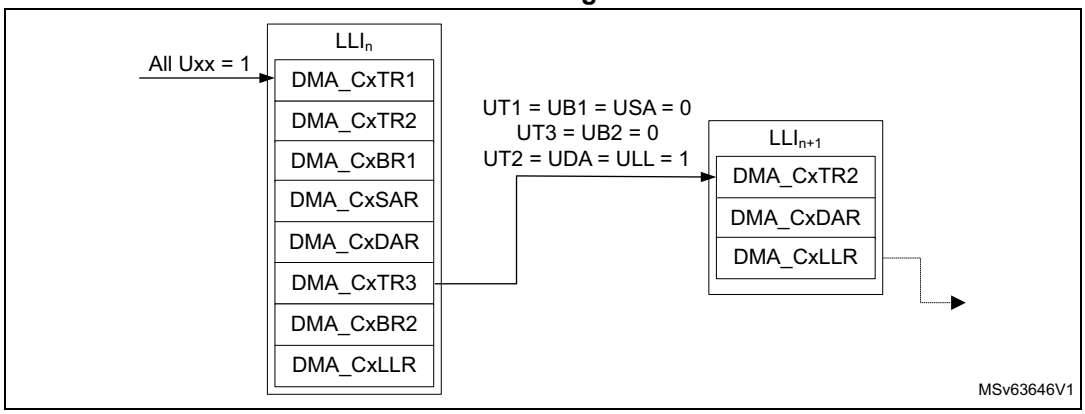


Figure 77. GPDMA dynamic linked-list data structure of a 2D addressing channel x



16.4.6 Linked-list item transfer execution

A LLI_n transfer is the sequence of:

1. a data transfer: GPDMA executes the data transfer as described by the GPDMA internal register file (this data transfer can be void/null for LLI_0)
2. a conditional link transfer: GPDMA automatically and conditionally updates its internal register file by the data structure of the next LLI_{n+1}, as defined by the GPDMA_CxLLR value of the LLI_n.

Note: The initial data transfer as defined by the internal register file (LLI_0) can be null (GPDMA_CxBR1.BNDT[15:0] = 0 and GPDMA_CxTR2.PFREQ = 0) provided that the conditional update bit UB1 in GPDMA_CxLLR is set (meaning there is a non-null data transfer described by the next LLI_1 in the memory to be executed).

Depending on the intended GPDMA usage, a GPDMA channel x can be executed as described by the full linked-list (run-to-completion mode, GPDMA_CxCR.LSM = 0) or a GPDMA channel x can be programmed for a single execution of a LLI (link step mode, GPDMA_CxCR.LSM = 1), as described in the next sections.

16.4.7 GPDMA channel state and linked-list programming in run-to-completion mode

When GPDMA_CxCR.LSM = 0 (in full list execution mode, execution of the full sequence of LLIs, named run-to-completion mode), a GPDMA channel x is initially programmed, started

by writing 1 to GPDMA_CxCR.EN, and after completed at channel level. The channel transfer is:

- configured with at least the following:
  - the first LLI_0, internal linked-list register file: GPDMA_CxTR1, GPDMA_CxTR2, GPDMA_CxBR1, GPDMA_CxSAR, GPDMA_CxDAR, and GPDMA_CxLLR, plus GPDMA_CxTR3 and GPDMA_CxBR2
  - the last LLI_N, described by the linked-list data structure in memory, as defined by the GPDMA_CxLLR reflecting the before last LLI_{N-1}
- completed when GPDMA_CxLLR[31:0] = 0, GPDMA_CxBR1.BRC[10:0] = 0, and GPDMA_CxBR1.BNDT[15:0] = 0, at the end of the last LLI_{N-1} transfer

GPDMA_CxLLR[31:0] = 0 is the condition of a linked-list based channel completion and means the following:

- The 16 low significant bits GPDMA_CxLLR.LA[15:0] of the next link address are null.
- All the update bits GPDMA_CxLLR.Uxx are null (UT1, UT2, UB1, USA, UDA and ULL, plus UB2 and UT3).

The channel may never be completed when GPDMA_CxLLR.LSM = 0:

- If the last LLI_N is recursive, pointing to itself as a next LLI:
  - either GPDMA_CxLLR.ULL = 1 and GPDMA_CxLLR.LA[15:2] is updated with the same value
  - or GPDMA_CxLLR.ULL = 0
- If LLI_N is pointing to a previous LLI

In the regular data transfer completion at a block level, GPDMA_CxBR1.BNDT[15:0] = 0 and GPDMA_CxBR1.BRC[10:0] = 0 (if present). Alternatively, a block transfer may be early completed by a peripheral (such as an I3C in Rx mode), and then BNDT[15:0] is not null (see *Section 16.4.14* for more details).

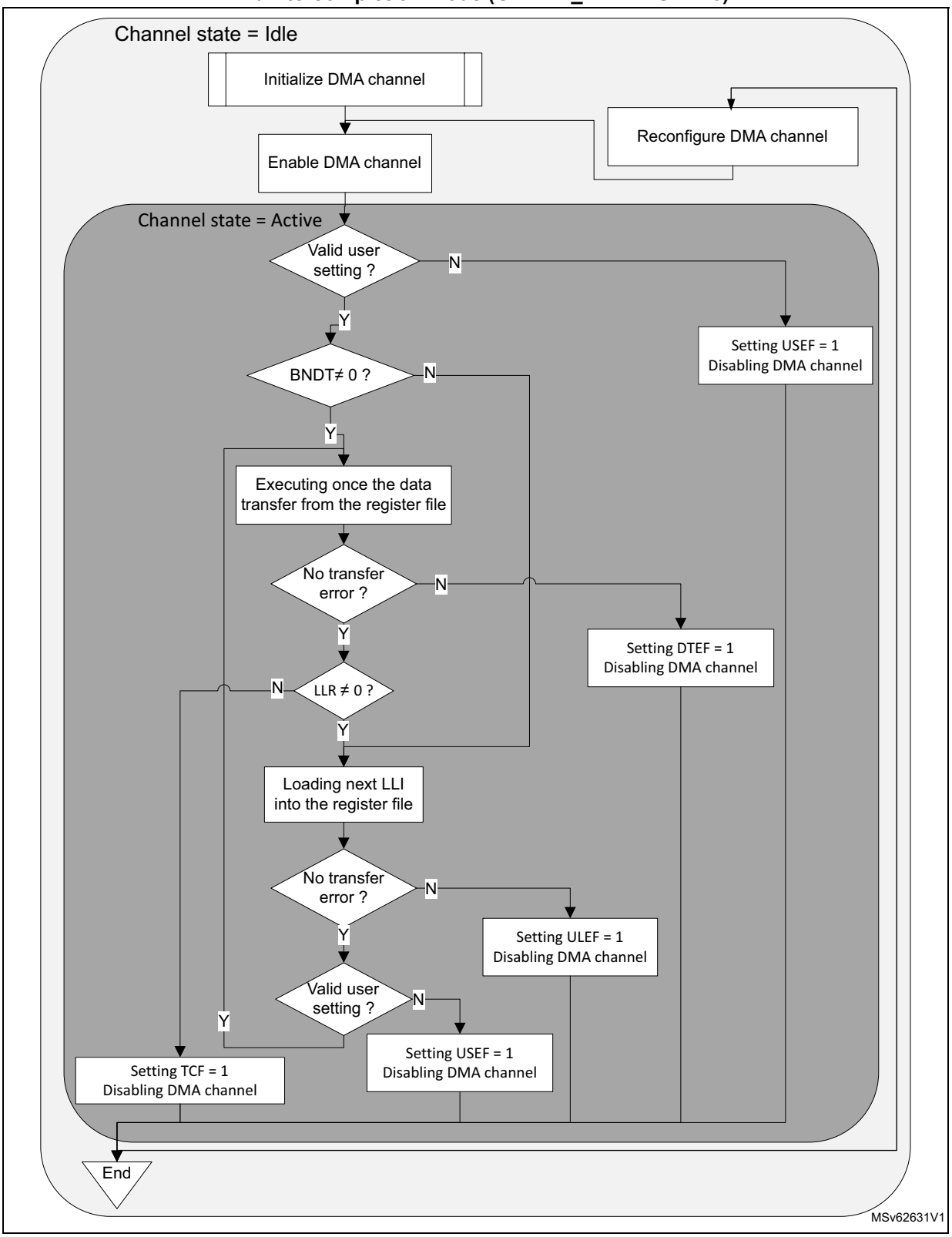
In the typical run-to-completion mode, the allocation of a GPDMA channel, including its fine programming, is done once during the GPDMA initialization. In order to have a reserved data communication link and GPDMA service during run-time, for continuously repeated transfers (from/to a peripheral respectively to/from memory or for memory-to-memory transfers). This reserved data communication link can consist of a channel, or the channel can be shared and a repeated transfer consists of a sequence of LLIs.

Figure 78 depicts the GPDMA channel execution and its registers programming in run-to-completion mode.

Note: Figure 78 is not intended to illustrate how often a TCEF can be raised, depending on the programmed value of TCEM[1:0] in GPDMA_CxTR2. It can be raised at (each) block completion, at (each) 2D block completion, at (each) LLI completion, or only at channel completion. In run-to-completion mode, whatever is the value of TCEM[1:0], at the channel completion, the hardware always set TCEF = 1 and disables the channel.

In Figure 78, BNDT ≠ 0 is the typical condition for starting the first data transfer in this figure. This condition becomes (BNDT ≠ 0 and PFREQ = 1) if the peripheral requests a data transfer with early termination (see Section 16.3.6).

Figure 78. GPDMA channel execution and linked-list programming in run-to-completion mode (GPDMA_CxCR.LSM = 0)



Run-time inserting a LLI_n via an auxiliary channel, in run-to-completion mode

The start of the link transfer of the LLI_{n-1} (start of the LLI_n loading) can be conditioned by the occurrence of a trigger, when programming the following fields of the GPDMA_CxTR2 in the data structure of the LLI_{n-1}:

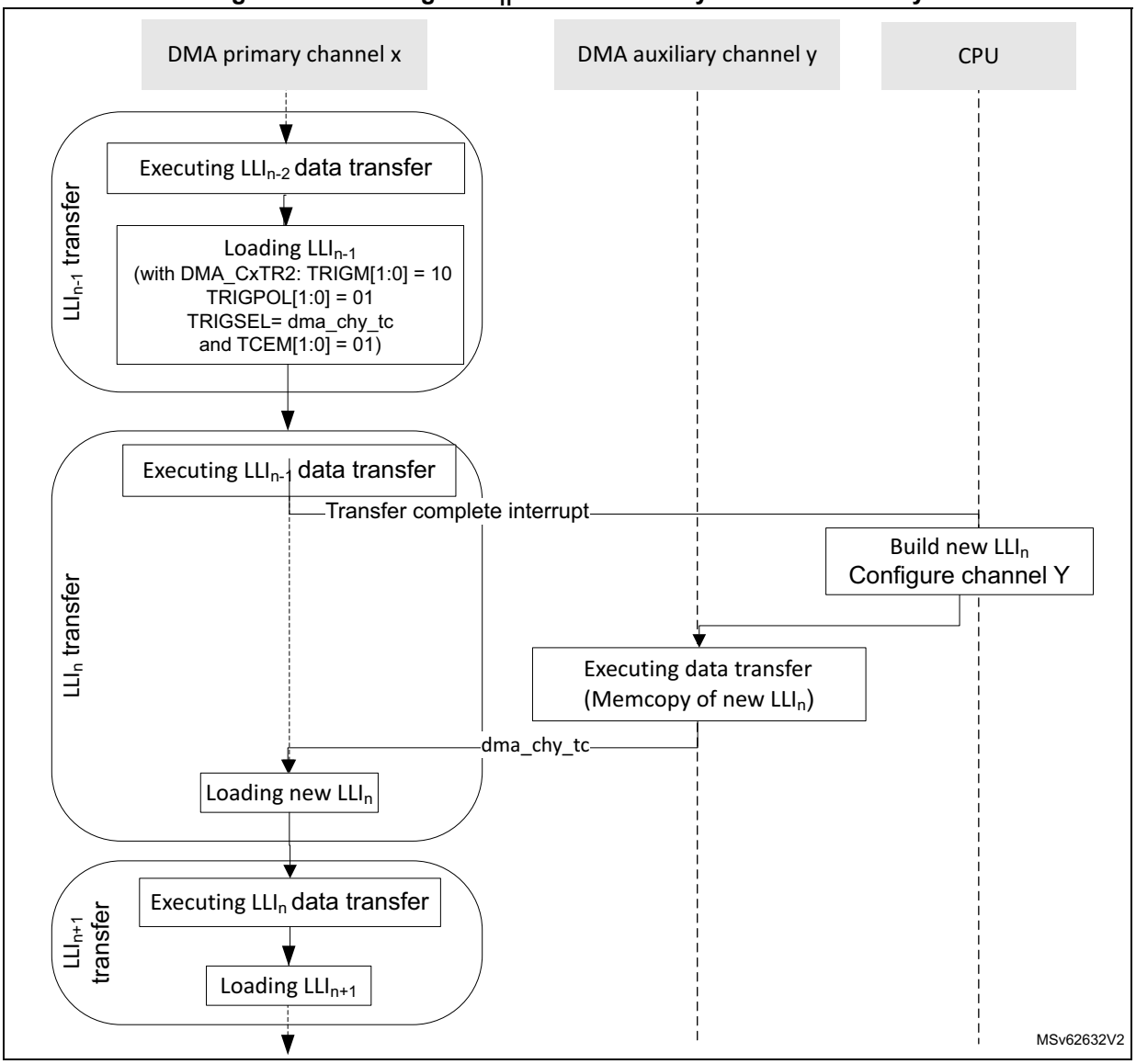
- TRIGM[1:0] = 10 (link transfer triggering mode)
- TRIGPOL[1:0] = 01 or 10 (rising or falling edge)
- TRIGSEL[6:0] (see *Section 16.3.7* for the trigger selection details)

Another auxiliary channel y can be used to store the channel x LLI_n in the memory and to generate a transfer complete event gpdma_chy_tc. By selecting this event as the input trigger of the link transfer of the LLI_{n-1} of the channel x, the software can pause the primary channel x after its LLI_{n-1} data transfer, until it is indeed written the LLI_n.

Figure 79 depicts such a dynamic elaboration of a linked-list of a primary channel x, via another auxiliary channel y.

Caution: This use case is restricted to an application with a LLI_{n-1} data transfer that does not need a trigger. The triggering mode of this LLI_{n-1} is used to load the next LLI_n.

Figure 79. Inserting a LLI_n with an auxiliary GPDMA channel y



16.4.8 GPDMA channel state and linked-list programming in link step mode

When GPDMA_CxCR.LSM = 1 (in link step execution mode, single execution of one LLI), a channel transfer is executed and completed after each single execution of a LLI, including its (conditional) data transfer and its (conditional) link transfer.

A GPDMA channel transfer can be programmed at LLI level, started by writing 1 into GPDMA_CxCR.EN, and after completed at LLI level:

- The current LLI_n transfer is described with:
  - GPDMA_CxTR1 defines the source/destination elementary single/burst transfers.
  - GPDMA_CxBR1 defines the number of bytes at a block level (BNDT[15:0]) and, for channel x (x = 10 to 11), the number of blocks at a 2D/repeated block level (BRC[10:0]+1) and the incrementing/decrementing mode for address offsets.

  - GPDMA_CxTR2 defines the input control (request, trigger) and the output control (transfer complete event) of the transfer.
  - GPDMA_CxSAR/GPDMA_CxDAR define the source/destination transfer start address.
  - GPDMA_CxTR3 for channel x (x = 10 to 11) defines the source/destination additional address offset between burst transfers.
  - GPDMA_CxBR2 for channel x (x = 10 to 11) defines the source/destination additional address offset between blocks at a 2D/repeated block level.
  - GPDMA_CxLLR defines the data structure and the address offset of the next LLI_{n+1} in the memory.
- The current LLI_n transfer is completed after the single execution of the current LLI_n:
  - after the (conditional) data transfer completion (when GPDMA_CxBR1.BRC[10:0] = 0, and GPDMA_CxBR1.BNDT[15:0] = 0
  - after the (conditional) update of the GPDMA link register file from the data structure of the next LLI_{n+1} in memory

Note: If a LLI is recursive (pointing to itself as a next LLI, either GPDMA_CxLLR.ULL = 1 and GPDMA_CxLLR.LA[15:2] is updated with the same value, or GPDMA_CxLLR.ULL = 0), a channel in link step mode is completed after each repeated single execution of this LLI.

In the regular data transfer completion at a block level, GPDMA_CxBR1.BNDT[15:0] = 0 and GPDMA_CxBR1.BRC[10:0] = 0. Alternatively, a block transfer may be early completed by a peripheral (such as an I3C in Rx mode), and then BNDT[15:0] is not null (see *Section 16.4.14* for more details).

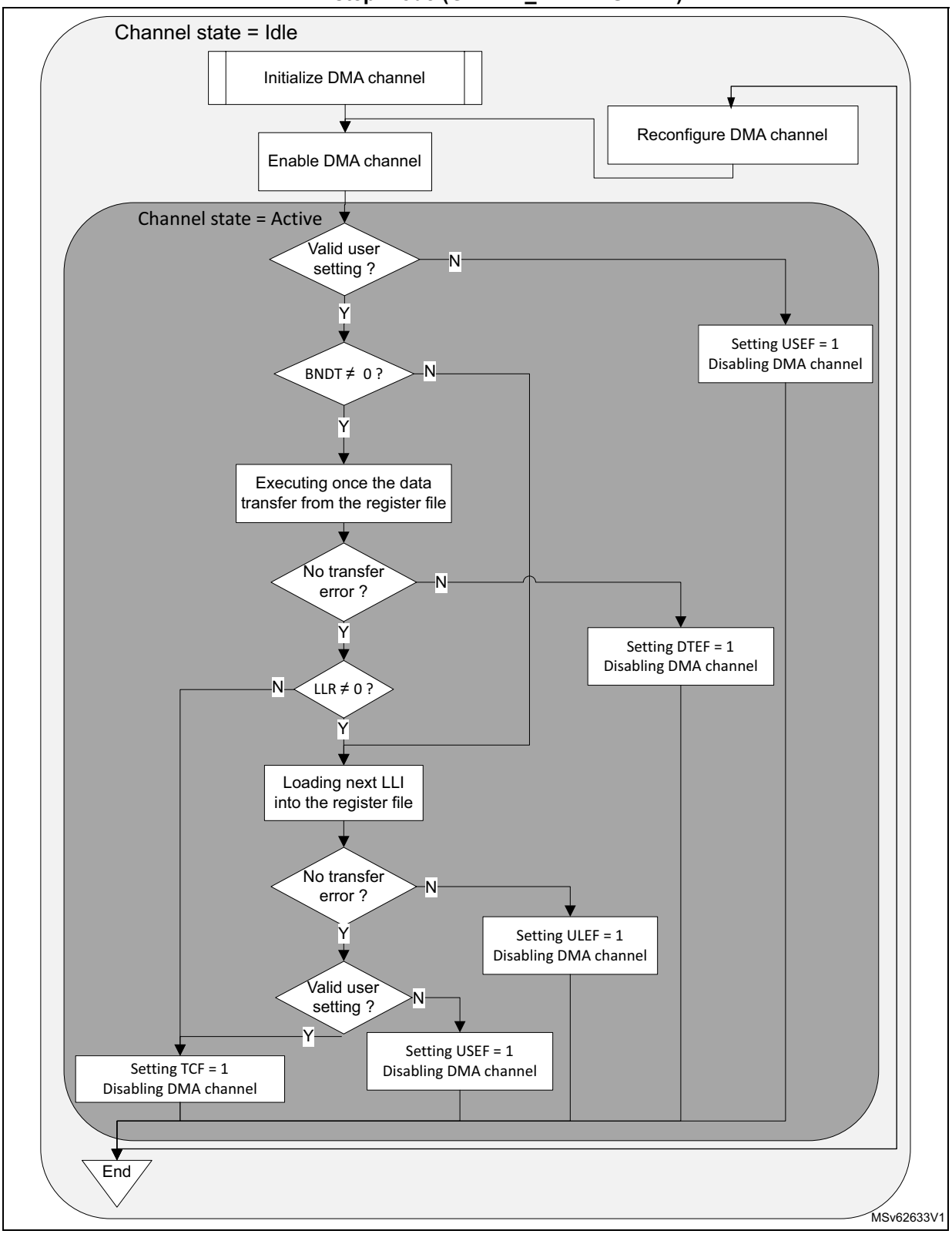
The link step mode can be used to elaborate dynamically LLIs in memory during run-time. The software can be facilitated by using a static data structure for any LLI_n (all update bits of GPDMA_CxLLR have a static value, LLI_n.LLR.LA = LLI_{n-1}.LLR.LA + constant).

Figure 80 depicts the GPDMA channel execution mode, and its programming in link step mode.

Note: Figure 80 is not intended to illustrate how often a TCEF can be raised, depending on the programmed value of TCEM[1:0] in GPDMA_CxTR2. It can be raised at (each) block completion, at (each) 2D block completion, at (each) LLI completion, or only at the last LLI data transfer completion. In link step mode, the channel is disabled after each single execution of a LLI, and depending on the value of TCEM[1:0] a TCEF is raised or not.

In Figure 80, BNDT ≠ 0 is the typical condition for starting the first data transfer. This condition becomes (BNDT ≠ 0 and PFREQ = 1) if the peripheral requests a data transfer with early termination (see Section 16.3.6).

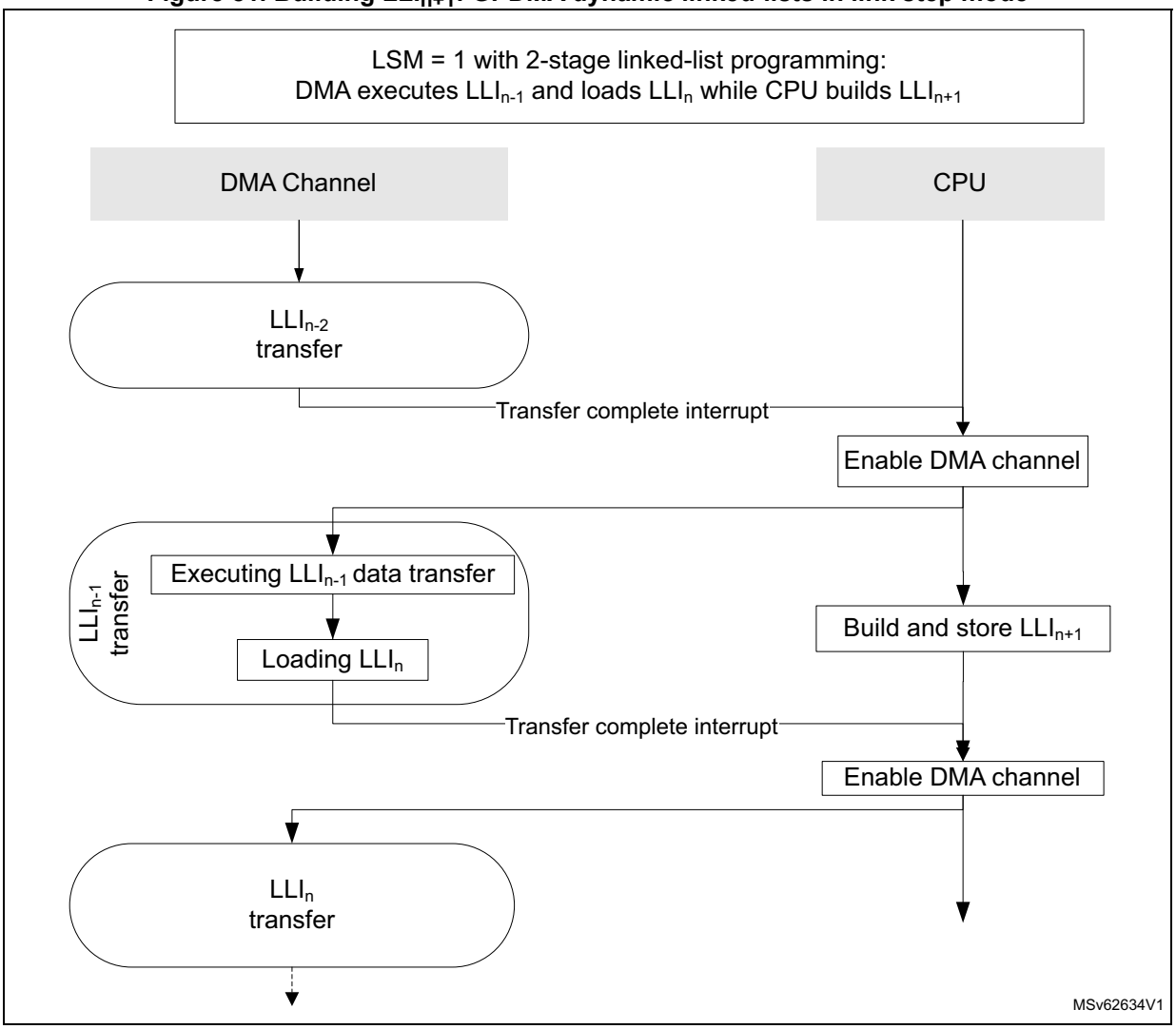
Figure 80. GPDMA channel execution and linked-list programming in link step mode (GPDMA_CxCR.LSM = 1)



Run-time adding a LLI_{n+1} in link step mode

During run-time, the software can defer the elaboration of the LLI_{n+1} (and next LLIs), until/after GPDMA executed the transfer from the LLI_{n-1} and loaded the LLI_n from the memory, as shown in *Figure 81*.

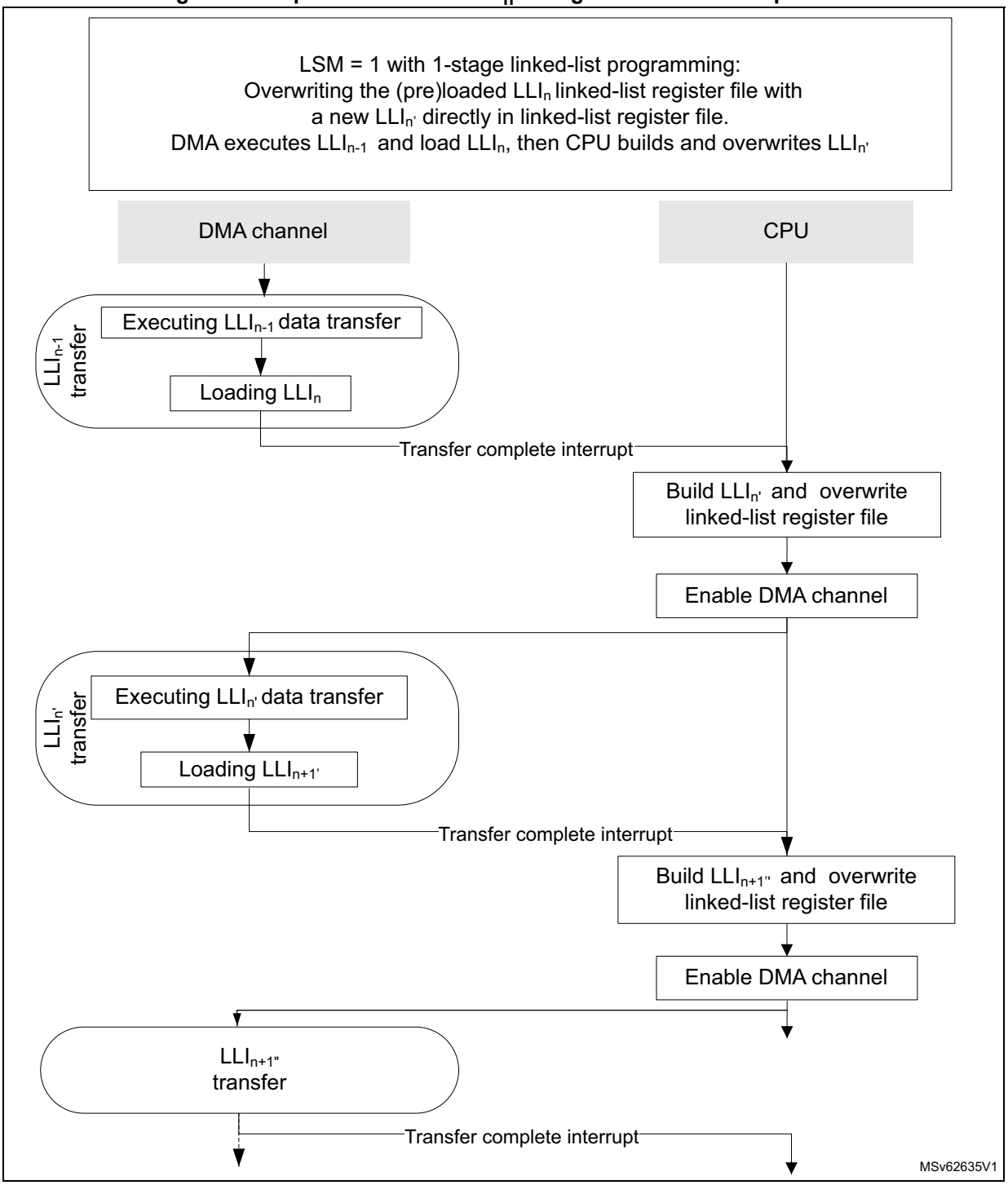
Figure 81. Building LLI_{n+1}: GPDMA dynamic linked-lists in link step mode



Run-time replacing a LLI_n with a new LLI_n', in link step mode (in linked-list register file)

In this link step mode, during run-time, the software can build and insert a new LLI_n', after GPDMA executed the transfer from the LLI_{n-1} and loaded a formerly elaborated LLI_n from the memory by overwriting directly the linked-list register file with the new LLI_n', as shown in *Figure 82*.

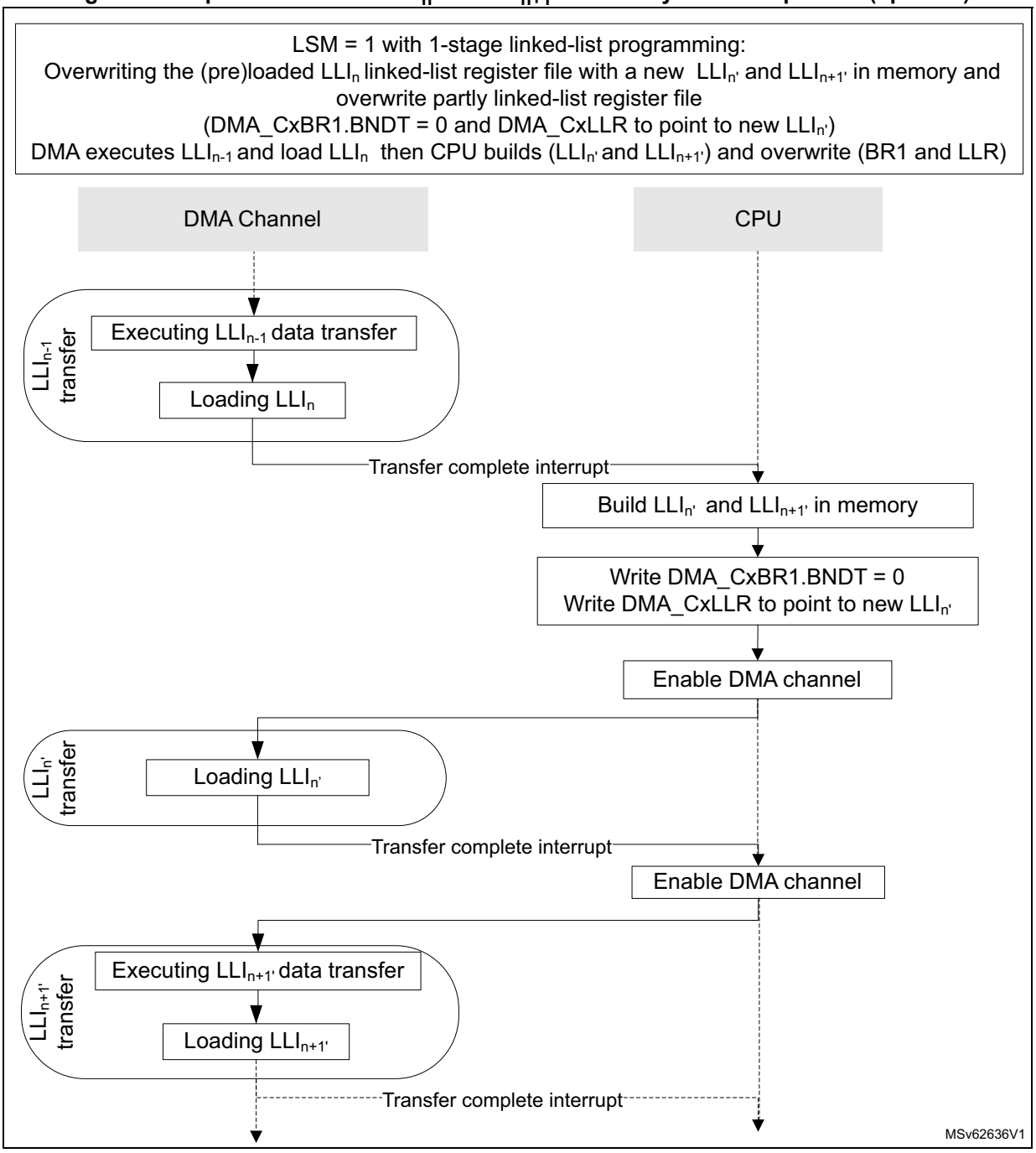
Figure 82. Replace with a new $LLI_{n'}$ in register file in link step mode



Run-time replacing a LLI_n with a new $LLI_{n'}$ in link step mode (in the memory)

The software can build and insert a new $LLI_{n'}$ and $LLI_{n+1'}$ in the memory, after GPDMA executed the transfer from the LLI_{n-1} and loaded a formerly elaborated LLI_n from the memory, by overwriting partly the linked-list register file (GPDMA_CxBR1.BNDT[15:0] to be null and GPDMA_CxLLR to point to new $LLI_{n')}$ as shown in *Figure 83*.

Figure 83. Replace with a new $LLI_{n'}$ and $LLI_{n+1'}$ in memory in link step mode (option 1)



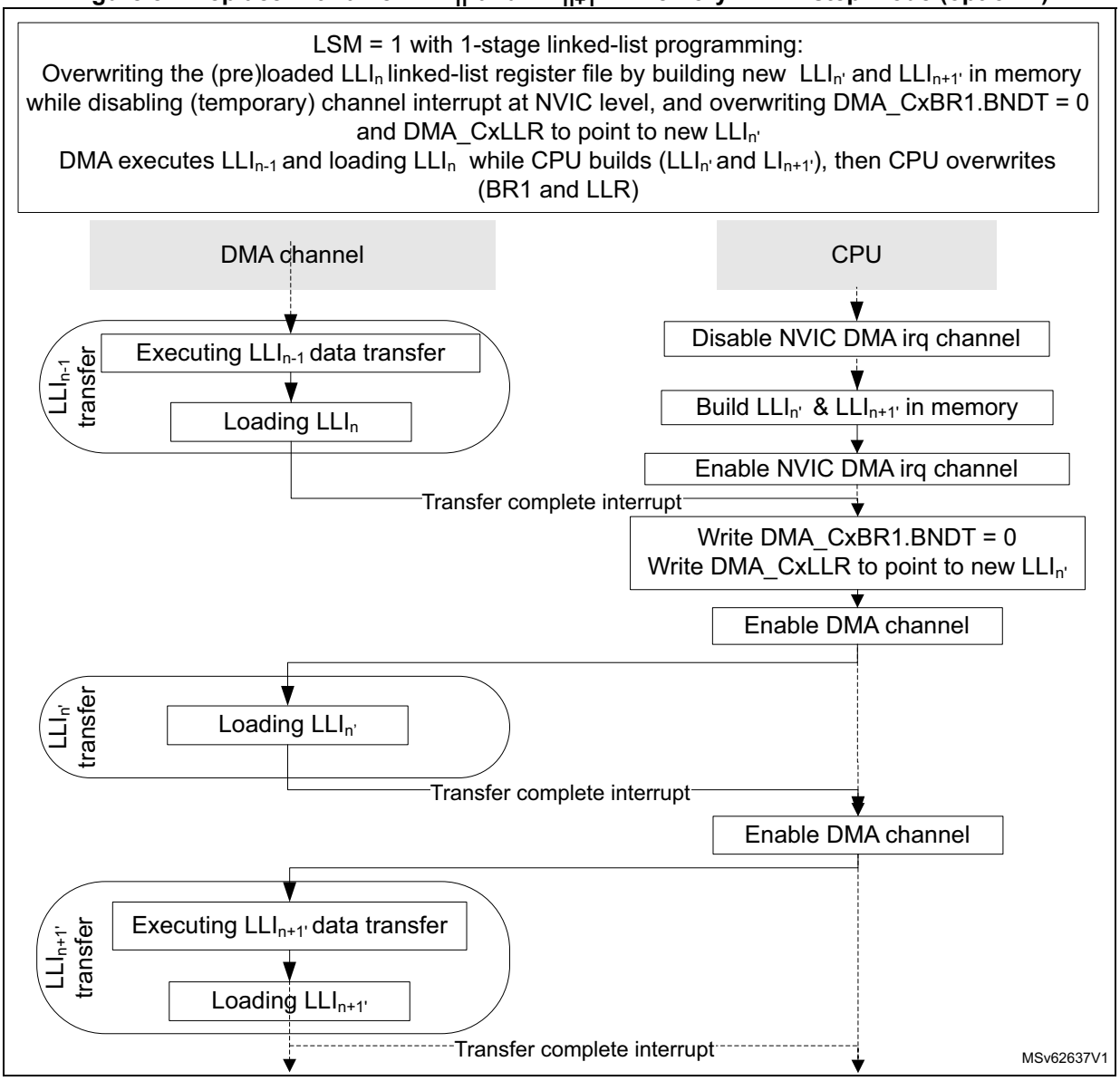
Run-time replacing a LLI_n with a new $LLI_{n'}$ in link step mode

Other software implementations exist. Meanwhile GPDMA executes the transfer from the LLI_{n-1} and loads a formerly elaborated LLI_n from the memory (or even earlier), the software can do the following:

1. Disable the NVIC for not being interrupted by the interrupt handling.
2. Build a new $LLI_{n'}$ and a new $LLI_{n+1'}$.
3. Enable again the NVIC for the channel interrupt (transfer complete) notification.

The software in the interrupt handler for LLI_{n-1} is then restricted to overwrite GPDMA_CxBR1.BNDT[15:0] to be null and GPDMA_CxLLR to point to new $LLI_{n'}$, as shown in *Figure 84*.

Figure 84. Replace with a new $LLI_{n'}$ and $LLI_{n+1'}$ in memory in link step mode (option 2)



16.4.9 GPDMA channel state and linked-list programming

The software can reconfigure a channel when the channel is disabled (GPDMA_CxCR.EN = 0) and update the execution mode (GPDMA_CxCR.LSM) to change from/to run-to-completion mode to/from link step mode.

In any execution mode, the software can:

- reprogram LLI_{n+1} in the memory to finally complete the channel by this LLI_{n+1} (clear the GPDMA_CxLLR of this LLI_{n+1}), before this LLI_{n+1} is loaded/used by the GPDMA channel
- abort and reconfigure the channel with a LSM update (see *Section 16.4.4*.)

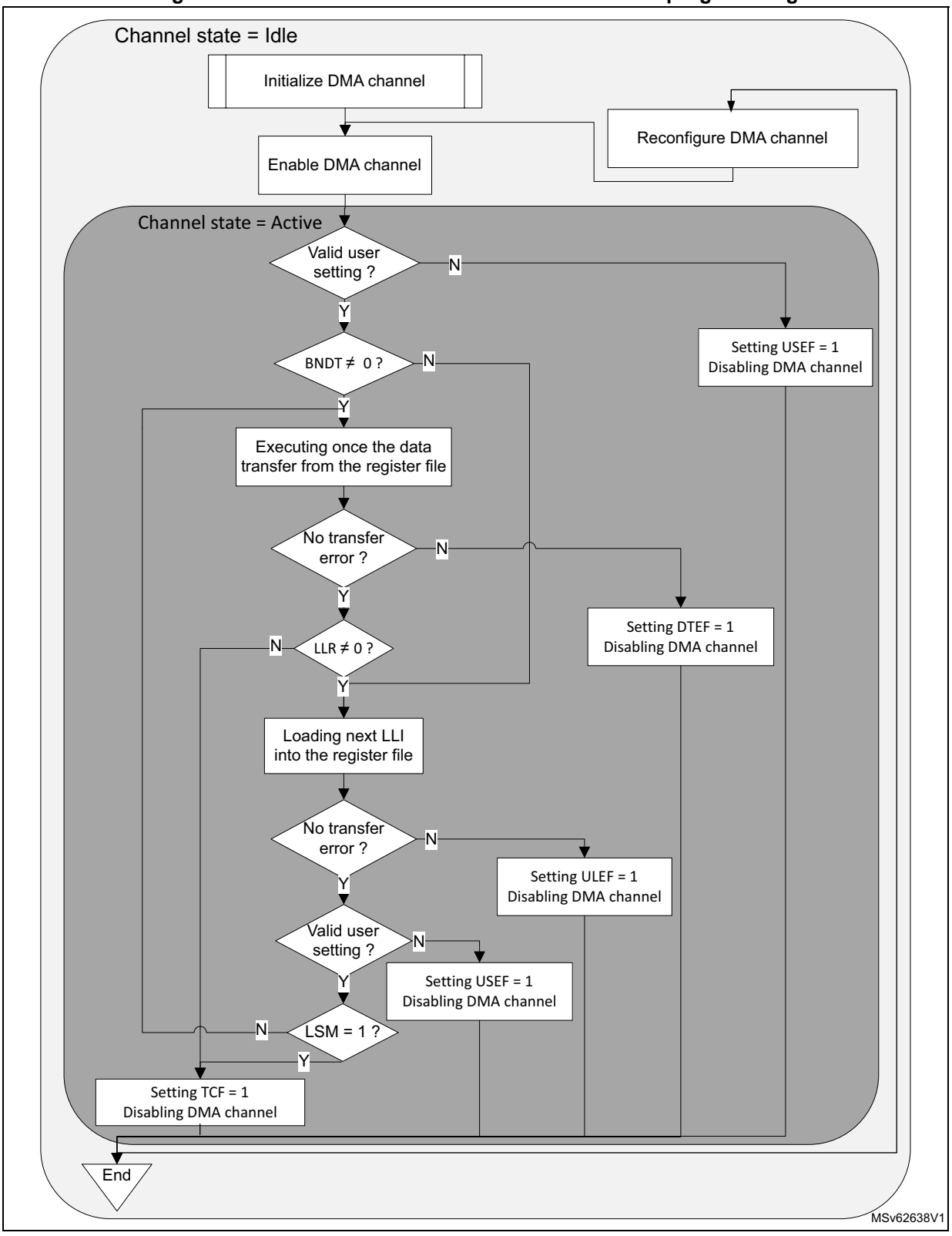
In link step mode, the software can clear LSM after each a single execution of any LLI, during LLI_{n-1}.

Figure 85 shows the overall and unified GPDMA linked-list programming, whatever is the execution mode.

Note: Figure 85 is not intended to illustrate how often a TCEF can be raised, depending on the programmed value of TCEM[1:0] in GPDMA_CxTR2. It can be raised at (each) block completion, at (each) 2D block completion, at (each) LLI completion, or only at the last LLI data transfer completion. In run-to-completion mode, whatever is the value of TCEM[1:0], at the channel completion the hardware always set TCEF = 1 and disables the channel. In link step mode, the channel is disabled after each single execution of a LLI, and depending on the value of TCEM[1:0] a TCEF is raised or not.

In Figure 85, BNDT ≠ 0 is the typical condition for starting the first data transfer. This condition becomes (BNDT ≠ 0 and PFREQ = 1) if the peripheral requests a data transfer with early termination (see Section 16.3.6).

Figure 85. GPDMA channel execution and linked-list programming



16.4.10 GPDMA FIFO-based transfers

There is a single transfer operation mode: the FIFO mode. There are FIFO-based transfers. Any channel x is implemented with a dedicated FIFO whose size is defined by dma_fifo_size[x] (see *Section 16.3.2* for more details).

GPDMA burst

A programmed transfer at the lowest level is a GPDMA burst.

A GPDMA burst is a burst of data received from the source, or a burst of data sent to the destination. A source (and destination) burst is programmed with a burst length by the field SBL_1[5:0] (respectively DBL_1[5:0]), and with a data width defined by the field SDW_LOG2[1:0] (respectively DDW_LOG2[1:0]) in the GPDMA_CxTR1 register.

The addressing mode after each data (named beat) of a GPDMA burst is defined by SINC and DINC in GPDMA_CxTR1, for source and destination respectively: either a fixed addressing or an incremented addressing with contiguous data.

The start and next addresses of a GPDMA source/destination burst (defined by GPDMA_CxSAR and GPDMA_CxDAR) must be aligned with the respective data width.

The table below lists the main characteristics of a GPDMA burst.

Table 133. Programmed GPDMA source/destination burst

SDW_LOG2[1:0] DDW_LOG2[1:0]	Data width (bytes)	SINC/DINC	SBL_1[5:0] DBL_1[5:0]	Burst length (data/beats)	Next data/ beat address	Next burst address	Burst address alignment
00	1	0 (fixed)	n = 0 to 63(1)	n+1	+ 0	+ 0	1
01	2						2
10	4						4
00	1	1 (contiguously incremented)			+ 1	+ (n + 1)	1
01	2				+ 2	+ 2 * (n + 1)	2
10	4				+ 4	+ 4 * (n + 1)	4
11	forbidden user setting, causing USEF generation and none burst to be issued.						

1. When S/DBL_1[5:0] = 0, burst is of length 1. Then burst can be also named as single.

The next burst address in the above table is the next source/destination default address pointed by GPDMA_CxSAR or GPDMA_CxDAR, once the programmed source/destination burst is completed. This default value refers to the fixed/contiguously incremented address.

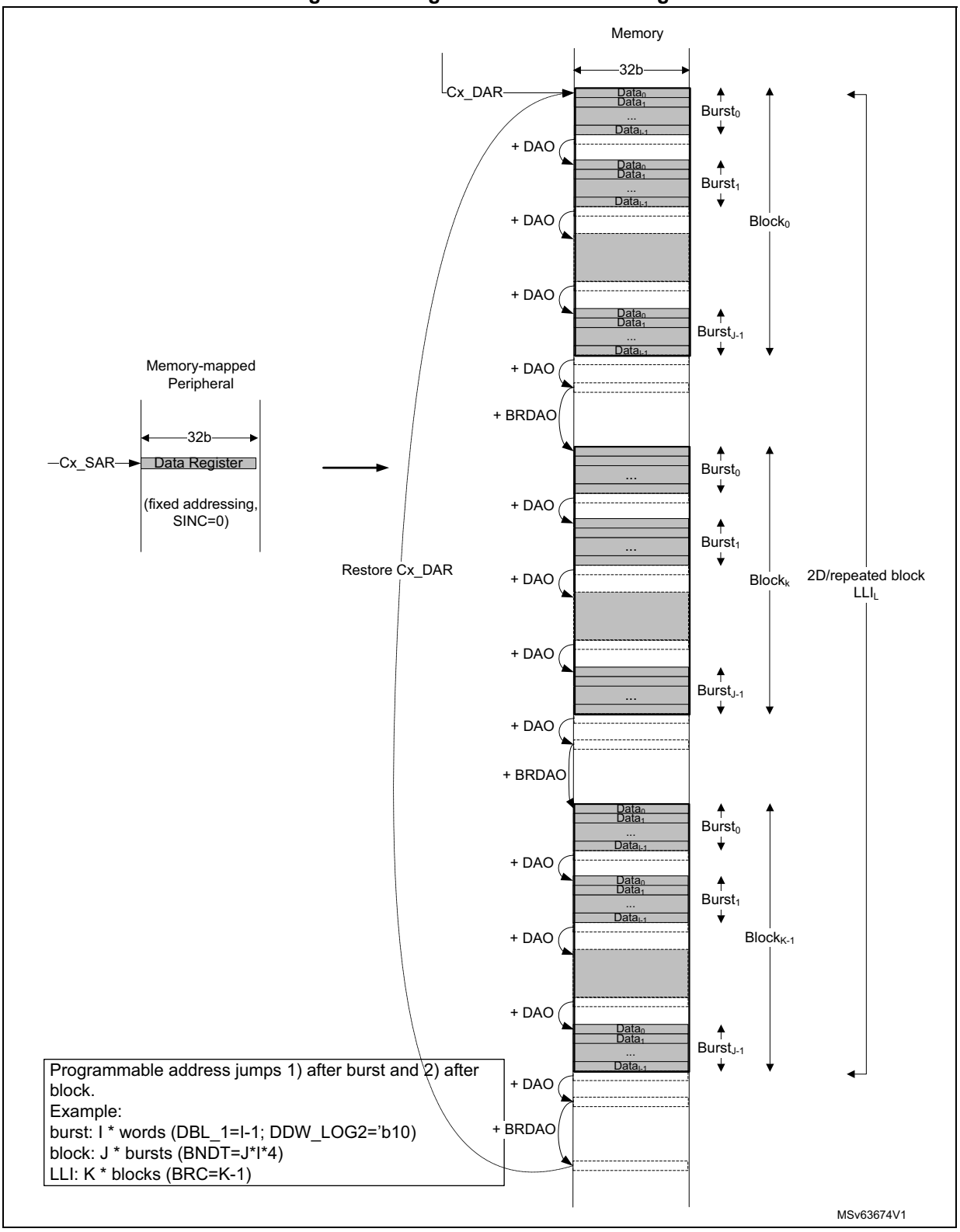
GPDMA burst with 2D addressing (channel x = 10 to 11)

When the channel has additional 2D addressing feature, this default value refers to the value without taking into account the two programmed incremented or decremented offsets. These two additional offsets (with a null default value) are applied:

- after each completed source/destination burst, as defined respectively by GPDMA_CxTR2.SAO[12:0]/DAO[12:0] and GPDMA_CxBR1.SDEC/DDEC
- after each completed block, as defined respectively by GPDMA_CxBR2.BRSAO[15:0]/BRDAO[15:0] and GPDMA_CxBR1.BRSDEC/BRDDEC)

Then, a 2D/repeated block can be addressed with a first programmed address jump after each completed burst, and with a second programmed address jump after each block, as depicted by *Figure 86* with a 2D destination buffer.

Figure 86. Programmed 2D addressing



GPDMA FIFO-based burst

In FIFO-mode, a transfer generally consists of two pipelined and separated burst transfers:

- one burst from the source to the FIFO over the allocated source master port, as defined by GPDMA_CxTR1.SAP
- one burst from the FIFO to the destination over the allocated destination master port, as defined by GPDMA_CxTR1.DAP

GPDMA source burst

The requested source burst transfer to the FIFO can be scheduled as early as possible over the allocated port, depending on the current FIFO level versus the programmed burst size (when the FIFO is ready to get one new burst from the source):

when FIFO level ≤ $2^{dma_fifo_size[x]}$ - (SBL_1[5:0]+1) * $2^{SDW_LOG2[1:0]}$

where:

- FIFO level is the current filling level of the FIFO, in bytes.
- $2^{dma_fifo_size[x]}$ is the half the FIFO size of channel x, in bytes (see *Section 16.3.2* for the implementation details and dma_fifo_size[x] value).
- (SBL_1[5:0]+1) * $2^{SDW_LOG2[1:0]}$ is the size of the programmed source burst transfer, in bytes.

Based on the channel priority (GPDMA_CxCR.PRIO[1:0]), this ready FIFO-based source transfer is internally arbitrated versus the other requested and active channels.

GPDMA destination burst

The requested destination burst transfer from the FIFO can be scheduled as early as possible over the allocated port, depending on the current FIFO level versus the programmed burst size (when the FIFO is ready to push one new burst to the destination):

when FIFO level ≥ (DBL_1[5:0]+1) * $2^{DDW_LOG2[1:0]}$

where:

- FIFO level is the current filling level of the FIFO, in bytes.
- (DBL_1[5:0]+1) * $2^{DDW_LOG2[1:0]}$ is the size of the programmed destination burst transfer, in bytes.

Based on the channel priority, this ready FIFO-based destination transfer is internally arbitrated versus the other requested and active channels.

GPDMA burst vs source block size, 1-Kbyte address boundary and FIFO size

The programmed source/destination GPDMA burst is implemented with an AHB burst as is, unless one of the following conditions is met:

- When half of the FIFO size of the channel x is lower than the programmed source/destination burst size, the programmed source/destination GPDMA burst is implemented with a series of singles or bursts of a lower size. Each transfer is of a size that is lower than or equal to half of the FIFO size, without any user constraint.
- If the source block size (GPDMA_CxBR1.BNDT[15:0]) is not a multiple of the source burst size but is a multiple of the data width of the source burst (GPDMA_CxTR1.SDW_LOG2[1:0]), the GPDMA modifies and shortens bursts into singles or bursts of lower length, in order to transfer exactly the source block size, without any user constraint.

- if the source/destination burst transfer have crossed the 1-Kbyte address boundary on a AHB transfer, the GPDMA modifies and shortens the programmed burst into singles or bursts of lower length, to be compliant with the AHB protocol, without any user constraint.
- If the source/destination burst length exceeds 16 on a AHB transfer, the GPDMA modifies and shortens the programmed burst into singles or bursts of lower length, to be compliant with the AHB protocol, without any user constraint.

In any case, the GPDMA keeps ensuring source/destination data (and address) integrity without any user constraint. The current FIFO level (software readable in GPDMA_CxSR) is compared to and updated with the effective transfer size, and the GPDMA re-arbitrates between each AHB single or burst transfer, possibly modified.

Based on the channel priority, each single or burst of a lower burst size versus the programmed burst, is internally arbitrated versus the other requested and active channels.

Note: In linked-list mode, the GPDMA read transfers related to the update of the linked-list parameters from the memory to the internal GPDMA registers, are scheduled over the link allocated port, as programmed by GPDMA_CxCR.LAP.

GPDMA data handling: byte-based reordering, packing/unpacking, padding/truncation, sign extension and left/right alignment

The data handling is controlled by GPDMA_CxTR1. The source/destination data width of the programmed burst is byte, half-word or word, as per the SDW_LOG2[1:0] and DDW_LOG2[1:0] fields (see *Table 134*).

The user can configure the data handling between transferred data from the source and transfer to the destination. More specifically, programmed data handling is orderly performed with:

1. Byte-based source reordering
   - If SBX = 1 and if source data width is a word, the two bytes of the unaligned half-word at the middle of each source data word are exchanged.
2. Data width conversion by packing, unpacking, padding or truncation, if destination data width is different than the source data width, depending on PAM[1:0]:
   - If destination data width > source data width, the post SBX source data is either right-aligned and padded with 0 s, or sign extended up to the destination data width, or is FIFO queued and packed up to the destination data width.
   - If destination data width < source data width, the post SBX data is either right-aligned and left-truncated down to the destination data width, or is FIFO queued and unpacked and streamed down to the destination data width.
3. Byte-based destination re-ordering:
   - If DBX = 1 and if the destination data width is not a byte, the two bytes are exchanged within the aligned post PAM[1:0] half-words.
   - If DHX = 1 and if the destination data width is neither a byte nor a half-word, the two aligned half-words are exchanged within the aligned post PAM[1:0] words.

Note: Left-alignment with 0s-padding can be achieved by programming both a right-alignment with a 0s-padding and a destination byte-based re-ordering.

The table below lists the possible data handling from the source to the destination.

Table 134. Programmed data handling

SDW_LOG2 [1:0]	Source data	Source data stream(1)	SBX	DDW_LOG2 [1:0]	Destination data	PAM[1:0](2)	DBX	DHX	Destination data stream(1)
00	Byte	$B_7,B_6,B_5,B_4,B_3,B_2,B_1,B_0$	x	00	Byte	xx	x	x	$B_7,B_6,B_5,B_4,B_3,B_2,B_1,B_0$
				01	Half-word	00 (RA, 0P)	0		$0B_3,0B_2,0B_1,0B_0$
							1		B_30,B_20,B_10,B_00
						01 (RA, SE)	0		SB_3,SB_2,SB_1,SB_0
							1		B_3S,B_2S,B_1S,B_0S
						1x (PACK)	0		$B_7B_6,B_5B_4,B_3B_2,B_1B_0$
							1		$B_6B_7,B_4B_5,B_2B_3,B_0B_1$
				10	Word	00 (RA, 0P)	0	0	$000B_1,000B_0$
							1		$00B_10,00B_00$
							0	1	$0B_100,0B_000$
							1		B_1000,B_0000
						01 (RA, SE)	0	0	$SSSB_1,SSSB_0$
							1		SSB_1S,SSB_0S
							0	1	SB_1SS,SB_0SS
							1		B_1SSS,B_0SSS
						1x (PACK)	0	0	$B_7B_6B_5B_4,B_3B_2B_1B_0$
							1		$B_6B_7B_4B_5,B_2B_3B_0B_1$
							0	1	$B_5B_4B_7B_6,B_1B_0B_3B_2$
							1		$B_4B_5B_6B_7,B_0B_1B_2B_3$
01	Half-word	$B_7B_6,B_5B_4,B_3B_2,B_1B_0$		00	Byte	00 (RA, LT)	x	x	B_6,B_4,B_2,B_0
						01 (LA, RT)			B_7,B_5,B_3,B_1
						1x (UNPACK)			$B_7,B_6,B_5,B_4,B_3,B_2,B_1,B_0$

Table 134. Programmed data handling (continued)

SDW_LOG2 [1:0]	Source data	Source data stream(1)	SBX	DDW_LOG2 [1:0]	Destination data	PAM[1:0](2)	DBX	DHX	Destination data stream(1)
01	Half-word	$B_7B_6,B_5B_4,B_3B_2,B_1B_0$	x	01	Half-word	xx	0	x	$B_7B_6,B_5B_4,B_3B_2,B_1B_0$
							1		$B_6B_7,B_4B_5,B_2B_3,B_0B_1$
				10	Word	00 (RA, 0P)	0	0	$00B_3B_2,00B_1B_0$
							1		$00B_2B_3,00B_0B_1$
							0	1	B_3B_200,B_1B_000
							1		B_2B_300,B_0B_100
						01 (RA, SE)	0	0	SSB_3B_2,SSB_1B_0
							1		SSB_2B_3,SSB_0B_1
							0	1	B_3B_2SS,B_1B_0SS
							1		B_2B_3SS,B_0B_1SS
						1x (PACK)	0	0	$B_7B_6B_5B_4,B_3B_2B_1B_0$
							1		$B_6B_7B_4B_5,B_2B_3B_0B_1$
							0	1	$B_5B_4B_7B_6,B_1B_0B_3B_2$
							1		$B_4B_5B_6B_7,B_0B_1B_2B_3$
10	Word	$B_7B_6B_5B_4,B_3B_2B_1B_0$	0	00	Byte	00 (RA, LT)	x	x	B_{12},B_8,B_4,B_0
						01 (LA, RT)			B_{15},B_{11},B_7,B_3
						10 (UNPACK)			$B_7,B_6,B_5,B_4,B_3,B_2,B_1,B_0$
				01	Half-word	00 (RA, LT)	0		B_5B_4,B_1B_0
							1		B_4B_5,B_0B_1
						01 (LA, RT)	0		B_7B_6,B_3B_2
							1		B_6B_7,B_2B_3
						1x (UNPACK)	0		$B_7B_6,B_5B_4,B_3B_2,B_1B_0$
							1		$B_6B_7,B_4B_5,B_2B_3,B_0B_1$

Table 134. Programmed data handling (continued)

SDW_LOG2 [1:0]	Source data	Source data stream(1)	SBX	DDW_LOG2 [1:0]	Destination data	PAM[1:0](2)	DBX	DHX	Destination data stream(1)
10	Word	$B_7B_6B_5B_4$, $B_3B_2B_1B_0$	0	10	Word	xx	0	0	$B_7B_6B_5B_4,B_3B_2B_1B_0$
							1		$B_6B_7B_4B_5,B_2B_3B_0B_1$
							0	1	$B_5B_4B_7B_6,B_1B_0B_3B_2$
							1		$B_4B_5B_6B_7,B_0B_1B_2B_3$
			1	00	Byte	00 (RA, LT)	x	x	B_{12},B_8,B_4,B_0
						01 (LA, RT)			B_{15},B_{11},B_7,B_3
						1x (UNPACK)			$B_7,B_5,B_6,B_4,B_3,B_1,B_2,B_0$
				01	Half-word	00 (RA, LT)	0		B_6B_4,B_2B_0
							1		B_4B_6,B_0B_2
						01 (LA, RT)	0		B_7B_5,B_3B_1
							1		B_5B_7,B_1B_3
						1x (UNPACK)	0		$B_7B_5,B_6B_4,B_3B_1,B_2B_0$
							1		$B_5B_7,B_4B_6,B_1B_3,B_0B_2$
				10	Word	xx	0	0	$B_7B_5B_6B_4,B_3B_1B_2B_0$
							1		$B_5B_7B_4B_6,B_1B_3B_0B_2$
							0	1	$B_6B_4B_7B_5,B_2B_0B_3B_1$
							1		$B_4B_6B_5B_7,B_0B_2B_1B_3$

1. Data stream is timely ordered starting from the byte with the lowest index (B_0).
2. RA= right aligned, LA = left aligned, RT = right truncated, LT = left truncated, 0P = zero bit padding up to the destination data width, SE = sign bit extended up to the destination data width.

16.4.11 GPDMA transfer request and arbitration

GPDMA transfer request

As defined by GPDMA_CxTR2, a programmed GPDMA data transfer is requested with one of the following:

- a software request if the control bit SWREQ = 1: This is used typically by the CPU for a data transfer from a memory-mapped address to another memory mapped address (memory-to-memory, GPIO to/from memory)
- an input hardware request coming from a peripheral if SWREQ = 0: The selection of the GPDMA hardware peripheral request is driven by the REQSEL[7:0] field (see *Section 16.3.4*). The selected hardware request can be one of the following:
  - an hardware request from a peripheral configured in GPDMA mode (for a transfer from/to the peripheral data register respectively to/from the memory)
  - an hardware request from a peripheral for its control registers update from the memory
  - an hardware request from a peripheral for a read of its status registers transferred to the memory

Caution: The user must not assign a same input hardware peripheral GPDMA request via GPDMA_CxTR.REQSEL[7:0] to two different channels, if at a given time this request is asserted by the peripheral and each channel is ready to execute this requested data transfer. There is no user setting error reporting.

GPDMA transfer request for arbitration

A ready FIFO-based GPDMA source single/burst transfer (from the source address to the FIFO) to be scheduled over the allocated master port (GPDMA_CxTR1.SAP) is arbitrated based on the channel priority (GPDMA_CxCR.PRIO[1:0]) versus the other simultaneous requested GPDMA transfers to the same master port.

A ready FIFO-based GPDMA destination single/burst transfer (from the FIFO to the destination address) to be scheduled over the allocated master port (GPDMA_CxTR1.DAP) is arbitrated based on the channel priority (GPDMA_CxCR.PRIO[1:0]) versus the other simultaneous requested GPDMA transfers to the same master port.

An arbitrated GPDMA requested link transfer consists of one 32-bit read from the linked-list data structure in memory to one of the linked-list registers (GPDMA_CxTR1, GPDMA_CxTR2, GPDMA_CxBR1, GPDMA_CxSAR, GPDMA_CxDAR or GPDMA_CxLLR, plus GPDMA_CxTR3, GPDMA_CxBR2). Each 32-bit read from memory is arbitrated with the same channel priority as for data transfers, in order to be scheduled over the allocated master port (GPDMA_CxCR.LAP).

Whatever the requested data transfer is programmed with a software request for a memory-to- memory transfer (GPDMA_CxTR2.SWREQ = 1), or with a hardware request (GPDMA_CxTR2.SWREQ = 0) for a memory-to-peripheral transfer or a peripheral-to-memory transfer and whatever is the hardware request type, re-arbitration occurs after each granted single/burst transfer.

When an hardware request is programmed from a destination peripheral (GPDMA_CxTR2.SWREQ = 0 and GPDMA_CxTR2.DREQ = 1), the first memory read of a (possibly 2D/repeated) block (the first ready FIFO-based source burst request), is gated by the occurrence of the corresponding and selected hardware request. This first read request to memory is not taken into account earlier by the arbiter (not as soon as the block transfer is enabled and executable).

GPDMA arbitration

The GPDMA arbitration is directed from the 4-grade assigned channel priority (GPDMA_CxCR.PRIO[1:0]). The arbitration policy, as illustrated in *Figure 87*, is defined by:

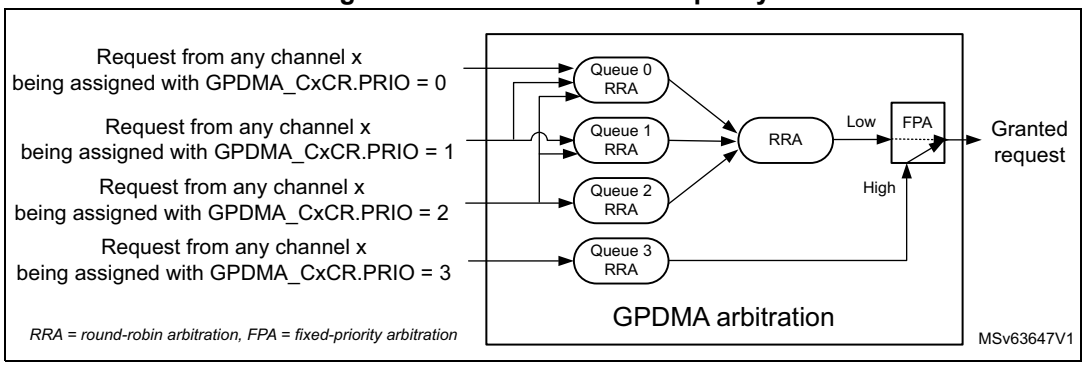
- one high-priority traffic class (queue 3), dedicated to the assigned channels with priority 3, for time-sensitive channels

  This traffic class is granted via a fixed-priority arbitration against any other low-priority traffic class. Within this class, requested single/burst transfers are round-robin arbitrated.
- three low-priority traffic classes (queues 0, 1, or 2) for non time-sensitive channels with priority 0, 1, or 2

  Each requested single/burst transfer within this class is round-robin arbitrated, with a weight that is monotonically driven from the programmed priority:
  - Requests with priority 0 are allocated to the queue 0.
  - Requests with priority 1 are allocated and replicated to the queue 0 and queue 1.

– Requests with priority 2 are allocated and replicated to the queue 0, queue 1, and queue 2.
– Any queue 0, 1, or 2 equally grants any of its active input requests in a round-robin manner, provided there are simultaneous requests.
– Additionally, there is a second stage for the low-traffic with a round-robin arbiter that fairly alternates between simultaneous selected requests from queue 0, queue 1, and queue 2.

Figure 87. GPDMA arbitration policy



GPDMA arbitration and bandwidth

With this arbitration policy, the following is guaranteed:

- Equal maximum bandwidth between requests with same priority
- Reserved bandwidth (noted as B_{Q3}) to the time-sensitive requests (with priority 3)
- Residual weighted bandwidth between different low-priority requests (priority 0 versus priority 1 versus priority 2).

The two following examples highlight that the weighted round-robin arbitration is driven by the programmed priorities:

- **Example 1**: basic application with two non time-sensitive GPDMA requests: req0 and req1. There are the following programming possibilities:
  – If they are assigned with same priority, the allocated bandwidth by the arbiter to req0 (B_{req0}) is **equal** to the allocated bandwidth to req1(B_{req1}).
  $B_{req0} = B_{req1} = 1/2 * (1 - B_{Q3})$
  – If req0 is assigned to priority 0 and req1 to priority 1, the allocated bandwidth to req0 (B_{P0}) is **3 times less** than the allocated bandwidth to req1 (B_{P1}).
  $B_{req0} = B_{P0} = 1/2 * 1/2 * (1 - B_{Q3}) = 1/4 * (1 - B_{Q3})$
  $B_{req1} = B_{P1} = (1/2 + 1) * 1/2 * (1 - B_{Q3}) = 3/4 * (1 - B_{Q3})$
  – If req0 is assigned to priority 0 and req1 to priority 2, the allocated bandwidth to req0 (B_{P0}) is **5 times less** than the allocated bandwidth to req1 (B_{P2}).
  $B_{req0} = B_{P0} = 1/2 * 1/3 * (1 - B_{Q3}) = 1/6 * (1 - B_{Q3})$
  $B_{req1} = B_{P2} = (1/2 + 1 + 1) * 1/3 * (1 - B_{Q3}) = 5/6 * (1 - B_{Q3})$
  The above computed bandwidth calculation is based on a theoretical input request, always active for any GPDMA clock cycle. This computed bandwidth from the arbiter must be weighted by the frequency of the request given by the application, that cannot be always active and may be quite much variable from one GPDMA client (example I2C at 400 kHz) to another one (PWM at 1 kHz) than the above x3 and x5 ratios.

- **Example 2**: application where the user distributes a same non-null N number of GPDMA requests to every non time-sensitive priority 0, 1 and 2. The bandwidth calculation is then the following:
  - The allocated bandwidth to the set of requests of priority 0 (B_{P0}) is
    $B_{P0} = 1/3 * 1/3 * (1 - B_{Q3}) = 1/9 * (1 - B_{Q3})$
  - The allocated bandwidth to the set of requests of priority 1(B_{P1}) is
    $B_{P1} = (1/3 + 1/2) * 1/3 * (1 - B_{Q3}) = 5/18 * (1 - B_{Q3})$
  - The allocated bandwidth to the set of requests of priority 2(B_{P2}) is
    $B_{P2} = (1/3 + 1/2 + 1) * 1/3 * (1 - B_{Q3}) = 11/18 * (1 - B_{Q3})$
  - The allocated bandwidth to any request n ($B_{n)}$ among the N requests of that priority Pi (i = 0 to 2) is $B_n = 1/N * B_{Pi}$
  - The allocated bandwidth to any request n of priority 0i ($B_{n, Pi}$) is
    $B_{n, P0} = 1/N *1/9 * (1 - B_{Q3})$
    $B_{n, P1} = 1/N *5/18 * (1 - B_{Q3})$
    $B_{n, P2} = 1/N *11/18 * (1 - B_{Q3})$

  In this example, when the master port bus bandwidth is not totally consumed by the time-sensitive queue 3, the residual bandwidth is such that 2.5 times less bandwidth is allocated to any request of priority 0 versus priority 1, and 5.5 times less bandwidth is allocated to any request of priority 0 versus priority 2.

More generally, assume that the following requests are present:

- I requests (I ≥ 0) assigned to priority 0
  If I > 0, these requests are noted from i = 0 to I-1.
- J requests (J ≥ 0) assigned to priority 1
  If J > 0, these requests are noted from j = 0 to J-1.
- K requests (K > 0) assigned to priority 2
  These requests are noted from k = 0 to K-1
- L requests (L ≥ 0) assigned to priority 3
  If L > 0, these requests are noted from l = 0 to L-1.

As B_{Q3} is the reserved bandwidth to time-sensitive requests, the bandwidth for each request L with priority 3 is:

- $B_l = B_{Q3} / L$ for L > 0 (else: $B_l = 0$)

The bandwidth for each non-time sensitive queue is:

- $B_{Q0} = 1/3 * (1 - B_{Q3})$
- $B_{Q1} = 1/3 * (1 - B_{Q3})$
- $B_{Q2} = 1/3 * (1 - B_{Q3})$

The bandwidth for the set of requests with priority 0 is:

- $B_{P0} = I / (I + J + K) * B_{Q0}$

The bandwidth for each request i with priority 0 is:

- $B_i = B_{P0} / I$ for L > 0 (else $B_{P0} = 0$)

The bandwidth for the set of requests with priority 1 and routed to queue 0 is:

- $B_{P1,Q0} = J / (I + J + K) * B_{Q0}$

The bandwidth for the set of requests with priority 1 and routed to queue 1 is:

- $B_{P1,Q1} = J / (J + K) * B_{Q1}$

The total bandwidth for the set of requests with priority 1 is:

- $B_{P1} = B_{P1,Q0} + B_{P1,Q1}$

The bandwidth for each request j with priority 1 is:

- $B_j = B_{P1} / J$ for $J > 0$ (else $B_j = 0$)

The bandwidth for the set of requests with priority 2 and routed to queue 0 is:

- $B_{P2,Q0} = K / (I + J + K) * B_{Q0}$

The bandwidth for the set of requests with priority 2 and routed to queue 1 is:

- $B_{P2,Q1} = K / (J + K) * B_{Q1}$

The bandwidth for the set of requests with priority 2 and routed to queue 2 is:

- $B_{P2,Q2} = B_{Q2}$

The total bandwidth for the set of requests with priority 2 is:

- $B_{P2} = B_{P2,Q0} + B_{P2,Q1} + B_{P2,Q2}$

The bandwidth for each request k with priority 2 is:

- $B_k = B_{P2} / K$ ($K>0$ in the general case)

Thus finally the maximum allocated residual bandwidths for any i, j, k non-time sensitive request are:

- in the general case (when there is at least one request k with a priority 2 ($K > 0$)):
  - $B_i = 1/I * 1/3 * I/(I + J + K) * (1 - B_{Q3})$
  - $B_j = 1/J * 1/3 *[J/(I + J + K) + J/(J + K)] * (1 - B_{Q3})$
  - $B_k = 1/K * 1/3 *[K/(I + J + K) + K/(J + K) + 1] * (1 - B_{Q3})$
- in the specific case (when there is no request k with a priority 2 ($K = 0$)):
  - $B_i = 1/I * 1/2 * I/(I + J) * (1 - B_{Q3})$
  - $B_j = 1/J * 1/2 *[J/(I + J) + 1] * (1 - B_{Q3})$

Consequently, the GPDMA arbiter can be used as a programmable weighted bandwidth limiter, for each queue and more generally for each request/channel. The different weights are monotonically resulting from the programmed channel priorities.

16.4.12 GPDMA triggered transfer

A programmed GPDMA transfer can be triggered by a rising/falling edge of a selected input trigger event, as defined by GPDMA_CxTR2.TRIGPOL[1:0] and GPDMA_CxTR2.TRIGSEL[6:0] (see *Section 16.3.7* for the trigger selection).

The triggered transfer, as defined by the trigger mode in GPDMA_CxTR2.TRIGM[1:0], can be at LLI data transfer level, to condition the first burst read of a block, the first burst read of a 2D/repeated block for channel x (x = 10 to 11), or each programmed single read. The trigger mode can also be programmed to condition the LLI link transfer (see TRIGM[1:0] in GPDMA_CxTR2 for more details).

Trigger hit memorization and trigger overrun flag generation

The GPDMA monitoring of a trigger for a channel x is started when the channel is enabled/loaded with a new active trigger configuration: rising or falling edge on a selected trigger (respectively TRIGPOL[1:0] = 01 or TRIGPOL[1:0] = 10).

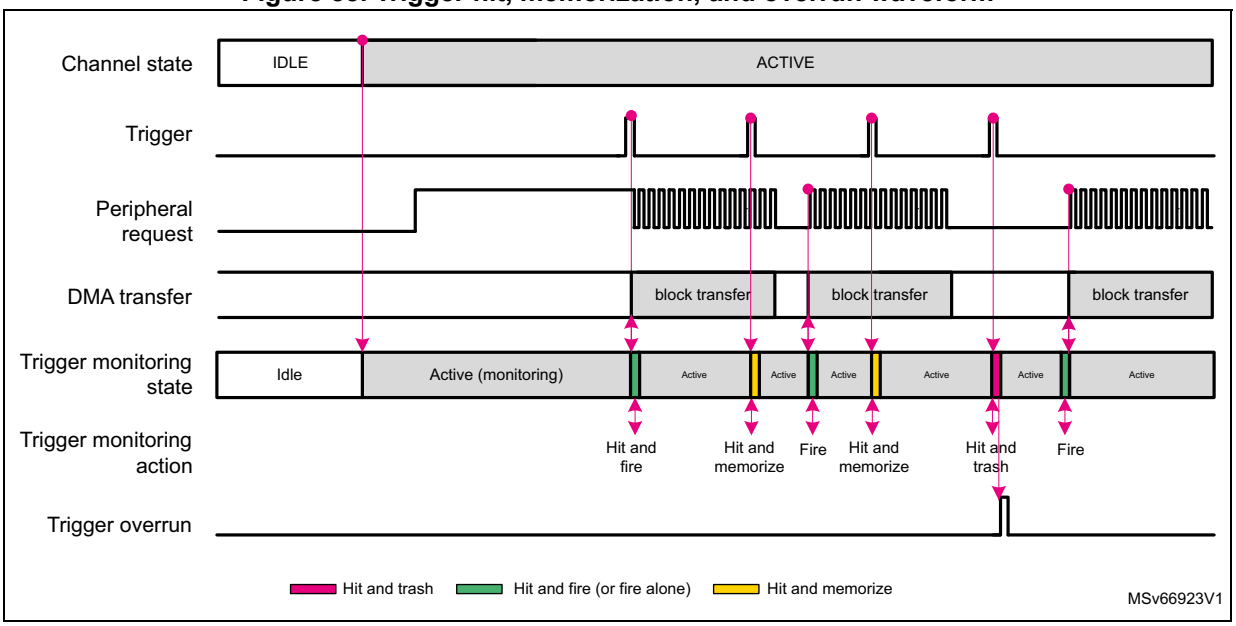
The monitoring of this trigger is kept active during the triggered and uncompleted (data or link) transfer. If a new trigger is detected, this hit is internally memorized to grant the next transfer, as long as the defined rising/falling edge and TRIGSEL[6:0] are not modified, and the channel is enabled.

Transferring a next $LLI_{n+1,}$ that updates the GPDMA_CxTR2 with a new value for any of TRIGSEL[6:0] or TRIGPOL[1:0], resets the monitoring, trashing the possible memorized hit of the formerly defined LLI_n trigger.

Caution: After a first new trigger hit_{n+1} is memorized, if another trigger hit_{n+2} is detected and if the hit_n triggered transfer is still not completed, hit_{n+2} is lost and not memorized. A trigger overrun flag is reported (GPDMA_CxSR.TOF = 1) and an interrupt is generated if enabled (if GPDMA_CxCR.TOIE = 1). The channel is not automatically disabled by hardware due to a trigger overrun.

Figure 88 illustrates the trigger hit, memorization and overrun in the configuration example with a block-level trigger mode and a rising edge trigger polarity.

Figure 88. Trigger hit, memorization, and overrun waveform



Note: The user can assign the same input trigger event to different channels. This can be used to trigger different channels on a broadcast trigger event.

16.4.13 GPDMA circular buffering with linked-list programming

GPDMA circular buffering for memory-to-peripheral and peripheral-to-memory transfers, with a linear addressing channel

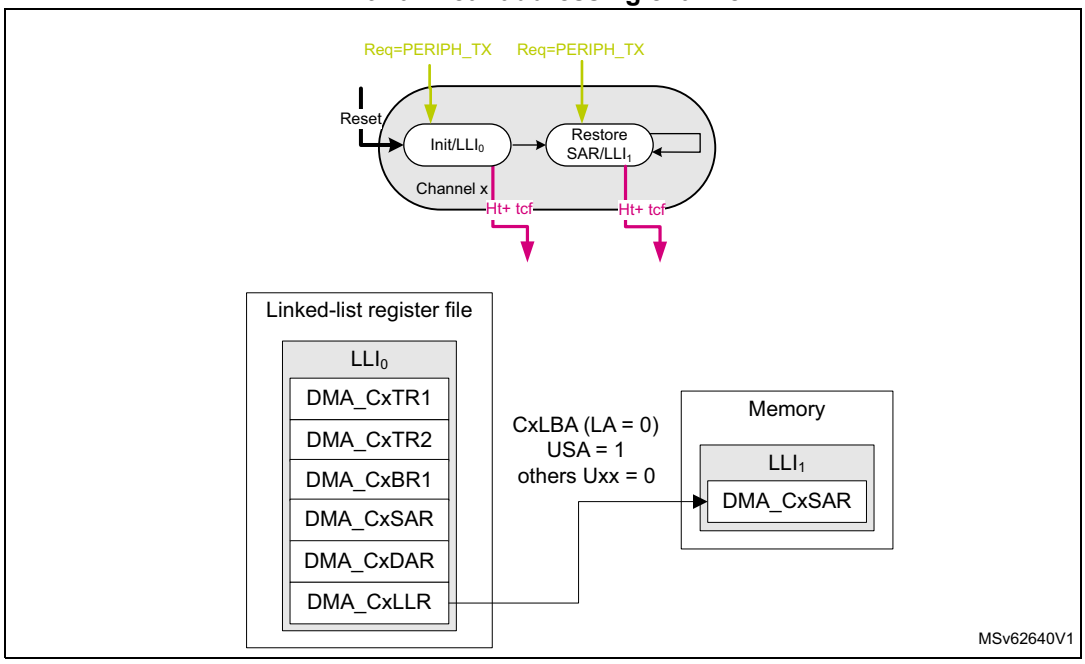
For a circular buffering, with a continuous memory-to-peripheral (or peripheral-to-memory) transfer, the software must set up a channel with half-transfer and complete transfer

events/interrupts generation (GPDMA_CxCR.HTIE = 1 and GPDMA_CxCR.TCIE = 1), in order to enable a concurrent buffer software processing.

LLI_0 is configured for the first block transfer with the linear addressing channel. A continuously-executed LLI_1 is needed to restore the memory source (or destination) start address, for the memory-to-peripheral transfer (respectively the peripheral-to-memory transfer). GPDMA automatically reloads the initially programmed GPDMA_CxBR1.BNDT[15:0] when a block transfer is completed, and there is no need to restore GPDMA_CxBR1.

Figure 89 illustrates this programming with a linear addressing GPDMA channel and a source circular buffer.

Figure 89. GPDMA circular buffer programming: update of the memory start address with a linear addressing channel

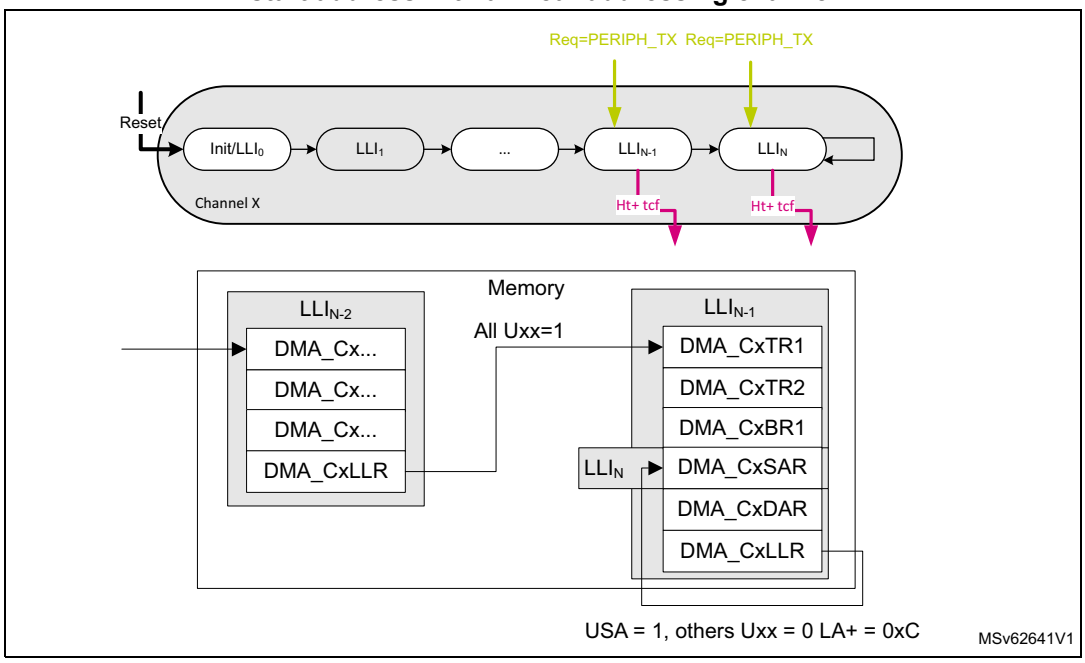


Note: With a 2D addressing channel, the user may use a single LLI with GPDMA_CxBR1.BRC[10:0] = 1, and program a negative memory block address offset with GDMA_CxBR2 and GDMA_CxBR1, in order to jump back to the memory source or the destination start address.

If circular buffering must be executed after some other transfers over the shared GPDMA channel x, the before-last LLI_{N-1} in memory is needed to configure the first block transfer. And the last LLI_N restores the memory source (or destination) start address in memory-to-peripheral transfer (respectively in peripheral-to-memory transfer).

Figure 90 illustrates this programming with a linear addressing shared GPDMA channel, and a source circular buffer.

Figure 90. Shared GPDMA channel with circular buffering: update of the memory start address with a linear addressing channel



16.4.14 GPDMA transfer in peripheral flow-control mode

A peripheral with the peripheral flow-control mode feature can decide to early terminate a GPDMA block transfer, provided that the allocated channel is implemented with this feature (see *Section 16.3.6*).

If the related GPDMA channel x is also programmed in peripheral flow-control mode (GPDMA_CxTR2.PFREQ = 1):

- The GPDMA block transfer starts as follows:
  - If GPDMA_CxBR1.BNDT[15:0] ≠ 0, the programmed value is internally taken into account by the GPDMA hardware.
  - If GPDMA_CxBR1.BNDT[15:0] = 0, the GPDMA hardware internally considers a 64-Kbyte value for the maximum source block size to be transferred.
- The GPDMA block transfer is completed as soon as the first occurrence of one of the following condition occurs:
  - when GPDMA_CxBR1.BNDT[15:0] = 0
  - when the peripheral early terminates the block. The complete transfer event is generated if programmed, depending on GPDMA_CxTR2 (see *GPDMA channel x transfer register 2 (GPDMA_CxTR2)*). Then the software can read the current number of transferred bytes from the source (GPDMA_CxBR1.BNDT[15:0]), and/or read the current source or destination address of the buffer in memory (GPDMA_CxSAR[31:0] or GPDMA_CxDAR[31:0]).

In peripheral flow-control mode:

- a destination peripheral with a hardware requested transfer is not supported: memory-to-peripheral transfer is not supported.
- Data packing from a source peripheral is not supported.
- 2D/repeated block is not supported.
- GPDMA_CxBR1.BNDT[15:0] must be programmed as a multiple of the source (peripheral) burst size.

16.4.15 GPDMA secure/nonsecure channel

The GPDMA controller is compliant with the TrustZone hardware architecture at channel level, partitioning all its resources so that they exist in one of the secure and nonsecure worlds at any given time.

Any channel x is a secure or a nonsecure hardware resource, as configured by GPDMA_SECCFGR.SECx.

When a channel x is configured in secure state by a secure and privileged agent, the following access control rules are applied:

- A nonsecure read access to a register field of this channel is forced to return 0, except for GPDMA_SECCFGR, GPDMA_PRIVCFGR, GPDMA_RCFGLOCKR that are readable by a nonsecure agent.
- A nonsecure write access to a register field of this channel has no impact.

When a channel x is configured in secure state, a secure agent can configure separately as secure or nonsecure the GPDMA data transfer from the source (GPDMA_CxTR1.SSEC) and the GPDMA data transfer to the destination (GPDMA_CxTR1.DSEC).

When a channel x is configured in secure state and in linked-list mode, the loading of the next linked-list data structure from the GPDMA memory into its register file, is automatically performed with secure transfers via the GPDMA_CxCR.LAP allocated master port.

The GPDMA generates a secure bus that reflects GPDMA_SECCFGR, to keep the other peripherals informed of the secure/nonsecure state of each GPDMA channel x.

The GPDMA also generates a security illegal access pulse signal on an illegal nonsecure access to a secure GPDMA register. This signal is routed to the TrustZone interrupt controller.

When the secure software must switch a channel from a secure state to a nonsecure state, the secure software must abort the channel or wait until the secure channel is completed before switching. This is needed to dynamically re-allocate a channel to a next nonsecure transfer as a nonsecure software is not allowed to do so and must have GPDMA_CxCR.EN = 0 before the nonsecure software can reprogram the GPDMA_CxCR for a next transfer. The secure software may reset not only the channel x (GPDMA_CxCR.RESET = 1) but also the full channel x register file to its reset value.

16.4.16 GPDMA privileged/unprivileged channel

Any channel x is a privileged or unprivileged hardware resource, as configured by a privileged agent via GPDMA_PRIVCFGR.PRIVx.

When a channel x is configured in a privileged state by a privileged agent, the following access control rules are applied:

- An unprivileged read access to a register field of this channel is forced to return 0, except for GPDMA_PRIVCFGR, GPDMA_SECCFGR, GPDMA_RCFGLOCKR that are readable by an unprivileged agent.
- An unprivileged write access to a register field of this channel has no impact.

When a channel is configured in a privileged (or unprivileged) state, the source and destination data transfers are privileged (respectively unprivileged) transfers over the AHB master port.

When a channel is configured in a privileged (or unprivileged) state and in linked-list mode, the loading of the next linked-list data structure from the GPDMA memory into its register file, is automatically performed with privileged (respectively unprivileged) transfers, via the GPDMA_CxCR.LAP allocated master port.

The GPDMA generates a privileged bus that reflects GPDMA_PRIVCFGR, to keep the other peripherals informed of the privileged/unprivileged state of each GPDMA channel x.

When the privileged software must switch a channel from a privileged state to an unprivileged state, the privileged software must abort the channel or wait until that the privileged channel is completed before switching. This is needed to dynamically re-allocate a channel to a next unprivileged transfer as an unprivileged software is not allowed to do so, and must have GPDMA_CxCR.EN = 0 before the unprivileged software can reprogram the GPDMA_CxCR for a next transfer. The privileged software may reset not only the channel x (GPDMA_CxCR.RESET = 1) but also the full channel x register file to its reset value.

16.4.17 GPDMA error management

The GPDMA is able to manage and report to the user a transfer error, as follows, depending on the root cause.

Data transfer error

On a bus access (as a AHB single or a burst) to the source or the destination:

- The source or destination target reports an AHB error.
- The programmed channel transfer is stopped (GPDMA_CxCR.EN cleared by the GPDMA hardware). The channel status register reports an idle state (GPDMA_CxSR.IDLEF = 1) and the data error (GPDMA_CxSR.DTEF = 1).
- After a GPDMA data transfer error, the user must perform a debug session, taking care of the product-defined memory mapping of the source and destination, including the protection attributes.
- After a GPDMA data transfer error, the user must issue a channel reset (set GPDMA_CxCR.RESET) to reset the hardware GPDMA channel data path and the content of the FIFO, before the user enables again the same channel for a next transfer.

Link transfer error

On a tentative update of a GPDMA channel register from the programmed LLI in the memory:

- The linked-list memory reports an AHB error.
- The programmed channel transfer is stopped (GPDMA_CxCR.EN cleared by the GPDMA hardware), the channel status register reports an idle state (GPDMA_CxSR.IDLEF = 1) and the link error (GPDMA_CxSR.ULEF = 1).
- After a GPDMA link error, the user must perform a debug session, taking care of the product-defined memory mapping of the linked-list data structure (GPDMA_CxLBAR and GPDMA_CxLLR), including the protection attributes.
- After a GPDMA link error, the user must explicitly write the linked-list register file (GPDMA_CxTR1, GPDMA_CxTR2, GPDMA_CxBR1, GPDMA_CxSAR, GPDMA_CxDAR and GPDMA_CxLLR, plus GPDMA_CxTR3 and GPDMA_CxBR2), before the user enables again the same channel for a next transfer.

User setting error

On a tentative execution of a GPDMA transfer with an unauthorized user setting:

- The programmed channel transfer is disabled (GPDMA_CxCR.EN forced and cleared by the GPDMA hardware) preventing the next unauthorized programmed data transfer from being executed. The channel status register reports an idle state (GPDMA_CxSR.IDLEF = 1) and a user setting error (GPDMA_CxSR.USEF = 1).
- After a GPDMA user setting error, the user must perform a debug session, taking care of the GPDMA channel programming. A user setting error can be caused by one of the following:
  - a programmed null source block size without a programmed update of this value from the next LLI_1 (GPDMA_CxBR1.BNDT[15:0] = 0 and GPDMA_CxLLR.UB1 = 0)
  - a programmed non-null source block size being not a multiple of the programmed data width of a source burst transfer (GPDMA_CxBR1.BNDT[2:0] versus GPDMA_CxTR1.SDW_LOG2[1:0])
  - when in packing/unpacking mode (if PAM[1] = 1), a programmed non-null source block size being not a multiple of the programmed data width of a destination burst transfer (GPDMA_CxBR1.BNDT[2:0] versus GPDMA_CxTR1.DDW_LOG2[1:0])
  - a programmed unaligned source start address, being not a multiple of the programmed data width of a source burst transfer (GPDMA_CxSAR[2:0] versus GPDMA_CxTR1.SDW_LOG2[1:0])
  - for channel x (x = 10 to 11): a programmed unaligned source address offset being not a multiple of the programmed data width of a source burst transfer (GPDMA_CxTR3.SAO[2:0] versus GPDMA_CxTR1.SDW_LOG2[1:0])
  - for channel x (x = 10 to 11): a programmed unaligned block repeated source address offset being not a multiple of the programmed data width of a source burst transfer (GPDMA_CxBR2.BRSAO[2:0] versus GPDMA_CxTR1.SDW_LOG2[1:0])
  - a programmed unaligned destination start address, being not a multiple of the programmed data width of a destination burst transfer (GPDMA_CxDAR[2:0] versus GPDMA_CxTR1.DDW_LOG2[1:0])
  - for channel x (x = 10 to 11): a programmed unaligned destination address offset being not a multiple of the programmed data width of a destination burst transfer (GPDMA_CxTR3.DAO[2:0] versus GPDMA_CxTR1.DDW_LOG2[1:0])

- for channel x (x = 10 to 11): a programmed unaligned block repeated destination address offset being not a multiple of the programmed data width of a destination burst transfer (GPDMA_CxBR2.BRDAO[2:0] versus GPDMA_CxTR1.DDW_LOG2[1:0])
- a programmed double-word source data width (GPDMA_CxTR1.SDW_LOG2[1:0] = 11)
- a programmed double-word destination data width (GPDMA_CxTR1.DDW_LOG2[1:0] = 11)
- a programmed linked-list item LLI_{n+1} with a null data transfer (GPDMA_CxLLR.UB1 = 1 and GPDMA_CxBR1. BNDT = 0)

16.5 GPDMA in debug mode

When the microcontroller enters debug mode (core halted), any channel x can be individually either continued (default) or suspended, depending on the programmable control bit in the DBGMCU module.

Note: In debug mode, GPDMA_CxSR.SUSPF is not altered by a suspension from the programmable control bit in the DBGMCU module. In this case, GPDMA_CxSR.IDLEF can be checked to know the completion status of the channel suspension.

16.6 GPDMA in low-power modes

Table 135. Effect of low-power modes on GPDMA

Mode	Description
Sleep	No effect. GPDMA interrupts cause the device to exit Sleep mode.
Stop(1)	The content of the GPDMA registers is kept when entering Stop mode.
Standby	The GPDMA is powered down and must be reinitialized after exiting Standby mode.

1. Refer to *Section 16.3.3* to know if any Stop mode is supported.

16.7 GPDMA interrupts

There is one GPDMA interrupt line for each channel, and separately for each CPU (if several ones in the devices).

Table 136. GPDMA interrupt requests

Interrupt acronym	Interrupt event	Interrupt enable	Event flag	Event clear method
GPDMA_CHx	Transfer complete	GPDMA_CxCR.TCIE	GPDMA_CxSR.TCF	Write 1 to GPDMA_CxFCR.TCF
	Half transfer	GPDMA_CxCR.HTIE	GPDMA_CxSR.HTF	Write 1 to GPDMA_CxFCR.HTF
	Data transfer error	GPDMA_CxCR.DTEIE	GPDMA_CxSR.DTEF	Write 1 to GPDMA_CxFCR.DTEF
	Update link error	GPDMA_CxCR.ULEIE	GPDMA_CxSR.ULEF	Write 1 to GPDMA_CxFCR.ULEF
	User setting error	GPDMA_CxCR.USEIE	GPDMA_CxSR.USEF	Write 1 to GPDMA_CxFCR.USEF
	Suspended	GPDMA_CxCR.SUSPIE	GPDMA_CxSR.SUSPF	Write 1 to GPDMA_CxFCR.SUSPF
	Trigger overrun	GPDMA_CxCR.TOFIE	GPDMA_CxSR.TOF	Write 1 to GPDMA_CxFCR.TOF

A GPDMA channel x event may be:

- a transfer complete
- a half-transfer complete
- a transfer error, due to either:
  - a data transfer error
  - an update link error
  - a user setting error completed suspension
- a trigger overrun

Note: When a channel x transfer complete event occurs, the output signal gpdma_chx_tc is generated as a high pulse of one clock cycle.

An interrupt is generated following any xx event, provided that both:

- the corresponding interrupt event xx is enabled (GPDMA_CxCR.xxIE = 1)
- the corresponding event flag is cleared (GPDMA_CxSR.xxF = 0). This means that, after a previous same xx event occurrence, a software agent must have written 1 into the corresponding xx flag clear control bit (write 1 into GPDMA_CxFCR.xxF).

TCF (transfer complete) and HTF (half transfer) events generation is controlled by GPDMA_CxTR2.TCEM[1:0] as follows:

- A transfer complete event is a block transfer complete, a 2D/repeated block transfer complete, or a LLI transfer complete including the upload of the next LLI if any, or the full linked-list completion, depending on the transfer complete event mode GPDMA_CxTR2.TCEM[1:0].

- A half-transfer event is a half-block transfer or a half 2D/repeated block transfer, depending on the transfer complete event mode GPDMA_CxTR2.TCEM[1:0].

  A half-block transfer occurs when half of the source block size bytes (rounded-up integer of GPDMA_CxBR1.BNDT[15:0] / 2) is transferred to the destination.

  A half 2D/repeated block transfer occurs when half of the repeated blocks (rounded-up integer of (GPDMA_CxBR1.BRC[10:0] + 1) / 2) is transferred to the destination.

See *GPDMA channel x transfer register 2 (GPDMA_CxTR2)* for more details.

A transfer error rises in one of the following situations:

- during a single/burst data transfer from the source or to the destination (DTEF)
- during an update of a GPDMA channel register from the programmed LLI in memory (ULEF)
- during a tentative execution of a GPDMA channel with an unauthorized setting (USEF)

  The user must perform a debug session to correct the GPDMA channel programming versus the USEF root causes list (see *Section 16.4.17*).

A trigger overrun is described in *Trigger hit memorization and trigger overrun flag generation*.

16.8 GPDMA registers

The GPDMA registers must be accessed with an aligned 32-bit word data access.

16.8.1 GPDMA secure configuration register (GPDMA_SECCFGR)

Address offset: 0x00

Reset value: 0x0000 0000

A write access to this register must be secure and privileged. A read access is secure or nonsecure, privileged or unprivileged.

A write access is ignored at bit level if the corresponding channel x is locked (GPDMA_RCFGLOCKR.LOCKx = 1).

This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN = 1.

This register must be programmed at a bit level, at the initialization/closure of a GPDMA channel (when GPDMA_CxCR.EN = 0), to securely allocate individually any channel x to the secure or nonsecure world.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	SEC11	SEC10	SEC9	SEC8	SEC7	SEC6	SEC5	SEC4	SEC3	SEC2	SEC1	SEC0
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **SECx**: secure state of channel x (x = 11 to 0)
0: Nonsecure
1: Secure

16.8.2 GPDMA privileged configuration register (GPDMA_PRIVCFGR)

Address offset: 0x04

Reset value: 0x0000 0000

A write access to this register must be privileged. A read access can be privileged or unprivileged, secure or nonsecure.

This register can mix secure and nonsecure information. If a channel x is configured as secure (GPDMA_SECCFGR.SECx = 1), the PRIVx bit can be written only by a secure (and privileged) agent.

A write access is ignored at bit level if the corresponding channel x is locked (GPDMA_RCFGLOCKR.LOCKx = 1).

This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN =1.

This register must be programmed at a bit level, at the initialization/closure of a GPDMA channel (GPDMA_CxCR.EN = 0), to individually allocate any channel x to the privileged or unprivileged world.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	PRIV11	PRIV10	PRIV9	PRIV8	PRIV7	PRIV6	PRIV5	PRIV4	PRIV3	PRIV2	PRIV1	PRIV0
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **PRIVx**: privileged state of channel x (x = 11 to 0)
0: unprivileged
1: privileged

16.8.3 GPDMA configuration lock register (GPDMA_RCFGLOCKR)

Address offset: 0x08

Reset value: 0x0000 0000

This register can be written by a software agent with secure privileged attributes in order to individually lock, for example at boot time, the secure privileged attributes of any GPDMA

channel/resource (to lock the setting of GPDMA_CxSECCFGR, GPDMA_CxPRIVCFGR for any channel x, for example at boot time).

A read access may be privileged or unprivileged, secure or nonsecure.

Note: If TZEN = 0, this register cannot be written.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	LOCK11	LOCK10	LOCK9	LOCK8	LOCK7	LOCK6	LOCK5	LOCK4	LOCK3	LOCK2	LOCK1	LOCK0
				rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **LOCKx**: lock the configuration of GPDMA_SECCFGR.SECx, GPDMA_PRIVCFGR.PRIVx until a global GPDMA reset (x = 11 to 0)

This bit is cleared after reset and, once set, it cannot be reset until a global GPDMA reset.

0: secure privilege configuration of the channel x is writable.

1: secure privilege configuration of the channel x is not writable.

16.8.4 GPDMA nonsecure masked interrupt status register (GPDMA_MISR)

Address offset: 0x0C

Reset value: 0x0000 0000

This register is a read register.

This is a nonsecure register, containing the masked interrupt status bit MISx for each nonsecure channel x (channel x configured with GPDMA_SECCFGR.SECx = 0). It is a logical OR of all the flags of GPDMA_CxSR, each source flag being enabled by the corresponding interrupt enable bit of GPDMA_CxCR.

Every bit is deasserted by hardware when writing 1 to the corresponding flag clear bit in GPDMA_CxFCR.

If a channel x is in secure state (GPDMA_SECCFGR.SECx = 1), a read access to the masked interrupt status bit MISx of this channel x returns zero.

This register may mix privileged and unprivileged information, depending on the privileged state of each channel GPDMA_PRIVCFGR.PRIVx. A privileged software can read the full nonsecure interrupt status. An unprivileged software is restricted to read the status of unprivileged (and nonsecure) channels, other privileged bit fields returning zero.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	MIS11	MIS10	MIS9	MIS8	MIS7	MIS6	MIS5	MIS4	MIS3	MIS2	MIS1	MIS0
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **MISx**: masked interrupt status of channel x (x = 11 to 0)
0: no interrupt occurred on channel x
1: an interrupt occurred on channel x

16.8.5 GPDMA secure masked interrupt status register (GPDMA_SMISR)

Address offset: 0x10

Reset value: 0x0000 0000

This is a secure read register, containing the masked interrupt status bit MISx for each secure channel x (GPDMA_SECCFGR.SECx = 1). It is a logical OR of all the GPDMA_CxSR flags, each source flag being enabled by the corresponding GPDMA_CxCR interrupt enable bit.

Every bit is deasserted by hardware when securely writing 1 to the corresponding GPDMA_CxFCR flag clear bit.

This register does not contain any information about a nonsecure channel.

This register can mix privileged and unprivileged information, depending on the privileged state of each channel GPDMA_PRIVCFGR.PRIVx. A privileged software can read the full secure interrupt status. An unprivileged software is restricted to read the status of unprivileged and secure channels, other privileged bit fields returning zero.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	MIS11	MIS10	MIS9	MIS8	MIS7	MIS6	MIS5	MIS4	MIS3	MIS2	MIS1	MIS0
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **MISx**: masked interrupt status of the secure channel x (x = 11 to 0)
0: no interrupt occurred on the secure channel x
1: an interrupt occurred on the secure channel x

16.8.6 GPDMA channel x linked-list base address register (GPDMA_CxLBAR)

Address offset: 0x50 + 0x80 * x (x = 0 to 11)

Reset value: 0x0000 0000

This register must be written by a privileged software. It is either privileged readable or not, depending on the privileged state of the channel x GPDMA_PRIVCFGR.PRIVx.

This register is either secure or nonsecure depending on the secure state of the channel x (GPDMA_SECCFGR.SECx).

This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN = 1.

This channel-based register is the linked-list base address of the memory region, for a given channel x, from which the LLIs describing the programmed sequence of the GPDMA transfers, are conditionally and automatically updated.

This 64-Kbyte aligned channel x linked-list base address is offset by the 16-bit GPDMA_CxLLR register that defines the word-aligned address offset for each LLI.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LBA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:16 **LBA[31:16]**: linked-list base address of GPDMA channel x

Bits 15:0 Reserved, must be kept at reset value.

16.8.7 GPDMA channel x flag clear register (GPDMA_CxFCR)

Address offset: 0x5C+ 0x80 * x (x = 0 to 11)

Reset value: 0x0000 0000

This is a write register, secure or nonsecure depending on the secure state of channel x (GPDMA_SECCFGR.SECx) and privileged or unprivileged, depending on the privileged state of the channel x (GPDMA_PRIVCFGR.PRIVx).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TOF	SUSPF	USEF	ULEF	DTEF	HTF	TCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	w	w	w	w	w	w	w								

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **TOF**: trigger overrun flag clear
0: no effect
1: corresponding TOF flag cleared

Bit 13 **SUSPF**: completed suspension flag clear
0: no effect
1: corresponding SUSPF flag cleared

Bit 12 **USEF**: user setting error flag clear
0: no effect
1: corresponding USEF flag cleared

Bit 11 **ULEF**: update link transfer error flag clear
0: no effect
1: corresponding ULEF flag cleared

Bit 10 **DTEF**: data transfer error flag clear
0: no effect
1: corresponding DTEF flag cleared

Bit 9 **HTF**: half-transfer flag clear
0: no effect
1: corresponding HTF flag cleared

Bit 8 **TCF**: transfer complete flag clear
0: no effect
1: corresponding TCF flag cleared

Bits 7:0 Reserved, must be kept at reset value.

16.8.8 GPDMA channel x status register (GPDMA_CxSR)

Address offset: 0x60 + 0x80 * x (x = 0 to 11)

Reset value: 0x0000 0001

This is a read register, reporting the channel status.

This register is secure or nonsecure, depending on the secure state of channel x (GPDMA_SECCFGR.SECx), and privileged or unprivileged, depending on the privileged state of the channel (GPDMA_PRIVCFGR.PRIVx).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FIFOL[7:0]							
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TOF	SUSPF	USEF	ULEF	DTEF	HTF	TCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IDLEF
	r	r	r	r	r	r	r								r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **FIFOL[7:0]**: monitored FIFO level
Number of available write beats in the FIFO, in units of the programmed destination data width (see GPDMA_CxTR1.DDW_LOG2[1:0], in units of bytes, half-words, or words).

Note: After having suspended an active transfer, the user may need to read FIFOL[7:0], additionally to GPDMA_CxBR1.BDNT[15:0] and GPDMA_CxBR1.BRC[10:0], to know how many data have been transferred to the destination. Before reading, the user may wait for the transfer to be suspended (GPDMA_CxSR.SUSPF = 1).

Bit 15 Reserved, must be kept at reset value.

Bit 14 **TOF**: trigger overrun flag
0: no trigger overrun event
1: a trigger overrun event occurred

Bit 13 **SUSPF**: completed suspension flag
0: no completed suspension event
1: a completed suspension event occurred

Bit 12 **USEF**: user setting error flag
0: no user setting error event
1: a user setting error event occurred

Bit 11 **ULEF**: update link transfer error flag
0: no update link transfer error event
1: a master bus error event occurred while updating a linked-list register from memory

Bit 10 **DTEF**: data transfer error flag
0: no data transfer error event
1: a master bus error event occurred on a data transfer

Bit 9 **HTF**: half-transfer flag
0: no half-transfer event
1: a half-transfer event occurred
A half-transfer event is either a half-block transfer or a half 2D/repeated block transfer, depending on the transfer complete event mode (GPDMA_CxTR2.TCEM[1:0]).
A half-block transfer occurs when half of the bytes of the source block size (rounded up integer of GPDMA_CxBR1.BNDT[15:0]/2) has been transferred to the destination.
A half 2D/repeated block transfer occurs when half of the repeated blocks (rounded up integer of (GPDMA_CxBR1.BRC[10:0] + 1) / 2)) has been transferred to the destination.

Bit 8 **TCF**: transfer complete flag
0: no transfer complete event
1: a transfer complete event occurred
A transfer complete event is either a block transfer complete, a 2D/repeated block transfer complete, or a LLI transfer complete including the upload of the next LLI if any, or the full linked-list completion, depending on the transfer complete event mode (GPDMA_CxTR2.TCEM[1:0]).

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **IDLEF**: idle flag
0: channel not in idle state
1: channel in idle state
This idle flag is deasserted by hardware when the channel is enabled (GPDMA_CxCR.EN = 1) with a valid channel configuration (no USEF to be immediately reported).
This idle flag is asserted after hard reset or by hardware when the channel is back in idle state (in suspended or disabled state).

16.8.9 GPDMA channel x control register (GPDMA_CxCR)

Address offset: 0x64 + 0x80 * x (x = 0 to 11)

Reset value: 0x0000 0000

This register is secure or nonsecure depending on the secure state of channel x (GPDMA_SECCFGR.SECx), and privileged or unprivileged, depending on the privileged state of the channel x (GPDMA_PRIVCFGR.PRIVx).

This register is used to control a channel (activate, suspend, abort or disable it).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIO[1:0]		Res.	Res.	Res.	Res.	LAP	LSM
								rw	rw					rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TOIE	SUSPIE	USEIE	ULEIE	DTEIE	HTIE	TCIE	Res.	Res.	Res.	Res.	Res.	SUSP	RESET	EN
	rw	rw	rw	rw	rw	rw	rw						rw	w	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:22 **PRIO[1:0]:** priority level of the channel x GPDMA transfer versus others
00: low priority, low weight
01: low priority, mid weight
10: low priority, high weight
11: high priority
Note: This bit must be written when EN = 0. This bit is read-only when EN = 1.

Bits 21:18 Reserved, must be kept at reset value.

Bit 17 **LAP**: linked-list allocated port
This bit is used to allocate the master port for the update of the GPDMA linked-list registers from the memory.
0: port 0 (AHB) allocated
1: port 1 (AHB) allocated
Note: This bit must be written when EN = 0. This bit is read-only when EN = 1.

Bit 16 **LSM**: Link step mode
0: channel executed for the full linked-list and completed at the end of the last LLI (GPDMA_CxLLR = 0). The 16 low-significant bits of the link address are null (LA[15:0] = 0) and all the update bits are null (UT1 = UB1 = UT2 = USA = UDA = ULL = 0 and UT3 = UB2 = 0). Then GPDMA_CxBR1.BNDT[15:0] = 0 and GPDMA_CxBR1.BRC[10:0] = 0.
1: channel executed **once** for the current LLI
First the (possible 1D/repeated) block transfer is executed as defined by the current internal register file until GPDMA_CxBR1.BNDT[15:0] = 0 and GPDMA_CxBR1.BRC[10:0] = 0. Secondly the next linked-list data structure is conditionally uploaded from memory as defined by GPDMA_CxLLR. Then channel execution is completed.
Note: This bit must be written when EN = 0. This bit is read-only when EN = 1.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **TOIE**: trigger overrun interrupt enable
0: interrupt disabled
1: interrupt enabled

Bit 13 **SUSPIE**: completed suspension interrupt enable
0: interrupt disabled
1: interrupt enabled

Bit 12 **USEIE**: user setting error interrupt enable
0: interrupt disabled
1: interrupt enabled

Bit 11 **ULEIE**: update link transfer error interrupt enable
0: interrupt disabled
1: interrupt enabled

Bit 10 **DTEIE**: data transfer error interrupt enable
0: interrupt disabled
1: interrupt enabled

Bit 9 **HTIE**: half-transfer complete interrupt enable
0: interrupt disabled
1: interrupt enabled

Bit 8 **TCIE**: transfer complete interrupt enable
0: interrupt disabled
1: interrupt enabled

Bits 7:3 Reserved, must be kept at reset value.

Bit 2 **SUSP:** suspend
Writing 1 into the field RESET (bit 1) causes the hardware to de-assert this bit, whatever is written into this bit 2. Else:
Software must write 1 in order to suspend an active channel (channel with an ongoing GPDMA transfer over its master ports).
The software must write 0 in order to resume a suspended channel, following the programming sequence detailed in *Figure 72*.
0: write: resume channel, read: channel not suspended
1: write: suspend channel, read: channel suspended.

Bit 1 **RESET:** reset
This bit is write only. Writing 0 has no impact. Writing 1 implies the reset of the following: the FIFO, the channel internal state, SUSP and EN bits (whatever is written receptively in bit 2 and bit 0).
The reset is effective when the channel is in steady state, meaning one of the following:
- active channel in suspended state (GPDMA_CxSR.SUSPF = 1 and GPDMA_CxSR.IDLEF = GPDMA_CxCR.EN = 1)
- channel in disabled state (GPDMA_CxSR.IDLEF = 1 and GPDMA_CxCR.EN = 0).
After writing a RESET, to continue using this channel, the user must explicitly reconfigure the channel including the hardware-modified configuration registers (GPDMA_CxBR1, GPDMA_CxSAR, and GPDMA_CxDAR) before enabling again the channel (see the programming sequence in *Figure 73*).
0: no channel reset
1: channel reset

Bit 0 **EN:** enable
Writing 1 into the field RESET (bit 1) causes the hardware to de-assert this bit, whatever is written into this bit 0. Else:
this bit is deasserted by hardware when there is a transfer error (master bus error or user setting error) or when there is a channel transfer complete (channel ready to be configured, for example if LSM = 1 at the end of a single execution of the LLI).
Else, this bit can be asserted by software.
Writing 0 into this EN bit is ignored.
0: write: ignored, read: channel disabled
1: write: enable channel, read: channel enabled

16.8.10 GPDMA channel x transfer register 1 (GPDMA_CxTR1)

Address offset: 0x90 + 0x80 * x (x = 0 to 11)

Reset value: 0x0000 0000

This register is secure or nonsecure depending on the secure state of channel x (GPDMA_SECCFGR.SECx) except for secure DSEC and SSEC, privileged or unprivileged, depending on the privileged state of the channel x in GPDMA_PRIVCFGR.PRIVx.

This register controls the transfer of a channel x.

This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN = 1.

This register must be written when the channel is completed. Then the hardware has deasserted GPDMA_CxCR.EN). A channel transfer can be completed and programmed at different levels: block, 2D/repeated block, LLI or full linked-list.

In linked-list mode, during the link transfer, this register is automatically updated by GPDMA from the memory if GPDMA_CxLLR.UT1 = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DSEC	DAP	Res.	Res.	DHX	DBX	DBL_1[5:0]						DINC	Res.	DDW_LOG2[1:0]	
rw	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SSEC	SAP	SBX	PAM[1:0]		Res.	SBL_1[5:0]						SINC	Res.	SDW_LOG2[1:0]	
rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw		rw	rw

Bit 31 **DSEC**: security attribute of the GPDMA transfer to the destination

If GPDMA_SECCFGR.SECx = 1 and the access is secure:

0: GPDMA transfer nonsecure

1: GPDMA transfer secure

This is a secure register bit. This bit can only be read by a secure software. This bit must be written by a secure software when GPDMA_SECCFGR.SECx = 1. A secure write is ignored when GPDMA_SECCFGR.SECx = 0.

When GPDMA_SECCFGR.SECx is deasserted, this DSEC bit is also deasserted by hardware (on a secure reconfiguration of the channel as nonsecure), and the GPDMA transfer to the destination is nonsecure.

Bit 30 **DAP**: destination allocated port

This bit is used to allocate the master port for the destination transfer

0: port 0 (AHB) allocated

1: port 1 (AHB) allocated

Note: This bit must be written when EN = 0. This bit is read-only when EN = 1.

Bits 29:28 Reserved, must be kept at reset value.

Bit 27 **DHX**: destination half-word exchange

If the destination data size is shorter than a word, this bit is ignored.

If the destination data size is a word:

0: no halfword-based exchanged within word

1: the two consecutive (post PAM) half-words are exchanged in each destination word.

Bit 26 **DBX**: destination byte exchange

If the destination data size is a byte, this bit is ignored.

If the destination data size is not a byte:

0:no byte-based exchange within half-word

1: the two consecutive (post PAM) bytes are exchanged in each destination half-word.

Bits 25:20 **DBL_1[5:0]**: destination burst length minus 1, between 0 and 63

The burst length unit is one data named beat within a burst. If DBL_1[5:0] = 0, the burst can be named as single. Each data/beat has a width defined by the destination data width DDW_LOG2[1:0].

Note: If a burst transfer crossed a 1-Kbyte address boundary on a AHB transfer, the GPDMA modifies and shortens the programmed burst into singles or bursts of lower length, to be compliant with the AHB protocol.

If a burst transfer is of length greater than the FIFO size of the channel x, the GPDMA modifies and shortens the programmed burst into singles or bursts of lower length, to be compliant with the FIFO size. Transfer performance is lower, with GPDMA re-arbitration between effective and lower singles/bursts, but the data integrity is guaranteed.

Bit 19 **DINC**: destination incrementing burst

0: fixed burst

1: contiguously incremented burst

The destination address, pointed by GPDMA_CxDAR, is kept constant after a burst beat/single transfer, or is incremented by the offset value corresponding to a contiguous data after a burst beat/single transfer.

Bit 18 Reserved, must be kept at reset value.

Bits 17:16 **DDW_LOG2[1:0]**: binary logarithm of the destination data width of a burst, in bytes

00: byte

01: half-word (2 bytes)

10: word (4 bytes)

11: user setting error reported and no transfer issued

Note: A destination burst transfer must have an aligned address with its data width (start address GPDMA_CxDAR[2:0] and if present address offset GPDMA_CxTR3.DAO[2:0], versus DDW_LOG2[1:0]). Otherwise a user setting error is reported and no transfer is issued.

When configured in packing mode (PAM[1] = 1 and destination data width different from source data width), a source block size must be a multiple of the destination data width (see GPDMA_CxBR1.BNDT[2:0] versus DDW_LOG2[1:0]). Else a user setting error is reported and none transfer is issued.

Setting a 8-byte data width causes a user setting error to be reported and none transfer is issued.

Bit 15 **SSEC**: security attribute of the GPDMA transfer from the source

If GPDMA_SECCFGR.SECx = 1 and the access is secure:

0: GPDMA transfer nonsecure

1: GPDMA transfer secure

This is a secure register bit. This bit can only be read by a secure software. This bit must be written by a secure software when GPDMA_SECCFGR.SECx = 1. A secure write is ignored when GPDMA_SECCFGR.SECx = 0.

When GPDMA_SECCFGR.SECx is deasserted, this SSEC bit is also deasserted by hardware (on a secure reconfiguration of the channel as nonsecure), and the GPDMA transfer from the source is nonsecure.

Bit 14 **SAP**: source allocated port

This bit is used to allocate the master port for the source transfer

0: port 0 (AHB) allocated

1: port 1 (AHB) allocated

Note: This bit must be written when EN = 0. This bit is read-only when EN = 1.

Bit 13 **SBX**: source byte exchange within the unaligned half-word of each source word

If the source data width is shorter than a word, this bit is ignored.

If the source data width is a word:

0:no byte-based exchange within the unaligned half-word of each source word

1: the two consecutive bytes within the unaligned half-word of each source word are exchanged.

Bits 12:11 **PAM[1:0]**: padding/alignment mode

If DDW_LOG2[1:0] = SDW_LOG2[1:0]: if the data width of a burst destination transfer is equal to the data width of a burst source transfer, these bits are ignored.

Else, in the following enumerated values, the condition PAM_1 is when destination data width is higher than source data width, and the condition PAM_2 is when source data width is higher than destination data width.

Condition: PAM_1

00: source data is transferred as right aligned, padded with 0s up to the destination data width

01: source data is transferred as right aligned, sign extended up to the destination data width

10-11: successive source data are FIFO queued and packed at the destination data width, in a left (LSB) to right (MSB) order (named little endian), before a destination transfer

Condition: PAM_2

00: source data is transferred as right aligned, left-truncated down to the destination data width

01: source data is transferred as left-aligned, right-truncated down to the destination data width

10-11: source data is FIFO queued and unpacked at the destination data width, to be transferred in a left (LSB) to right (MSB) order (named little endian) to the destination

Note: If the transfer from the source peripheral is configured with peripheral flow-control mode (SWREQ = 0 and PFREQ = 1 and DREQ = 0), and if the destination data width > the source data width, packing is not supported.

Bit 10 Reserved, must be kept at reset value.

Bits 9:4 **SBL_1[5:0]**: source burst length minus 1, between 0 and 63

The burst length unit is one data named beat within a burst. If SBL_1[5:0] = 0, the burst can be named as single. Each data/beat has a width defined by the destination data width SDW_LOG2[1:0].

Note: If a burst transfer crossed a 1-Kbyte address boundary on a AHB transfer, the GPDMA modifies and shortens the programmed burst into singles or bursts of lower length, to be compliant with the AHB protocol.

If a burst transfer is of length greater than the FIFO size of the channel x, the GPDMA modifies and shortens the programmed burst into singles or bursts of lower length, to be compliant with the FIFO size. Transfer performance is lower, with GPDMA re-arbitration between effective and lower singles/bursts, but the data integrity is guaranteed.

Bit 3 **SINC**: source incrementing burst

0: fixed burst

1: contiguously incremented burst

The source address, pointed by GPDMA_CxSAR, is kept constant after a burst beat/single transfer or is incremented by the offset value corresponding to a contiguous data after a burst beat/single transfer.

Bit 2 Reserved, must be kept at reset value.

Bits 1:0 **SDW_LOG2[1:0]**: binary logarithm of the source data width of a burst in bytes
00: byte
01: half-word (2 bytes)
10: word (4 bytes)
11: user setting error reported and no transfer issued

Note: A source block size must be a multiple of the source data width (GPDMA_CxBR1.BNDT[2:0] versus SDW_LOG2[1:0]). Otherwise, a user setting error is reported and no transfer is issued.

A source burst transfer must have an aligned address with its data width (start address GPDMA_CxSAR[2:0] versus SDW_LOG2[1:0]). Otherwise, a user setting error is reported and none transfer is issued.

Setting a 8-byte data width causes a user setting error to be reported and no transfer is issued.

16.8.11 GPDMA channel x transfer register 2 (GPDMA_CxTR2)

Address offset: 0x94 + 0x80 * x (x = 0 to 11)

Reset value: 0x0000 0000

This register is secure or nonsecure depending on the secure state of channel x (GPDMA_SECCFGR.SECx), and privileged or unprivileged, depending on the privileged state of channel x (GPDMA_PRIVCFGR.PRIVx).

This register controls the transfer of a channel x. This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN = 1.

This register must be written when the channel is completed (the hardware deasserted GPDMA_CxCR.EN). A channel transfer can be completed and programmed at different levels: block or LLI or full linked-list.

In linked-list mode, during the link transfer, this register is automatically updated by GPDMA from the memory, if GPDMA_CxLLR.UT2 = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TCEM[1:0]		Res.	Res.	Res.	Res.	TRIGPOL[1:0]		Res.	TRIGSEL[6:0]						
rw	rw					rw	rw		rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRIGM[1:0]		Res.	PFREQ	BREQ	DREQ	SWREQ	Res.	REQSEL[7:0]							
rw	rw		rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 **TCEM[1:0]**: transfer complete event mode

These bits define the transfer granularity for the transfer complete and half-transfer complete events generation.

00: at block level (when GPDMA_CxBR1.BNDT[15:0] = 0): the complete (and the half) transfer event is generated at the (respectively half of the) end of a block.

Note: If the initial LLI_0 data transfer is null/void (directly programmed by the internal register file with GPDMA_CxBR1.BNDT[15:0] = 0), then neither the complete transfer event nor the half-transfer event is generated.

01: channel x (x = 0 to 9), same as 00, channel x (x = 10 to 11), at 2D/repeated block level (when GPDMA_CxBR1.BRC[10:0] = 0 and GPDMA_CxBR1.BNDT[15:0] = 0). The complete (and the half) transfer event is generated at the end (respectively half of the end) of the 2D/repeated block.

Note: If the initial LLI_0 data transfer is null/void (directly programmed by the internal register file with GPDMA_CxBR1.BNDT[15:0] = 0), then neither the complete transfer event nor the half-transfer event is generated.

10: at LLI level: the complete transfer event is generated at the end of the LLI transfer, including the update of the LLI if any. The half-transfer event is generated at the half of the LLI data transfer The LLI data transfer is a block transfer or a 2D/repeated block transfer for channel x (x = 10 to 11), if any data transfer.

Note: If the initial LLI_0 data transfer is null/void (directly programmed by the internal register file with GPDMA_CxBR1.BNDT[15:0] = 0), then the half-transfer event is not generated, and the transfer complete event is generated when is completed the loading of the LLI_1.

11: at channel level: the complete transfer event is generated at the end of the last LLI transfer. The half-transfer event is generated at the half of the data transfer of the last LLI. The last LLI updates the link address GPDMA_CxLLR.LA[15:2] to zero and clears all the GPDMA_CxLLR update bits (UT1, UT2, UB1, USA, UDA and ULL, plus UT3 and UB2). If the channel transfer is continuous/infinite, no event is generated.

Bits 29:26 Reserved, must be kept at reset value.

Bits 25:24 **TRIGPOL[1:0]**: trigger event polarity

These bits define the polarity of the selected trigger event input defined by TRIGSEL[6:0].

00: no trigger (masked trigger event)

01: trigger on the rising edge

10: trigger on the falling edge

11: same as 00

Bit 23 Reserved, must be kept at reset value.

Bits 22:16 **TRIGSEL[6:0]**: trigger event input selection

These bits select the trigger event input of the GPDMA transfer (as per *Section 16.3.7*), with an active trigger event if TRIGPOL[1:0] ≠ 00.

Bits 15:14 **TRIGM[1:0]**: trigger mode

These bits define the transfer granularity for its conditioning by the trigger.

If the channel x is enabled (GPDMA_CxCR.EN asserted) with TRIGPOL[1:0] = 00 or 11, these TRIGM[1:0] bits are ignored.

Else, a GPDMA transfer is conditioned by one trigger hit:

00: at block level: the first burst read of each block transfer is conditioned by one hit trigger (channel x (x = 10 to 11): same, each block also if a 2D/repeated block is configured with GPDMA_CxBR1.BRC[10:0] ≠ 0).

01: channel x (x = 0 to 9): same as 00; channel x (x = 10 to 11): at 2D/repeated block level: the first burst read of the 2D/repeated block transfer is conditioned by one hit trigger.

10: at link level: a LLI link transfer is conditioned by one hit trigger. LLI data transfer is not conditioned.

11: at programmed burst level: If SWREQ = 1, each programmed burst read is conditioned by one hit trigger. If SWREQ = 0, each programmed burst that is requested by the selected peripheral, is conditioned by one hit trigger:

– If the peripheral is the source (DREQ = 0) of the LLI data transfer, each programmed burst read is conditioned.

– If the peripheral is the destination (DREQ = 1) of the LLI data transfer, each programmed burst write is conditioned. The first memory burst read of a (possibly 2D/repeated) block, also named as the first ready FIFO-based source burst, is gated by the occurrence of both the hardware request and one trigger hit.

As shown in *Figure 88: Trigger hit, memorization, and overrun waveform*, the GPDMA monitoring of a trigger for channel x is started when the channel is enabled/loaded with a new active trigger configuration: rising or falling edge on a selected trigger (TRIGPOL[1:0] = 01 or respectively TRIGPOL[1:0] = 10). The monitoring of this trigger is kept active during the triggered and uncompleted (data or link) transfer; and if a new trigger is detected then, this hit is internally memorized to grant the next transfer, as long as the defined rising or falling edge is not modified, and the TRIGSEL[6:0] is not modified, and the channel is enabled. After a first new trigger hit_{n+1} is memorized, if another second trigger hit_{n+2} is detected and if the hit_n triggered transfer is still not completed, hit_{n+2} is lost and not memorized. A trigger overrun flag is reported (GPDMA_CxSR.TOF = 1), and an interrupt is generated if enabled (GPDMA_CxCR.TOIE = 1). The channel is not automatically disabled by hardware due to a trigger overrun.

Transferring a next LLI_{n+1} that updates the GPDMA_CxTR2 with a new value for any of TRIGSEL[6:0] or TRIGPOL[1:0], resets the monitoring, trashing the memorized hit of the formerly defined LLI_n trigger.

Note: When the source block size is not a multiple of the source burst size and is a multiple of the source data width, then the last programmed source burst is not completed and is internally shorten to match the block size. In this case, if TRIGM[1:0] = 11 and (SWREQ = 1 or (SWREQ = 0 and DREQ = 0)), the shortened burst transfer (by singles or/and by bursts of lower length) is conditioned once by the trigger.

When the programmed destination burst is internally shortened by singles or/and by bursts of lower length (versus FIFO size, versus block size, 1-Kbyte boundary address crossing): if the trigger is conditioning the programmed destination burst (if TRIGM[1:0] = 11 and SWREQ = 0 and DREQ = 1), this shortened destination burst transfer is conditioned once by the trigger.

Bit 13 Reserved, must be kept at reset value.

Bit 12 **PFREQ**: Hardware request in peripheral flow control mode

Important: If a given channel x is not implemented with this feature, this bit is reserved and PFREQ is not present (see Section 16.3.2 for the list of the implemented channels with this feature).

If the channel x is activated (GPDMA_CxCR.EN asserted) with SWREQ = 1 (software request for a memory-to-memory transfer), this bit is ignored. Else:

0: the selected hardware request is driven by a peripheral with a hardware request/acknowledge protocol in GPDMA control mode. The GPDMA is programmed with GPDMA_CxTR1.BNDT[15:0] and this is internally used by the hardware for the block transfer completion.

1: the selected hardware request is driven by a peripheral with a hardware request/acknowledge protocol in peripheral control mode. The GPDMA block transfer can be early completed by the peripheral itself (see *Section 16.3.6* for more details).

Note: In peripheral flow control mode, there are the following restrictions:

- no 2D/repeated block support (GPDMA_CxBR1.BRC[10:0] must be set to 0)

- the peripheral must be set as the source of the transfer (DREQ = 0).

- data packing to a wider destination width is not supported (if destination width > source data width, GPDMA_CxTR1.PAM[1] must be set to 0).

- GPDMA_CxBR1.BNDT[15:0] must be programmed as a multiple of the source (peripheral) burst size.

Bit 11 **BREQ**: Block hardware request

If the channel x is activated (GPDMA_CxCR.EN asserted) with SWREQ = 1 (software request for a memory-to-memory transfer), this bit is ignored. Else:

0: the selected hardware request is driven by a peripheral with a hardware request/acknowledge protocol at a burst level.

1: the selected hardware request is driven by a peripheral with a hardware request/acknowledge protocol at a block level (see *Section 16.3.4*).

Bit 10 **DREQ**: destination hardware request

This bit is ignored if channel x is activated (GPDMA_CxCR.EN asserted) with SWREQ = 1 (software request for a memory-to-memory transfer). Else:

0: selected hardware request driven by a source peripheral (request signal taken into account by the GPDMA transfer scheduler over the source/read port)

1: selected hardware request driven by a destination peripheral (request signal taken into account by the GPDMA transfer scheduler over the destination/write port)

Note: If the channel x is activated (GPDMA_CxCR.EN is asserted) with SWREQ = 0 and PFREQ = 1 (peripheral hardware request with peripheral flow-control mode), any software assertion to this DREQ bit is ignored: in peripheral flow-control mode, only a peripheral-to-memory transfer is supported.

Bit 9 **SWREQ**: software request

This bit is internally taken into account when GPDMA_CxCR.EN is asserted.

0: no software request. The selected hardware request REQSEL[7:0] is taken into account.

1: software request for a memory-to-memory transfer. The default selected hardware request as per REQSEL[7:0] is ignored.

Bit 8 Reserved, must be kept at reset value.

Bits 7:0 **REQSEL[7:0]**: GPDMA hardware request selection

These bits are ignored if channel x is activated (GPDMA_CxCR.EN asserted) with SWREQ = 1(software request for a memory-to-memory transfer). Else, the selected hardware request is internally taken into account as per *Section 16.3.4*.

Caution: The user must not assign a same input hardware request (same REQSEL[7:0] value) to different active GPDMA channels (GPDMA_CxCR.EN = 1 and GPDMA_CxTR2.SWREQ = 0 for these channels). GPDMA is not intended to hardware support the case of simultaneous enabled channels incorrectly configured with a same hardware peripheral request signal, and there is no user setting error reporting.

16.8.12 GPDMA channel x block register 1 (GPDMA_CxBR1)

Address offset: 0x98 + 0x80 * x (x = 0 to 9)

Reset value: 0x0000 0000

This register is secure or nonsecure depending on the secure state of channel x (GPDMA_SECCFGR.SECx), and privileged or unprivileged, depending on the privileged state of channel x (GPDMA_PRIVCFGR.PRIVx).

This register controls the transfer of a channel x at a block level.

This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN = 1.

This register must be written when channel x is completed (then the hardware has deasserted GPDMA_CxCR.EN). A channel transfer can be completed and programmed at different levels: block, or LLI or full linked-list.

In linked-list mode, during the link transfer:

- if GPDMA_CxLLR.UB1 = 1, this register is automatically updated by the GPDMA from the next LLI in memory.
- If GPDMA_CxLLR.UB1 = 0 and if there is at least one linked-list register to be updated from the next LLI in memory, this register is automatically and internally restored with the programmed value for the field BNDT[15:0].
- If all the update bits GPDMA_CxLLR.Uxx are null and if GPDMA_CxLLR.LA[15:0] ≠ 0, the current LLI is the last one and is continuously executed: this register is automatically and internally restored with the programmed value for BNDT[15:0] after each execution of this final LLI
- If GPDMA_CxLLR = 0, this register and BNDT[15:0] are kept as null, channel x is completed.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BNDT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **BNDT[15:0]**: block number of data bytes to transfer from the source

Block size transferred from the source. When the channel is enabled, this field becomes read-only and is decremented, indicating the remaining number of data items in the current source block to be transferred. BNDT[15:0] is programmed in number of bytes, maximum source block size is 64 Kbytes -1.

Once the last data transfer is completed (BNDT[15:0] = 0):

- if GPDMA_CxLLR.UB1 = 1, this field is updated with the LLI in the memory.
- if GPDMA_CxLLR.UB1 = 0 and if there is at least one non null Uxx update bit, this field is internally restored to the programmed value.
- if all GPDMA_CxLLR.Uxx = 0 and if GPDMA_CxLLR.LA[15:0] = 0, this field is internally restored to the programmed value (infinite/continuous last LLI).
- if GPDMA_CxLLR = 0, this field is kept as zero following the last LLI data transfer.

Note: A non-null source block size must be a multiple of the source data width (BNDT[2:0] versus GPDMA_CxTR1.SDW_LOG2[1:0]). Else a user setting error is reported and no transfer is issued.

When configured in packing mode (GPDMA_CxTR1.PAM[1] = 1 and destination data width different from source data width), a non-null source block size must be a multiple of the destination data width (BNDT[2:0] versus GPDMA_CxTR1.DDW_LOG2[1:0]). Else a user setting error is reported and no transfer is issued.

16.8.13 GPDMA channel x alternate block register 1 (GPDMA_CxBR1)

Address offset: 0x98 + 0x80 * x (x = 10 to 11)

Reset value: 0x0000 0000

This register is secure or nonsecure depending on the secure state of channel x (GPDMA_SECCFGR.SECx), and privileged or unprivileged, depending on the privileged state of channel x (GPDMA_PRIVCFGR.PRIVx).

This register controls the transfer of a channel x at a block level.

This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN = 1.

This register must be written when channel x is completed (then the hardware has deasserted GPDMA_CxCR.EN). A channel transfer can be completed and programmed at different levels: block, or LLI or full linked-list.

In linked-list mode, during the link transfer:

- if GPDMA_CxLLR.UB1 = 1, this register is automatically updated by the GPDMA from the next LLI in memory.
- If GPDMA_CxLLR.UB1 = 0 and if there is at least one linked-list register to be updated from the next LLI in memory, this register is automatically and internally restored with the programmed value for the fields BNDT[15:0] and BRC[10:0].
- If all the update bits GPDMA_CxLLR.Uxx are null and if GPDMA_CxLLR.LA[15:0] ≠ 0, the current LLI is the last one and is continuously executed: this register is

automatically and internally restored with the programmed value for the fields BNDT[15:0] and BRC[10:0] after each execution of this final LLI

- If GPDMA_CxLLR = 0, BNDT[15:0] and BRC[10:0] are kept as null, channel x is completed.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BRDDEC	BRSDEC	DDEC	SDEC	Res.	BRC[10:0]										
rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BNDT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **BRDDEC**: Block repeat destination address decrement

0: at the end of a block transfer, the GPDMA_CxDAR register is updated by adding the programmed offset GPDMA_CxBR2.BRDAO to the current GPDMA_CxDAR value (current destination address)

1: at the end of a block transfer, the GPDMA_CxDAR register is updated by subtracting the programmed offset GPDMA_CxBR2.BRDAO from the current GPDMA_CxDAR value (current destination address)

Note: On top of this increment/decrement (depending on BRDDEC), GPDMA_CxDAR is in the same time also updated by the increment/decrement (depending on DDEC) of the GPDMA_CxTR3.DAO value, as it is usually done at the end of each programmed burst transfer.

Bit 30 **BRSDEC**: Block repeat source address decrement

0: at the end of a block transfer, the GPDMA_CxSAR register is updated by adding the programmed offset GPDMA_CxBR2.BRSAO to the current GPDMA_CxSAR value (current source address)

1: at the end of a block transfer, the GPDMA_CxSAR register is updated by subtracting the programmed offset GPDMA_CxBR2.BRSAO from the current GPDMA_CxSAR value (current source address)

Note: On top of this increment/decrement (depending on BRSDEC), GPDMA_CxSAR is in the same time also updated by the increment/decrement (depending on SDEC) of the GPDMA_CxTR3.SAO value, as it is done after any programmed burst transfer.

Bit 29 **DDEC**: destination address decrement

0: At the end of a programmed burst transfer to the destination, the GPDMA_CxDAR register is updated by adding the programmed offset GPDMA_CxTR3.DAO to the current GPDMA_CxDAR value (current destination address)

1: At the end of a programmed burst transfer to the destination, the GPDMA_CxDAR register is updated by subtracting the programmed offset GPDMA_CxTR3.DAO to the current GPDMA_CxDAR value (current destination address)

Bit 28 **SDEC**: source address decrement

0: At the end of a programmed burst transfer from the source, the GPDMA_CxSAR register is updated by adding the programmed offset GPDMA_CxTR3.SAO to the current GPDMA_CxSAR value (current source address)

1: At the end of a programmed burst transfer from the source, the GPDMA_CxSAR register is updated by subtracting the programmed offset GPDMA_CxTR3.SAO to the current GPDMA_CxSAR value (current source address)

Bit 27 Reserved, must be kept at reset value.

Bits 26:16 **BRC[10:0]**: Block repeat counter

This field contains the number of repetitions of the current block (0 to 2047).

When the channel is enabled, this field becomes read-only. After decrements, this field indicates the remaining number of blocks, excluding the current one. This counter is hardware decremented for each completed block transfer.

Once the last block transfer is completed (BRC[10:0] = BNDT[15:0] = 0):

– If GPDMA_CxLLR.UB1 = 1, all GPDMA_CxBR1 fields are updated by the next LLI in the memory.

– If GPDMA_CxLLR.UB1 = 0 and if there is at least one not null Uxx update bit, this field is internally restored to the programmed value.

– if all GPDMA_CxLLR.Uxx = 0 and if GPDMA_CxLLR.LA[15:0] ≠ 0, this field is internally restored to the programmed value (infinite/continuous last LLI).

– if GPDMA_CxLLR = 0, this field is kept as zero following the last LLI and data transfer.

Bits 15:0 **BNDT[15:0]**: block number of data bytes to transfer from the source

Block size transferred from the source. When the channel is enabled, this field becomes read-only and is decremented, indicating the remaining number of data items in the current source block to be transferred. BNDT[15:0] is programmed in number of bytes, maximum source block size is 64 Kbytes -1.

Once the last data transfer is completed (BNDT[15:0] = 0):

- if GPDMA_CxLLR.UB1 = 1, this field is updated with the LLI in the memory.

- if GPDMA_CxLLR.UB1 = 0 and if there is at least one not null Uxx update bit, this field is internally restored to the programmed value.

- if all GPDMA_CxLLR.Uxx = 0 and if GPDMA_CxLLR.LA[15:0] ≠ 0, this field is internally restored to the programmed value (infinite/continuous last LLI).

- if GPDMA_CxLLR = 0, this field is kept as zero following the last LLI data transfer.

Note: A non-null source block size must be a multiple of the source data width (BNDT[2:0] versus GPDMA_CxTR1.SDW_LOG2[1:0]). Else a user setting error is reported and no transfer is issued.

When configured in packing mode (GPDMA_CxTR1.PAM[1] = 1 and destination data width different from source data width), a non-null source block size must be a multiple of the destination data width (BNDT[2:0] versus GPDMA_CxTR1.DDW_LOG2[1:0]). Else a user setting error is reported and no transfer is issued.

16.8.14 GPDMA channel x source address register (GPDMA_CxSAR)

Address offset: 0x9C + 0x80 * x (x = 0 to 11)

Reset value: 0x0000 0000

This register is secure or nonsecure depending on the secure state of channel x (GPDMA_SECCFGR.SECx), and privileged or unprivileged, depending on the privileged state of channel x (GPDMA_PRIVCFGR.PRIVx).

This register configures the source start address of a transfer.

This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN = 1, and continuously updated by hardware, in order to reflect the address of the next burst transfer from the source.

This register must be written when the channel is completed (then the hardware has deasserted GPDMA_CxCR.EN). A channel transfer can be completed and programmed at different levels: block, 2D/repeated block, LLI or full linked-list.

In linked-list mode, during the link transfer, this register is automatically updated by the GPDMA from the memory if GPDMA_CxLLR.USA = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SA[31:0]**: source address

This field is the pointer to the address from which the next data is read.

During the channel activity, depending on the source addressing mode (GPDMA_CxTR1.SINC), this field is kept fixed or incremented by the data width (GPDMA_CxTR1.SDW_LOG2[1:0]) after each burst source data, reflecting the next address from which data is read.

During the channel activity, this address is updated after each completed source burst, consequently to:

– the programmed source burst; either in fixed addressing mode or in contiguous-data incremented mode. If contiguously incremented (GPDMA_CxTR1.SINC = 1), then the additional address offset value is the programmed burst size, as defined by GPDMA_CxTR1.SBL_1[5:0] and GPDMA_CxTR1.SDW_LOG2[1:0]

– the additional source incremented/decremented offset value as programmed by GPDMA_CxBR1.SDEC and GPDMA_CxTR3.SAO[12:0].

In linked-list mode, after a LLI data transfer is completed, this register is automatically updated by GPDMA from the memory, provided the LLI is set with GPDMA_CxLLR.USA = 1.

Note: A source address must be aligned with the programmed data width of a source burst (SA[2:0] versus GPDMA_CxTR1.SDW_LOG2[1:0]). Else, a user setting error is reported and no transfer is issued.

When the source block size is not a multiple of the source burst size and is a multiple of the source data width, the last programmed source burst is not completed and is internally shorten to match the block size. In this case, the additional GPDMA_CxTR3.SAO[12:0] is not applied.

16.8.15 GPDMA channel x destination address register (GPDMA_CxDAR)

Address offset: 0xA0 + 0x80 * x (x = 0 to 11)

Reset value: 0x0000 0000

This register is secure or nonsecure depending on the secure state of channel x (GPDMA_SECCFGR.SECx), and privileged or unprivileged, depending on the privileged state of channel x (GPDMA_PRIVCFGR.PRIVx).

This register configures the destination start address of a transfer.

This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN = 1, and continuously updated by hardware, in order to reflect the address of the next burst transfer to the destination.

This register must be written when the channel is completed (then the hardware has deasserted GPDMA_CxCR.EN). A channel transfer can be completed and programmed at different levels: block, 2D/repeated block, LLI or full linked-list.

In linked-list mode, during the link transfer, this register is automatically updated by GPDMA from the memory if GPDMA_CxLLR.UDA = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DA[31:0]**: destination address

This field is the pointer to the address from which the next data is written.

During the channel activity, depending on the destination addressing mode (GPDMA_CxTR1.DINC), this field is kept fixed or incremented by the data width (GPDMA_CxTR1.DDW_LOG2[1:0]) after each burst destination data, reflecting the next address from which data is written.

During the channel activity, this address is updated after each completed destination burst, consequently to:

– the programmed destination burst; either in fixed addressing mode or in contiguous-data incremented mode. If contiguously incremented (GPDMA_CxTR1.DINC = 1), then the additional address offset value is the programmed burst size, as defined by GPDMA_CxTR1.DBL_1[5:0] and GPDMA_CxTR1.DDW_LOG2[1:0]

– the additional destination incremented/decremented offset value as programmed by GPDMA_CxBR1.DDEC and GPDMA_CxTR3.DAO[12:0].

In linked-list mode, after a LLI data transfer is completed, this register is automatically updated by the GPDMA from the memory, provided the LLI is set with GPDMA_CxLLR.UDA = 1.

Note: A destination address must be aligned with the programmed data width of a destination burst (DA[2:0] versus GPDMA_CxTR1.DDW_LOG2[1:0]). Else, a user setting error is reported and no transfer is issued.

16.8.16 GPDMA channel x transfer register 3 (GPDMA_CxTR3)

Address offset: 0xA4 + 0x80 * x (x = 10 to 11)

Reset value: 0x0000 0000

This register is secure or nonsecure depending on the secure state of channel x (GPDMA_SECCFGR.SECx), and privileged or unprivileged, depending on the privileged state of channel x (GPDMA_PRIVCFGR.PRIVx).

This register controls the transfer of a channel x.

This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN = 1.

This register must be written when the channel is completed (then the hardware has deasserted GPDMA_CxCR.EN). A channel transfer can be completed and programmed at different levels: block or LLI or full linked-list.

In linked-list mode, during the link transfer, this register is automatically updated by the GPDMA from the memory if GPDMA_CxLLR.UT3 = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	DAO[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	SAO[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:16 **DAO[12:0]**: destination address offset increment

The destination address, pointed by GPDMA_CxDAR, is incremented or decremented (depending on GPDMA_CxBR1.DDEC) by this offset DAO[12:0] for each programmed destination burst. This offset is not including and is added to the programmed burst size when the completed burst is addressed in incremented mode (GPDMA_CxTR1.DINC = 1).

Note: A destination address offset must be aligned with the programmed data width of a destination burst (DAO[2:0] versus GPDMA_CxTR1.DDW_LOG2[1:0]). Else, a user setting error is reported and no transfer is issued.

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:0 **SAO[12:0]**: source address offset increment

The source address, pointed by GPDMA_CxSAR, is incremented or decremented (depending on GPDMA_CxBR1.SDEC) by this offset SAO[12:0] for each programmed source burst. This offset is not including and is added to the programmed burst size when the completed burst is addressed in incremented mode (GPDMA_CxTR1.SINC = 1).

Note: A source address offset must be aligned with the programmed data width of a source burst (SAO[2:0] versus GPDMA_CxTR1.SDW_LOG2[1:0]). Else a user setting error is reported and none transfer is issued.

When the source block size is not a multiple of the destination burst size, and is a multiple of the source data width, then the last programmed source burst is not completed and is internally shorten to match the block size. In this case, the additional GPDMA_CxTR3.SAO[12:0] is not applied.

16.8.17 GPDMA channel x block register 2 (GPDMA_CxBR2)

Address offset: 0xA8 + 0x80 * x (x = 10 to 11)

Reset value: 0x0000 0000

This register is secure or nonsecure depending on the secure state of channel x (GPDMA_SECCFGR.SECx), and privileged or unprivileged, depending on the privileged state of channel x (GPDMA_PRIVCFGR.PRIVx).

This register controls the transfer of a channel x at a 2D/repeated block level.

This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN = 1.

This register must be written when the channel is completed (then the hardware has deasserted GPDMA_CxCR.EN). A channel transfer can be completed and programmed at different levels: block, 2D/repeated block, LLI or full linked-list.

In linked-list mode, during the link transfer, this register is automatically updated by the GPDMA from the memory if GPDMA_CxLLR.UB2 = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BRDAO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BRSAO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **BRDAO[15:0]**: Block repeated destination address offset

For a channel with 2D addressing capability, this field is used to update (by addition or subtraction depending on GPDMA_CxBR1.BRDDEC) the current destination address (GPDMA_CxDAR) at the end of a block transfer.

Note: A block repeated destination address offset must be aligned with the programmed data width of a destination burst (BRDAO[2:0] versus GPDMA_CxTR1.DDW_LOG2[1:0]). Else a user setting error is reported and no transfer is issued. BRDAO[15:0] must be set to 0 in peripheral flow-control mode (if GPDMA_CxTR2.PFREQ = 1).

Bits 15:0 **BRSAO[15:0]**: Block repeated source address offset

For a channel with 2D addressing capability, this field is used to update (by addition or subtraction depending on GPDMA_CxBR1.BRSDEC) the current source address (GPDMA_CxSAR) at the end of a block transfer.

Note: A block repeated source address offset must be aligned with the programmed data width of a source burst (BRSAO[2:0] versus GPDMA_CxTR1.SDW_LOG2[1:0]). Else a user setting error is reported and no transfer is issued. BRSAO[15:0] must be set to 0 in peripheral flow-control mode (if GPDMA_CxTR2.PFREQ = 1).

16.8.18 GPDMA channel x linked-list address register (GPDMA_CxLLR)

Address offset: 0xCC + 0x80 * x (x = 0 to 9)

Reset value: 0x0000 0000

This register is secure or nonsecure depending on the secure state of channel x (GPDMA_SECCFGR.SECx), and privileged or unprivileged, depending on the privileged state of channel x (GPDMA_PRIVCFGR.PRIVx).

This register configures the data structure of the next LLI in the memory and its address pointer. A channel transfer is completed when this register is null.

This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN = 1.

This register must be written when the channel is completed (then the hardware has deasserted GPDMA_CxCR.EN). A channel transfer can be completed and programmed at different levels: block or LLI or full linked-list.

In linked-list mode, during the link transfer, this register is automatically updated by the GPDMA from the memory if GPDMA_CxLLR.ULL = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UT1	UT2	UB1	USA	UDA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ULL
rw	rw	rw	rw	rw											rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LA[15:2]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bit 31 **UT1**: Update GPDMA_CxTR1 from memory

This bit controls the update of GPDMA_CxTR1 from the memory during the link transfer.
0: no GPDMA_CxTR1 update
1: GPDMA_CxTR1 update

Bit 30 **UT2**: Update GPDMA_CxTR2 from memory

This bit controls the update of GPDMA_CxTR2 from the memory during the link transfer.
0: no GPDMA_CxTR2 update
1: GPDMA_CxTR2 update

Bit 29 **UB1**: Update GPDMA_CxBR1 from memory

This bit controls the update of GPDMA_CxBR1 from the memory during the link transfer.
If UB1 = 0 and if GPDMA_CxLLR ≠ 0, the linked-list is not completed.
GPDMA_CxBR1.BNDT[15:0] is then restored to the programmed value after data transfer is completed and before the link transfer.
0: no GPDMA_CxBR1 update from memory (GPDMA_CxBR1.BNDT[15:0] restored if any link transfer)
1: GPDMA_CxBR1 update

Bit 28 **USA**: update GPDMA_CxSAR from memory

This bit controls the update of GPDMA_CxSAR from the memory during the link transfer.
0: no GPDMA_CxSAR update
1: GPDMA_CxSAR update

Bit 27 **UDA**: Update GPDMA_CxDAR register from memory

This bit is used to control the update of GPDMA_CxDAR from the memory during the link transfer.

0: no GPDMA_CxDAR update

1: GPDMA_CxDAR update

Bits 26:17 Reserved, must be kept at reset value.

Bit 16 **ULL**: Update GPDMA_CxLLR register from memory

This bit is used to control the update of GPDMA_CxLLR from the memory during the link transfer.

0: no GPDMA_CxLLR update

1: GPDMA_CxLLR update

Bits 15:2 **LA[15:2]**: pointer (16-bit low-significant address) to the next linked-list data structure

If UT1 = UT2 = UB1 = USA = UDA = ULL = 0 and if LA[15:2] = 0, the current LLI is the last one. The channel transfer is completed without any update of the linked-list GPDMA register file.

Else, this field is the pointer to the memory address offset from which the next linked-list data structure is automatically fetched from, once the data transfer is completed, in order to conditionally update the linked-list GPDMA internal register file (GPDMA_CxTR1, GPDMA_CxTR2, GPDMA_CxBR1, GPDMA_CxSAR, GPDMA_CxDAR, and GPDMA_CxLLR).

Caution: The user must program this pointer not to exceed the 64-Kbyte addressable space defined by the link base address register GPDMA_CxLBAR. The complete linked-list data structure must be included in the 64-Kbyte addressable space.

Note: The user must program the pointer to be 32-bit aligned. The two low-significant bits are write ignored.

Bits 1:0 Reserved, must be kept at reset value.

16.8.19 GPDMA channel x alternate linked-list address register (GPDMA_CxLLR)

Address offset: 0xCC + 0x80 * x (x = 10 to 11)

Reset value: 0x0000 0000

This register is secure or nonsecure depending on the secure state of channel x (GPDMA_SECCFGR.SECx), and privileged or unprivileged, depending on the privileged state of channel x (GPDMA_PRIVCFGR.PRIVx).

This register configures the data structure of the next LLI in the memory and its address pointer. A channel transfer is completed when this register is null.

This register must be written when GPDMA_CxCR.EN = 0.

This register is read-only when GPDMA_CxCR.EN = 1.

This register must be written when the channel is completed (then the hardware has deasserted GPDMA_CxCR.EN). A channel transfer can be completed and programmed at different levels: block or LLI or full linked-list.

In linked-list mode, during the link transfer, this register is automatically updated by the GPDMA from the memory if GPDMA_CxLLR.ULL = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UT1	UT2	UB1	USA	UDA	UT3	UB2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ULL
rw	rw	rw	rw	rw	rw	rw									rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LA[15:2]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bit 31 **UT1**: Update GPDMA_CxTR1 from memory

This bit controls the update of GPDMA_CxTR1 from the memory during the link transfer.

0: no GPDMA_CxTR1 update

1: GPDMA_CxTR1 update

Bit 30 **UT2**: Update GPDMA_CxTR2 from memory

This bit controls the update of GPDMA_CxTR2 from the memory during the link transfer.

0: no GPDMA_CxTR2 update

1: GPDMA_CxTR2 update

Bit 29 **UB1**: Update GPDMA_CxBR1 from memory

This bit controls the update of GPDMA_CxBR1 from the memory during the link transfer.
If UB1 = 0 and if GPDMA_CxLLR ≠ 0, the linked-list is not completed.
GPDMA_CxBR1.BNDT[15:0] is then restored to the programmed value after data transfer is completed and before the link transfer.

0: no GPDMA_CxBR1 update from memory (GPDMA_CxBR1.BNDT[15:0] restored if any link transfer)

1: GPDMA_CxBR1 update

Bit 28 **USA**: update GPDMA_CxSAR from memory

This bit controls the update of GPDMA_CxSAR from the memory during the link transfer.

0: no GPDMA_CxSAR update

1: GPDMA_CxSAR update

Bit 27 **UDA**: Update GPDMA_CxDAR register from memory
This bit is used to control the update of GPDMA_CxDAR from the memory during the link transfer.
0:no GPDMA_CxDAR update
1: GPDMA_CxDAR update

Bit 26 **UT3**: Update GPDMA_CxTR3 from memory
This bit controls the update of GPDMA_CxTR3 from the memory during the link transfer.
0: no GPDMA_CxTR3 update
1: GPDMA_CxTR3 update

Bit 25 **UB2**: Update GPDMA_CxBR2 from memory
This bit controls the update of GPDMA_CxBR2 from the memory during the link transfer.
0: no GPDMA_CxBR2 update
1: GPDMA_CxBR2 update

Bits 24:17 Reserved, must be kept at reset value.

Bit 16 **ULL**: Update GPDMA_CxLLR register from memory
This bit is used to control the update of GPDMA_CxLLR from the memory during the link transfer.
0: no GPDMA_CxLLR update
1: GPDMA_CxLLR update

Bits 15:2 **LA[15:2]**: pointer (16-bit low-significant address) to the next linked-list data structure
If UT1 = UT2 = UB1 = USA = UDA = ULL = 0 and if LA[15:2] = 0, the current LLI is the last one. The channel transfer is completed without any update of the linked-list GPDMA register file.
Else, this field is the pointer to the memory address offset from which the next linked-list data structure is automatically fetched from, once the data transfer is completed, in order to conditionally update the linked-list GPDMA internal register file (GPDMA_CxTR1, GPDMA_CxTR2, GPDMA_CxBR1, GPDMA_CxSAR, GPDMA_CxDAR, and GPDMA_CxLLR).

Caution: The user must program this pointer not to exceed the 64-Kbyte addressable space defined by the link base address register GPDMA_CxLBAR. The complete linked-list data structure must be included in the 64-Kbyte addressable space.

Note: The user must program the pointer to be 32-bit aligned. The two low-significant bits are write ignored.

Bits 1:0 Reserved, must be kept at reset value.

16.8.20 GPDMA register map

Table 137. GPDMA register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	GPDMA_ SECCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEC11	SEC10	SEC9	SEC8	SEC7	SEC6	SEC5	SEC4	SEC3	SEC2	SEC1	SEC0
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x04	GPDMA_ PRIVCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV11	PRIV10	PRIV9	PRIV8	PRIV7	PRIV6	PRIV5	PRIV4	PRIV3	PRIV2	PRIV1	PRIV0
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0

Table 137. GPDMA register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x08	GPDMA_ RCFGLOCKR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCK11	LOCK10	LOCK9	LOCK8	LOCK7	LOCK6	LOCK5	LOCK4	LOCK3	LOCK2	LOCK1	LOCK0
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x0C	GPDMA_MISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MIS11	MIS10	MIS9	MIS8	MIS7	MIS6	MIS5	MIS4	MIS3	MIS2	MIS1	MIS0
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x10	GPDMA_SMISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MIS11	MIS10	MIS9	MIS8	MIS7	MIS6	MIS5	MIS4	MIS3	MIS2	MIS1	MIS0
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x14 - 0x4C	Reserved	Reserved																															
0x50+0x80 * x (x = 0 to 11)	GPDMA_ CxLBAR	LBA[31:16]																Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																
0x5C+0x80 * x (x = 0 to 11)	GPDMA_CxFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TOF	SUSPF	USEF	ULEF	DTEF	HTF	TCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																		0	0	0	0	0	0	0								
0x60+0x80 * x (x = 0 to 11)	GPDMA_CxSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FIFOL[7:0]								Res.	TOF	SUSPF	USEF	ULEF	DTEF	HTF	TCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IDLEF
	Reset value									0	0	0	0	0	0	0	0		0	0	0	0	0	0	0								1
0x64+0x80 * x (x = 0 to 11)	GPDMA_CxCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIO [1:0]		Res.	Res.	Res.	Res.	LAP	LSM	Res.	TOIE	SUSPIE	USEIE	ULEIE	DTEIE	HTIE	TCIE	Res.	Res.	Res.	Res.	Res.	SUSP	RESET	EN
	Reset value									0	0					0	0		0	0	0	0	0	0	0						0	0	0
0x90+0x80 * x (x = 0 to 11)	GPDMA_CxTR1	DSEC	DAP	Res.	Res.	DHX	DBX	DBL_1[5:0]						DINC	Res.	DDW_LOG2 [1:0]		SSEC	SAP	SBX	PAM[1:0]		Res.	SBL_1[5:0]						SINC	Res.	SDW_LOG2 [1:0]	
	Reset value	0	0			0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0		0	0	0	0	0	0	0		0	0
0x94+0x80 * x (x = 0 to 11)	GPDMA_CxTR2	TCEM[1:0]		Res.	Res.	Res.	Res.	TRIGPOL [1:0]		Res.	TRIGSEL[6:0]							TRIGM [1:0]		Res.	PFREQ	BREQ	DREQ	SWREQ	REQSEL[7:0]								
	Reset value	0	0					0	0		0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
0x98+0x80 * x (x = 0 to 9)	GPDMA_CxBR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BNDT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x98+0x80 * x (x = 10 to 11)	GPDMA_CxBR1	BRDDEC	BRSDEC	DDEC	SDEC	Res.	BRC[10:0]											BNDT[15:0]															
	Reset value	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x9C+0x80 * x (x = 0 to 11)	GPDMA_CxSAR	SA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xA0+0x80 * x (x = 0 to 11)	GPDMA_CxDAR	DA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xA4+0x80 * x (x = 10 to 11)	GPDMA_CxTR3	Res.	Res.	Res.	DAO[12:0]													Res.	Res.	Res.	SAO[12:0]												
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0	0
0xA8+0x80 * x (x = 10 to 11)	GPDMA_CxBR2	BRDAO[15:0]																BRSAO[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xCC+0x80 * x (x = 0 to 9)	GPDMA_CxLLR	UT1	UT2	UB1	USA	UDA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ULL	LA[15:2]														Res.	Res.
	Reset value	0	0	0	0	0											0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
0xCC+0x80 * x (x = 10 to 11)	GPDMA_CxLLR	UT1	UT2	UB1	USA	UDA	UT3	UB2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ULL	LA[15:2]														Res.	Res.
	Reset value	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

17 Chrom-ART2 accelerator controller (DMA2D)

17.1 DMA2D introduction

The Chrom-ART2 accelerator (DMA2D) is a specialized DMA dedicated to image manipulation. It can perform the following operations:

- Filling a part or the whole of a destination image with a specific color
- Copying a part or the whole of a source image into a part or the whole of a destination image
- Copying a part or the whole of a source image into a part or the whole of a destination image with a pixel format conversion
- Blending a part and/or two complete source images with different pixel format and copying the result into a part or the whole of a destination image with a different color format
- 90°/180°/270° rotation and mirroring
- Downscaling
- Stenciling
- Command list support

All the classical color coding schemes are supported from 1-bit up to 32-bit per pixel with indexed or direct color mode, including block based YC_BC_R to handle JPEG decoder output. The DMA2D has its own dedicated memories for CLUTs (color look-up tables).

17.2 DMA2D main features

The main DMA2D features are:

- Single AHB master bus architecture
- AHB register interface supporting 8-,16-,32-bit accesses (except for CLUT accesses which are 32-bit)
- User-programmable working area size
- User-programmable offset for sources and destination areas expressed in pixels or bytes
- User-programmable sources and destination addresses on the whole memory space
- Up to two sources with blending operation
- Alpha value that can be modified (source value, fixed value, or modulated value)
- User programmable source and destination color format
- Up to 12 color formats supported from 1-bit up to 32-bit per pixel with indirect or direct color coding
- Stencil buffer support from 1-bit up to 8-bit
- 90/180/270° rotation and mirroring
- Downscaling from 1 down to 1/4096
- JPEG block based (8×8/16×8/16×16) YC_BC_R support with 4:4:4, 4:2:2 and 4:2:0 chroma sub-sampling factors
- Two internal memories for CLUT storage in indirect color mode
- Automatic CLUT loading or CLUT programming via the CPU
- User programmable CLUT size
- Internal timer to control AHB bandwidth
- Six operating modes: register-to-memory, memory-to-memory, memory-to-memory with pixel format conversion, memory-to-memory with pixel format conversion and blending, memory-to-memory with pixel format conversion, blending and fixed color foreground, and memory-to-memory with pixel format conversion, blending, and fixed color background.
- Area filling with a fixed color
- Copy from an area to another
- Copy with pixel format conversion between source and destination images
- Copy from two sources with independent color format and blending
- Output buffer byte swapping to support refresh of displays through parallel interface
- Abort and suspend of DMA2D operations
- Watermark interrupt on a user-programmable destination line
- Interrupt generation on bus error or access conflict
- Interrupt generation on process completion
- Four general purpose flags for system synchronization, breakpoints and external triggering/debug

17.3 DMA2D functional description

17.3.1 General description

The DMA2D controller performs direct memory transfer. As an AHB master, it can take the control of the AHB bus matrix to initiate AHB transactions.

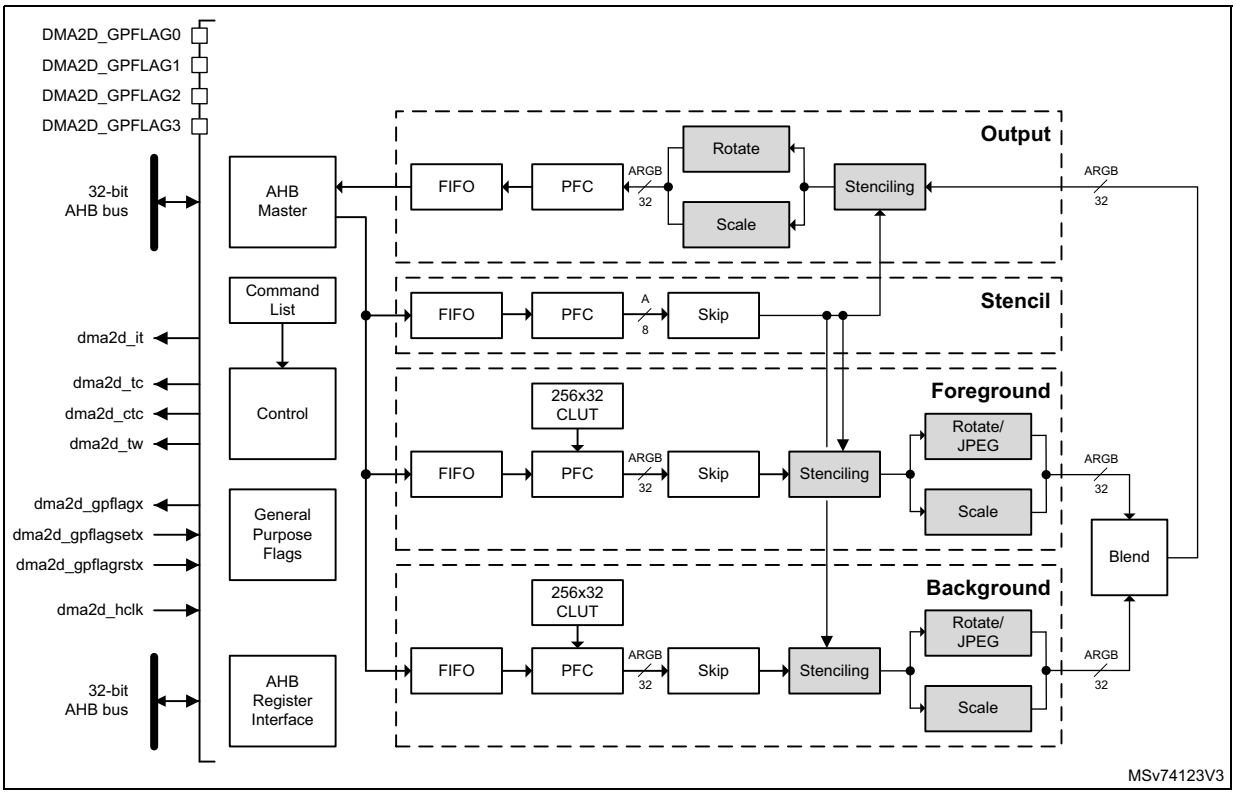
The DMA2D can operate in the following modes:

- Register-to-memory
- Memory-to-memory
- Memory-to-memory with pixel format conversion
- Memory-to-memory with pixel format conversion and blending
- Memory-to-memory with pixel format conversion, blending, and fixed color foreground
- Memory-to-memory with pixel format conversion, blending, and fixed color background

The AHB register interface port is used to program the DMA2D controller.

The block diagram of the DMA2D is shown in *Figure 91*.

Figure 91. DMA2D block diagram



17.3.2 DMA2D internal signals

The input/output pins and internal signals of the DMA2D are given in the tables below:

Table 138. DMA2D input/ouput pins

Names	Signal type	Description
DMA2D_GPFLAG0	Output	DMA2D general purpose flag 0 output
DMA2D_GPFLAG1	Output	DMA2D general purpose flag 1 output
DMA2D_GPFLAG2	Output	DMA2D general purpose flag 2 output
DMA2D_GPFLAG3	Output	DMA2D general purpose flag 3 output

Table 139. DMA2D internal signals

Names	Signal type	Description
dma2d_hclk	Input	DMA2D AHB clock
dma2d_it	Output	DMA2D global interrupt request
dma2d_ctc	Output	DMA2D CLUT transfer complete trigger
dma2d_tc	Output	DMA2D transfer complete trigger
dma2d_tw	Output	DMA2D transfer watermark trigger
dma2d_gpflag0	Output	DMA2D general purpose flag 0
dma2d_gpflag1	Output	DMA2D general purpose flag 1
dma2d_gpflag2	Output	DMA2D general purpose flag 2
dma2d_gpflag3	Output	DMA2D general purpose flag 3
dma2d_gpflagset0	Input	DMA2D general purpose flag 0 set
dma2d_gpflagset1	Input	DMA2D general purpose flag 1 set
dma2d_gpflagset2	Input	DMA2D general purpose flag 2 set
dma2d_gpflagset3	Input	DMA2D general purpose flag 3 set
dma2d_gpflagrst0	Input	DMA2D general purpose flag 0 reset
dma2d_gpflagrst1	Input	DMA2D general purpose flag 1 reset
dma2d_gpflagrst2	Input	DMA2D general purpose flag 2 reset
dma2d_gpflagrst3	Input	DMA2D general purpose flag 3 reset

Table 140. DMA2D trigger interconnections

Trigger name	Direction	Trigger source/destination
dma2d_tc	Output	gpdma1_trigsel[47]
		gpdma2_trigsel[47]
dma2d_ctc	Output	gpdma1_trigsel[48]
		gpdma2_trigsel[48]
dma2d_tw	Output	gpdma1_trigsel[49]
		gpdma2_trigsel[49]

Table 140. DMA2D trigger interconnections (continued)

Trigger name	Direction	Trigger source/destination
dma2d_gpflag0	Output	gpdma1_trigsel[50]
		gpdma2_trigsel[50]
dma2d_gpflag1	Output	gpdma1_trigsel[51]
		gpdma2_trigsel[51]
dma2d_gpflag2	Output	gpdma1_trigsel[52]
		gpdma2_trigsel[52]
dma2d_gpflag3	Output	gpdma1_trigsel[53]
		gpdma2_trigsel[53]
		Used also for debug
dma2d_gpflagset0	Input	Reserved
dma2d_gpflagset1	Input	Reserved
dma2d_gpflagset2	Input	Reserved
dma2d_gpflagset3	Input	Used also for debug
dma2d_gpflagrst0	Input	Reserved
dma2d_gpflagrst1	Input	Reserved
dma2d_gpflagrst2	Input	Reserved
dma2d_gpflagrst3	Input	Used also for debug

17.3.3 DMA2D pipeline

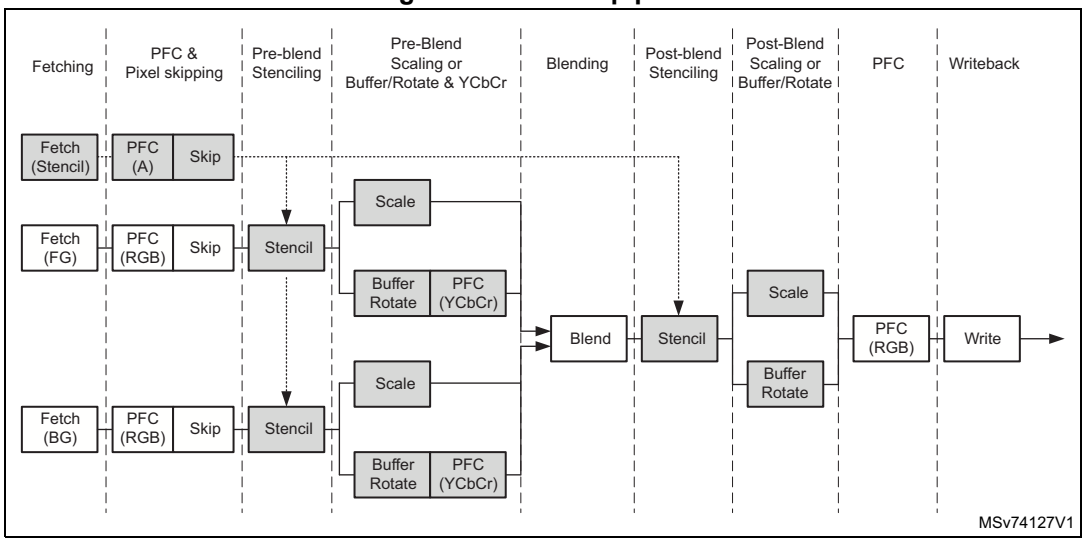
The functional blocks of the DMA2D are pipelined in a configurable manner.

Each functional block can be positioned at a different stage of the pipeline depending on their respective source (SRC) fields.

As the scaler is working only in scan line mode and the tile buffer only in tile mode, they cannot be enable in the same configuration.

As the tile buffer is also responsible of YC_BC_R conversion, it’s not possible to enable in the same time scaling and JPEG.

Figure 92. DMA2D pipeline



Fetching and input PFC and pixel skipping stage

The fetching and PFC and pixel skipping stage are performed by the PFC block of the foreground and the background layer and by the stencil block for the stencil buffer.

Pre-blend stencil stage

The stencil buffer can be configured to be at the output of either the foreground layer or the background layer.

Pre-blend scaling or buffer/rotate and YC_BC_R stage

The scaler can be configured to be at the output of either the foreground layer or the background layer. If stencil is allocated to the layer selected for the scaler, the scaler is directly connected to the stencil output.

As a consequence in case of layer scaling with stenciling, the size of the stencil buffer is equal to the size of the layer before scaling (DMA2D, SNLR).

The tile buffer performs the buffering, the rotation, and the YC_BC_R conversion in case of JPEG processing.

As the tile buffer is only working on tile mode and the scaler in scanline mode, both functions are exclusive and cannot be enable in the same time.

The tile buffer can be configured to be at the output of either the foreground layer or the background layer. If stencil is allocated to the layer selected for the tile buffer, the tile buffer is directly connected to the stencil output.

Blending stage

The blending stage is doing the blending between the foreground and the background layer.

Post-blend stenciling stage

The stencil buffer can be configured to be at the output of either the blender to apply the stencil on the composed image.

Post-blend scaling or buffer/rotate

The scaler can be configured to be at the output of the blender. If stencil is allocated to the blender output, the scaler is directly connected to the stencil output.

As a consequence in case of blender scaling with stenciling, the size of the stencil buffer is equal to the size of the layers before scaling (DMA2D, SNLR).

The tile buffer performs the buffering and the rotation. As the blender is RGB, no YC_BC_R conversion can be done at this stage.

As the tile buffer is only working on tile mode and the scaler in scanline mode, both functions are exclusive and cannot be enable in the same time.

The tile buffer can be configured to be at the output of the blender. If stencil is allocated to the blender output, the tile buffer is directly connected to the stencil output.

Output PFC stage and write back stage

The output PFC stage does the final pixel format conversion and write the pixel in the output memory.

17.3.4 DMA2D control and global operating mode

The DMA2D controller is configured through DMA2D_CR. The user application can perform the following operations:

- Select the operating mode.
- Enable/disable the DMA2D interrupt.
- Start/suspend/abort ongoing data transfers.

The operating mode is one of the following

- Register-to-memory
- Memory-to-memory
- Memory-to-memory with pixel format conversion
- Memory-to-memory with pixel format conversion and blending
- Memory-to-memory with pixel format conversion, blending, and fixed color foreground
- Memory-to-memory with pixel format conversion, blending, and fixed color background

Regardless of the data arrangement in the memory, the DMA2D can process the data in tile mode of either when the tile buffer is used (this includes JPEG data ordering).

17.3.5 DMA2D fetching stage

The DMA2D foreground (FG) and background (BG) fetch stages are retrieving the input data to be copied and/or processed.

When the DMA2D operates in register-to-memory mode, none of the fetch stages are activated.

When the DMA2D operates in memory-to-memory mode (no pixel format conversion nor blending operation), only the FG fetch is activated, and acts as a buffer.

When the DMA2D operates in memory-to-memory operation with pixel format conversion (no blending operation), the BG fetch is not activated.

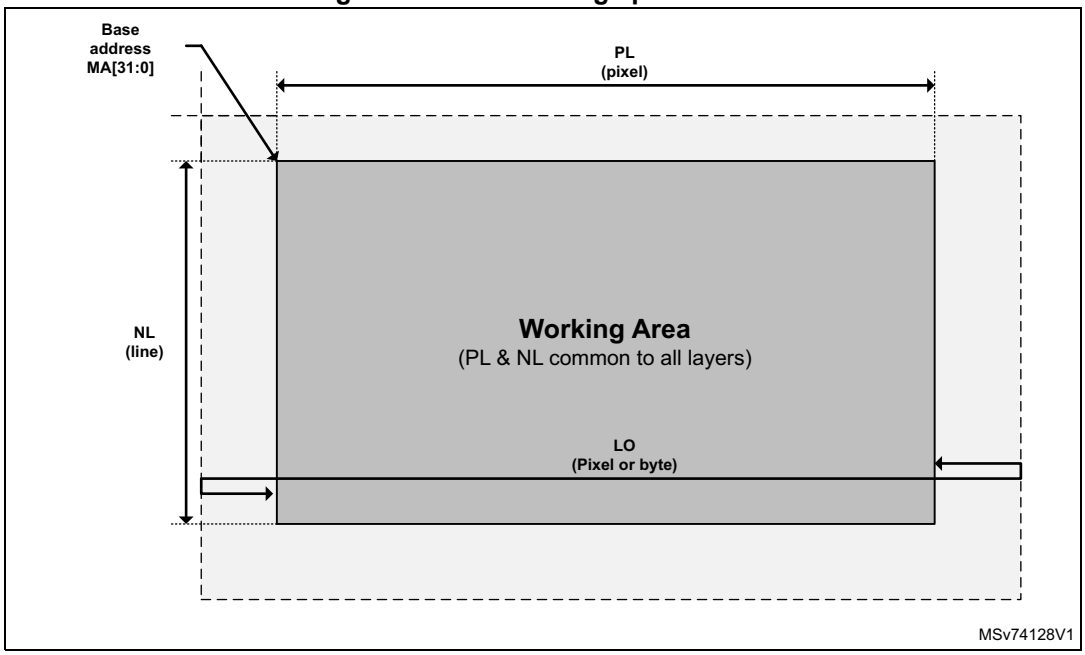
Image parameters

The pixels are fetched according to the color format defined in their respective pixel format converter (PFC).

They are programmed through the following control registers:

- DMA2D foreground memory address register (DMA2D_FGMAR)
- DMA2D foreground offset register (DMA2D_FGOR)
- DMA2D background memory address register (DMA2D_BGMAR)
- DMA2D background offset register (DMA2D_BGBOR)
- DMA2D number of lines register (number of lines and pixel per line) (DMA2D_NLR)

Figure 93. DMA2D image parameters



Pixel components arrangement in memory

The standard order of the pixels components in the system memory is defined in the *Table 141*.

Table 141. Pixel components order in memory

Color mode	@ + 3	@ + 2	@ + 1	@ + 0
ARGB8888	A_0[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
RGB888	B_1[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
	G_2[7:0]	B_2[7:0]	R_1[7:0]	G_1[7:0]
	R_3[7:0]	G_3[7:0]	B_3[7:0]	R_2[7:0]
RGB565	R_1[4:0]G_1[5:3]	G_1[2:0]B_1[4:0]	R_0[4:0]G_0[5:3]	G_0[2:0]B_0[4:0]
ARGB1555	A_1[0]R_1[4:0]G_1[4:3]	G_1[2:0]B_1[4:0]	A_0[0]R_0[4:0]G_0[4:3]	G_0[2:0]B_0[4:0]
ARGB4444	A_1[3:0]R_1[3:0]	G_1[3:0]B_1[3:0]	A_0[3:0]R_0[3:0]	G_0[3:0]B_0[3:0]
L8	L_3[7:0]	L_2[7:0]	L_1[7:0]	L_0[7:0]
AL44	A_3[3:0]L_3[3:0]	A_2[3:0]L_2[3:0]	A_1[3:0]L_1[3:0]	A_0[3:0]L_0[3:0]
AL88	A_1[7:0]	L_1[7:0]	A_0[7:0]	L_0[7:0]
L4	L_7[3:0]L_6[3:0]	L_5[3:0]L_4[3:0]	L_3[3:0]L_2[3:0]	L_1[3:0]L_0[3:0]
A8	A_3[7:0]	A_2[7:0]	A_1[7:0]	A_0[7:0]
A4	A_7[3:0]A_6[3:0]	A_5[3:0]A_4[3:0]	A_3[3:0]A_2[3:0]	A_1[3:0]A_0[3:0]
A2	A_{15}[1:0]A_{14}[1:0]A_{13}[1:0]A_{12}[1:0]	A_{11}[1:0]A_{10}[1:0]A_9[1:0]A_8[1:0]	A_7[1:0]A_6[1:0]A_5[1:0]A_4[1:0]	A_3[1:0]A_2[1:0]A_1[1:0]A_0[1:0]
A1	$A_{31}A_{30}A_{29}A_{28}A_{27}A_{26}A_{25}A_{24}$	$A_{23}A_{22}A_{21}A_{20}A_{19}A_{18}A_{17}A_{16}$	$A_{15}A_{14}A_{13}A_{12}A_{11}A_{10}A_9A_8$	$A_7A_6A_5A_4A_3A_2A_1A_0$
ARGB2222	A_3[1:0]R_3[1:0]G_3[1:0]B_3[1:0]	A_2[1:0]R_2[1:0]G_2[1:0]B_2[1:0]	A_1[1:0]R_1[1:0]G_1[1:0]B_1[1:0]	A_0[1:0]R_0[1:0]G_0[1:0]B_0[1:0]

The 24-bit RGB888 aligned on 32-bit is supported through the ARGB8888 mode.

For ARGB and RGB color formats, the component order can be modified by the Red/Blue swap (RBS) bit and/or the alpha position (APOS) bit of the DMA2D foreground pixel format converter control register. (DMA2D_FGPFCCR) or DMA2D background pixel format converter control register (DMA2D_BGPFCCR) as shown in *Table 142*.

Table 142. ARGB/RGB component reordering

RBS = 0, APOS = 0	RBS = 1, APOS = 0	RBS = 0, APOS = 1	RBS = 1, APOS = 1
ARGB8888	ABGR8888	RGBA8888	BGRA8888
RGB888	BGR888	RGB888	BGR888
RGB565	BGR565	RGB565	BGR565
ARGB1555	ABGR1555	RGBA5551	BGRA5551
ARGB4444	ABGR4444	RGBA4444	BGRA4444
ARGB2222	ABGR2222	RGBA2222	BGRA2222

Pixel arrangement in memory

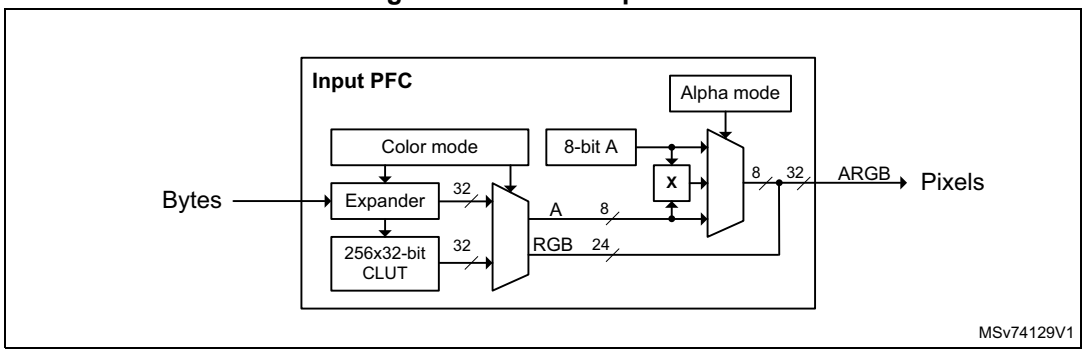
The pixels are arranged in scan line in the memory

- The image is not divided.
- All the pixels of a line are consecutive.
- All the lines are consecutive.

17.3.6 DMA2D input pixel format conversion stage

DMA2D foreground pixel format converter (PFC) and background pixel format converter perform the pixel format conversion to generate a 32-bit per pixel value. The PFC can also modify the alpha channel.

Figure 94. DMA2D input PFC



The first PFC stage converts the color format. The original color format of the foreground and background pixels are configured through CM[3:0] in DMA2D_FGPFCCR and DMA2D_BGPFCCR, respectively.

The supported input formats are given in the table below.

Table 143. Supported color mode in input

CM[3:0]	Color mode
0000	ARGB8888
0001	RGB888
0010	RGB565
0011	ARGB1555
0100	ARGB4444
0101	L8
0110	AL44
0111	AL88
1000	L4
1001	A8
1010	A4
1011	JPEG
1100	A2

Table 143. Supported color mode in input (continued)

CM[3:0]	Color mode
1101	A1
1110	ARGB2222
1111	Reserved

The color formats are coded as follows:

- Alpha value field: transparency
  0xFF value corresponds to an opaque pixel and 0x00 to a transparent one.
- R field for Red
- G field for Green
- B field for Blue
- L field: luminance
  This field is the index to a CLUT to retrieve the three/four RGB/ARGB components.

If the original format was direct color mode (ARGB/RGB), the extension to 8-bit per channel is performed by copying the MSBs into the LSBs. This ensures a perfect linearity of the conversion.

If the original format does not include an alpha channel, the alpha value is automatically set to 0xFF (opaque).

If the original format is indirect color mode (L/AL), a CLUT is required, and each pixel format converter is associated with a 256 entry 32-bit CLUT.

For the specific alpha modes A1, A2, A4, and A8, no color information is stored nor indexed. The color to be used for the image generation is fixed and defined in DMA2D_FGCOLR for foreground pixels, and in DMA2D_BGCOLR for background pixels.

Once the 32-bit value is generated, the alpha channel can be modified according to AM[1:0] in DMA2D_FGPFCCR or DMA2D_BGPFCCR, as shown in *Table 144*.

One of the following happens for the alpha channel:

- It is kept as it is (no modification).
- It is replaced by ALPHA[7:0] value in DMA2D_FGPFCCR/DMA2D_BGPFCCR.
- It is replaced by the original alpha value multiplied by ALPHA[7:0] in DMA2D_FGPFCCR/DMA2D_BGPFCCR divided by 255.

Table 144. Alpha mode configuration

AM[1:0]	Alpha mode
00	No modification
01	Replaced by value in DMA2D_xxPFCCR
10	Replaced by original value multiplied by the value in DMA2D_xxPFCCR / 255
11	Reserved

Note: To support the alternate format, the incoming alpha value can be inverted by setting AI in DMA2D_FGPFCCR or DMA2D_BGPFCCR. This applies also to the Alpha value stored in the DMA2D_FGPFCCR or DMA2D_BGPFCCR, and in the CLUT.

The R and B fields can also be swapped setting RBS in DMA2D_FGPFCCR or DMA2D_BGPFCCR, and the Alpha position can be changed setting the APOS in DMA2D_FGPFCCR or DMA2D_BGPFCCR. This applies also to the RGB order used in the CLUT, and in DMA2D_FGCOLR or DMA2D_BGCOLR.

17.3.7 DMA2D foreground and background CLUT interface

The CLUT interface manages the CLUT memory access and the automatic loading of the CLUT.

The CLUT loading cannot be done concurrently with an image transfer. Each CLUT must be loaded sequentially and independently prior to the image transfer.

Three kinds of access are possible:

- CLUT read by the PFC during pixel format conversion operation
- CLUT accessed through the AHB register interface when the CPU is reading or writing data into the CLUT
- CLUT written through the AHB master port when an automatic loading of the CLUT is performed

The CLUT memory loading can be done in two different ways:

- Manual loading

  The application has to program the CLUT manually through the DMA2D AHB register interface port to which the local CLUT memory is mapped. The foreground CLUT (FGCLUT) is located at address offset 0x0400 and the background CLUT (BGCLUT) at address offset 0x0800.

  The written value must be in ARGB8888 format.

- Automatic loading

  The following sequence must be followed to load the CLUT:

  a) Program the CLUT address into DMA2D_FGCMAR (foreground CLUT) or DMA2D_BGCMAR (background CLUT).

  b) Program the CLUT size with CS[7:0] field and the color coding with the CM[3:0] field in DMA2D_FGPFCCR (foreground CLUT), or DMA2D_BGPFCCR (background CLUT).

  c) Set START in DMA2D_FGPFCCR (foreground CLUT) or DMA2D_BGPFCCR (background CLUT) to start the transfer. During this automatic loading process, the CLUT is not accessible by the CPU. If a conflict occurs, a CLUT access error interrupt is raised assuming CAEIE = 1 in DMA2D_IER.

In automatic loading, the PFC is used to convert the CLUT source format which can be 8 to 32 bits per pixel. It is configured through CM in DMA2D_FGPFCCR (foreground CLUT) or DMA2D_BGPFCCR (background CLUT) as shown in table below.

Table 145. Supported CLUT color mode

CM[3:0]	CLUT color mode
0000	ARGB8888
0001	RGB888

Table 145. Supported CLUT color mode (continued)

CM[3:0]	CLUT color mode
0010	RGB565
0011	ARGB1555
0100	ARGB4444
1110	ARGB2222
others	Reserved

The way the CLUT data are organized in the system memory is following the pixel organization defined in *Table 141: Pixel components order in memory*.

The following functions are also supported by CLUT loading:

- AI for alpha inversion
- RBS and APOS for RGB/BGR/ARGB/BGRA support
- ALPHA to add a specific alpha value in the CLUT during its loading
- AM for modifying alpha value during the CLUT loading

17.3.8 DMA2D pixel skipper stage

Once the pixels have been fetched and converted by the PFC, pixels can be skipped at the beginning and/or at the end of each line to allow a pixel accurate positioning in A1, A2, A4, and L4 modes.

The number of pixels to skip is programmed in the DMA2D foreground memory skip register (DMA2D_FGMSR) or DMA2D background memory skip register (DMA2D_BGMSR):

- The HPRE field defines the number of pixels to be skipped at the beginning of a line
- The HTRAIL field defines the number of pixels to be skipped at the end of a line

HPRE and HTRAIL are used to byte align the data in A1, A2, A4, and L4 modes.

As a consequence, the number of pixels per line (PL) + HPRE + HTRAIL must be aligned with the chosen pixel format:

- HPRE and HTRAIL are in the range [0..1] and HPRE + PL + HTRAIL must be multiple of 2 for the A4 or L4 mode
- HPRE and HTRAIL are in the range [0..3] and HPRE + PL + HTRAIL must be multiple of 4 for the A2 mode
- HPRE and HTRAIL are in the range [0..7] and HPRE + PL + HTRAIL must be multiple of 8 for the A1 mode

In JPEG mode, as the base address of a layer must be at the beginning of an MCU, both pixels and lines can be skipped at the beginning and/or at the end of image to allow a pixel accurate positioning.

The number of lines and the number of pixels to skip are programmed in the DMA2D foreground memory skip register (DMA2D_FGMSR) or DMA2D background memory skip register (DMA2D_BGMSR):

- The HPRE field defines the number of pixels to be skipped at the beginning of a line
- The HTRAIL field defines the number of pixels to be skipped at the end of a line
- The VPRE field defines the number of lines to be skipped at the beginning of an image
- The VTRAIL field defines the number of lines to be skipped at the end of an image

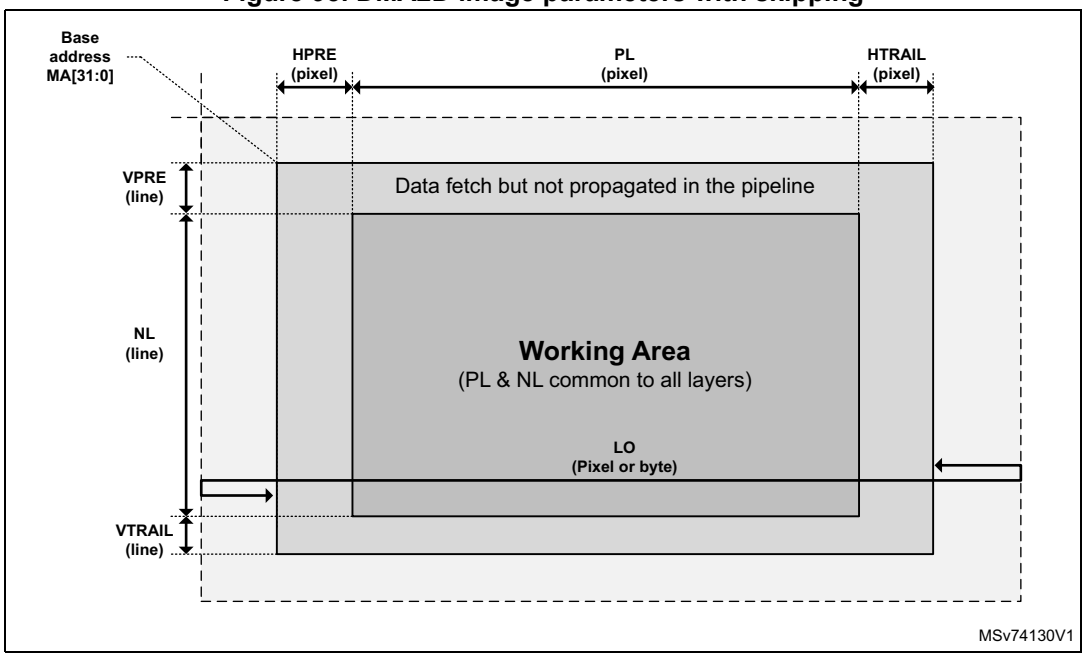
As a consequence, the number of pixels per line (PL) + HPRE + HTRAIL must be aligned with the chosen chroma sub-sampling format:

- HPRE and HTRAIL are in the range [0..7] and HPRE + PL + HTRAIL must be multiple of 8 for the JPEG 4:4:4 mode
- HPRE and HTRAIL are in the range [0..15] and HPRE + PL + HTRAIL must be multiple of 16 for the JPEG 4:2:2 or 4:2:0 mode

The number of lines (NL) + VPRE + VTRAIL must be aligned with the chosen chroma sub-sampling format:

- VPRE and VTRAIL are in the range [0..7] and VPRE + NL + VTRAIL must be multiple of 8 for the JPEG 4:4:4 or 4:2:2 mode
- VPRE and VTRAIL are in the range [0..15] and VPRE + NL + VTRAIL must be multiple of 16 for the JPEG 4:2:0 mode

Figure 95. DMA2D image parameters with skipping



17.3.9 DMA2D stenciling stage (pre-blend or post-blend)

The DMA2D support 1 bpp up to 8 bpp stencil on foreground or background layer or on the output of the blender.

The source (SRC) field of the DMA2D stencil buffer control register (DMA2D_SBCR) defined on which layer the stencil buffer is allocated to. It can be either:

- Foreground layer
- Background layer
- Blender output

The format of the stencil is configured in the mode (MODE) field of the DMA2D stencil buffer control register (DMA2D_SBCR) and can be either 1 bpp, 2 bpp, 4 bpp and 8 bpp.

The stencil buffer description is done as for the foreground and background plane through the following registers:

- Stencil buffer memory address register (DMA2D_SBMAR)
- Stencil buffer offset register (DMA2D_SBOR)
- Stencil buffer memory skip register (DMA2D_SBMSR)

Please refer to foreground and background plane section for a detailed description

Once configured and linked for the foreground or background layer or the blender output, the emitted pixel from the stenciling is a pixel with an alpha value modified according to the stencil alpha value. The color value of the pixel is not changed.

The final alpha value of the emitted pixel is the multiplication of the original alpha of the pixel by the alpha given by the stencil buffer.

17.3.10 DMA2D scaling stage (pre-blend or post-blend)

The DMA2D scaler is a pixel decimator allowing down-scaling on foreground or background layer or on the output of the blender.

The source (SRC) field of the DMA2D scaler control register (DMA2D_SCR) defined on which layer the scaler is allocated to. It can be either:

- Foreground layer
- Background layer
- Blender output

When the scaler is used, the size of the layer on which the scaler is applying is different from the size defined in the DMA2D number of line register (DMA2D_NLR). In this case, the size of the layer on which the scaler is applying is taken from the DMA2D scaler number of line register (DMA2D_SNLR).

Table 146 gives which register defines the size of the foreground layer, background layer, and output layer depending on the source (SRC) field of the DMA2D scaler control register (DMA2D_SCR).

Table 146. Layer size definition vs scaler mode

Source (SRC)		Foreground	Background	Output
00	No scaler	DMA2D_NLR	DMA2D_NLR	DMA2D_NLR
01	Scale foreground	DMA2D_SNLR	DMA2D_NLR	DMA2D_NLR
10	Scale background	DMA2D_NLR	DMA2D_SNLR	DMA2D_NLR
11	Scale blender output	DMA2D_SNLR	DMA2D_SNLR	DMA2D_NLR

The scaling ratio is defined by the HSTEP and VSTEP of the DMA2D scaler step register (DMA2D_SSR).

The scaler phase can also be initialized to a nonzero value to support partial redrawing of scaled images. The horizontal and vertical phases can be set using the HPHASE and VPHASE field of the DMA2D scaler phase register (DMA2D_SPR).

Once the scaler is enabled on a layer or on the output of the blender, pixels are decimated according to a 12-bit horizontal scale counter and lines are decimated according to a 12-bit vertical scale counter.

For each pixel, the horizontal scale counter is incremented by the HSTEP+1 value of the DMA2D scaler step register (DMA2D_SSR). If the horizontal counter overflows, the pixel is emitted, if not, the pixel is discarded.

As the counters are on 12-bit, the scaling factor can go from 4096/4096 down to 1/4096. As an example, the layer needs to be downscaled by 2 horizontally (x0.5), the horizontal step value must be set to 0,5 * 4096 = 2048 so HSTEP = 2048 -1 = 2047 = 0x7FF.

The initial value of the horizontal scale counter can be programmed with the HPHASE value of the DMA2D scaler phase register (DMA2D_SPR). This allows partial redrawing of scaled images.

For each line, the same process is applied with the vertical scale counter incremented by the VSTEP+1 value. If the vertical counter overflows, the line is emitted, if not, the line is discarded.

As for the horizontal counter, the initial value of the vertical scale counter can be programmed with the VPHASE value of the DMA2D scaler phase register (DMA2D_SPR).

In case the programmed size in the DMA2D scaler number of line register (DMA2D_SNLR) is greater than the number of produced pixels, the last generated pixel is repeated to fill the gap.

17.3.11 DMA2D buffer/rotate stage

The DMA2D embeds 16×16 pixels tile buffers to handle the following operations

- X mirroring
- Y mirroring
- X/Y index swap

This buffer is used to do any kind of mirroring or 90°/180°/270° rotations.

When using a tile buffer, the DMA2D operates in tile mode. The size of the tile is fixed to 16×16 (except for JPEG with 4:4:4 sub-sampling where the tile size is 8×8 and 4:2:2 sub-sampling where the tile size is 16×8).

The source (SRC) field of the DMA2D tile buffer control register (DMA2D_TBCR) defined on which layer the tile buffer is allocated to. It can be either:

- Foreground layer
- Background layer
- Blender output

The operation done by the tile buffers is selected by setting the following bits in the DMA2D tile buffer control register (DMA2D_TBCR):

- X mirroring enable (XMEN) to enable X mirroring
- Y mirroring enable (YMEN) to enable Y mirroring
- X/Y swap enable (XYSEN) to swap X and Y index

Once configured and linked for the foreground or background layer or the blender output, the emitted pixels from the tile buffer are in the order shown in *Figure 92* and *Figure 17.3.23*.

Note that X/Y swap is also swapping the values of the width and the height of the foreground and/or background layer depending on the chosen source for the tile buffer. As a consequence when X/Y swap is used the number of lines (NL) field of the DMA2D_NLR is limited to 14-bit.

Table 147. Layer size definition in DMA2D_NLR vs tile buffer mode

X/Y Swap	Source (SRC)	Foreground		Background		Output	
		Width	Height	Width	Height	Width	Height
No	Any	PL	NL	PL	NL	PL	NL
Yes	Foreground	NL	PL	PL	NL		
	Background	PL	NL	NL	PL		
	Blender	NL	PL	NL	PL		

Figure 96. Tile buffer operations XYSEN = 0

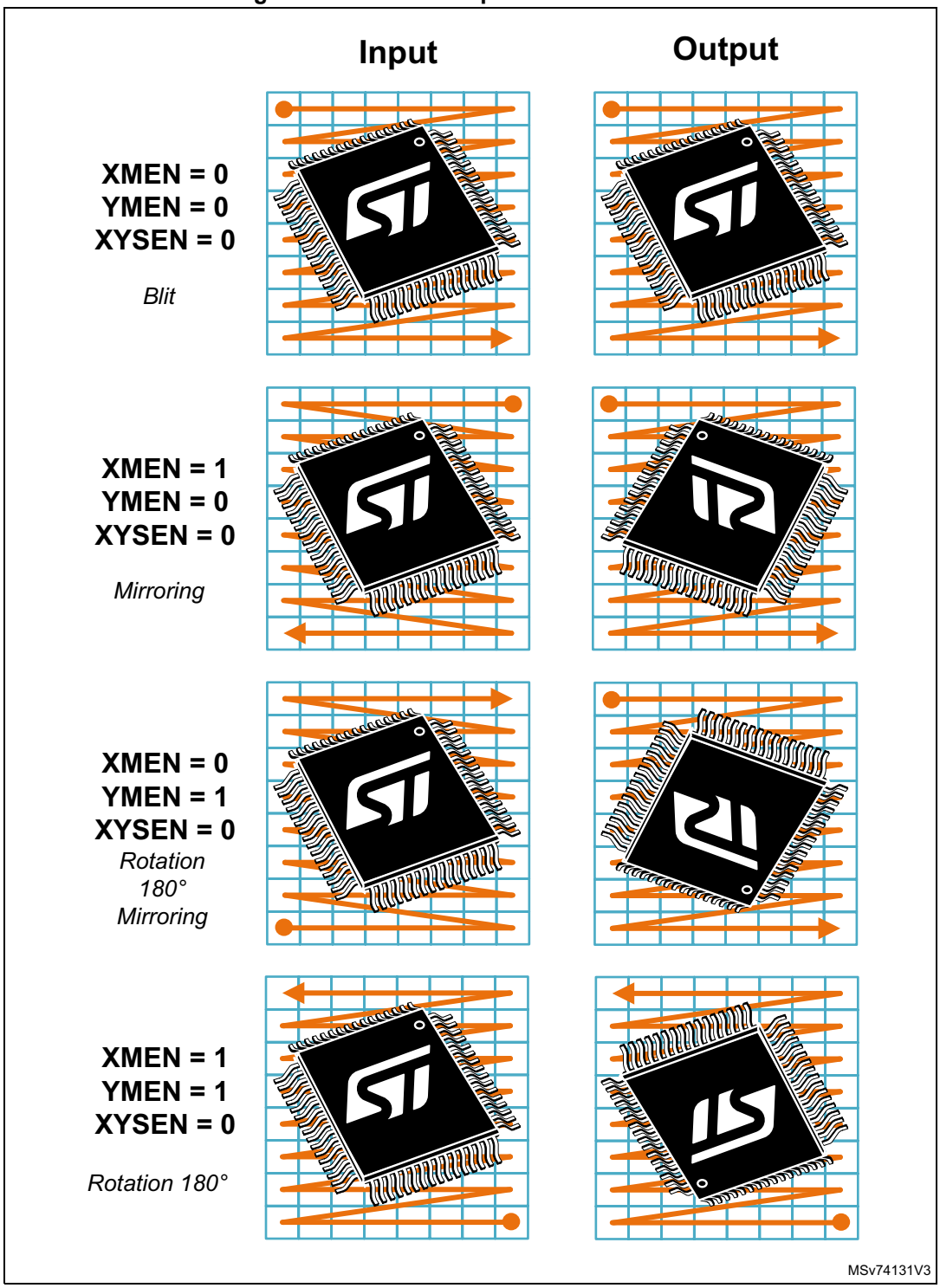
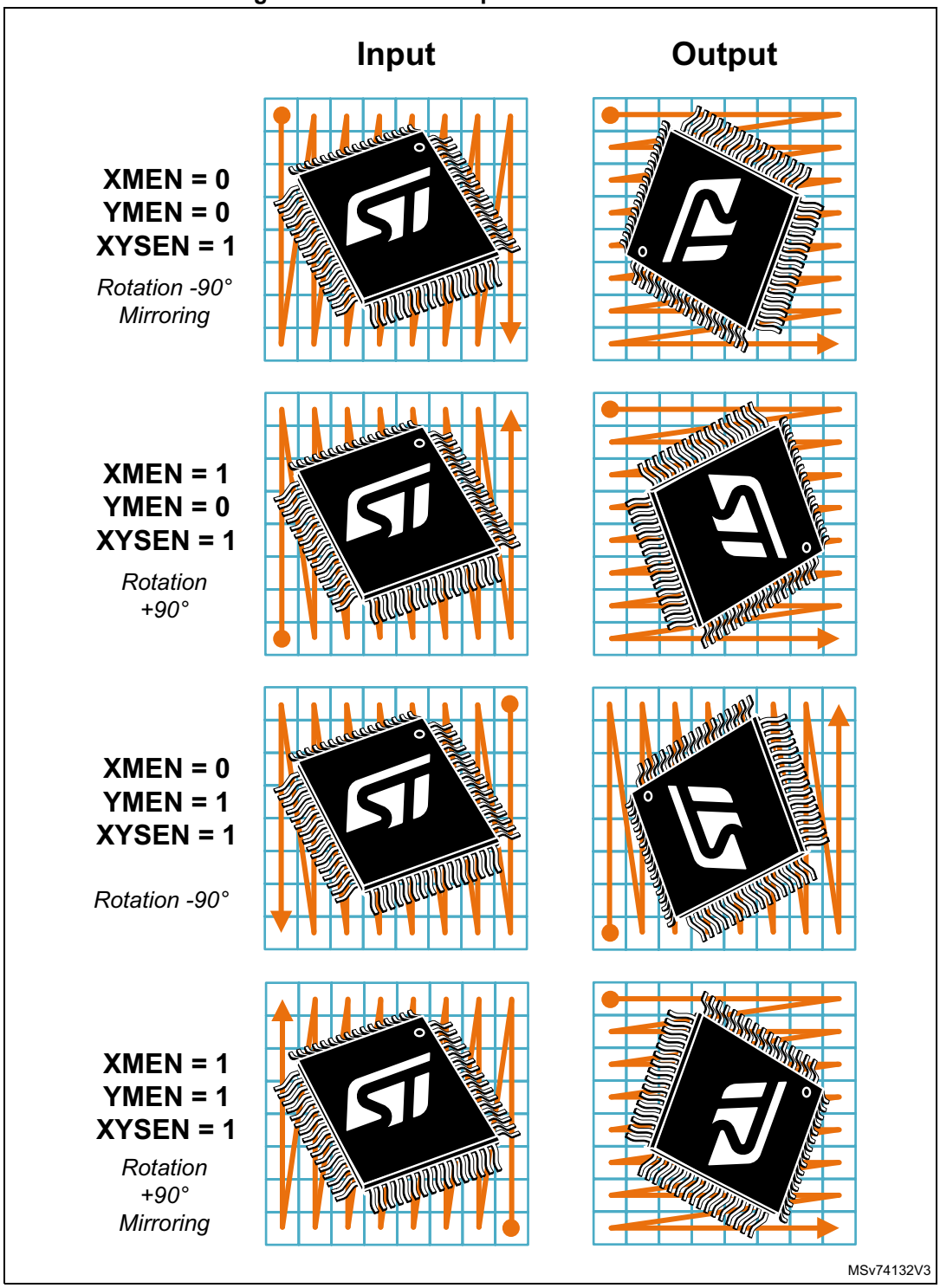


Figure 97. Tile buffer operations XYSEN = 1



17.3.12 DMA2D YC_BC_R PFC stage / JPEG decoding

The DMA2D foreground and background layers can support 8×8 block-based YC_BC_R as output by the JPEG decoder with different chroma sub-sampling factors.

This mode must be used in conjunction with a tile buffer as the Y, the Cb and the Cr data are accumulated in a tile buffer before the YC_BC_R to RGB conversion.

The memory organization follows the standard JFIF rules:

- Each of the three color components must be coded on 8 bits.
- Each component must be arranged by blocks of 8×8 (64 bytes).
- Each block of 8×8 are arranged by MCU (minimum coded unit).

Depending on the chroma sub-sampling factor, the block making an MCU is arranged in the memory as described in the table below.

Table 148. MCU order in memory

Offset	+0	+64	+128	+192	+256	+320	+384	+448	+512	+576	+640	+704
4:4:4	MCU1 (8×8 pixels)			MCU2 (8×8 pixels)			MCU3 (8×8 pixels)			MCU4 (8×8 pixels)		
	$Y_{1,1}$	$Cb_{1,1}$	$Cr_{1,1}$	$Y_{2,1}$	$Cb_{2,1}$	$Cr_{2,1}$	$Y_{3,1}$	$Cb_{3,1}$	$Cr_{3,1}$	$Y_{4,1}$	$Cb_{4,1}$	$Cr_{4,1}$
4:2:2	MCU1 (16×8 pixels)				MCU2 (16×8 pixels)				MCU3 (16×8 pixels)			
	$Y_{1,1}$	$Y_{2,1}$	$Cb_{1/2,1}$	$Cr_{1/2,1}$	$Y_{3,1}$	$Y_{4,1}$	$Cb_{3/4,1}$	$Cr_{3/4,1}$	$Y_{5,1}$	$Y_{6,1}$	$Cb_{5/6,1}$	$Cr_{5/6,1}$
4:2:0	MCU1 (16×16 pixels)						MCU2 (16×16 pixels)					
	$Y_{1,1}$	$Y_{2,1}$	$Y_{1,2}$	$Y_{2,2}$	$Cb_{1/2,1/2}$	$Cr_{1/2,1/2}$	$Y_{3,1}$	$Y_{4,1}$	$Y_{3,2}$	$Y_{4,2}$	$Cb_{3/4,1/2}$	$Cr_{3/4,1/2}$

Foreground or background plane is configured in JPEG mode setting the color mode (CM) field of the DMA2D foreground pixel format converter configuration register (DMA2D_FGPFCCR) or DMA2D background pixel format converter configuration register (DMA2D_BGPFFCR).

The chroma sub-sampling factor is configured through chroma sub-sampling (CSS) field in DMA2D_FGPFCCR or the DMA2D_BGPFCCR.

The address of the JPEG source programmed in the DMA2D foreground memory address register (DMA2D_FGMAR) or in the DMA2D background memory address register (DMA2D_BGMAR) points to the beginning of a JPEG MCU.

The line offset (LO) for the layer configured in JPEG format must be multiple of the size of an MCU:

- Multiple of 64 pixels or 192 bytes in 4:4:4 mode
- Multiple of 128 pixels or 256 bytes in 4:2:2 mode
- Multiple of 256 pixels of 384 bytes in 4:2:0 mode

As a consequence the maximum JPEG width is

- In 4:4:4 mode: 2048 pixels when the line offset is expressed in pixel and 2728 when the line offset is expressed in bytes.
- In 4:2:2 mode: 2048 pixels when the line offset is expressed in pixel and 4096 when the line offset is expressed in bytes.
- In 4:2:0 mode: 1024 pixels when the line offset is expressed in pixel and 2720 when the line offset is expressed in bytes.

The pixel skipper must be programmed to skip the necessary number of lines and pixels at the beginning and the end of the image to have an integer number of MCU processed.

As a consequence, the number of pixels per line (PL) + HPRE + HTRAIL must be aligned with the chosen sub-sampling format:

- HPRE and HTRAIL are in the range [0..7] and HPRE + PL + HTRAIL must be multiple of 8 for the 4:4:4 mode
- HPRE and HTRAIL are in the range [0..15] and HPRE + PL + HTRAIL must be multiple of 16 for the 4:2:2 and 4:2:0 modes
- VPRE and VTRAIL are in the range [0..7] and VPRE + NL + VTRAIL must be multiple of 8 for the 4:4:4 and 4:2:2 modes
- VPRE and VTRAIL are in the range [0..15] and VPRE + NL + VTRAIL must be multiple of 16 for the 4:2:0 mode

If the JPEG mode is selected for a given layer, it's not possible to select it for the other one (a configuration error is generated).

Once JPEG mode is selected:

- The DMA2D is automatically configured to operate in tile mode.
- The DMA2D tile size is automatically configured to 8×8 (4:4:4 sub-sampling), 16×8 (4:2:2 sub-sampling) or to 16×16 (4:2:0 sub-sampling).

The tile buffer must be linked to the foreground or background setting source (SRC) field of the DMA2D tile buffer control register (DMA2D_TBCR). If no tile buffer is linked to the configured layer, a configuration error is generated.

17.3.13 DMA2D blender stage

The DMA2D blender blends the source pixels by pair to compute the resulting pixel.

The blending is performed according to the following equation:

$$\text{with } \alpha_{Mult} = \frac{\alpha_{FG} \cdot \alpha_{BG}}{255}$$

$$\alpha_{OUT} = \alpha_{FG} + \alpha_{BG} - \alpha_{Mult}$$

$$C_{OUT} = \frac{C_{FG}.\alpha_{FG} + C_{BG}.\alpha_{BG} - C_{BG}.\alpha_{Mult}}{\alpha_{OUT}} \quad \text{with C = R or G or B}$$

Division is rounded to the nearest lower integer

No configuration register is required by the blender. The blender use depends on the DMA2D operating mode defined by MODE[2:0] in DMA2D_CR.

17.3.14 DMA2D output PFC stage

The output PFC performs the pixel format conversion from 32 bits to the output format defined by CM[3:0] in DMA2D_OPFCCR.

Supported output formats are given in the table below

Table 149. Supported color mode in output

CM[3:0]	Color mode
0000	ARGB8888
0001	RGB888
0010	RGB565
0011	ARGB1555
0100	ARGB4444
1110	ARGB2222
others	Reserved

Note: To support the alternate format, the calculated alpha value can be inverted by setting AI bit in DMA2D_OPFCCR. This applies also to the Alpha value used in DMA2D_OCOLR.

The R and B fields can also be swapped setting RBS in DMA2D_OPFCCR, and the Alpha position can be changed setting the APOS in DMA2D_OPFCCR. This applies also to the RGB order used in DMA2D_OCOLR.

17.3.15 DMA2D write stage

The output FIFO programs the pixels according to the color format defined in the output PFC.

The destination area is defined through the following registers:

- DMA2D output memory address register (DMA2D_OMAR)
- DMA2D output offset register (DMA2D_OOR**)**
- DMA2D number of lines register (number of lines and pixels per line) (DMA2D_NLR**)**

If the DMA2D operates in register-to-memory mode, the configured output rectangle is filled by the color specified in DMA2D_OCOLR.

The format is selected by CM[2:0] in DMA2D_OPFCCR.

The data are stored into the memory in the order defined in the table below.

Table 150. Data order in memory

Color mode	@ + 3	@ + 2	@ + 1	@ + 0
ARGB8888	A_0[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
RGB888	B_1[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
	G_2[7:0]	B_2[7:0]	R_1[7:0]	G_1[7:0]
	R_3[7:0]	G_3[7:0]	B_3[7:0]	R_2[7:0]
RGB565	R_1[4:0]G_1[5:3]	G_1[2:0]B_1[4:0]	R_0[4:0]G_0[5:3]	G_0[2:0]B_0[4:0]

Table 150. Data order in memory (continued)

ARGB1555	A_1[0]R_1[4:0]G_1[4:3]	G_1[2:0]B_1[4:0]	A_0[0]R_0[4:0]G_0[4:3]	G_0[2:0]B_0[4:0]
ARGB4444	A_1[3:0]R_1[3:0]	G_1[3:0]B_1[3:0]	A_0[3:0]R_0[3:0]	G_0[3:0]B_0[3:0]
ARGB2222	A_3[1:0]R_3[1:0]G_3[1:0]B_3[1:0]	A_2[1:0]R_2[1:0]G_2[1:0]B_2[1:0]	A_1[1:0]R_1[1:0]G_1[1:0]B_1[1:0]	A_0[1:0]R_0[1:0]G_0[1:0]B_0[1:0]

The RGB888 aligned on 32 bits is supported through the ARGB8888 mode.

For ARGB and RGB color formats, the component order can be modified by the Red/Blue swap (RBS) bit and/or the Alpha position (APOS) *Table 151: ARGB/RGB component reordering*.

Table 151. ARGB/RGB component reordering

RBS = 0, APOS = 0	RBS = 1, APOS = 0	RBS = 0, APOS = 1	RBS = 1, APOS = 1
ARGB8888	ABGR8888	RGBA8888	BGRA8888
RGB888	BGR888	RGB888	BGR888
RGB565	BGR565	RGB565	BGR565
ARGB1555	ABGR1555	RGBA5551	BGRA5551
ARGB4444	ABGR4444	RGBA4444	BGRA4444
ARGB2222	ABGR2222	RGBA2222	BGRA2222

17.3.16 DMA2D output FIFO byte reordering

The output FIFO bytes can be reordered to support display frame buffer update through a parallel interface (F(S)MC) directly from the DMA2D.

The reordering of bytes can be done using:

- RBS bit to swap red and blue component
- SB bit to swap bytes two by two in the output FIFO

When the byte swapping is activated (SB = 1 in DMA2D_OPFCCR), the number of pixels per line (PL field in DMA2D_NLR) must be even, and the output memory address (MA field in DMA2D_OMAR) must be even. The output line offset computed in bytes (resulting from LOM field in DMA2D_CR and LO field in DMA2D_OOR values) must also be even. If not a configuration error is detected.

It is not possible to use the swap bytes feature when the tile buffer is used or in memory-to-memory mode.

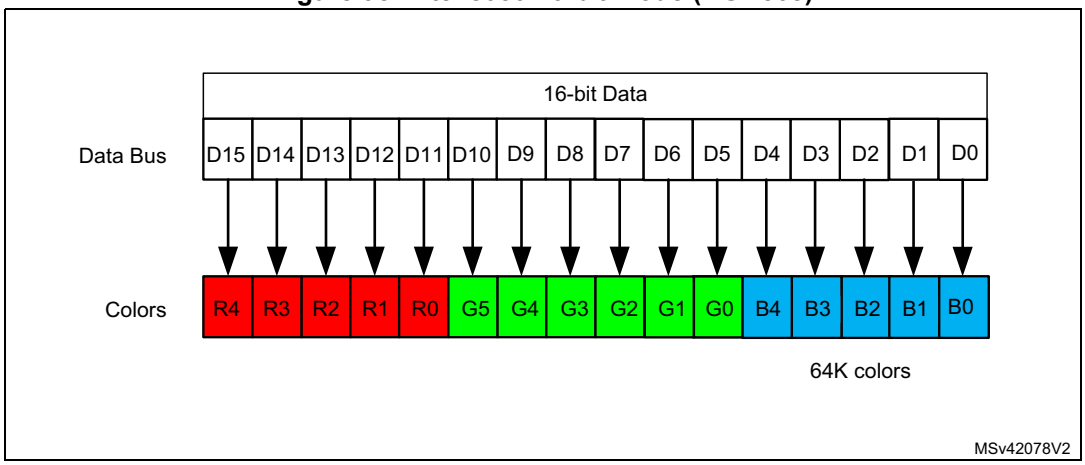
Table 152. Standard data order in memory

Color Mode	@ + 3	@ + 2	@ + 1	@ + 0
RGB888	B_1[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
	G_2[7:0]	B_2[7:0]	R_1[7:0]	G_1[7:0]
	R_3[7:0]	G_3[7:0]	B_3[7:0]	R_2[7:0]
RGB565	R_1[4:0]G_1[5:3]	G_1[2:0]B_1[4:0]	R_0[4:0]G_0[5:3]	G_0[2:0]B_0[4:0]

16-bit mode (RGB565)

This mode is supported without byte reordering by the DMA2D.

Figure 98. Intel 8080 16-bit mode (RGB565)



18/24-bit mode (RGB888)

This mode needs data reordering:

1. The red and the blue have to be swapped (setting the RBS bit).
2. MSB and the LSB bytes of a half-word must be swapped (setting SB bit).

Figure 99. Intel 8080 18/24-bit mode (RGB888)

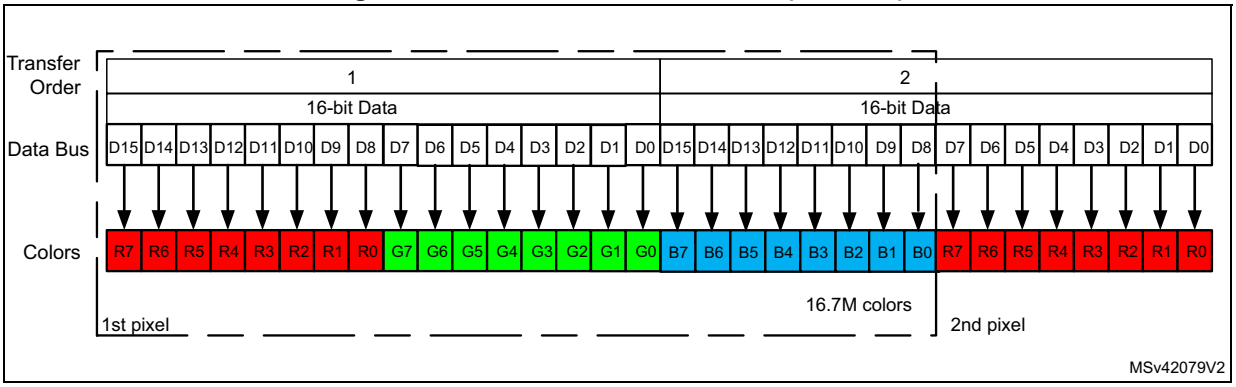


Table 153. Output FIFO byte reordering steps

Steps	@ + 3	@ + 2	@ + 1	@ + 0
Original data ordering	B_1[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
	G_2[7:0]	B_2[7:0]	R_1[7:0]	G_1[7:0]
	R_3[7:0]	G_3[7:0]	B_3[7:0]	R_2[7:0]
Setting the RBS bit				
Data ordering after Red and Blue swap (RBS set)	R_1[7:0]	B_0[7:0]	G_0[7:0]	R_0[7:0]
	G_2[7:0]	R_2[7:0]	B_1[7:0]	G_1[7:0]
	B_3[7:0]	G_3[7:0]	R_3[7:0]	B_2[7:0]

Table 153. Output FIFO byte reordering steps (continued)

Steps	@ + 3	@ + 2	@ + 1	@ + 0
Setting the SB bit				
Data ordering after byte swapping (SB set)	B_0[7:0]	R_1[7:0]	R_0[7:0]	G_0[7:0]
	R_2[7:0]	G_2[7:0]	G_1[7:0]	B_1[7:0]
	G_3[7:0]	B_3[7:0]	B_2[7:0]	R_3[7:0]

17.3.17 Watermark

A watermark can be programmed to generate an interrupt when the last pixel of a given line has been written to the destination memory area.

The line number is defined in LW[15:0] in DMA2D_LWR.

When the last pixel of this line has been transferred, TWIF flag is raised in DMA2D_ISR, and an interrupt is generated if TWIE is set in DMA2D_IER.

17.3.18 DMA2D AHB master port timer

An 8-bit timer is embedded into the AHB master port to provide an optional limitation of the bandwidth on the crossbar. This timer is clocked by the AHB clock and counts a dead time between two consecutive accesses. This limits the bandwidth usage.

This timer can be enabled by setting EN in DMA2D_AMTCR.

The dead time between two consecutive AHB accesses can be programmed in dead time (DT) field of the DMA2D AHB master timer configuration register (DMA2D_AMTCR). This value represents the guaranteed minimum number of cycles between two consecutive transactions on AHB bus.

The update of the dead-time value while the DMA2D is running is taken into account for the next AHB transfer.

17.3.19 DMA2D configuration

Both source and destination data transfers can target peripherals and memories in the whole 4-Gbyte memory area, at addresses ranging between 0x0000 0000 and 0xFFFF FFFF.

The DMA2D can operate in any of the following modes selected through MODE[2:0] in DMA2D_CR:

- Register-to-memory
- Memory-to-memory
- Memory-to-memory with PFC
- Memory-to-memory with PFC and blending
- Memory-to-memory with PFC, blending, and fixed FG color
- Memory-to-memory with PFC, blending, and fixed BG color

Register-to-memory

The register-to-memory mode is used to fill a user-defined area with a predefined color. The color format is set in DMA2D_OPFCCR.

The DMA2D does not perform any data fetching from any source. It just writes the color defined in DMA2D_OCOLR to the area located at the address pointed by DMA2D_OMAR and defined in DMA2D_NLR and DMA2D_OOR.

Memory-to-memory

In memory-to-memory mode, the DMA2D does not perform any graphical data transformation. The foreground input FIFO acts as a buffer, and data are transferred from the source memory location defined in DMA2D_FGMAR, to the destination memory location pointed by DMA2D_OMAR.

The color mode programmed by CM[3:0] in DMA2D_FGPFCCR defines the number of bits per pixel for both input and output. This is used to count the number of data according to the value defined in pixels like the number of pixels per line. As a consequence:

- The chosen color mode must be greater than 8 bpp.
- The color ordering is meaningless (L8 does the same than A8; AL88 does the same than RGB565).

In this specific mode, the PFC, the pixel skipper, and the stenciling is not active on the foreground, and no other processing blocks are available: the input FIFO is directly connected to the output FIFO.

The size of the area to be transferred is defined by DMA2D_NLR and DMA2D_FGOR for the source, and by DMA2D_NLR and DMA2D_OOR for the destination.

Memory-to-memory with PFC

In this mode, the DMA2D performs a pixel format conversion of the source data, and stores them in the destination memory location.

The size of the areas to be transferred is defined by DMA2D_NLR and DMA2D_FGOR for the source, and by DMA2D_NLR and DMA2D_OOR for the destination.

Data are fetched from the location defined in DMA2D_FGMAR, and processed by the foreground PFC. The original pixel format is configured through DMA2D_FGPFCCR.

If the original pixel format is direct-color mode, the color channels are all expanded to 8 bits.

If the pixel format is indirect color mode, the associated CLUT has to be loaded into the CLUT memory.

The CLUT loading can be done automatically by following the sequence below:

1. Set the CLUT address into DMA2D_FGCMAR.
2. Set the CLUT size with CS[7:0] in DMA2D_FGPFCCR.
3. Set the CLUT format CM[3:0] in DMA2D_FGPFCCR.
4. Start the CLUT loading by setting START in DMA2D_FGPFCCR.

Once the CLUT loading is complete, CTCIF flag in DMA2D_ISR is raised, and an interrupt is generated if CTCIE is set in DMA2D_IER. The automatic CLUT loading process cannot work in parallel with classical DMA2D transfers.

The CLUT can also be filled by the CPU or by any other master through the AHB register interface. The access to the CLUT is not possible when a DMA2D transfer is ongoing, and uses the CLUT (indirect color format).

In parallel to the color conversion process, the alpha value can be added or changed depending on the value programmed in DMA2D_FGPFCCR. If the original image does not

have an alpha channel, a default alpha value of 0xFF is automatically added to obtain a fully opaque pixel.

The alpha value is modified as follows according to AM[1:0] in DMA2D_FGPFCCR:

- It is unchanged.
- It is replaced by ALPHA[7:0] value in DMA2D_FGPFCCR.
- It is replaced by the original value multiplied by ALPHA[7:0] value in DMA2D_FGPFCCR divided by 255.

The pixel skipper can be configured through the DMA2D_FGMSR.

The resulting 32-bit data are encoded by the output PFC into the format specified by CM[2:0] in DMA2D_OPFCCR. The output pixel format cannot be the indirect mode since no CLUT generation process is supported.

All the processing blocks can be added inside the pipeline with the following restriction:

- Usage of the scaler is only allowed when the DMA2D is not operating in tile mode (no JPEG nor tile buffer usage).

A processing block is inserted in the pipeline configuring its SRC field of its configuration register.

Processed data are written into destination memory location pointed by DMA2D_OMAR.

Memory-to-memory with PFC and blending

In this mode, two sources are fetched in the foreground and background FIFOs from the memory locations defined by DMA2D_FGMAR and DMA2D_BGMAR respectively.

The two pixel format converters have to be configured as described in memory-to-memory mode. Their configurations can be different as each pixel format converter is independent and has its own CLUT memory.

Once each pixel has been converted into 32 bits by its respective PFC, all pixels are blended according to the equation below:

$$\text{with } \alpha_{Mult} = \frac{\alpha_{FG} \cdot \alpha_{BG}}{255}$$

$$\alpha_{OUT} = \alpha_{FG} + \alpha_{BG} - \alpha_{Mult}$$

$$C_{OUT} = \frac{C_{FG}.\alpha_{FG} + C_{BG}.\alpha_{BG} - C_{BG}.\alpha_{Mult}}{\alpha_{OUT}} \quad \text{with C = R or G or B}$$

Division are rounded to the nearest lower integer

The resulting 32-bit pixel value is encoded by the output PFC according to the specified output format, and data are written into the destination memory location pointed by DMA2D_OMAR.

If the two input pixels are fully transparent, the resulting output pixel is also transparent and each R, G, B components are saturated to 0xFF.

All the processing blocks can be added inside the pipeline with the restriction detailed in the previous paragraph.

Memory-to-memory with PFC, blending, and fixed color FG

In this mode, only one source is fetched in the background FIFO from the memory location defined by DMA2D_BGMAR.

The value of the foreground color is given by DMA2D_FGCOLR, and the alpha value is set to 0xFF (opaque).

The alpha value can be replaced or modified according to AM[1:0] and ALPHA[7:0] in DMA2D_FGPFCCR.

The two pixel format converters have to be configured as described in memory-to-memory mode. Their configurations can be different as each pixel format converter is independent and has its own CLUT memory

Once each pixel has been converted into 32 bits by its respective PFC, all pixels are blended together. The resulting 32-bit pixel value is encoded by the output PFC according to the specified output format. Data are written into the destination memory location pointed by DMA2D_OMAR.

All the precessing blocks can be added inside the pipeline with the restriction detailed in the previous paragraph.

Memory-to-memory with PFC, blending, and fixed color BG

In this mode, only open source is fetched in the foreground FIFO from the memory location defined by DMA2D_FGMAR.

The value of the background color is given by DMA2D_BGCOLR, and the alpha value is set to 0xFF (opaque).

The alpha value can be replaced or modified according to AM[1:0] and ALPHA[7:0] in DMA2D_BGPFCCR.

The two pixel format converters have to be configured as described in memory-to-memory mode. Their configurations can be different as each pixel format converter is independent and has its own CLUT memory

Once each pixel has been converted into 32 bits by their respective PFCs, all pixels are blended together. The resulting 32-bit pixel value is encoded by the output PFC according to the specified output format. Data are written into the destination memory location pointed by DMA2D_OMAR.

All the precessing blocks can be added inside the pipeline with the restriction detailed in the previous paragraph.

17.3.20 DMA2D configuration error detection

The DMA2D checks that the configuration is correct before any transfer. The configuration error interrupt flag is set by hardware when a wrong configuration is detected when a new transfer/automatic loading starts. An interrupt is then generated if CEIE = 1 in DMA2D_IER.

The wrong configurations that can be detected are listed below:

- Foreground CLUT automatic loading:
  - MA bits in DMA2D_FGCMAR are not aligned with CM in DMA2D_FGPFCCR.
  - CM in DMA2D_FGCMAR is not a direct color format (ARGB8888, RGB8888, RGB565, ARGB1555, ARGB4444, or ARGB2222).

- Background CLUT automatic loading:
  - MA bits in DMA2D_BGCMAR are not aligned with CM in DMA2D_BGPFCCR.
  - CM in DMA2D_BGCMAR is not a direct color format (ARGB8888, RGB8888, RGB565, ARGB1555, ARGB4444, or ARGB2222).
- Memory transfer (except in register-to-memory and memory-to-memory with blending and fixed color FG):
  - MA bits in DMA2D_FGMAR are not aligned with CM in DMA2D_FGPFCCR.
  - LO bits in DMA2D_FGOR are not aligned with CM in DMA2D_FGPFCCR when LOM = 0 (pixel counting) and color mode is 1 bpp, 2 bpp or 4 bpp.
  - DMA2D_FGMSR.HPRE + number of pixels + DMA2D_FGMSR.HTRAIL is not aligned with CM in DMA2D_FGPFCCR when color mode is 1 bpp, 2 bpp or 4 bpp.
  - DMA2D_FGMSR.HPRE + number of pixels + DMA2D_FGMSR.HTRAIL equal 0.
  - DMA2D_FGMSR.HPRE and DMA2D_FGMSR.HTRAIL are not in the range [0..7] when DMA2D_FGPFCR.CM = A1, or not in the range [0..3] when DMA2D_FGPFCR.CM = A2, or not in the range [0..1] when DMA2D_FGPFCR.CM = A4 or L4.
  - CM bits in DMA2D_FGPFCCR are set to reserved value.
  - AM bits in DMA2D_FGPFCCR are set to reserved value.
- Memory transfer (only in blending and blending with fixed color FG mode):
  - MA bits in DMA2D_BGMAR are not aligned with CM in DMA2D_BGPFCCR.
  - LO bits in DMA2D_BGOR are not aligned with CM in DMA2D_BGPFCCR when LOM = 0 (pixel counting) and color mode is 1 bpp, 2 bpp or 4 bpp.
  - DMA2D_BGMSR.HPRE + number of pixels + DMA2D_BGMSR.HTRAIL is not aligned with CM in DMA2D_BGPFCCR when color mode is 1 bpp, 2 bpp or 4 bpp.
  - DMA2D_BGMSR.HPRE + number of pixels + DMA2D_BGMSR.HTRAIL equal 0.
  - DMA2D_BGMSR.HPRE and DMA2D_BGMSR.HTRAIL are not in the range [0..7] when DMA2D_BGPFCR.CM = A1, or are not in the range [0..3] when DMA2D_BGPFCR.CM = A2, or are not in the range [0..1] when DMA2D_BGPFCR.CM = A4 or L4.
  - CM bits in DMA2D_BGPFCCR are set to reserved value.
  - AM bits in DMA2D_BGPFCCR are set to reserved value.
- Memory transfer (except in memory-to-memory):
  - MA bits in DMA2D_OMAR are not aligned with CM in DMA2D_OPFCCR.
  - CM bits in DMA2D_OPFCCR are set to reserved value.
- Memory transfer (memory-to-memory):
  - MA bits in DMA2D_OMAR are not aligned with CM in DMA2D_FGPFCCR.
  - LO bits in DMA2D_OOR are not aligned with CM in DMA2D_FGPFCCR when LOM = 0 (pixel counting) and color mode is 1 bpp, 2 bpp or 4 bpp.
  - CM bits in DMA2D_FGPFCCR are set to JPEG.
- Memory transfer (except register-to-memory and memory-to-memory)
  - Tile buffer and the scaler are both active.
- Any transfer (with byte swapping enabled):
  - PL bits in DMA2D_NLR are odd, or MA bits in DMA2D_OMAR are odd, or LO in bytes (resulting from LOM in DMA2D_CR and LO in DMA2D_OOR) are odd while SB = 1 in DMA2D_OPFCCR.

- Any transfer:
  - NL bits in DMA2D_NLR are all zeros.
  - PL bits in DMA2D_NLR are all zeros.
  - MODE bits in DMA2D_CR are invalid.
- Transfers with stencil buffer:
  - DMA2D_SBMSR.HPRE + number of pixels + DMA2D_SBMSR.HTRAIL is not aligned with MODE in DMA2D_SBCR when mode is 1 bpp, 2 bpp or 4 bpp.
  - DMA2D_SBMSR.HPRE and DMA2D_SBMSR.HTRAIL are not in the range [0..7] when DMA2D_SBCR.MODE = 1bpp, or are not in the range [0..3] when DMA2D_SBCR.MODE = 2bpp, or are not in the range [0..1] when DMA2D_SBCR.MODE = 4bpp.
  - LO bits in DMA2D_SBCR are not aligned with MODE in DMA2D_SBCR when LOM = 0 (pixel counting) and color mode is 1 bpp, 2 bpp or 4 bpp.
- Transfers with JPEG on foreground (memory-to-memory with PFC, memory-to-memory with blending and memory-to-memory with blending and fixed color BG):
  - JPEG also enabled on background (only for memory-to-memory with PFC).
  - JPEG enabled DMA2D_FGPFCCR.CM = JPEG and DMA2D_FGPFCCR.CSS is set to a reserved value.
  - JPEG enabled DMA2D_FGPFCCR.CM = JPEG and the tile buffer is not linked to the foreground DMA2D_TBCR.SRC ≠ 1.
  - DMA2D_FGMSR.HPRE + number of pixels + DMA2D_FGMSR.HTRAIL is not aligned with the MCU width (8 when DMA2D_FGPFCCR.CSS = 4:4:4 and 16 when DMA2D_FGPFCCR.CSS = 4:2:2 or 4:2:0).
  - DMA2D_FGMSR.HPRE and DMA2D_FGMSR.HTRAIL are not in the range [0..7] when DMA2D_FGPFCCR.CSS = 4:4:4, or are not in the range [0..15] when DMA2D_FGPFCCR.CSS = 4:2:2 or 4:2:0.
  - DMA2D_FGMSR.VPRE + number of lines + DMA2D_FGMSR.VTRAIL is not aligned with the MCU height (8 when DMA2D_FGPFCCR.CSS = 4:4:4 or 4:2:2 and 16 when DMA2D_FGPFCCR.CSS = 4:2:0).
  - DMA2D_FGMSR.VPRE and DMA2D_FGMSR.VTRAIL are not in the range [0..7] when DMA2D_FGPFCCR.CSS = 4:4:4 or 4:2:2, or are not in the range [0..15] when DMA2D_FGPFCCR.CSS = 4:2:0.
  - LO bits in DMA2D_FGOR are not aligned to an MCU size when LOM = 0 (64 pixels when DMA2D_FGPFCCR.CSS = 4:4:4, 128 pixels when DMA2D_FGPFCCR.CSS = 4:2:2 and 256 pixels when DMA2D_FGPFCCR.CSS = 4:2:0).

- Transfers with JPEG on background (memory-to-memory with blending and memory-to-memory with blending and fixed color FG):
  - JPEG also enabled on foreground (memory-to-memory with PFC).
  - JPEG enabled DMA2D_BGPFCCR.CM = JPEG and DMA2D_BGPFCCR.CSS is set to a reserved value.
  - JPEG enabled DMA2D_BGPFCCR.CM = JPEG and the tile buffer is not linked to the foreground DMA2D_TBCR.SRC ≠ 2.
  - DMA2D_BGMSR.HPRE + number of pixels + DMA2D_BGMSR.HTRAIL is not aligned with the MCU width (8 when DMA2D_BGPFCCR.CSS = 4:4:4 and 16 when DMA2D_BGPFCCR.CSS = 4:2:2 or 4:2:0).
  - DMA2D_BGMSR.HPRE and DMA2D_BGMSR.HTRAIL are not in the range [0..7] when DMA2D_BGPFCCR.CSS = 4:4:4, or are not in the range [0..15] when DMA2D_BGPFCCR.CSS = 4:2:2 or 4:2:0.
  - DMA2D_BGMSR.VPRE + number of lines + DMA2D_BGMSR.VTRAIL is not aligned with the MCU height (8 when DMA2D_BGPFCCR.CSS = 4:4:4 or 4:2:2 and 16 when DMA2D_BGPFCCR.CSS = 4:2:0).
  - DMA2D_BGMSR.VPRE and DMA2D_BGMSR.VTRAIL are not in the range [0..7] when DMA2D_BGPFCCR.CSS = 4:4:4 or 4:2:2, or are not in the range [0..15] when DMA2D_BGPFCCR.CSS = 4:2:0.
  - LO bits in DMA2D_BGOR are not aligned to an MCU size when LOM = 0 (64 pixels when DMA2D_BGPFCCR.CSS = 4:4:4, 128 pixels when DMA2D_BGPFCCR.CSS = 4:2:2 and 256 pixels when DMA2D_BGPFCCR.CSS = 4:2:0).

17.3.21 DMA2D transfer control (start, suspend, abort, and completion)

Once the DMA2D is configured, the transfer can be launched by setting START in DMA2D_CR. Once the transfer is completed, START is automatically reset, and TCIF flag is raised in DMA2D_ISR. An interrupt can be generated if TCIE is set in DMA2D_IER.

The user application can suspend the DMA2D at any time by setting SUSP in DMA2D_CR. The transaction can be aborted by setting ABORT in DMA2D_CR, or can be restarted by resetting SUSP in DMA2D_CR.

The user application can abort at any time an ongoing transaction by setting ABORT in DMA2D_CR. In this case, the TCIF flag is not raised.

It is not recommended to set START, SUSP, or ABORT at the same time. In such cases, ABORT is having the priority over the SUSP and START, and the SUSP is having the priority over the START.

17.3.22 DMA2D error management

Four kinds of error can be triggered:

- AHB master port errors signaled by TEIF flag in DMA2D_ISR
- Conflicts caused by CLUT access (CPU trying to access the CLUT while a CLUT loading or a DMA2D transfer using a CLUT is ongoing) signaled by CAEIF flag in DMA2D_ISR
- Ring buffer error signaled by RBEIF flag in the DMA2D_ISR
- Linear command list error signaled by LCLEIF in the DMA2D_ISR

Each flag is associated to its own interrupt enable flag in DMA2D_IER to generate an interrupt if need be (TEIE and CAEIE).

17.3.23 General purpose flags

The DMA2D offers four general purpose flags (GPFLAG) to generate various events for software or hardware synchronization including debug.

Each GPFLAG can be set or reset by:

- CPU software
- DMA2D software (command list instruction)
- Hardware (internal triggers)

Each GPFLAG can:

- Generate an interrupt
- Generate a trigger
- Suspend the command list execution

Each GPFLAG can be output on an individual pin for external triggering or debug.

Each of the four GPFLAG can be configured individually through the DMA2D general purpose flag configuration register (DMA2D_GPFCR).

The event of setting or resetting a GPFLAG (whatever by hardware or software) can set a general purpose flag x interrupt flag (GPFxIF) in the DMA2D interrupt and status register (DMA2D_ISR). The type of event setting the GPFxIF is defined by the general purpose flag x interrupt configuration (GPFxIC) field of the DMA2D general purpose flag configuration register (DMA2D_GPFCR).

When a GPFLAG is set, it can also suspend the command list execution. The behavior of the flag regarding the command list suspension is defined by the DMA2D general purpose flag x suspend configuration (DMA2D_GPFxSC) bit of the DMA2D general purpose flag configuration register (DMA2D_GPFCR).

The GPFLAG values are accessible by software through the DMA2D general purpose flag register (DMA2D_GPFR). This register is read only.

The set and the reset of the GPFLAG can be done by software setting the corresponding set general purpose flag x (SGPFx) resp. reset general purpose flag x (RGPFx) bits in the DMA2D general purpose flag set register (DMA2D_GPFSR) resp. DMA2D general purpose flag reset register (DMA2D_GPFRR). This can be done by the CPU or by an instruction in a DMA2D linear command list.

A GPFLAG can also be set or reset by hardware through external triggers. Because of resynchronization, a delay of 3 or 4 cycles can be observed between the hardware event and the effective action on the GPFLAG.

In case of concurrent set and reset events, the set has the priority.

Once set, a GPFLAG can suspend the command list execution if its corresponding DMA2D_GPFxSC bit is set. Refer to the *Section 17.3.24: Command list management* for additional information about command list suspension.

When the event selected by the corresponding GPFxIC occurs, the corresponding GPFxIF interrupt flag is set and an interrupt is generated if the general purpose flag x interrupt enable (GPFxIE) bit of the DMA2D interrupt enable register (DMA2D_IER) is set.

The GPFxIF flag can be reset by setting the clear general purpose flag x interrupt flag (CGPFxIF) bit of the DMA2D interrupt flag clear register (DMA2D_IFCR).

17.3.24 Command list management

The DMA2D is supporting command list for efficient graphic task management.

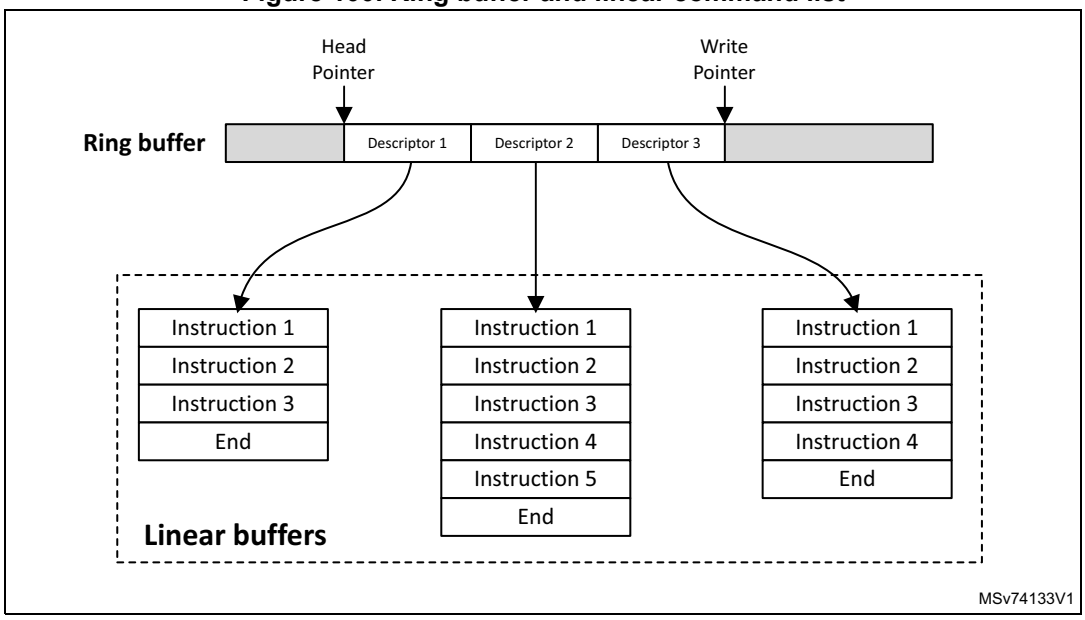
The command list management is done combining:

- Ring buffer
- Linear command lists

The ring buffer is a circular buffer in the system memory in which are stored the descriptors of the linear command list to be executed by the DMA2D.

The linear command lists are series of standard or SIMD instructions which are updating the internal registers of the DMA2D.

Figure 100. Ring buffer and linear command list



Ring buffer configuration

The base address of the ring buffer is programmed in the DMA2D ring buffer memory address register (DMA2D_RBBAR). As each descriptor of the ring buffer is made of 64 bits, the DMA2D ring buffer memory address must be double-word aligned (64-bit).

The size of the ring buffer can be configured through the Ring buffer size (RBS) field of the DMA2D command list configuration register (DMA2D_CLCR) and can go from 64 bytes (8 descriptors) up to 8 Kbytes (1024 descriptors).

Ring buffer's linear command list descriptors

The linear command list descriptors are made of 64-bit with the following mapping.

Table 154. Linear command list descriptor

Command list descriptor higher word @+0x04

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
POSTGPF3		POSTGPF2		POSTGPF1		POSTGPF0		PREGPF3		PREGPF2		PREGPF1		PREGPF0	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	SIZE[11:0]											

Command list descriptor lower word @

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADDRESS[31:16]															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDRESS[15:0]															

- The ADDRESS field is the address of the linear command list in the system memory. The address must be 32-bit aligned (ADDRESS[1] and ADDRESS[0] are ignored) The SIZE field is the size of the linear command list in words (number of words - 1) between 1 and 4096 words.
- PREGPFx defines if an operation needs to be done on the GPFLAGx when prior to the start of the execution of the linear command list
  - 00: no operation
  - 01: set GPFLAGx
  - 10: reset GPFLAGx
  - 11: toggle GPFLAGx
- POSTGPFx defines if on operation needs to be done on the GPFLAGx when after the execution of the linear command list
  - 00: no operation
  - 01: set GPFLAGx
  - 10: reset GPFLAGx
  - 11: toggle GPFLAGx

Linear command list instructions

The linear command list instructions can be the following:

- NOP: No operation
- LD: Load of an internal register
- LDM: Load multiple of several internal registers
- END: Mandatory at the end of the linear command list

If an LD or LDM instruction sets START bit of the DMA2D_CR, the START setting is buffered and is done once the LD/LDM instruction is finished. This is thus starting the DMA2D operation.

If an LD or LDM instruction sets START bit of the DMA2D_FGPFCR or of the DMA2D_BGPFCR, the START setting is buffered and is done once the LD/LDM instruction is finished. This is thus starting the DMA2D CLUT transfer operation.

It is not allowed to set several START bit in the same LDM instruction. In such a case an error is generated.

NOP instruction

The no operation (NOP) instruction doesn't perform any operation. It can be used to reserve space inside a linear command list.

The total size in the linear command list of a NOP instruction is one word.

Table 155. NOP instruction coding

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NOP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LD instruction

The load (LD) instruction makes a direct load into a DMA2D register.

The registers accessible with an LD instruction are all the register available for LDM (refer to *Table 157: LDM instruction coding*) and DMA2D_LWR, DMA2D_AMTCR, DMA2D_DPFCR, DMA2D_GPFSR and DMA2D_GPFRR.

Bit 11 to bit 0 define the 12-bit address of the register to be loaded.
After the instruction word, a data word is following with the value to be loaded.

The total size in the linear command list of an LD instruction is two words.

Table 156. LD instruction coding

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LD	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ADDRESS[11:0]											

LD instruction example:

Load the DMA2D foreground memory address register (DMA2D_FGMAR) with 0x2400 0000:

- Operation: LD DMA2D_FGMAR, 0x24000000
- Binary: 0x8000 0040 - 0x2400 0000

LDM Instruction

The load multiple (LDM) instruction allows single instruction multiple data (SIMD) for DMA2D configuration.

Bit 31 of the instruction is always 0, whereas bit 30 to bit 0 are coding which registers or group of registers are to be loaded.
After the instruction word, a variable number of data words are following according to the number of registers to be loaded.

The order of the data word is fixed:

- The DMA2D_CR selected by bit 30 is always the first one when selected.
- The DMA2D_SNLR, DMA2D_SSR and DMA2D_SPR selected by bit 2 is always The latest ones when selected.

The total size in the linear command list of an LDM instruction is thus between one word (NOP) up to 30 words (update all 29 possible registers covered by LDM instruction).

Table 157: LDM instruction coding gives the correspondence between the instruction bit and the registers or group of registers to be loaded.

Table 157. LDM instruction coding

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LDM	0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	-	x	-	-	-	x	x	-	-
DMA2D_CR		x																														
DMA2D_IER			x																													
DMA2D_IFCR				x																												
DMA2D_FGMAR					x																											
DMA2D_FGOR					x																											
DMA2D_FGMSR						x																										
DMA2D_FGPFCCR							x																									
DMA2D_FGCOLR								x																								
DMA2D_FGCMAR									x																							
DMA2D_BGMAR										x																						
DMA2D_BGOR										x																						
DMA2D_BGMSR											x																					
DMA2D_BGPFCCR												x																				
DMA2D_BGCOLR													x																			
DMA2D_BGCMAR														x																		
DMA2D_OPFCCR															x																	
DMA2D_OCOLR																x																
DMA2D_OMAR																	x															
DMA2D_OOR																	x															
DMA2D_NLR																		x														
DMA2D_SBCR																			x													
DMA2D_SBMAR																				x												
DMA2D_SBOR																				x												
DMA2D_SBMSR																					x											
DMA2D_TBCR																									x							
DMA2D_SCR																													x			
DMA2D_SNLR																														x		
DMA2D_SSR																														x		
DMA2D_SPR																														x		

LDM instruction example:

Load the DMA2D_FGMAR with 0x2400 0000, the DMA2D_FGOR with 0x0000 0100

- Operation: LDM DMA2D_FGMAR, 0x2400 0000, DMA2D_FGOR, 0x0000 0100
- Binary: 0x0800 0000 - 0x2400 0000 - 0x0000 0100

Load the DMA2D_FGMAR with 0x0801 2000, the DMA2D_FGOR with 0x0000 0100, the DMA2D_OMAR with 0x2400 4000, the DMA2D_OOR with 0x0000 2000 and the DMA2D_NLR with 0x0040 0060

- Operation: LDM DMA2D_FGMAR, 0x0801 2000, DMA2D_FGOR, 0x0000 0100, DMA2D_OMAR, 0x2400 4000, DMA2D_OOR, 0x0000 2000, DMA2D_NLR, 0x0040 0060
- Binary: 0x0800 C000 - 0x0801 2000 - 0x0000 0100 - 0x2400 4000 - 0x0000 2000 - 0x0040 0060

END instruction

The end (END) instruction doesn't perform any operation. It is used to identify the end of a linear command list.

This instruction is mandatory and is counting in the size calculation of a linear command list.

The total size in the linear command list of an END instruction is one word.

Table 158. END instruction coding

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
END	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Ring buffer and linear command list functional description

When a linear command list need to be submitted to the DMA2D, its 64-bit descriptor must be written into the ring buffer memory.

This new descriptor must be written in the first available free location pointed by the write pointer (WP) field of the DMA2D ring buffer write pointer register (DMA2D_RBWPR).

Once the descriptor is written, the WP field must be incremented to point to the new free available location. The WP field can be updated anytime even when the DMA2D is up and running.

The descriptor of the first command list to be executed is pointed by the head pointer (HP) field of the DMA2D ring buffer head pointer register (DMA2D_RBHPR).

This HP field can be updated by software when ring buffer execution is stopped, or automatically by hardware when the related linear command list execution is done. It cannot be updated by software when the ring buffer execution is running or suspended.

The WP and HP fields are offsets relative to the DMA2D ring buffer base address.

The ring buffer execution is started by setting the START bit of the (DMA2D_CLCR).

Once the head pointer (HP) becomes equal to the write pointer (WP) the DMA2D ring buffer execution is automatically stopped and the START bit is automatically reset and the command list complete flag (RBCF) of the DMA2D interrupt status register (DMA2D_ISR) is set.

If the command list complete interrupt enable (RBCIE) bit is set, an interrupt is generated.

Command list abort

The command list execution can be aborted by software setting the ABORT bit on the DMA2D command list control register (DMA2D_CLCR).

When the abort is requested, the abort is effective after the full execution of the current instruction (DMA2D operations are not aborted but finished prior to a command list execution effective abort).

Once the abort is effective, the START bit of the DMA2D command list control register (DMA2D_CLCR) is reset.

Command list execution suspension

The command list can be suspended by

- software setting the suspend (SUSP) bit of the DMA2D command list control register (DMA2D_CLCR)
- software/hardware when a GPFLAG is set and configured to suspend the command list execution

When a command list suspend condition occurs, the suspension is effective after the full execution of the current instruction (DMA2D operations are not suspended but finished prior to a command list execution effective suspension).

Once the command list suspension is effective, the command list suspend interrupt flag (CLSIF) bit of the DMA2D interrupt and status register (DMA2D_ISR) is set, and an interrupt is generated if the command list suspend interrupt enable (CLSIE) bit of the DMA2D interrupt enable register (DMA2D_IER) is set.

The state of the command list execution suspension is given by the suspend bits of the DMA2D command list status register (DMA2D_CLSR). The suspend bits are cleared once the corresponding suspending condition is clear.

It is not recommended to set START, SUSP, or ABORT at the same time. In such cases, ABORT is having the priority over the SUSP and START, and the SUSP is having the priority over the START.

Command list error management

When an error occurred during the command list execution, the START bit of the DMA2D_CLCR is automatically reset.

If the error is due to a DMA2D error (configuration error, CLUT access error or transfer errors), the corresponding error bit is set in DMA2D interrupt and status register (DMA2D_ISR) is set and an interrupt is generated if the corresponding enable bit in the DMA2D interrupt enable register (DMA2D_IER) is set.

If the error is related to the ring buffer reading, the ring buffer error interrupt flag (RBEIF) bit of the DMA2D interrupt and status register (DMA2D_ISR) is set and an interrupt is generated if the ring buffer error interrupt enable (RBEIE) bit of the DMA2D interrupt enable register (DMA2D_IER) is set.

A ring buffer error can be caused either by:

- Descriptor read error: AHB error while reading the descriptor.
- Ring buffer oversize: the ring buffer overflows the 4GB range.
- Head pointer error: the programmed head pointer is outside the ring buffer.
- Write pointer error: the programmed write pointer is outside the ring buffer.

If a ring buffer error occurs while the DMA2D is running (one of the START bit is set), the current operation is not aborted. It is recommended to either wait for the end of the operations (wait for the clear of the corresponding START bit) or to abort it manually setting the ABORT bit of the DMA2D control register (DMA2D_CR).

If the error is related to the linear command list execution, the command list error interrupt flag (CLEIF) bit of the DMA2D interrupt and status register (DMA2D_ISR) is set and an interrupt is generated if the command list error interrupt enable (CLEIE) bit of the DMA2D interrupt enable register (DMA2D_IER) is set.

The exact linear command list error is given by the error bits of the DMA2D command list status register (DMA2D_CLSR) and can be:

- Linear command list read error, an abort of the current DMA2D operation, or a configuration error generated by the loaded instruction.
- Illegal instruction or end of linear command list mismatch error (END instruction missing or not matching the size of the command list given in its descriptor)
- Linear command list multiple start error (more than one START bit is set in a single linear command list instruction)

The error bits are automatically cleared when the CLEIF flag is cleared setting the clear command list error interrupt flag (CCLEIF) bit of the DMA2D interrupt flag clear register (DMA2D_IFCR).

17.4 DMA2D interrupts

An interrupt can be generated on the following events:

- General purpose flag event
- Command list error
- Command list suspended
- Ring buffer error
- Ring buffer completed
- Configuration error
- CLUT transfer complete
- CLUT access error
- Transfer watermark reached
- Transfer complete
- Transfer error

Separate interrupt enable bits are available for flexibility.

Table 159. DMA2D interrupt requests

Interrupt event	Event flag	Enable control bit
General purpose flag event	GPFxIF	GPFxIE
Command list error	CLEIF	CLEIE
Command list suspended	CLSIF	CLSIE
Ring buffer error	RBEIF	RBEIE
Ring buffer completed	RBCIF	RBCIE
Configuration error	CEIF	CEIE
CLUT transfer complete	CTCIF	CTCIE
CLUT access error	CAEIF	CAEIE
Transfer watermark	TWF	TWIE
Transfer complete	TCIF	TCIE
Transfer error	TEIF	TEIE

17.5 DMA2D registers

17.5.1 DMA2D control register (DMA2D_CR)

Address offset: 0x000

Reset value: 0x0000 0000

This register configures and controls the DMA2D. The configuration part can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution has started, the configuration part of this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOM	Res.	Res.	Res.	ABORT	SUSP	START
									rw				rs	rw	rs

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **MODE[2:0]**: DMA2D mode

This bit is set and cleared by software. It cannot be modified while a transfer is ongoing.

000: Memory-to-memory (FG fetch only)

001: Memory-to-memory with PFC (FG fetch only with FG PFC active)

010: Memory-to-memory with blending (FG and BG fetch with PFC and blending)

011: Register-to-memory (no FG nor BG, only output stage active)

100: Memory-to-memory with blending and fixed color FG (BG fetch only with FG and BG PFC active)

101: Memory-to-memory with blending and fixed color BG (FG fetch only with FG and BG PFC active)

110: Reserved

111: Reserved

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **LOM**: Line offset mode

This bit configures how the line offset is expressed (pixels or bytes) for the foreground, background and output.

This bit is set and cleared by software. It can not be modified while a transfer is ongoing.

0: Line offsets expressed in pixels

1: Line offsets expressed in bytes

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **ABORT**: Abort

This bit can be used to abort the current transfer. This bit is set by software, and is automatically reset by hardware when the START bit of the current operation is reset (data transfer or automatic CLUT loading).

0: No transfer abort requested

1: Transfer abort requested

Bit 1 **SUSP**: Suspend

This bit can be used to suspend the current transfer. This bit is set and reset by software. It is automatically reset by hardware when the START bit of the current operation is reset (data transfer or automatic CLUT loading).

0: Transfer not suspended

1: Transfer suspended

Bit 0 **START**: Start

This bit can be used to launch the DMA2D according to parameters loaded in the various configuration registers. This bit controls the DMA2D data transfer (not the automatic CLUT loading).

This bit is automatically reset by the following events:

- At the end of the transfer
- When the data transfer is aborted by the user by setting ABORT in this register
- When a data transfer error occurs
- When the data transfer has not started due to a configuration error, or another transfer operation already ongoing (automatic CLUT loading)

0: No DMA2D data transfer on going

1: DMA2D data transfer on going

17.5.2 DMA2D interrupt status register (DMA2D_ISR)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPF3IF	GPF2IF	GPF1IF	GPF0IF
												r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CLEIF	CLSIF	Res.	Res.	RBEIF	RBCIF	Res.	Res.	CEIF	CTCIF	CAEIF	TWIF	TCIF	TEIF
		r	r			r	r			r	r	r	r	r	r

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **GPF3IF**: General purpose flag 3 interrupt flag

This bit is set when general purpose flag 3 event is triggered and the flag is allowed to generate an interrupt.

0: No general purpose flag 3 event detected

1: General purpose flag 3 event detected

Bit 18 **GPF2IF**: General purpose flag 2 interrupt flag

This bit is set when general purpose flag 2 event is triggered and the flag is allowed to generate an interrupt.

0: No general purpose flag 2 event detected

1: General purpose flag 2 event detected

Bit 17 **GPF1IF**: General purpose flag 1 interrupt flag

This bit is set when general purpose flag 1 event is triggered and the flag is allowed to generate an interrupt.

0: No general purpose flag 1 event detected

1: General purpose flag 1 event detected

Bit 16 **GPF0IF**: General purpose flag 0 interrupt flag
This bit is set when general purpose flag 0 event is triggered and the flag is allowed to generate an interrupt.
0: No general purpose flag 0 event detected
1: General purpose flag 0 event detected

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **CLEIF**: Command list error interrupt flag
This bit is set when an error occurred during the command list execution.
0: No error detected during the command list execution
1: An error has been detected during the command list execution

Bit 12 **CLSIF**: Command list suspended interrupt flag
This bit is set when the command list execution is suspended.
0: Command list not suspended
1: Command list execution has been suspended

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **RBEIF**: Ring buffer error interrupt flag
This bit is set when the ring buffer error occurred.
0: No error detected during the ring buffer execution
1: An error has been detected during the ring buffer execution

Bit 8 **RBCIF**: Ring buffer completed interrupt flag
This bit is set when the ring buffer execution is completed.
0: Ring buffer execution not yet completed
1: Ring buffer execution complete

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **CEIF**: Configuration error interrupt flag
This bit is set when START is set in DMA2D_CR, DMA2D_FGPFCCR or DMA2D_BGPFCCR, and a wrong configuration has been programmed.
0: No configuration error detected
1: A configuration error has been detected

Bit 4 **CTCIF**: CLUT transfer complete interrupt flag
This bit is set when the CLUT copy from a system memory area to the internal DMA2D memory is complete.
0: CLUT transfer not yet complete
1: CLUT transfer complete

Bit 3 **CAEIF**: CLUT access error interrupt flag
This bit is set when the CPU accesses the CLUT while the CLUT is being automatically copied from a system memory to the internal DMA2D or while the CLUT is used by the current DMA2D operation.
0: No CLUT access error detected
1: CLUT transfer error detected

Bit 2 **TWIF**: Transfer watermark interrupt flag
This bit is set when the last pixel of the watermarked line has been transferred.
0: Transfer watermark not yet reached
1: Transfer watermark reached

Bit 1 **TCIF**: Transfer complete interrupt flag
This bit is set when a DMA2D transfer operation is complete (data transfer only).
0: DMA2D data transfer not yet complete
1: DMA2D data transfer transfer complete

Bit 0 **TEIF**: Transfer error interrupt flag
This bit is set when an error occurs during a DMA transfer (data transfer or automatic CLUT loading).
0: No DMA2D transfer error detected
1: DMA2D transfer error detected

17.5.3 DMA2D interrupt enable register (DMA2D_IER)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPF3IE	GPF2IE	GPF1IE	GPF0IE
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CLEIE	CLSIE	Res.	Res.	RBEIE	RBCIE	Res.	Res.	CEIE	CTCIE	CAEIE	TWIE	TCIE	TEIE
		rw	rw			rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **GPF3IE**: General purpose flag 3 interrupt enable
This bit is set and cleared by software.
0: GP flag 3 interrupt is disabled
1: GP flag 3 interrupt is enabled

Bit 18 **GPF2IE**: General purpose flag 2 interrupt enable
This bit is set and cleared by software.
0: GP flag 2 interrupt is disabled
1: GP flag 2 interrupt is enabled

Bit 17 **GPF1IE**: General purpose flag 1 interrupt enable
This bit is set and cleared by software.
0: GP flag 1 interrupt is disabled
1: GP flag 1 interrupt is enabled

Bit 16 **GPF0IE**: General purpose flag 0 interrupt enable
This bit is set and cleared by software.
0: GP flag 0 interrupt is disabled
1: GP flag 0 interrupt is enabled

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **CLEIE**: Command list error interrupt enable
This bit is set and cleared by software.
0: Command list error interrupt is disabled
1: Command list error interrupt is enabled

Bit 12 **CLSIE**: Command list suspended interrupt enable
This bit is set and cleared by software.
0: Command list suspended interrupt is disabled
1: Command list suspended interrupt is enabled

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **RBEIE**: Ring buffer error interrupt enable
This bit is set and cleared by software.
0: Ring buffer error interrupt is disabled
1: Ring buffer error interrupt is enabled

Bit 8 **RBCIE**: Ring buffer completed interrupt enable
This bit is set and cleared by software.
0: Ring buffer completed interrupt is disabled
1: Ring buffer completed interrupt is enabled

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **CEIE**: Configuration error interrupt enable
This bit is set and cleared by software.
0: Configuration error interrupt is disabled
1: Configuration error interrupt is enabled

Bit 4 **CTCIE**: CLUT transfer complete interrupt enable
This bit is set and cleared by software.
0: CLUT transfer complete interrupt is disabled
1: CLUT transfer complete interrupt is enabled

Bit 3 **CAEIE**: CLUT access error interrupt enable
This bit is set and cleared by software.
0: CLUT access error interrupt is disabled
1: CLUT access error interrupt is enabled

Bit 2 **TWIE**: Transfer watermark interrupt enable
This bit is set and cleared by software.
0: Transfer watermark interrupt is disabled
1: Transfer watermark interrupt is enabled

Bit 1 **TCIE**: Transfer complete interrupt enable
This bit is set and cleared by software.
0: Transfer complete interrupt is disabled
1: Transfer complete interrupt is enabled

Bit 0 **TEIE**: Transfer error interrupt enable
This bit is set and cleared by software.
0: Transfer error interrupt is disabled
1: Transfer error interrupt is enabled

17.5.4 DMA2D interrupt flag clear register (DMA2D_IFCR)

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CGPF3IF	CGPF2IF	CGPF1IF	CGPF0IF
												w	w	w	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CCLEIF	CCLSIF	Res.	Res.	CRBEIF	CRBCIF	Res.	Res.	CCEIF	CCTCIF	CCAEIF	CTWIF	CTCIF	CTEIF
		w	w			w	w			w	w	w	w	w	w

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **CGPF3IF**: Clear general purpose flag 3 interrupt flag
Setting this bit clears the GPF3IF flag in DMA2D_ISR.
0: Do nothing
1: Clear GPF3IF flag in DMA2D_ISR

Bit 18 **CGPF2IF**: Clear general purpose flag 2 interrupt flag
Setting this bit clears the GPF2IF flag in DMA2D_ISR.
0: Do nothing
1: Clear GPF2IF flag in DMA2D_ISR

Bit 17 **CGPF1IF**: Clear general purpose flag 1interrupt flag
Setting this bit clears the GPF1IF flag in DMA2D_ISR.
0: Do nothing
1: Clear GPF2IF flag in DMA2D_ISR

Bit 16 **CGPF0IF**: Clear general purpose flag 0 interrupt flag
Setting this bit clears the GPF0IF flag in DMA2D_ISR.
0: Do nothing
1: Clear GPF1IF flag in DMA2D_ISR

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **CCLEIF**: Clear command list error interrupt flag
Setting this bit clears the CLEIF flag in DMA2D_ISR.
0: Do nothing
1: Clear CLEIF flag in DMA2D_ISR

Bit 12 **CCLSIF**: Clear command list suspended interrupt flag
Setting this bit clears the CLSIF flag in DMA2D_ISR.
0: Do nothing
1: Clear CLSIF flag in DMA2D_ISR

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **CRBEIF**: Clear ring buffer error interrupt flag
Setting this bit clears the RBEIF flag in DMA2D_ISR.
0: Do nothing
1: Clear RBEIF flag in DMA2D_ISR

Bit 8 **CRBCIF**: Clear ring buffer completed interrupt flag
Setting this bit clears the RBCIF flag in DMA2D_ISR.
0: Do nothing
1: Clear RBCIF flag in DMA2D_ISR

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **CCEIF**: Clear configuration error interrupt flag
Setting this bit clears the CEIF flag in DMA2D_ISR.
0: Do nothing
1: Clear CEIF flag in DMA2D_ISR

Bit 4 **CCTCIF**: Clear CLUT transfer complete interrupt flag
Setting this bit clears the CTCIF flag in DMA2D_ISR.
0: Do nothing
1: Clear CTCIF flag in DMA2D_ISR

Bit 3 **CCAEIF**: Clear CLUT access error interrupt flag
Setting this bit clears the CAEIF flag in DMA2D_ISR.
0: Do nothing
1: Clear CAEIF flag in DMA2D_ISR

Bit 2 **CTWIF**: Clear transfer watermark interrupt flag
Setting this bit clears the TWIF flag in DMA2D_ISR.
0: Do nothing
1: Clear TWIF flag in DMA2D_ISR

Bit 1 **CTCIF**: Clear transfer complete interrupt flag
Setting this bit clears the TCIF flag in DMA2D_ISR.
0: Do nothing
1: Clear TCIF flag in DMA2D_ISR

Bit 0 **CTEIF**: Clear transfer error interrupt flag
Setting this bit clears the TEIF flag in DMA2D_ISR.
0: Do nothing
1: Clear TEIF flag in DMA2D_ISR

17.5.5 DMA2D foreground memory address register (DMA2D_FGMAR)

Address offset: 0x040

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MA[31:0]**: Memory address

Address of the data used for the layer image.
The address alignment must match the image format selected: a 32-bit per pixel format must be 32-bit aligned, a 16-bit per pixel format must be 16-bit aligned, and all other pixel format must be 8-bit aligned.
In JPEG mode, the address must be aligned with a MCU.

17.5.6 DMA2D foreground offset register (DMA2D_FGOR)

Address offset: 0x044

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **LO[15:0]**: Line offset

This field gives the line offset used for the layer image, expressed:

- In pixels when LOM = 0 in DMA2D_CR. Only LO[13:0] bits are considered, LO[15:14] bits are ignored.
- In bytes when LOM = 1

This value is used for the address generation. It is added at the end of each line to determine the starting address of the next line.
When the line offset is expressed in pixel, it must be mutiple of 2 if the image format is 4-bit per pixel, multiple of 4 if the image format is 2-bit per pixel and multiple of 8 if the image format is 1-bit per pixel.

17.5.7 DMA2D foreground memory skip register (DMA2D_FGMSR)

Address offset: 0x04C

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	VTRAIL[3:0]				Res.	Res.	Res.	Res.	VPRE[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	HTRAIL[3:0]				Res.	Res.	Res.	Res.	HPRE[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **VTRAIL[3:0]**: Vertical trailing lines

In JPEG mode, this field specifies the number of lines fetched but skipped internally at the end of a surface.

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **VPRE[3:0]**: Vertical pre lines

In JPEG mode, this field specifies the number of lines fetched but skipped internally at the beginning of a surface.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **HTRAIL[3:0]**: Horizontal trailing pixels

In JPEG mode, or in A1, A2, A4 or L4 mode, this field specifies the number of pixel fetched but skipped internally at the end of a line.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **HPRE[3:0]**: Horizontal pre pixels

In JPEG mode, or in A1, A2, A4 or L4 mode, this field specifies the number of pixel fetched but skipped internally at the beginning of a line during.

17.5.8 DMA2D foreground PFC control register (DMA2D_FGPFCCR)

Address offset: 0x050

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALPHA[7:0]								Res.	APOS	RBS	AI	CSS[1:0]		AM[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CS[7:0]								Res.	Res.	START	Res.	CM[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw			rs		rw	rw	rw	rw

Bits 31:24 **ALPHA[7:0]**: Alpha value

These bits define a fixed alpha channel value which can replace the original alpha value, or be multiplied by the original alpha value, according to the alpha mode selected through AM[1:0] in this register.

Bit 23 Reserved, must be kept at reset value.

Bit 22 **APOS**: Alpha position

This bit allows to change the position of the Alpha channel.
0: Regular mode: xRGB or ARGB (default after reset)
1: Swap mode: RGBx or RGBA

Bit 21 **RBS**: Red/Blue swap

This bit allows to swap Red and Blue to support BGR or ABGR color formats.
0: Regular mode (RGB or ARGB)
1: Swap mode (BGR or ABGR)

Bit 20 **AI**: Alpha inverted
This bit inverts the alpha value.
0: Regular alpha
1: Inverted alpha

Bits 19:18 **CSS[1:0]**: Chroma sub-sampling
These bits define the chroma sub-sampling mode for JPEG color mode.
00: 4:4:4 (no chroma sub-sampling)
01: 4:2:2
10: 4:2:0
11: Reserved

Bits 17:16 **AM[1:0]**: Alpha mode
These bits select the alpha channel value to be used for the layer image.
00: No modification of the layer image alpha channel value
01: Replace original layer image alpha channel value by ALPHA[7: 0]
10: Replace original layer image alpha channel value by ALPHA[7:0] multiplied with original alpha channel value
11: Reserved

Bits 15:8 **CS[7:0]**: CLUT size
These bits define the size of the CLUT used for the layer image.
The number of CLUT entries is equal to CS[7:0] + 1.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **START**: Start
This bit can be set to start the automatic loading of the CLUT. It is automatically reset:
- At the end of the transfer
- When the transfer is aborted by the user by setting ABORT in DMA2D_CR
- When a transfer error occurs
- When the transfer has not started due to a configuration error or another transfer operation already ongoing (data transfer or automatic background CLUT transfer)

0: No automatic CLUT loading on going
1: Automatic CLUT loading on going

Bit 4 Reserved, must be kept at reset value.

Bits 3:0 **CM[3:0]**: Color mode
These bits define the color format of the layer image.
They also define the color format of the CLUT for automatic CLUT loading.
0000: ARGB8888
0001: RGB888
0010: RGB565
0011: ARGB1555
0100: ARGB4444
0101: L8
0110: AL44
0111: AL88
1000: L4
1001: A8
1010: A4
1011: JPEG
1100: A2
1101: A1
1110: ARGB2222
1111: Reserved

17.5.9 DMA2D foreground color register (DMA2D_FGCOLR)

Address offset: 0x054

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RED[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GREEN[7:0]								BLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **RED[7:0]**: Red value for the A1, A2, A4 or A8 mode of the layer image
Used also for fixed color in memory-to-memory mode with blending and fixed color layer.

Bits 15:8 **GREEN[7:0]**: Green value for the A1, A2, A4 or A8 mode of the foreground image
Used also for fixed color in memory-to-memory mode with blending and fixed color layer.

Bits 7:0 **BLUE[7:0]**: Blue value for the A1, A2, A4 or A8 mode of the foreground image
Used also for fixed color in memory-to-memory mode with blending and fixed color layer.

17.5.10 DMA2D foreground CLUT memory address register (DMA2D_FGCMAR)

Address offset: 0x058

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MA[31:0]**: Memory address

Address of the data used for the CLUT address dedicated to the layer image.
The address alignment must match the image format selected: a 32-bit per pixel format must be 32-bit aligned, a 16-bit per pixel format must be 16-bit aligned, and all other pixel format must be 8-bit aligned.

17.5.11 DMA2D background memory address register (DMA2D_BGMAR)

Address offset: 0x080

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MA[31:0]**: Memory address

Address of the data used for the layer image.
The address alignment must match the image format selected: a 32-bit per pixel format must be 32-bit aligned, a 16-bit per pixel format must be 16-bit aligned, and all other pixel format must be 8-bit aligned.
In JPEG mode, the address must be aligned with a MCU.

17.5.12 DMA2D background offset register (DMA2D_BGOR)

Address offset: 0x084

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **LO[15:0]**: Line offset

This field gives the line offset used for the background layer image, expressed:

- In pixels when LOM = 0 in DMA2D_CR. Only LO[13:0] bits are considered, LO[15:14] bits are ignored.
- In bytes when LOM = 1

This value is used for the address generation. It is added at the end of each line to determine the starting address of the next line.

When the line offset is expressed in pixel, it must be multiple of 2 If the image format is 4-bit per pixel, multiple of 4 if the image format is 2-bit per pixel and multiple of 8 if the image format is 1-bit per pixel.

17.5.13 DMA2D background memory skip register (DMA2D_BGMSR)

Address offset: 0x08C

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	VTRAIL[3:0]				Res.	Res.	Res.	Res.	VPRE[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	HTRAIL[3:0]				Res.	Res.	Res.	Res.	HPRE[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **VTRAIL[3:0]**: Vertical trailing lines

In JPEG mode, this field specifies the number of lines fetched but skipped internally at the end of a surface.

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **VPRE[3:0]**: Vertical pre lines
In JPEG mode, this field specifies the number of lines fetched but skipped internally at the beginning of a surface.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **HTRAIL[3:0]**: Horizontal trailing pixels
In JPEG mode, or in A1, A2, A4 or L4 mode, this field specifies the number of pixel fetched but skipped internally at the end of a line.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **HPRE[3:0]**: Horizontal pre pixels
In JPEG mode, or in A1, A2, A4 or L4 mode, this field specifies the number of pixel fetched but skipped internally at the beginning of a line during.

17.5.14 DMA2D background PFC control register (DMA2D_BGPFCCR)

Address offset: 0x090

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALPHA[7:0]								Res.	APOS	RBS	AI	CSS[1:0]		AM[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CS[7:0]								Res.	Res.	START	Res.	CM[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw			rs		rw	rw	rw	rw

Bits 31:24 **ALPHA[7:0]**: Alpha value
These bits define a fixed alpha channel value which can replace the original alpha value, or be multiplied by the original alpha value, according to the alpha mode selected through AM[1:0] in this register.

Bit 23 Reserved, must be kept at reset value.

Bit 22 **APOS**: Alpha position
This bit allows to change the position of the Alpha channel.
0: Regular mode: xRGB or ARGB (default after reset)
1: Swap mode: RGBx or RGBA

Bit 21 **RBS**: Red/Blue swap
This bit allows to swap Red and Blue to support BGR or ABGR color formats.
0: Regular mode (RGB or ARGB)
1: Swap mode (BGR or ABGR)

Bit 20 **AI**: Alpha inverted
This bit inverts the alpha value.
0: Regular alpha
1: Inverted alpha

Bits 19:18 **CSS[1:0]**: Chroma sub-sampling
These bits define the chroma subsampling mode for JPEG color mode.
00: 4:4:4 (no chroma subsampling)
01: 4:2:2
10: 4:2:0
11: Reserved

Bits 17:16 **AM[1:0]**: Alpha mode
These bits select the alpha channel value to be used for the layer image.
00: No modification of the laeyr image alpha channel value
01: Replace original layer image alpha channel value by ALPHA[7: 0]
10: Replace original layer image alpha channel value by ALPHA[7:0] multiplied with original alpha channel value
11: Reserved

Bits 15:8 **CS[7:0]**: CLUT size
These bits define the size of the CLUT used for the layer image.
The number of CLUT entries is equal to CS[7:0] + 1.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **START**: Start
This bit can be set to start the automatic loading of the CLUT. It is automatically reset:
- At the end of the transfer
- When the transfer is aborted by the user by setting ABORT in DMA2D_CR
- When a transfer error occurs
- When the transfer has not started due to a configuration error or another transfer operation already ongoing (data transfer or automatic background CLUT transfer)

0: No automatic CLUT loading on going
1: Automatic CLUT loading on going

Bit 4 Reserved, must be kept at reset value.

Bits 3:0 **CM[3:0]**: Color mode
These bits define the color format of the layer image.
They also define the color format of the CLUT for automatic CLUT loading.
0000: ARGB8888
0001: RGB888
0010: RGB565
0011: ARGB1555
0100: ARGB4444
0101: L8
0110: AL44
0111: AL88
1000: L4
1001: A8
1010: A4
1011: JPEG
1100: A2
1101: A1
1110: ARGB2222
1111: Reserved

17.5.15 DMA2D background color register (DMA2D_BGCOLR)

Address offset: 0x094

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RED[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GREEN[7:0]								BLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **RED[7:0]**: Red value for the A1, A2, A4 or A8 mode of the layer image
Used also for fixed color in memory-to-memory mode with blending and fixed color layer.

Bits 15:8 **GREEN[7:0]**: Green value for the A1, A2, A4 or A8 mode of the foreground image
Used also for fixed color in memory-to-memory mode with blending and fixed color layer.

Bits 7:0 **BLUE[7:0]**: Blue value for the A1, A2, A4 or A8 mode of the foreground image
Used also for fixed color in memory-to-memory mode with blending and fixed color layer.

17.5.16 DMA2D background CLUT memory address register (DMA2D_BGCMAR)

Address offset: 0x098

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MA[31:0]**: Memory address
Address of the data used for the CLUT address dedicated to the layer image.
The address alignment must match the image format selected: a 32-bit per pixel format must be 32-bit aligned, a 16-bit per pixel format must be 16-bit aligned, and all other pixel format must be 8-bit aligned.

17.5.17 DMA2D output PFC control register (DMA2D_OPFCCR)

Address offset: 0x0C0

Reset value: 0x0000 0000

This register can only be written when transfers or the command list execution are disabled. Once the CLUT transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APOS	RBS	AI	Res.	Res.	Res.	Res.
									rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	SB	Res.	Res.	Res.	Res.	CM[3:0]			
							rw					rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **APOS**: Alpha position
This bit allows to change the position of the Alpha channel.
0: Regular mode: xRGB or ARGB (default after reset)
1: Swap mode: RGBx or RGBA

Bit 21 **RBS**: Red/Blue swap
This bit allows to swap Red and Blue to support BGR or ABGR color formats.
0: Regular mode (RGB or ARGB)
1: Swap mode (BGR or ABGR)

Bit 20 **AI**: Alpha Inverted
This bit inverts the alpha value.
0: Regular alpha
1: Inverted alpha

Bits 19:9 Reserved, must be kept at reset value.

Bit 8 **SB**: Swap bytes
When this bit is set, the bytes in the output FIFO are swapped two by two. The number of pixels per line (PL) must be even, the output memory address (OMAR) must be even and the tile buffer must not be used.
0: Bytes in regular order in the output FIFO
1: Bytes swapped two by two in the output FIFO

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **CM[3:0]**: Color mode
These bits define the color format of the output image.
0000: ARGB8888
0001: RGB888
0010: RGB565
0011: ARGB1555
0100: ARGB4444
0101: Reserved
0110: Reserved
0111: Reserved
1000: Reserved
1001: Reserved
1010: Reserved
1011: Reserved
1100: Reserved
1101: Reserved
1110: ARGB2222
1111: Reserved

17.5.18 DMA2D output color register (DMA2D_OCOLR)

Address offset: 0x0C4

Reset value: 0x0000 0000

The same register is used to show the color values, with different formats depending on the color mode.

This register can only be written when transfers or the command list execution are disabled. Once a transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALPHA[7:0]								RED[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GREEN[7:0]								BLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **ALPHA[7:0]**: Alpha channel value of the output color in ARGB8888 mode (otherwise reserved)

Bits 23:16 **RED[7:0]**: Red value of the output image in ARGB8888 or RGB888 mode

Bits 15:8 **GREEN[7:0]**: Green value of the output image in ARGB8888 or RGB888

Bits 7:0 **BLUE[7:0]**: Blue value of the output image in ARGB8888 or RGB888

17.5.19 DMA2D output memory address register (DMA2D_OMAR)

Address offset: 0x0C8

Reset value: 0x0000 0000

This register can only be written when transfers or the command list execution are disabled. Once the CLUT transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MA[31:0]**: Memory address

Address of the data used for the output FIFO.
The address alignment must match the image format selected: a 32-bit per pixel format must be 32-bit aligned, a 16-bit per pixel format must be 16-bit aligned, and all other pixel format must be 8-bit aligned.

17.5.20 DMA2D output offset register (DMA2D_OOR)

Address offset: 0x0CC

Reset value: 0x0000 0000

This register can only be written when transfers or the command list execution are disabled. Once the CLUT transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **LO[15:0]**: Line offset

This field gives the line offset used for the output, expressed:

- In pixels when LOM = 0 in DMA2D_CR. Only LO[13:0] bits are considered, LO[15:14] bits are ignored.
- In bytes when LOM = 1

This value is used for the address generation. It is added at the end of each line to determine the starting address of the next line.

17.5.21 DMA2D number of line register (DMA2D_NLR)

Address offset: 0x0D0

Reset value: 0x0000 0000

This register can only be written when transfers or the command list execution are disabled. Once the CLUT transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	PL[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:16 **PL[13:0]**: Pixel per lines
Pixel per lines of the area to be transferred.

Bits 15:0 **NL[15:0]**: Number of lines
Number of lines of the area to be transferred.
This field is limited to 14-bit when the tile buffer is used with X/Y swapping.

17.5.22 DMA2D line watermark register (DMA2D_LWR)

Address offset: 0x0E0

Reset value: 0x0000 0000

This register can only be written when transfers or the command list execution are disabled. Once the CLUT transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LW[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **LW[15:0]**: Line watermark for interrupt generation
An interrupt is raised when the last pixel of the watermarked line has been transferred.

17.5.23 DMA2D AHB master timer configuration register (DMA2D_AMTCR)

Address offset: 0x0F0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DT[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	EN
rw	rw	rw	rw	rw	rw	rw	rw								rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **DT[7:0]**: Dead time

Dead time value in the AHB clock cycle inserted between two consecutive accesses on the AHB master port. These bits represent the minimum guaranteed number of cycles between two consecutive AHB accesses.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **EN**: Dead-time functionality enable

17.5.24 DMA2D stencil buffer configuration register (DMA2D_SBCR)

Address offset: 0x100

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AI	Res.	Res.	Res.	Res.
											rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE[1:0]		Res.	Res.	SRC[1:0]	
										rw	rw			rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **AI**: Alpha Inverted

This bit inverts the alpha value.

0: Regular alpha

1: Inverted alpha

Bits 19:6 Reserved, must be kept at reset value.

Bits 5:4 **MODE[1:0]**: mode
This fields selects the stencil buffer format
00: 1 bpp (default after reset)
01: 2 bpp
10: 4 bpp
11: 8 bpp

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **SRC[1:0]**: Source
This field selects the source on which shall applies the stencil buffer.
00: No stencil buffer (default after reset)
01: Foreground plane
10: Background plane
11: Blender output

17.5.25 DMA2D stencil buffer memory address register (DMA2D_SBMAR)

Address offset: 0x104

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MA[31:0]**: Memory address, address of the data used for the stencil buffer

17.5.26 DMA2D stencil buffer offset register (DMA2D_SBOR)

Address offset: 0x108

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **LO[15:0]**: Line offset

This field gives the line offset used for the stencil buffer, expressed:

- In pixels when LOM = 0 in DMA2D_CR. Only LO[13:0] bits are considered, LO[15:14] bits are ignored.
- In bytes when LOM = 1

This value is used for the address generation. It is added at the end of each line to determine the starting address of the next line.

When the line offset is expressed in pixel, it must be mutiple of 2 If the image format is 4-bit per pixel, multiple of 4 if the image format is 2-bit per pixel and multiple of 8 if the image format is 1-bit per pixel.

17.5.27 DMA2D stencil buffer memory skip register (DMA2D_SBMSR)

Address offset: 0x110

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	HTRAIL[3:0]				Res.	Res.	Res.	Res.	HPRE[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:8 **HTRAIL[3:0]**: Horizontal trailing pixels

In 1/2/4 bpp mode, this field specifies the number of pixel fetched but skipped internally at the end of a line.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **HPRE[3:0]**: Horizontal pre pixels

In 1/2/4 bpp mode, this field specifies the number of pixel fetched but skipped internally at the beginning of a line during.

17.5.28 DMA2D tile buffer configuration register (DMA2D_TBCR)

Address offset: 0x140

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XYSEN	YMEN	XMEN	Res.	Res.	SRC[1:0]	
									rw	rw	rw			rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **XYSEN**: X/Y swap enable
This bit swap X and Y when pixel are read out from the tile buffer
0: X/Y not swapped (default after reset)
1: X/Y swapped

Bit 5 **YMEN**: Y mirroring enable
This bit enables the Y mirroring when pixel are read out from the tile buffer
0: Y not mirrored (default after reset)
1: Y mirrored

Bit 4 **XMEN**: X mirroring enable
This bit enables the X mirroring when pixel are read out from the tile buffer
0: X not mirrored (default after reset)
1: X mirrored

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **SRC[1:0]**: Source
This field selects the source of the tile buffer.
00: No tile buffer (default after reset)
01: Foreground plane
10: Background plane
11: Blender output

17.5.29 DMA2D scaler configuration register (DMA2D_SCR)

Address offset: 0x180

Reset value: 0x0000 0000

This register can only be written when data transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SRC[1:0]	
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bits 1:0 **SRC[1:0]**: Source

This field selects the source of the scaler
00: Scaler is disabled (default after reset)
01: Foreground plane
10: Background plane
11: Blender output

17.5.30 DMA2D scaler number of line register (DMA2D_SNLR)

Address offset: 0x184

Reset value: 0x0000 0000

This register can only be written when transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	PL[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:16 **PL[13:0]**: Pixel per lines

Pixel per lines of the area to be scaled.

Bits 15:0 **NL[15:0]**: Number of lines

Number of lines of the area to be scaled.

17.5.31 DMA2D scaler step register (DMA2D_SSR)

Address offset: 0x188

Reset value: 0x0000 0000

This register can only be written when transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	VSTEP[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	HSTEP[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **VSTEP[11:0]**: vertical step
This field is the fractional vertical step minus one to be used by the scaler.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **HSTEP[11:0]**: horizontal step
This field is the fractional horizontal step minus one to be used by the scaler.

17.5.32 DMA2D scaler phase register (DMA2D_SPR)

Address offset: 0x18C

Reset value: 0x0000 0000

This register can only be written when transfers or the command list execution are disabled. Once the data transfer or the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	VPHASE[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	HPHASE[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **VPHASE[11:0]**: vertical phase
This field is the fractional vertical phase to be used by the scaler.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **HPHASE[11:0]**: horizontal phase
This field is the fractional horizontal phase to be used by the scaler.

17.5.33 DMA2D general purpose flag configuration register (DMA2D_GPFCR)

Address offset: 0x200

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPF3SC	GPF2SC	GPF1SC	GPF0SC
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPF3IC[1:0]		GPF2IC[1:0]		GPF1IC[1:0]		GPF0IC[1:0]	
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **GPF3SC**: General purpose flag 3 suspend configuration
This bit specifies if the general purpose flag 3 can suspend the execution of a command list.
0: No effect
1: The command list execution is suspended when GPF3 is set

Bit 18 **GPF2SC**: General purpose flag 2 suspend configuration
This bit specifies if the general purpose flag 2 can suspend the execution of a command list.
0: No effect
1: The command list execution is suspended when GPF2 is set

Bit 17 **GPF1SC**: General purpose flag 1 suspend configuration
This bit specifies if the general purpose flag 1 can suspend the execution of a command list.
0: No effect
1: The command list execution is suspended when GPF1 is set

Bit 16 **GPF0SC**: General purpose flag 0 suspend configuration
This bit specifies if the general purpose flag 0 can suspend the execution of a command list.
0: No effect
1: The command list execution is suspended when GPF0 is set

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:6 **GPF3IC[1:0]**: General purpose flag 3 interrupt configuration
This field specifies the behavior of the general purpose interrupt flag 3 (in the DMA2D_ISR) versus the event on the general purpose flag 3.
00: GPIF3 is never set
01: GPIF3 is set on a rising edge of the GPF3
10: GPIF3 is set on a falling edge of the GPF3
11: GPIF3 is set on a rising or a falling edge of the GPF3

Bits 5:4 **GPF2IC[1:0]**: General purpose flag 2 interrupt configuration
This field specifies the behavior of the general purpose interrupt flag 2 (in the DMA2D_ISR) versus the event on the general purpose flag 2.
00: GPIF2 is never set
01: GPIF2 is set on a rising edge of the GPF2
10: GPIF2 is set on a falling edge of the GPF2
11: GPIF2 is set on a rising or a falling edge of the GPF2

Bits 3:2 **GPF1IC[1:0]**: General purpose flag 1 interrupt configuration
This field specifies the behavior of the general purpose interrupt flag 1 (in the DMA2D_ISR) versus the event on the general purpose flag 1.
00: GPIF1 is never set
01: GPIF1 is set on a rising edge of the GPF1
10: GPIF1 is set on a falling edge of the GPF1
11: GPIF1 is set on a rising or a falling edge of the GPF1

Bits 1:0 **GPF0IC[1:0]**: General purpose flag 0 interrupt configuration
This field specifies the behavior of the general purpose interrupt flag 0 (in the DMA2D_ISR) versus the event on the general purpose flag 0.
00: GPIF0 is never set
01: GPIF0 is set on a rising edge of the GPF0
10: GPIF0 is set on a falling edge of the GPF0
11: GPIF0 is set on a rising or a falling edge of the GPF0

17.5.34 DMA2D general purpose flag register (DMA2D_GPFR)

Address offset: 0x204

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPF3	GPF2	GPF1	GPF0
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **GPF3**: General purpose flag 3
This bit gives the value of the general purpose flag 3
0: GPF3 is reset
1: GPF3 is set

Bit 2 **GPF2**: General purpose flag 2
This bit gives the value of the general purpose flag 2
0: GPF2 is reset
1: GPF2 is set

Bit 1 **GPF1**: General purpose flag 1
This bit gives the value of the general purpose flag 1
0: GPF1 is reset
1: GPF1 is set

Bit 0 **GPF0**: General purpose flag 0
This bit gives the value of the general purpose flag 0
0: GPF0 is reset
1: GPF0 is set

17.5.35 DMA2D general purpose flag set register (DMA2D_GPFSR)

Address offset: 0x208

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SGPF3	SGPF2	SGPF1	SGPF0
												w	w	w	w

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **SGPF3**: Set general purpose flag 3
This bit set the general purpose flag 3
0: No effect
1: Set GPF3

Bit 2 **SGPF2**: Set general purpose flag 2
This bit set the general purpose flag 2
0: No effect
1: Set GPF2

Bit 1 **SGPF1**: Set general purpose flag 1
This bit set the general purpose flag 1
0: No effect
1: Set GPF1

Bit 0 **SGPF0**: Set general purpose flag 0
This bit set the general purpose flag 0
0: No effect
1: Set GPF0

17.5.36 DMA2D general purpose flag reset register (DMA2D_GPFRR)

Address offset: 0x20C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RGPF3	RGPF2	RGPF1	RGPF0
												w	w	w	w

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **RGPF3**: Reset general purpose flag 3
This bit reset the general purpose flag 3
0: No effect
1: Reset GPF3

Bit 2 **RGPF2**: Reset general purpose flag 2
This bit reset the general purpose flag 2
0: No effect
1: Reset GPF2

Bit 1 **RGPF1**: Reset general purpose flag 1
This bit reset the general purpose flag 1
0: No effect
1: Reset GPF1

Bit 0 **RGPF0**: Reset general purpose flag 0
This bit reset the general purpose flag 0
0: No effect
1: Reset GPF0

17.5.37 DMA2D command list configuration register (DMA2D_CLCR)

Address offset: 0x240

Reset value: 0x0000 0000

This register can only be written when the command list execution is disabled. Once the the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RBS[2:0]			Res.	ABORT	SUSP	START
									rw	rw	rw		rs	rw	rs

Bits 31:7 Reserved, must be kept at reset value.

Bits 6:4 **RBS[2:0]**: Ring buffer size
This field defines the size of the ring buffer for the command list. The ring buffer size is equal to 2^{RBS+6}. The minimum size is 64 bytes (2^6) and the maximum size is 8KBytes (2^{13})
This field can be read by software anytime and can be written by software only when the command list is not active (START = 0 in the DMA2D_CLCR)

Bit 3 Reserved, must be kept at reset value.

Bit 2 **ABORT**: Abort
This bit can be used to abort the current command list. The abort is done after the completion of the current command being executed.
This bit is set by software, and is automatically reset by hardware when START = 0 in the DM2D_CLCR.
0: No command list execution abort requested
1: Command list execution abort requested

Bit 1 **SUSP**: Suspend

This bit can be used to suspend the current command list. The suspend is effective after the completion of the current command being executed.
This bit is set by software writing 1, or can be set by hardware when the suspension is caused by a GPFLAG. It can be reset by software when the command list is effectively suspended (at least one suspend bit of the DMA2D_CLSR is set).
It is automatically reset by hardware when START = 0 in the DMA2D_CLCR.
0: No command list execution suspension request
1: Command list execution suspension requested

Bit 0 **START**: Start

This bit start the execution of the ring buffer. This bit is set by software and is automatically reset by hardware when by the following events:

- At the end of the ring buffer execution
- When a command list execution is aborted by the user by setting the ABORT in the DMA2D_CLCR
- When a command list error occurs
- When a data transfer is aborted by the user by setting the ABORT in the DMA2D_CR
- When a data transfer error occurs
- When the data transfer has not started due to a configuration error

0: No ring buffer execution on going
1: Ring buffer execution on going

17.5.38 DMA2D command list status register (DMA2D_CLSR)

Address offset: 0x244

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	LCLMSE	LCLIE	LCLRE	Res.	Res.	Res.	GPF3S	GPF2S	GPF1S	GPF0S	SUSPS
					r	r	r				r	r	r	r	r

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **LCLMSE**: Linear command list multiple start error

This bit indicates that multiple start bit have been set in the same instruction of the command list.
This bit is set in conjunction with the Command list error interrupt flag (CLEIF) of the DMA2D_ISR.
This field is set by hardware and reset by software clearing the CLEIF in the DMA2D_IFCR.
0: No error
1: Linear command list multi start error occurred

Bit 9 **LCLIE**: Linear command list instruction error

This bit indicates that the END instruction of a linear command list didn't match with the linear command list size (missing or occurred before the end of the linear command list) or an illegal instruction is detected.
This bit is set in conjunction with the Command list error interrupt flag (CLEIF) of the DMA2D_ISR.
This field is set by hardware and reset by software clearing the CLEIF in the DMA2D_IFCR.
0: No error
1: Linear command list end mismatch/illegal instruction error occurred

Bit 8 **LCLRE**: Linear command list read error

This bit indicates that an error occured during a linear command list read, or a configuration error has been generated during the execution, or an abort of the current DMA2D operation has been done.
This bit is set in conjunction with the command list error interrupt flag (CLEIF) of the DMA2D_ISR.
This field is set by hardware and reset by software clearing the CLEIF in the DMA2D_IFCR.
0: No error
1: Linear command list read error occurred

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **GPF3S**: General purpose flag 3 suspend

This field indicates if the linear command list is currently suspended by a general purpose flag 3. This flag is set by hardware when the suspension is effective and is reset by hardware once the suspending general purpose flag 3 is reset.
0: The command list is not suspended
1: The command list is suspended by general purpose flag 3

Bit 3 **GPF2S**: General purpose flag 2 suspend

This field indicates if the linear command list is currently suspended by a general purpose flag 2. This flag is set by hardware when the suspension is effective and is reset by hardware once the suspending general purpose flag 2 is reset.
0: The command list is not suspended
1: The command list is suspended by general purpose flag 2

Bit 2 **GPF1S**: General purpose flag 1 suspend

This field indicates if the linear command list is currently suspended by a general purpose flag 1. This flag is set by hardware when the suspension is effective and is reset by hardware once the suspending general purpose flag 1 is reset.
0: The command list is not suspended
1: The command list is suspended by general purpose flag 1

Bit 1 **GPF0S**: General purpose flag 0 suspend

This field indicates if the linear command list is currently suspended by a general purpose flag 0. This flag is set by hardware when the suspension is effective and is reset by hardware once the suspending general purpose flag 0 is reset.
0: The command list is not suspended
1: The command list is suspended by general purpose flag 0

Bit 0 **SUSPS**: SUSP bit suspend

This field indicates if the linear command list is currently suspended by the SUSP bit. This flag is set by hardware when the suspension is effective and is reset by hardware once the suspending SUSP bit is reset.
0: The command list is not suspended
1: The command list is suspended by the SUSP bit

17.5.39 DMA2D ring buffer base address register (DMA2D_RBBAR)

Address offset: 0x250

Reset value: 0x0000 0000

This register can only be written when the command list execution is disabled. Once the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADDRESS[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDRESS[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ADDRESS[31:0]**: Address

This field defines the base address of the ring buffer.
The address must be 64-bit aligned (bit 0, 1 and 2 ignored).
It can be read by software anytime and can be written by software only when the DMA2D is not active (START = 0 in the DMA2D_CLCR)
The address is double-word aligned.

17.5.40 DMA2D ring buffer head pointer register (DMA2D_RBHPR)

Address offset: 0x254

Reset value: 0x0000 0000

This register can only be written when the command list execution is disabled. Once the command list execution started, this register is read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	HP[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bits 13:0 **HP[13:0]**: Head Pointer

This field is the head in the ring buffer.
The pointer must be 64-bit aligned (bit 0, 1 and 2 ignored).
It can be read and is updated at each command fetch to point to the next command to be fetch.
It can be read by software anytime and can be written by software only when the DMA2D is not active (START = 0 in the DMA2D_CLCR)
When this pointer is equal to the write pointer, the DMA2D is automatically stopped.

17.5.41 DMA2D ring buffer write pointer register (DMA2D_RBWPR)

Address offset: 0x258

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	WP[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bits 13:0 **WP[13:0]**: Write Pointer

This field defines the write pointer on the ring buffer.
The pointer must be 64-bit aligned (bit 0, 1 and 2 ignored).
It can be written by software only and must point to the first free slot of the command list.

17.5.42 DMA2D linear buffer current base address register (DMA2D_LBCBAR)

Address offset: 0x260

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADDRESS[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDRESS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **ADDRESS[31:0]**: Address

This field defines the base address of the linear buffer being currently executed.
It can only be read by software.

17.5.43 DMA2D linear buffer current size register (DMA2D_LBCSR)

Address offset: 0x264

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	SIZE[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **SIZE[11:0]**: Size
This field gives the size in word of the linear buffer being currently executed.
It can only be read by software.

17.5.44 DMA2D linear buffer current address register (DMA2D_LBCAR)

Address offset: 0x268

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADDRESS[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDRESS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **ADDRESS[31:0]**: Address
This field gives the address in the linear buffer of the instruction being currently executed.
It can only be read by software.

17.5.45 DMA2D foreground CLUTx (DMA2D_FGCLUTx)

Address offset: 0x400 + 0x4 * x, (x = 0 to 255)

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALPHA[7:0]								RED[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GREEN[7:0]								BLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **ALPHA[7:0]**: Alpha
Alpha value for index {x} for the foreground

Bits 23:16 **RED[7:0]**: Red
Red value for index {x} for the foreground

Bits 15:8 **GREEN[7:0]**: Green
Green value for index {x} for the foreground

Bits 7:0 **BLUE[7:0]**: Blue
Blue value for index {x} for the foreground

17.5.46 DMA2D background CLUTx (DMA2D_BGCLUTx)

Address offset: 0x800 + 0x4 * x, (x = 0 to 255)

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALPHA[7:0]								RED[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GREEN[7:0]								BLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **ALPHA[7:0]**: Alpha
Alpha value for index {x} for the background

Bits 23:16 **RED[7:0]**: Red
Red value for index {x} for the background

Bits 15:8 **GREEN[7:0]**: Green
Green value for index {x} for the background

Bits 7:0 **BLUE[7:0]**: Blue
Blue value for index {x} for the background

17.5.47 DMA2D register map

Table 160. DMA2D register map and reset values

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**DMA2D_CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE [2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOM	Res.	Res.	Res.	ABORT	SUSP	START
	Reset value														0	0	0										0				0	0	0
0x004 - 0x00C	Reserved	Res.																															
0x010	**DMA2D_ISR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPF3IF	GPF2IF	GPF1IF	GPF0IF	Res.	Res.	CLEIF	CLSIF	Res.	Res.	RBEIF	RBCIF	Res.	Res.	CEIF	CTCIF	CAEIF	TWIF	TCIF	TEIF
	Reset value													0	0	0	0			0	0			0	0			0	0	0	0	0	0
0x014	**DMA2D_IER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPF3IE	GPF2IE	GPF1IE	GPF0IE	Res.	Res.	CLEIE	CLSIE	Res.	Res.	RBEIE	RBCIE	Res.	Res.	CEIE	CTCIE	CAEIE	TWIE	TCIE	TEIE
	Reset value													0	0	0	0			0	0			0	0			0	0	0	0	0	0
0x018	**DMA2D_IFCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CGPF3IF	CGPF2IF	CGPF1IF	CGPF0IF	Res.	Res.	CCLEIF	CCLSIF	Res.	Res.	CRBEIF	CRBCIF	Res.	Res.	CCEIF	CCTCIF	CAECIF	CTWIF	CTCIF	CTEIF
	Reset value													0	0	0	0			0	0			0	0			0	0	0	0	0	0
0x01C - 0x03C	Reserved	Res.																															
0x040	**DMA2D_ FGMAR**	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x044	**DMA2D_FGOR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LO[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x048	Reserved	Res.																															
0x04C	**DMA2D_ FGMSR**	Res.	Res.	Res.	Res.	VTRAIL[3:0]				Res.	Res.	Res.	Res.	VPRE[3:0]				Res.	Res.	Res.	Res.	HTRAIL[3:0]				Res.	Res.	Res.	Res.	HPRE[3:0]			
	Reset value					0	0	0	0					0	0	0	0					0	0	0	0					0	0	0	0
0x050	**DMA2D_ FGPFCCR**	ALPHA[7:0]								Res.	APOS	RBS	AI	CSS [1:0]		AM [1:0]		CS[7:0]								Res.	Res.	START	Res.	CM[3:0]			
	Reset value	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0		0	0	0	0
0x054	**DMA2D_ FGCOLR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RED[7:0]								GREEN[7:0]								BLUE[7:0]							
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x058	**DMA2D_ FGCMAR**	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x05C - 0x07C	Reserved	Res.																															
0x080	**DMA2D_ BGMAR**	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x084	**DMA2D_BGOR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LO[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x088	Reserved	Res.																															
0x08C	**DMA2D_ BGMSR**	Res.	Res.	Res.	Res.	VTRAIL[3:0]				Res.	Res.	Res.	Res.	VPRE[3:0]				Res.	Res.	Res.	Res.	HTRAIL[3:0]				Res.	Res.	Res.	Res.	HPRE[3:0]			
	Reset value					0	0	0	0					0	0	0	0					0	0	0	0					0	0	0	0
0x090	**DMA2D_ BGPFCCR**	ALPHA[7:0]								Res.	APOS	RBS	AI	CSS [1:0]		AM [1:0]		CS[7:0]								Res.	Res.	START	Res.	CM[3:0]			
	Reset value	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0		0	0	0	0

Table 160. DMA2D register map and reset values (continued)

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x094	**DMA2D_ BGCOLR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RED[7:0]								GREEN[7:0]								BLUE[7:0]							
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x098	**DMA2D_ BGCMAR**	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x09C - 0x0BC	Reserved	Res.																															
0x0C0	**DMA2D_ OPFCCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APOS	RBS	AI	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SB	Res.	Res.	Res.	Res.	CM[3:0]			
	Reset value										0	0	0												0					0	0	0	0
0x0C4	**DMA2D_ OCOLR**	ALPHA[7:0]								RED[7:0]								GREEN[7:0]								BLUE[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C8	**DMA2D_OMAR**	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0CC	**DMA2D_OOR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LO[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0D0	**DMA2D_NLR**	Res.	Res.	PL[13:0]														NL[15:0]															
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0D4 - 0x0DC	Reserved	Reserved																															
0x0E0	**DMA2D_LWR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LW[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0E4 - 0x0EC	Reserved	Res.																															
0x0F0	**DMA2D_ AMTCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DT[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	EN
	Reset value																	0	0	0	0	0	0	0	0								0
0x0F4 - 0x0FC	Reserved	Res.																															
0x100	**DMA2D_SBCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AI	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE[1:0]		Res.	Res.	SRC [1:0]	
	Reset value												0															0	0			0	0
0x104	**DMA2D_ SBMAR**	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x108	**DMA2D_SBOR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LO[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10C	Reserved	Res.																															
0x110	**DMA2D_ SBMSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HTRAIL[3:0]				Res.	Res.	Res.	Res.	HPRE[3:0]			
	Reset value																					0	0	0	0					0	0	0	0
0x114 - 0x13C	Reserved	Res.																															
0x140	**DMA2D_TBCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XYSEN	YMEN	XMEN	Res.	Res.	SRC [1:0]	
	Reset value																										0	0	0			0	0
0x144 - 0x17C	Reserved	Res.																															
0x180	**DMA2D_SCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SRC [1:0]	
	Reset value																															0	0

Table 160. DMA2D register map and reset values (continued)

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x184	**DMA2D_SNLR**	Res.	Res.	PL[13:0]														NL[15:0]															
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x188	**DMA2D_SSR**	Res.	Res.	Res.	Res.	VSTEP[11:0]												Res.	Res.	Res.	Res.	HSTEP[11:0]											
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x18C	**DMA2D_SPR**	Res.	Res.	Res.	Res.	VPHASE[11:0]												Res.	Res.	Res.	Res.	HPHASE[11:0]											
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x190 - 0x1FC	Reserved	Res.																															
0x200	**DMA2D_ GPFCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPF3SC	GPF2SC	GPF1SC	GPF0SC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPF3IC[1:0]		GPF2IC[1:0]		GPF1IC[1:0]		GPF0IC[1:0]	
	Reset value													0	0	0	0									0	0	0	0	0	0	0	0
0x204	**DMA2D_GPFR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPF3	GPF2	GPF1	GPF0
	Reset value																													0	0	0	0
0x208	**DMA2D_ GPFSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SGPF3	SGPF2	SGPF1	SGPF0
	Reset value																													0	0	0	0
0x20C	**DMA2D_ GPFRR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RGPF3	RGPF2	RGPF1	RGPF0
	Reset value																													0	0	0	0
0x210 - 0x23C	Reserved	Res.																															
0x240	**DMA2D_CLCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RBS[2:0]			Res.	ABOTRT	SUSP	START	
	Reset value																									0	0	0		0	0	0	
0x244	**DMA2D_CLSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LCLMSE	LCLIE	LCLRE	Res.	Res.	Res.	GPF3S	GPF2S	GPF1S	GPF0S	SUSPS
	Reset value																						0	0	0				0	0	0	0	0
0x248 - 0x24C	Reserved	Res.																															
0x250	**DMA2D_ RBBAR**	ADDRESS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x254	**DMA2D_ RBHPR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HP[13:0]													
	Reset value																			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x258	**DMA2D_ RBWPR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WP[13:0]													
	Reset value																			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x25C	Reserved	Res.																															
0x260	**DMA2D_ LBCBAR**	ADDRESS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x264	**DMA2D_ LBCSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x268	**DMA2D_ LBCAR**	ADDRESS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x26C - 0x3FC	Reserved	Res.																															

Table 160. DMA2D register map and reset values (continued)

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x400 + 0x4*x, (x=0 to 255)	**DMA2D_ FGCLUTx**	ALPHA[7:0]								RED[7:0]								GREEN[7:0]								BLUE[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x800 + 0x4*x, (x=0 to 255)	**DMA2D_ BGCLUTx**	ALPHA[7:0]								RED[7:0]								GREEN[7:0]								BLUE[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

18 Graphic timer (GFXTIM)

18.1 GFXTIM introduction

The graphic timer (GFXTIM) is a graphic oriented timer allowing smart management of graphical events for frame or line counting.

18.2 GFXTIM main features

- Integrated frame and line-clock generation
- One absolute frame counter with one compare channel
- Two auto-reload relative frame counters
- One line timer with two compare channels
- External tearing-effect line management and synchronization
- Four programmable event generators with external trigger generation
- One watchdog counter

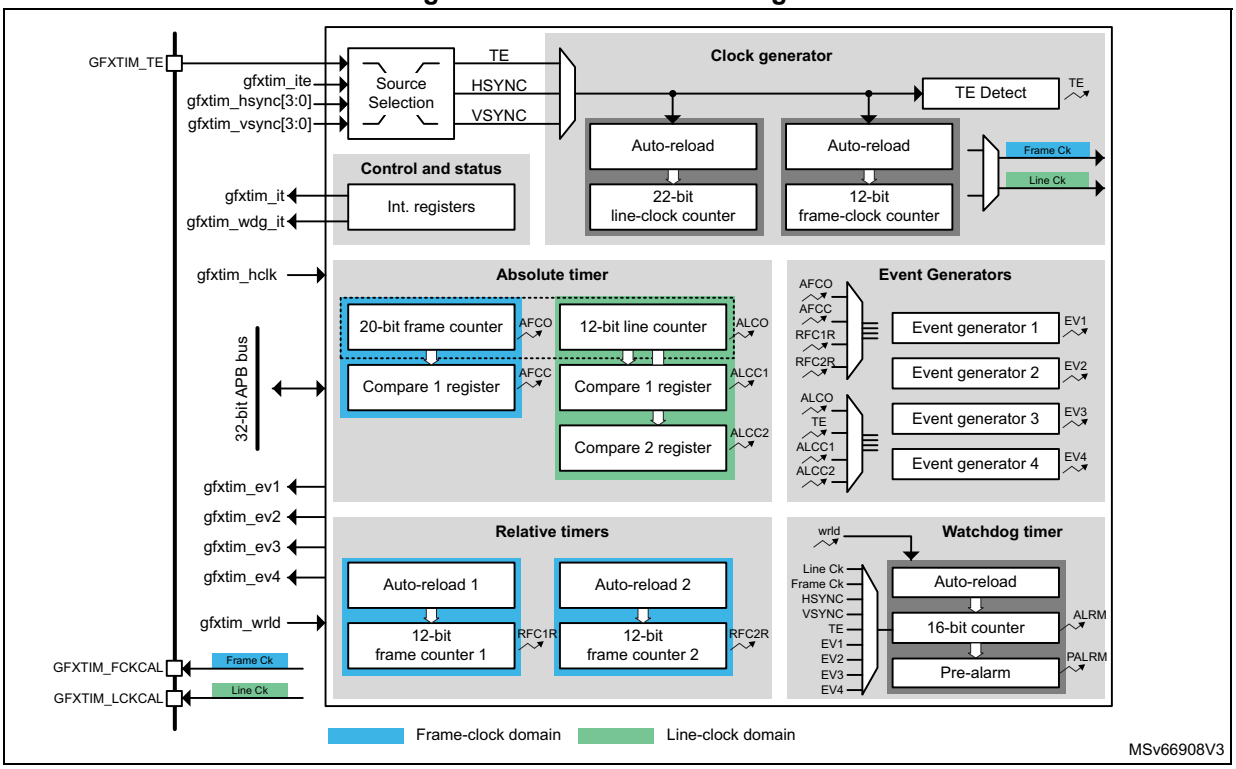
18.3 GFXTIM functional description

18.3.1 Block diagram

The graphic timer is split into six functional blocks

- Clock generator
- Absolute timers
- Relative timers
- Tearing-effect detection
- Event generators
- Watchdog timer

Figure 101. GFXTIM block diagram



18.3.2 GFXTIM pins and internal signals

Table 161. GFXTIM input/output pins

Pin name	Signal type	Description
GFXTIM_TE	Input	Tearing effect
GFXTIM_FCKCAL	Output	Frame-clock calibration output
GFXTIM_LCKCAL	Output	line-clock calibration output

Table 162. GFXTIM internal signals

Signal name	Signal type	Description
gfxtim_hclk	Digital input	Kernel and register interface clock
gfxtim_it	Digital output	Global interrupt
gfxtim_wdg_it	Digital output	Watchdog interrupt
gfxtim_ev1	Digital output	Graphic timer event 1
gfxtim_ev2	Digital output	Graphic timer event 2
gfxtim_ev3	Digital output	Graphic timer event 3
gfxtim_ev4	Digital output	Graphic timer event 4
gfxtim_wrld	Digital input	Watchdog reload
gfxtim_ite	Digital input	Internal tearing effect

Table 162. GFXTIM internal signals (continued)

Signal name	Signal type	Description
gfxtim_hsync[3:0]	Digital input	Horizontal synchronization
gfxtim_vsync[3:0]	Digital input	Vertical synchronization

The table below shows how GFXTIM triggers are connected.

Table 163. GFXTIM trigger interconnections

Trigger name	Direction	Trigger source/destination
gfxtim_ev1	Output	gpdma1_trigsel[59] gpdma2_trigsel[59]
gfxtim_ev2	Output	gpdma1_trigsel[60] gpdma2_trigsel[60]
gfxtim_ev3	Output	gpdma1_trigsel[61] gpdma2_trigsel[61]
gfxtim_ev4	Output	gpdma1_trigsel[62] gpdma2_trigsel[62]
gfxtim_wrld	Input	reserved
gfxtim_ite	Input	reserved
gfxtim_hsync[0]	Input	LCD_HSYNC
gfxtim_hsync[1]	Input	DCMI_HSYNC
gfxtim_hsync[2]	Input	reserved
gfxtim_hsync[3]	Input	reserved
gfxtim_vsync[0]	Input	LCD_VSYNC
gfxtim_vsync[1]	Input	DCMI_VSYNC
gfxtim_vsync[2]	Input	reserved
gfxtim_vsync[3]	Input	reserved

18.3.3 Clock generator

Two clocks are generated internally to fed the absolute and relative timers:

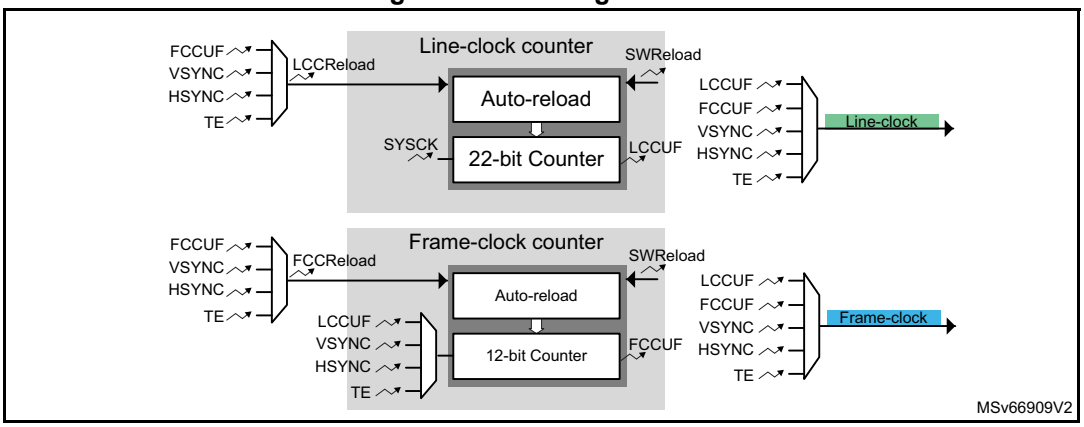
- the frame-clock: clocking frame counters
- the line-clock: clocking line counters

Internal counter for time base generation

The GFXTIM embeds a two-clock generation counter:

- a 22-bit auto-reload down-counter on the system clock
- a 12-bit auto-reload down-counter on selectable internal or external event

Figure 102. Clock generator



Line-clock counter

The line-clock counter is a 22-bit auto-reload down-counter on the system clock.

The line-clock counter is enabled selecting its clock source with LCCCS (line-clock counter clock source) in GFXTIM_CGCR (clock generator control register).

The line-clock counter can be reloaded automatically when one of the following event occurs:

- frame-clock counter underflows
- VSYNC edge (with control of polarity)
- HSYNC edge (with control of polarity)
- TE edge (with control of polarity)

The hardware reload function and source can be selected with LCCHRS (line-clock counter hardware reload source) in GFXTIM_CGCR (clock generator control register).

The line-clock counter can be reloaded by software, setting LCCFR (line-clock counter force reload) in GFXTIM_CGCR (clock generator control register).

The reload value is programmed in GFXTIM_LCCRR (line-clock counter reload register).

Frame-clock counter

The frame-clock counter if an 12-bit auto-reload down-counter clocked by either, TE, HYSNC, VSYNC or a line-clock counter underflow.

The frame-clock counter is enabled selecting its clock source with FCCCS in GFXTIM_CGCR.

The frame-clock counter can be reloaded automatically when one of the following event occurs:

- line-clock counter underflow
- VSYNC edge (with control of polarity)
- HSYNC edge (with control of polarity)
- TE edge (with control of polarity)

The hardware reload function and source can be selected with FCCHRS in GFXTIM_CGCR.

The frame-clock counter can be reloaded by software, setting FCCFR in GFXTIM_CGCR.

The reload value is programmed in GFXTIM_FCCRR.

Clock generation

The line-clock source can be one of the following:

- underflow flag of the internal 22-bit down-counter
- underflow flag of the internal 12-bit down-counter
- HSYNC, VSYNC or TE pin (with control of polarity)

The frame-clock source can be one of the following:

- underflow flag of the internal 22-bit down-counter
- underflow flag of the internal 12-bit down-counter
- HSYNC, VSYNC or TE pin (with control of polarity)

Clock calibration output

For calibration/debug purpose, the frame-clock and line-clock can be output on a specific I/O.

The frame-clock calibration output is enabled by setting FCCOE (frame-clock calibration output enable) in GFXTIM_CR (configuration register).

The line-clock calibration output is enabled by setting LCCOE in GFXTIM_CR.

Synchronization and tearing-effect sources

The GFXTIM can be connected to peripherals providing HSYNC and/or VSYNC synchronization signals, like the LCD-TFT controller or the camera interface.

The source of HSYNC and/or VSYNC is selected through SYNCS (synchronization source) in GFXTIM_CR.

The tearing-effect source can be an external pin or can be provided by the MIPI® DSI Host on system embedding this interface. To extend the orthogonality versus the synchronization signals, the tearing-effect source can be also the selected HSYNC or VSYNC input.

The tearing-effect source can be selected with TES (TE source) in GFXTIM_CR.

18.3.4 Example of clock generator configuration

The clock generator can have several configuration to work:

- in standalone (without any external synchronization)
- with external HSYNC and VSYNC
- with external HSYNC only
- with external VSYNC only
- with external CSYNC (TE) only

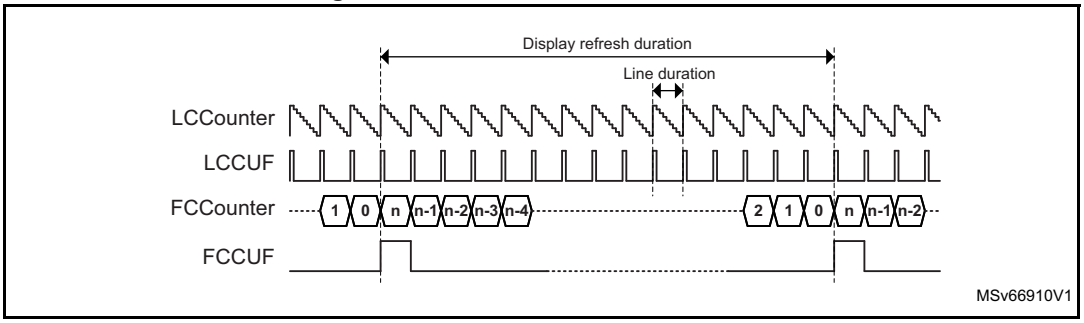
The synchronization signals, HSYNC, VSYNC and TE, are symmetrical in the implementation and can be exchanged if needed.

The set of examples detailed below are given for reference, but other combinations can be programmed int the clock generator.

Standalone

In standalone configuration, the clock generator provides to the GFXTIM, the frame-clock and the line-clock without any external signals.

Figure 103. Waveforms in standalone

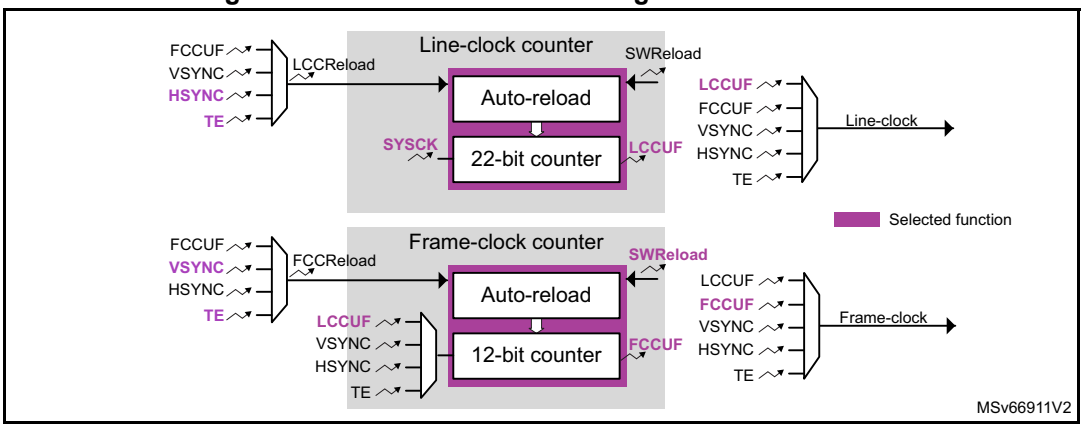


The LCCUF (line-clock counter underflow) event acts as line-clock and the FCCUF (frame-clock counter underflow) acts as frame-clock.

The clock generator can be synchronized by one of the following ways:

- by software reload, setting the FCCFR in GFXTIM_CGCR.
- by hardware reload on an external VSYNC (or TE)

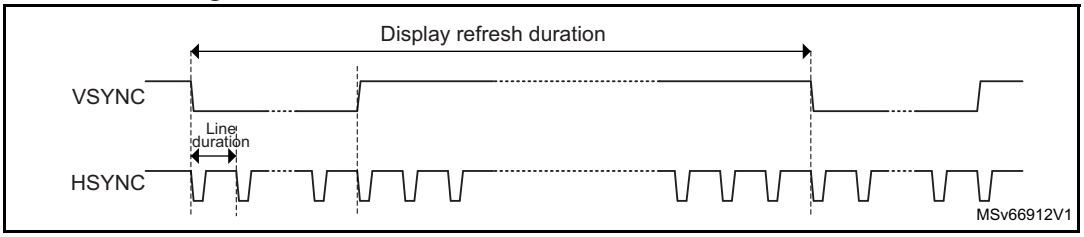
Figure 104. Active counters and signals in standalone



External HSYNC and VSYNC

When using external HSYNC and VSYNC, the counters are not used for the line and frame-clock generation. The clock generator copy directly HSYNC to the line-clock and VSYNC to the frame-clock.

Figure 105. Waveforms with external HSYNC and VSYNC

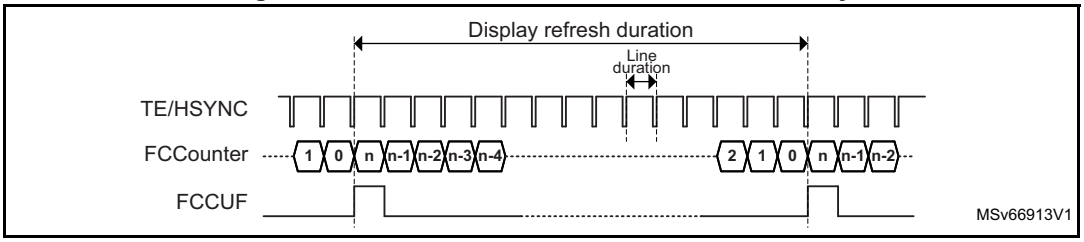


HSYNC acts as line-clock and VSYNC acts as frame-clock.

External HSYNC only

With external HSYNC only, the clock generator provides to the GFXTIM, the frame-clock and the line-clock based only on HSYNC.

Figure 106. Waveforms with external HSYNC only

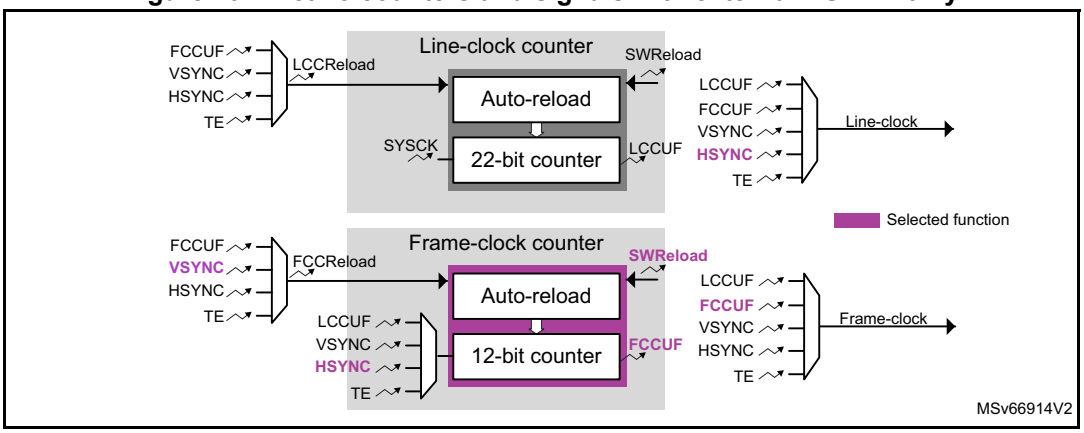


HSYNC acts as line-clock and FCCUF acts as frame-clock.

The clock generator can be synchronized by one of the following ways:

- by software reload, setting FCCFR in GFXTIM_CGCR
- by hardware reload on an external VSYNC (or TE)

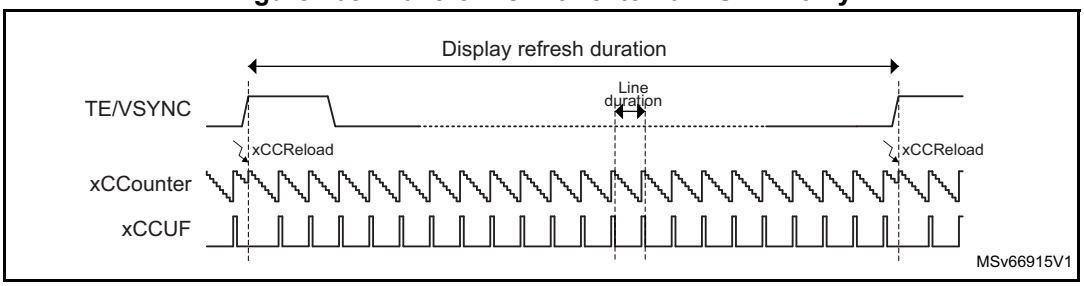
Figure 107. Active counters and signals with external HSYNC only



External VSYNC only

With external VSYNC only, the clock generator provides to the GFXTIM, the frame-clock and the line-clock based only on VSYNC.

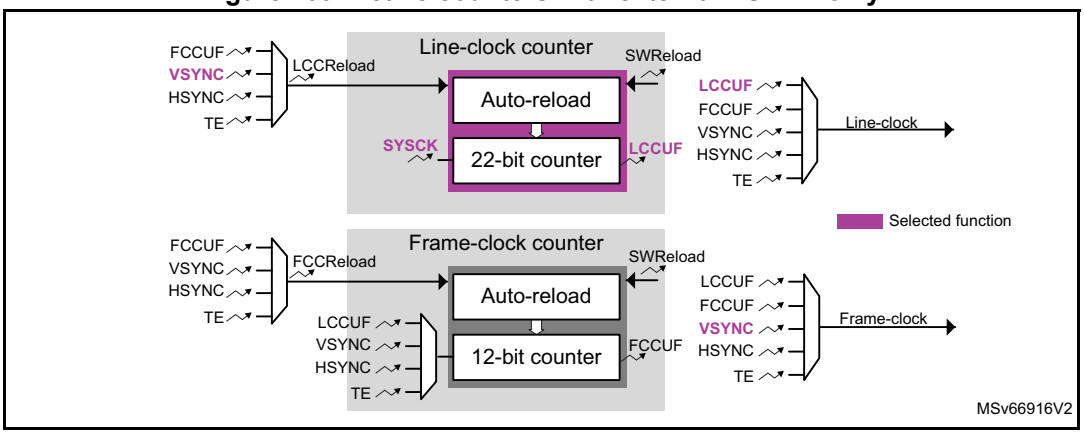
Figure 108. Waveforms with external VSYNC only



LCCUF (line-clock counter underflow) acts as line-clock and VSYNC acts as frame-clock.

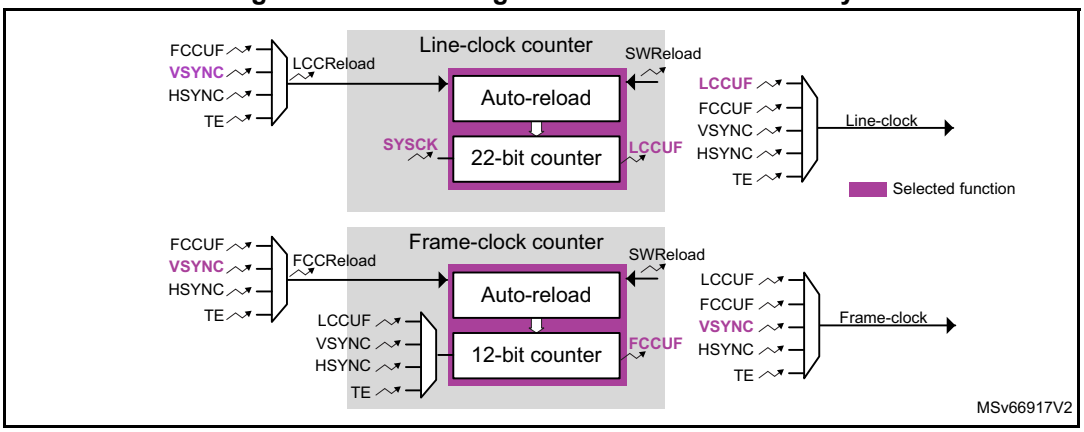
The line-clock counter generating the line-clock is reloaded on VSYNC event.

Figure 109. Active counters with external VSYNC only



The line-clock counter can also act as a prescaler for the frame-clock counter to have a wider range of counting. FCCUF acts as line-clock.

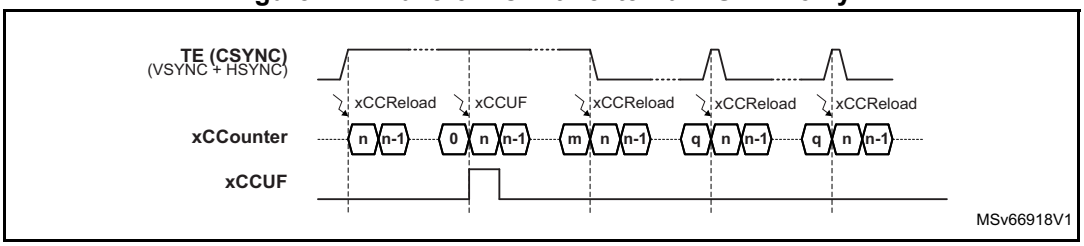
Figure 110. Prescaling when external VSYNC only



External CSYNC only

With external CSYNC only, the clock generator provides to the GFXTIM, the frame-clock and the line-clock based only on CSYNC (in the following figures, CSYNC is input on TE).

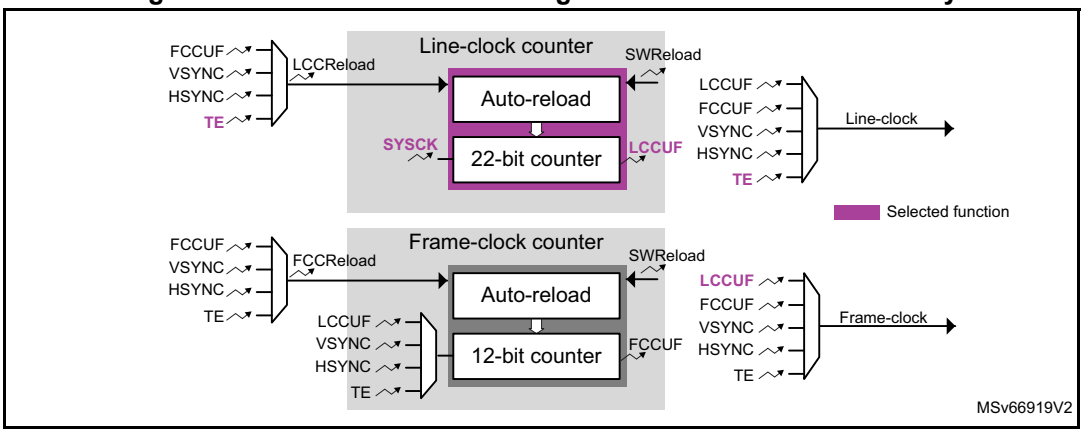
Figure 111. Waveforms with external CSYNC only



The CSYNC (on TE pin in this example) acts as line-clock and LCCUF acts as frame-clock.

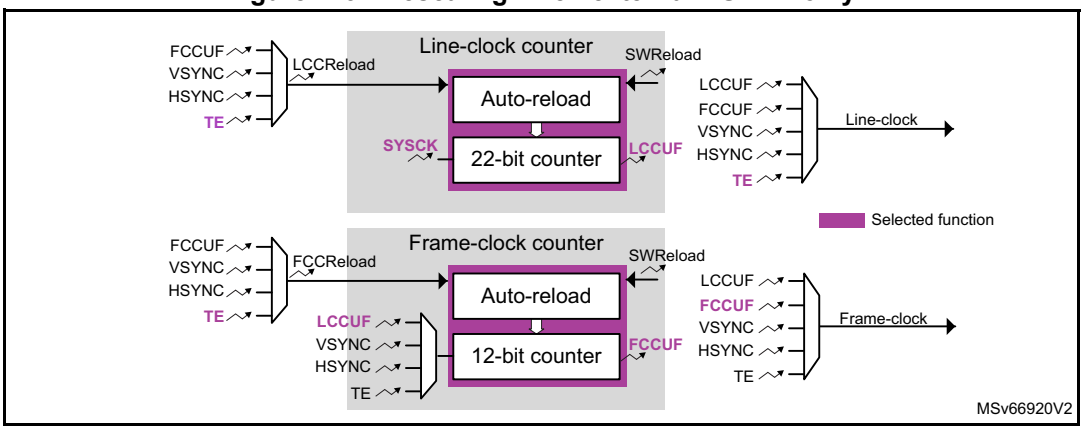
The line-clock counter generating the frame-clock is reloaded on CSYNC event.

Figure 112. Active counters and signals with external CSYNC only



The line-clock counter can also act as a prescaler for the frame-clock counter to have a wider range of counting. FCCUF acts as frame-clock.

Figure 113. Prescaling when external CSYNC only



18.3.5 Absolute timers

Absolute time

The absolute time 32-bit value can be read directly in GFXTIM_ATR (absolute time register) to provide a global time and to generate absolute time accurate event to synchronize the graphical software.

The absolute time is generated by the combination of:

- the absolute frame counter
- the absolute line counter

Absolute frame counter

The absolute frame counter is a 20-bit free running up-counter with a software controlled reset.

It can be enabled by writing 1 in AFCEN (absolute-frame counter enable) of GFXTIM_TCR (timers configuration register).

The counter is incremented at each rising edge of the frame-clock and is reset by setting FAFCR (force absolute-frame counter reset) in GFXTIM_TCR.

In case of overflow of the absolute frame counter, AFCOF (overflow flag) is set in GFXTIM_ISR (interrupt status register), and an interrupt is generated if AFCOIE (overflow interrupt enable) is set in (interrupt enable register).

A 20-bit compare register can generate an absolute-frame counter compare event when the counter value matches the compare value. When a compare event occurs, AFCC1F (compare 1 flag) is set in GFXTIM_ISR, and an interrupt is generated if AFCC1IE (compare 1 interrupt enable) is set in GFXTIM_IER.

The absolute frame counter can be disabled by writing 1 in AFCDIS (counter disable) of GFXTIM_TDR (timers disable register).

The status (enabled/disabled) can be monitored through AFCS (counter status) in GFXTIM_TSR (timers status register).

Absolute line counter

The absolute line counter is 12-bit free running-up counter with an hardware controlled reset.

It can be enabled by writing 1 in ALCEN of GFXTIM_TCR.

The counter is incremented at each rising edge of the line-clock an is reset at each rising edge of the frame-clock or setting FALCR in GFXTIM_TCR).

In case of overflow of the absolute line counter, ALCOF is set in GFXTIM_ISR, and an interrupt is generated if ALCOIE is set in GFXTIM_IER.

Two 12-bit compare registers can generate an absolute line counter compare events when the counter value matches the compare value. When a compare event occurs, ALCC1F or ALCC2F is set in GFXTIM_ISR, and an interrupt is generated if ALCC1IE or ALCC2IE is set in GFXTIM_IER.

The absolute line counter can be disabled writing 1 in ALCDIS of GFXTIM_TDR.

The status (enabled/disabled) can be monitored through ALCS in GFXTIM_TSR.

18.3.6 Relative timers

The relative timers can generate periodic events to synchronize the graphical tasks at frame level.

The relative frame counters are 12-bit down-counting auto-reload timers that are decremented at each rising edge of the frame-clock. The counter is started by writing 1 in RFCxEN (relative frame counter x enable) of GFXTIM_TCR. The starting value is automatically loaded from GFXTIM_RFCxRR (relative frame counter x reload register).

The current relative frame counter value can be read directly in GFXTIM_RFCxR.

Once the counter reaches zero, it is automatically reloaded with the value of GFXTIM_RFCxRR. RFCxRF (reload flag) is set in GFXTIM_ISR is set, and an interrupt is generated if RFCxRIE (interrupt enable) is set in GFXTIM_IER.

Once the reload operation occurs, the timer can be disabled automatically or continue counting if RFCxCM (continuous mode) is set in GFXTIM_TCR.

The status (enabled/disabled) can be monitored through RFCxS in GFXTIM_TSR.

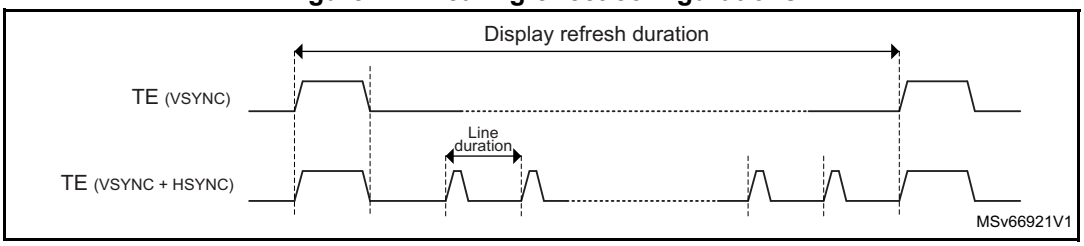
The counter can be reloaded on the fly by setting FRFCRx in GFXTIM_TCR. This force reload neither stop the timer (even if RFCxCM = 0 in GFXTIM_TCR), nor set RFCxRF (reload flag) in GFXTIM_ISR.

The relative frame counter can be disabled by setting RFCxDIS (disable) in GFXTIM_TDR.

18.3.7 Tearing-effect detection

A tearing-effect line can work in one of the two configurations shown in the figure below.

Figure 114. Tearing-effect configurations



A tearing-effect event can be generated on rising or falling edge depending on TEPOL (tearing-effect polarity) in GFXTIM_CR.

When a tearing-effect event is detected, TEF (tearing-event flag) is set in GFXTIM_ISR, and an interrupt is generated if TEIE (interrupt enable) is set in GFXTIM_IER.

18.3.8 Event generator

The event generator can combine timer events into complex events. Up to four combined events can be generated.

The events can be used for:

- interrupt generation
- watchdog clocking
- external trigger generation

A complex event is a combination between a frame event and a line event.

Once a frame event occurs, the GFXTIM waits for the line event to occur before generating the complex event.

The frame event is selected by the corresponding FESx (frame event selection x) in GFXTIM_EVSR (events selection y register). The line event is selected by the corresponding LESx in GFXTIM_EVSR.

The complex event generation is enabled by setting the corresponding EVxEN (event x enable) in GFXTIM_EVCR (event control register).

It is recommended to disable the event generation prior to any event configuration to avoid spurious complex event generation

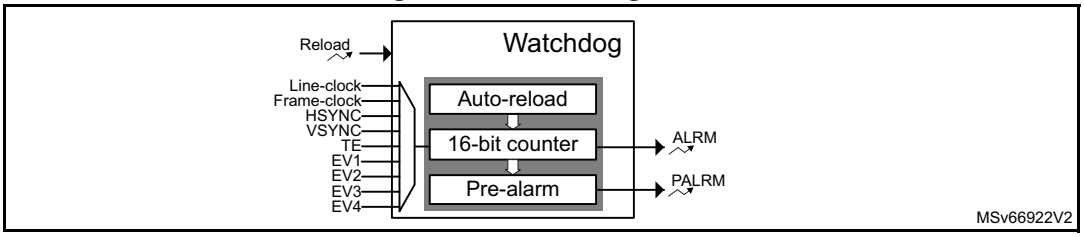
When a complex event occurs, the corresponding EVxF (event x flag) is set in GFXTIM_ISR, and an interrupt is generated if EVxIE (event x interrupt enable) is set in GFXTIM_IER.

Each of the events can be connected to another peripherals (such as DMA) to generate hardware triggers.

18.3.9 Watchdog timer

The watchdog timer is a 16-bit auto-reload down-counter with a programmable clock source.

Figure 115. Watchdog timer



Clock source

The watchdog clock source can be selected through WDGCS (clock source) in GTXTIM_WDGTCR (watchdog timer configuration register), between one of the following:

- line-clock
- frame-clock
- HSYNC
- VSYNC
- TE
- event 1
- event 2
- event 3
- event 4

Startup

The watchdog is started by setting WDGEN in GFXTIM_WDGTCR and stops automatically when reaching 0.

On start, the watchdog counter is automatically loaded with the auto-reload value programmed in GFXTIM_WDGRR (watchdog reload register).

The current watchdog value can be read through GFXTIM_WDGCR.

Auto-reload

The auto-reload can be forced in one of the following ways:

- by software, setting FWDGR (force watchdog reload) in GTXTIM_WDGTCR (watchdog timer configuration register)
- by hardware through an external trigger (gfxtim_wrld signal)

  The polarity of the trigger is configured by WDGHRC (watchdog hardware reload configuration) in GFXTIM_WDGTCR.

Event and interrupt generation

The watchdog can generate two events:

- an alarm when the watchdog down-counter reaches 0

  The watchdog counter is automatically stopped, and WDGAF (alarm flag) is set in GFXTIM_ISR. An interrupt is generated if WDGAIE (alarm interrupt enable) is set in GFXTIM_IER.
- a pre-alarm when the watchdog counter matches the pre-alarm register value in GFXTIM_WDGPAR (watchdog pre-alarm register)

  WDGPF (pre-alarm flag) is set in GFXTIM_ISR, and an interrupt is generated if WDGPIE (pre-alarm interrupt enable) is set in GFXTIM_IER.

18.4 GFXTIM interrupts

An interrupt can be produced on the following events:

- absolute frame counter compare event
- absolute frame counter overflow
- absolute line counter compare events
- absolute line counter overflow
- relative frame counter reload events
- external tearing effect
- combined events
- watchdog alarm event
- watchdog pre-alarm event

Separate interrupt enable bits are available for flexibility.

Table 164. Graphic timer interrupt requests

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method
GFXTIM	Absolute frame counter overflow	AFCOF	AFCOIE	write 1 in CAFCOF
	Absolute frame counter compare 1	AFCC1F	AFCC1IE	write 1 in CAFCC1F
	Absolute line counter overflow	ALCOF	ALCOIE	write 1 in CALCOF
	Absolute line counter compare 1	ALCC1F	ALCC1IE	write 1 in CALCC1F
	Absolute line counter compare 2	ALCC2F	ALCC2IE	write 1 in CALCC2F
	Relative frame counter 1 reload	RFC1RF	RFC1RIE	write 1 in CRFC1RF
	Relative frame counter 2 reload	RFC2RF	RFC2RIE	write 1 in CRFC2RF
	External tearing effect	TEF	TEIE	write 1 in CTEF
	Event 1	EV1F	EV1IE	write 1 in CEV1F
	Event 2	EV2F	EV2IE	write 1 in CEV2F
	Event 3	EV3F	EV3IE	write 1 in CEV3F
	Event 4	EV4F	EV4IE	write 1 in CEV4F

Table 164. Graphic timer interrupt requests (continued)

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method
GFXTIM_WDG	Watchdog alarm	WDGAF	WDGAIE	write 1 in CWDGAF
	Watchdog pre-alarm	WDGPF	WDGPIE	write 1 in CWDGPF

18.5 GFXTIM registers

18.5.1 GFXTIM configuration register (GFXTIM_CR)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LCCOE	FCCOE
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	SYNCS[1:0]		Res.	Res.	Res.	TEPOL	Res.	Res.	TES[1:0]	
						rw	rw				rw			rw	rw

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **LCCOE**: Line-clock calibration output enable
This bit enables the line-clock output.
0: Line-clock output disabled
1: Line-clock output enabled

Bit 16 **FCCOE**: Frame-clock calibration output enable
This bit enables the frame-clock output.
0: Frame-clock output disabled
1: Frame-clock output enabled

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **SYNCS[1:0]**: Synchronization source
This bitfield selects the synchronization signals (HSYNC and VSYNC) sources.
00: gfxtim_hsync[0] and gfxtim_vsync[0] selected
01: gfxtim_hsync[1] and gfxtim_vsync[1] selected
10: gfxtim_hsync[2] and gfxtim_vsync[2] selected
11: gfxtim_hsync[3] and gfxtim_vsync[3] selected

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **TEPOL**: Tearing--effect polarity
This bit selects the tearing-effect polarity.
0: Tearing effect active on rising edge
1: Tearing effect active on falling edge

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **TES[1:0]**: Tearing source
This bitfield selects the tearing-effect source.
00: TE input pad selected
01: gfxtim_ite selected
10: HSYNC input selected by SYNCS[1:0]
11: VSYNC input selected by SYNCS[1:0]

18.5.2 GFXTIM clock generator configuration register (GFXTIM_CGCR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	FCCHRS[2:0]			Res.	Res.	Res.	FCCFR	Res.	FCCCS[2:0]			Res.	FCS[2:0]		
	rw	rw	rw				w		rw	rw	rw		rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	LCCHRS[2:0]			Res.	Res.	Res.	LCCFR	Res.	Res.	Res.	LCCCS	Res.	LCS[2:0]		
	rw	rw	rw				w				rw		rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:28 **FCCHRS[2:0]**: Frame-clock counter hardware reload source
This bitfield configures the hardware reload source for the frame-clock counter.
000: No hardware reload
001: Line- -clock counter underflow
010: HSYNC rising edge
011: HSYNC falling edge
100: VSYNC rising edge
101: VSYNC falling edge
110: TE rising edge
111: TE falling edge

Bits 27:25 Reserved, must be kept at reset value.

Bit 24 **FCCFR**: Frame-clock counter force reload
This bit forces frame-clock counter reload
0: No effect
1: Frame-clock counter reload forced

Bit 23 Reserved, must be kept at reset value.

Bits 22:20 **FCCCS[2:0]**: Frame-clock counter clock source
This bitfield configures the clock source for the frame-clock counter.
000: Frame-clock counter disabled
001: Line-clock counter underflow
010: HSYNC rising edge
011: HSYNC falling edge
100: VSYNC rising edge
101: VSYNC falling edge
110: TE rising edge
111: TE falling edge

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **FCS[2:0]**: Frame-clock source
This bitfield configures the frame-clock source.
000: Line-clock counter underflow
001: Frame-clock counter underflow
010: HSYNC rising edge
011: HSYNC falling edge
100: VSYNC rising edge
101: VSYNC falling edge
110: TE rising edge
111: TE falling edge

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **LCCHRS[2:0]**: Line-clock counter hardware reload source
This bitfield configures the hardware reload source for the line-clock counter.
000: No hardware reload
001: Frame-clock counter underflow
010: HSYNC rising edge
011: HSYNC falling edge
100: VSYNC rising edge
101: VSYNC falling edge
110: TE rising edge
111: TE falling edge

Bits 11:9 Reserved, must be kept at reset value.

Bit 8 **LCCFR**: Line-clock counter force reload
This bit forces line-clock counter reload.
0: No effect
1: Line-clock counter reload forced

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **LCCCS**: Line-clock counter clock source
This bit configures the clock source for the line-clock counter.
0: Line-clock counter disabled
1: System clock selected

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **LCS[2:0]**: Line-clock source
This bitfield configures the line-clock source.
000: Line-clock counter underflow
001: Frame-clock counter underflow
010: HSYNC rising edge
011: HSYNC falling edge
100: VSYNC rising edge
101: VSYNC falling edge
110: TE rising edge
111: TE falling edge

18.5.3 GFXTIM timers configuration register (GFXTIM_TCR)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRFC2R	RFC2CM	RFC2EN	Res.	FRFC1R	RFC1CM	RFC1EN
									w	rw	w		w	rw	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FALCR	ALCEN	Res.	Res.	FAFCR	AFCEN
										w	w			w	w

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **FRFC2R**: Force relative frame counter 2 reload
This bit forces the reload of the relative frame counter 2.
0: No effect
1: Relative frame counter 2 reload forced

Bit 21 **RFC2CM**: Relative frame counter 2 continuous mode
This bit enables the continuous mode of the relative frame counter 2.
0: Relative frame counter 2 is one shot.
1: Relative frame counter 2 is in continuous mode.

Bit 20 **RFC2EN**: Relative frame counter 2 enable
This bit enables the relative frame counter 2.
0: No effect
1: Relative frame counter 2 enabled

Bit 19 Reserved, must be kept at reset value.

Bit 18 **FRFC1R**: Force relative frame counter 1 reload
This bit forces the reload of the relative frame counter 1.
0: No effect
1: Relative frame counter 1 reload forced

Bit 17 **RFC1CM**: Relative frame counter 1 continuous mode
This bit enables the continuous mode of the relative frame counter 1.
0: Relative frame counter 1 is one shot.
1: Relative frame counter 1 is in continuous mode.

Bit 16 **RFC1EN**: Relative frame counter 1 enable
This bit enables the relative frame counter 1.
0: No effect
1: Relative frame counter enabled

Bits 15:6 Reserved, must be kept at reset value.

Bit 5 **FALCR**: Force absolute line counter reset
This bit forces the reset of the absolute line counter.
0: No effect
1: Absolute line counter reset forced

Bit 4 **ALCEN**: Absolute line counter enable
This bit enables the absolute line counter.
0: No effect
1: Absolute line counter enabled

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **FAFCR**: Force absolute frame counter reset
This bit forces the reset of the absolute frame counter.
0: No effect
1: Absolute frame counter reset forced

Bit 0 **AFCEN**: Absolute frame counter enable
This bit enables the absolute frame counter.
0: No effect
1: Absolute frame counter enabled

18.5.4 GFXTIM timers disable register (GFXTIM_TDR)

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFC2DIS	Res.	Res.	Res.	RFC1DIS
											w				w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALCDIS	Res.	Res.	Res.	AFCDIS
											w				w

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **RFC2DIS**: Relative frame counter 2 disable
This bit disables the relative frame counter 2.
0: No effect
1: Relative frame counter 2 disabled

Bits 19:17 Reserved, must be kept at reset value.

Bit 16 **RFC1DIS**: Relative frame counter 1 disable
This bit disables the relative frame counter 1.
0: No effect
1: Relative frame counter 1 disabled

Bits 15:5 Reserved, must be kept at reset value.

Bit 4 **ALCDIS**: Absolute line counter disable
This bit disables the absolute line counter.
0: No effect
1: Absolute line counter disabled

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **AFCDIS**: Absolute frame counter disable
This bit disables the absolute frame counter.
0: No effect
1: Absolute frame counter disabled

18.5.5 GFXTIM events control register (GFXTIM_EVCR)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EV4EN	EV3EN	EV2EN	EV1EN
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **EV4EN**: Event 4 enable
This bit enables the complex event 4 generation.
0: Event 4 generation disabled
1: Event 4 generation enabled

Bit 2 **EV3EN**: Event 3 enable
This bit enables the complex event 3 generation.
0: Event 3 generation disabled
1: Event 3 generation enabled

Bit 1 **EV2EN**: Event 2 enable
This bit enables the complex event 2 generation.
0: Event 2 generation disabled
1: Event 2 generation enabled

Bit 0 **EV1EN**: Event 1 enable
This bit enables the complex event 1 generation.
0: Event 1 generation disabled
1: Event 1 generation enabled

18.5.6 GFXTIM events selection register (GFXTIM_EVSR)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	FES4[2:0]			Res.	LES4[2:0]			Res.	FES3[2:0]			Res.	LES3[2:0]		
	rw	rw	rw		rw	rw	rw		rw	rw	rw		rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	FES2[2:0]			Res.	LES2[2:0]			Res.	FES1[2:0]			Res.	LES1[2:0]		
	rw	rw	rw		rw	rw	rw		rw	rw	rw		rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:28 **FES4[2:0]**: Frame-event selection 4
This bitfield defines the frame-event selection for complex event 4 generation.
000: No frame event
001: Absolute frame counter overflow
010: Absolute frame counter compare
100: Relative frame counter 1 reload
101: Relative frame counter 2 reload
Others: Reserved

Bit 27 Reserved, must be kept at reset value.

Bits 26:24 **LES4[2:0]**: Line-event selection 4
This bitfield defines the line-event selection for complex event 4 generation.
000: No line event
001: Absolute line counter overflow
010: Tearing effect
100: Absolute line counter 1 compare
101: Absolute line counter 2 compare
Others: Reserved

Bit 23 Reserved, must be kept at reset value.

Bits 22:20 **FES3[2:0]**: Frame-event selection 3
This bitfield defines the frame-event selection for complex event 3 generation.
000: No frame event
001: Absolute frame counter overflow
010: Absolute frame counter compare
100: Relative frame counter 1 reload
101: Relative frame counter 2 reload
Others: Reserved

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **LES3[2:0]**: Line-event selection 3
This bitfield defines the line-event selection for complex event 3 generation.
000: No line event
001: Absolute line counter overflow
010: Tearing effect
100: Absolute line counter 1 compare
101: Absolute line counter 2 compare
Others: Reserved

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **FES2[2:0]**: Frame-event selection 2
This bitfield defines the frame-event selection for complex event 2 generation.
000: No frame event
001: Absolute frame counter overflow
010: Absolute frame counter compare
100: Relative frame counter 1 reload
101: Relative frame counter 2 reload
Others: Reserved

Bit 11 Reserved, must be kept at reset value.

Bits 10:8 **LES2[2:0]**: Line-event selection 2
This bitfield defines the line-event selection for complex event 2 generation.
000: No line event
001: Absolute line counter overflow
010: Tearing effect
100: Absolute line counter 1 compare
101: Absolute line counter 2 compare
Others: Reserved

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **FES1[2:0]**: Frame-event selection 1
This bitfield defines the frame-event selection for complex event 1 generation.
000: No frame event
001: Absolute frame counter overflow
010: Absolute frame counter compare
100: Relative frame counter 1 reload
101: Relative frame counter 2 reload
Others: Reserved

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **LES1[2:0]**: Line-event selection 1
This bitfield defines the line-event selection for complex event 1 generation.
000: No line event
001: Absolute line counter overflow
010: Tearing effect
100: Absolute line counter 1 compare
101: Absolute line counter 2 compare
Others: Reserved

18.5.7 GFXTIM watchdog timer configuration register (GFXTIM_WDGTCR)

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FWDGR
															w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	WDGCS[3:0]				Res.	Res.	WDGHRC[1:0]		Res.	WDGS	WDGDIS	WDGEN
				rw	rw	rw	rw			rw	rw		r	w	w

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **FWDGR**: Force watchdog reload
This bit forces the reload of the graphic watchdog.
0: nNo effect
1: Graphic watchdog reload forced

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **WDGCS[3:0]**: Watchdog clock source
This bitfield selects the watchdog clock source.
0000: Line-clock
0001: Frame-clock
0010: HSYNC rising edge
0011: HSYNC falling edge
0100: VSYNC rising edge
0101: VSYNC falling edge
0110: TE rising edge
0111: TE falling edge
1000: Event 1
1001: Event 2
1010: Event 3
1011: Event 4
Others: Reserved

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **WDGHRC[1:0]**: Watchdog hardware reload configuration
This bitfield configures the watchdog hardware reload.
00: Watchdog hardware reload disabled
01: Watchdog reloaded a rising edge of gfxtim_wrld
10: Watchdog reloaded a falling edge of gfxtim_wrld
11: Reserved

Bit 3 Reserved, must be kept at reset value.

Bit 2 **WDGS**: Watchdog status
This bit returns the status of the graphic watchdog.
0: Graphic watchdog disabled
1: Graphic watchdog enabled

Bit 1 **WDGDIS**: Watchdog disable
This bit disables the graphic watchdog.
0: No effect
1: Graphic watchdog disabled

Bit 0 **WDGEN**: Watchdog enable
This bit enables the graphic watchdog.
0: No effect
1: Graphic watchdog enabled

18.5.8 GFXTIM interrupt status register (GFXTIM_ISR)

Address offset: 0x030

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	WDGPF	WDGAF	Res.	Res.	Res.	Res.	EV4F	EV3F	EV2F	EV1F
						r	r					r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	RFC2RF	RFC1RF	Res.	Res.	ALCC2F	ALCC1F	Res.	Res.	Res.	AFCC1F	Res.	TEF	ALCOF	AFCOF
		r	r			r	r				r		r	r	r

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **WDGPF**: Watchdog pre-alarm flag
This bit indicates that a graphic watchdog pre-alarm occurred.
0: No graphic watchdog pre-alarm occurred.
1: A graphic watchdog pre-alarm occurred.

Bit 24 **WDGAF**: Watchdog alarm flag
This bit indicates that a graphic watchdog alarm occurred.
0: No graphic watchdog alarm occurred.
1: A graphic watchdog alarm occurred.

Bits 23:20 Reserved, must be kept at reset value.

Bit 19 **EV4F**: Event 4 flag
This bit indicates a complex event 4 occurred.
0: No complex event 4 occurred.
1: A complex event 4 occurred.

Bit 18 **EV3F**: Event 3 flag
This bit indicates a complex event 3 occurred.
0: No complex event 3 occurred.
1: A complex event 3 occurred.

Bit 17 **EV2F**: Event 2 flag
This bit indicates a complex event 2 occurred.
0: No complex event 2 occurred.
1: A complex event 2 occurred.

Bit 16 **EV1F**: Event 1 flag
This bit indicates a complex event 1 occurred.
0: No complex event 1 occurred.
1: Complex event 1 occurred.

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **RFC2RF**: Relative frame counter 2 reload flag
This bit indicates relative frame counter 2 has been reloaded.
0: No reload occurred on relative frame counter 2.
1: A reload on relative frame counter 2 occurred.

Bit 12 **RFC1RF**: Relative frame counter 1 reload flag
This bit indicates relative frame counter 1 has been reloaded.
0: No reload occurred on relative frame counter 1.
1: A reload on relative frame counter 1 occurred.

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **ALCC2F**: Absolute line counter compare 2 flag
This bit indicates match on compare 2 of the absolute line counter.
0: No match occurred on compare 2 of the absolute line counter.
1: A match on compare 2 of the absolute line counter occurred.

Bit 8 **ALCC1F**: Absolute line counter compare 1 flag
This bit indicates match on compare 1 of the absolute line counter.
0: No match occurred on compare 1 of the absolute line counter.
1: A match on compare 1 of the absolute line counter occurred.

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **AFCC1F**: Absolute frame counter compare 1 flag
This bit indicates match on compare 1 of the absolute frame counter.
0: No match occurred on compare 1 of the absolute frame counter.
1: A match on compare 1 of the absolute frame counter occurred.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **TEF**: Tearing-effect flag
This bit indicates a tearing effect event occurred.
0: No tearing effect occurred.
1: A tearing effect occurred.

Bit 1 **ALCOF**: Absolute line counter overflow flag
This bit indicates an overflow occurred on the absolute line counter.
0: No overflow occurred on the absolute line counter.
1: A overflow on the absolute line counter occurred.

Bit 0 **AFCOF**: absolute frame counter overflow flag
This bit indicates an overflow occurred on the absolute frame counter.
0: No overflow occurred on the absolute frame counter.
1: An overflow on the absolute frame counter occurred.

18.5.9 GFXTIM interrupt clear register (GFXTIM_ICR)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	CWDGPF	CWDGAF	Res.	Res.	Res.	Res.	CEV4F	CEV3F	CEV2F	CEV1F
						w	w					w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CRFC2RF	CRFC1RF	Res.	Res.	CALCC2F	CALCC1F	Res.	Res.	Res.	CAFCC1F	Res.	CTEF	CALCOF	CAFCOF
		w	w			w	w				w		w	w	w

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **CWDGPF**: Clear watchdog pre-alarm flag
This bit clears WDGPF in GXFXTIM_ISR.
0: No effect
1: WDGPF cleared

Bit 24 **CWDGAF**: Clear watchdog alarm flag
This bit clears WDGAF in GXFXTIM_ISR.
0: No effect
1: WDGAF cleared

Bits 23:20 Reserved, must be kept at reset value.

Bit 19 **CEV4F**: Clear event 4 flag
This bit clears EV4F in GXFXTIM_ISR.
0: No effect
1: EV4F cleared

Bit 18 **CEV3F**: Clear event 3 flag
This bit clears EV3F in GXFXTIM_ISR.
0: No effect
1: EV3F cleared

Bit 17 **CEV2F**: Clear event 2 flag
This bit clears EV2F in GXFXTIM_ISR.
0: No effect
1: EV2F cleared

Bit 16 **CEV1F**: Clear event 1 flag
This bit EV1F in GXFXTIM_ISR.
0: No effect
1: EV1F cleared

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **CRFC2RF**: Clear relative frame counter 2 reload flag
This bit clears RFC2RF in GXFXTIM_ISR.
0: No effect
1: RFC2RF cleared

Bit 12 **CRFC1RF**: Clear relative frame counter 1 reload flag
This bit clears RFC1RF in GXTIM_ISR.
0: No effect
1: RFC1RF cleared

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **CALCC2F**: Clear absolute line counter compare 2 flag
This bit clears ALCC2F in GXTIM_ISR.
0: No effect
1: ALCC2F cleared

Bit 8 **CALCC1F**: Clear absolute line counter compare 1 flag
This bit clears ALCC1F in GXTIM_ISR.
0: No effect
1: ALCC1F cleared

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **CAFCC1F**: Clear absolute frame counter compare 1 flag
This bit clears AFCC1F in GXTIM_ISR.
0: No effect
1: AFCC1F cleared

Bit 3 Reserved, must be kept at reset value.

Bit 2 **CTEF**: Clear tearing-effect flag
This bit clears TEF in GXTIM_ISR.
0: No effect
1: TEF cleared

Bit 1 **CALCOF**: Clear absolute line counter overflow flag
This bit clears ALCOF in GXTIM_ISR.
0: No effect
1: ALCOF cleared

Bit 0 **CAFCOF**: Clear absolute frame counter overflow flag
This bit clears AFCOF in GXTIM_ISR.
0: No effect
1: AFCOF cleared

18.5.10 GFXTIM interrupt enable register (GFXTIM_IER)

Address offset: 0x038

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	WDGPIE	WDGAIE	Res.	Res.	Res.	Res.	EV4IE	EV3IE	EV2IE	EV1IE
						rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	RFC2RIE	RFC1RIE	Res.	Res.	ALCC2IE	ALCC1IE	Res.	Res.	Res.	AFCC1IE	Res.	TEIE	ALCOIE	AFCOIE
		rw	rw			rw	rw				rw		rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **WDGPIE**: Watchdog pre-alarm interrupt enable
This bit enables the watchdog pre-alarm interrupt generation.
0: Watchdog pre-alarm interrupt disabled
1: Watchdog pre-alarm interrupt enabled

Bit 24 **WDGAIE**: Watchdog alarm interrupt enable
This bit enables the watchdog alarm interrupt generation.
0: Watchdog alarm interrupt disabled
1: Watchdog alarm interrupt enabled

Bits 23:20 Reserved, must be kept at reset value.

Bit 19 **EV4IE**: Event 4 interrupt enable
This bit enables the complex event 4 interrupt generation.
0: Event 4 interrupt disabled
1: Event 4 interrupt enabled

Bit 18 **EV3IE**: Event 3 interrupt enable
This bit enables the complex event 3 interrupt generation.
0: Event 3 interrupt disabled
1: Event 3 interrupt enabled

Bit 17 **EV2IE**: Event 2 interrupt enable
This bit enables the complex event 2 interrupt generation.
0: Event 2 interrupt disabled
1: Event 2 interrupt enabled

Bit 16 **EV1IE**: Event 1 interrupt enable
This bit enables the complex event 1 interrupt generation.
0: Event 1 interrupt disabled
1: Event 1 interrupt enabled

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **RFC2RIE**: Relative frame counter 2 reload interrupt enable
This bit enables the relative frame counter 2 reload interrupt generation.
0: Relative frame counter 2 reload interrupt disabled
1: Relative frame counter 2 reload interrupt enabled

Bit 12 **RFC1RIE**: Relative frame counter 1 reload interrupt enable
This bit enables the relative frame counter 1 reload interrupt generation.
0: Relative frame counter 1 reload interrupt disabled
1: Relative frame counter 1 reload interrupt enabled

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **ALCC2IE**: Absolute line counter compare 2 interrupt enable
This bit enables the absolute line counter compare 2 interrupt generation.
0: Absolute line counter compare 2 interrupt disabled
1: Absolute line counter compare 2 interrupt enabled

Bit 8 **ALCC1IE**: Absolute line counter compare 1 interrupt enable
This bit enables the absolute line counter compare 1 interrupt generation.
0: Absolute line counter compare 1 interrupt disabled
1: Absolute line counter compare 1 interrupt enabled

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **AFCC1IE**: Absolute frame counter compare 1 interrupt enable
This bit enables the absolute frame counter compare interrupt generation.
0: Absolute frame counter compare 1 interrupt disabled
1: Absolute frame counter compare 1 interrupt enabled

Bit 3 Reserved, must be kept at reset value.

Bit 2 **TEIE**: Tearing-effect interrupt enable
This bit enables the Tearing Effect interrupt generation.
0: Tearing-effect interrupt disabled
1: Tearing-effect interrupt enabled

Bit 1 **ALCOIE**: Absolute line counter overflow interrupt enable
This bit enables the absolute line counter overflow interrupt generation.
0: Absolute line counter overflow interrupt disabled
1: Absolute line counter overflow interrupt enabled

Bit 0 **AFCOIE**: Absolute frame counter overflow interrupt enable
This bit enables the absolute frame counter overflow interrupt generation.
0: Absolute frame counter overflow interrupt disabled
1: Absolute frame counter overflow interrupt enabled

18.5.11 GFXTIM timers status register (GFXTIM_TSR)

Address offset: 0x03C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFC2S	Res.	Res.	Res.	RFC1S
											r				r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALCS	Res.	Res.	Res.	AFCS
											r				r

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **RFC2S**: Relative frame counter 2 status
This bit returns the status of the relative frame counter 2.
0: Relative frame counter 2 disabled
1: Relative frame counter 2 enabled

Bits 19:17 Reserved, must be kept at reset value.

Bit 16 **RFC1S**: Relative frame counter 1 status
This bit returns the status of the relative frame counter 1.
0: Relative frame counter 1 disabled
1: Relative frame counter 1 enabled

Bits 15:5 Reserved, must be kept at reset value.

Bit 4 **ALCS**: Absolute line counter status
This bit returns the status of the absolute line counter.
0: Absolute line counter disabled
1: Absolute line counter enabled

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **AFCS**: Absolute frame counter status
This bit returns the status of the absolute frame counter.
0: Absolute frame counter disabled
1: Absolute frame counter enabled

18.5.12 GFXTIM line-clock counter reload register (GFXTIM_LCCRR)

Address offset: 0x040

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RELOAD[21:16]					
										rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RELOAD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:0 **RELOAD[21:0]**: Reload value
Reload value of the line-clock counter.

18.5.13 GFXTIM frame-clock counter reload register (GFXTIM_FCCRR)

Address offset: 0x044

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	RELOAD[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **RELOAD[11:0]**: Reload value
Reload value of the frame-clock counter.

18.5.14 GFXTIM absolute time register (GFXTIM_ATR)

Address offset: 0x050

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FRAME[19:4]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FRAME[3:0]				LINE[11:0]											
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 **FRAME[19:0]**: Fame number
Current value of the absolute frame counter.

Bits 11:0 **LINE[11:0]**: Line number
Current value of the absolute line counter.

18.5.15 GFXTIM absolute frame counter register (GFXTIM_AFCR)

Address offset: 0x054

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRAME[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FRAME[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **FRAME[19:0]**: Frame number
Current value of the absolute frame counter.
Note: This bitfield can only be written when the absolute frame counter is disabled.

18.5.16 GFXTIM absolute line counter register (GFXTIM_ALCR)

Address offset: 0x058

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	LINE[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **LINE[11:0]**: Line number
Current value of the absolute line counter.
Note: This bitfield can only be written when the absolute line counter is disabled.

18.5.17 GFXTIM absolute frame counter compare 1 register (GFXTIM_AFCC1R)

Address offset: 0x060

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRAME[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FRAME[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **FRAME[19:0]**: Frame number
Compare 1 value for the absolute frame counter.

18.5.18 GFXTIM absolute line counter compare 1 register (GFXTIM_ALCC1R)

Address offset: 0x070

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	LINE[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **LINE[11:0]**: Line number
Compare value 1 for the absolute line counter.

18.5.19 GFXTIM absolute line counter compare 2 register (GFXTIM_ALCC2R)

Address offset: 0x074

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	LINE[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **LINE[11:0]**: Line number
Compare value 2 for the absolute line counter.

18.5.20 GFXTIM relative frame counter 1 register (GFXTIM_RFC1R)

Address offset: 0x080

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	FRAME[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **FRAME[11:0]**: Frame number
Current value of the relative frame counter 1.

18.5.21 GFXTIM relative frame counter 1 reload register (GFXTIM_RFC1RR)

Address offset: 0x084

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	FRAME[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **FRAME[11:0]**: Frame reload value
Reload value for the relative frame counter 1.

18.5.22 GFXTIM relative frame counter 2 register (GFXTIM_RFC2R)

Address offset: 0x088

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	FRAME[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **FRAME[11:0]**: Frame number
Current value of the relative frame counter 2.

18.5.23 GFXTIM relative frame counter 2 reload register (GFXTIM_RFC2RR)

Address offset: 0x08C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	FRAME[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **FRAME[11:0]**: Frame reload value
Reload value for the relative frame counter 2.

18.5.24 GFXTIM watchdog counter register (GFXTIM_WDGCR)

Address offset: 0x0A0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VALUE[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **VALUE[15:0]**: Value
Current value of the watchdog counter.

18.5.25 GFXTIM watchdog reload register (GFXTIM_WDGRR)

Address offset: 0x0A4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RELOAD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **RELOAD[15:0]**: Reload value
Reload value of the watchdog counter.

18.5.26 GFXTIM watchdog pre-alarm register (GFXTIM_WDGPAR)

Address offset: 0x0A8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PREALARM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **PREALARM[15:0]**: Pre-alarm value
Pre-alarm value of the watchdog counter.

18.5.27 GFXTIM register map

Table 165. GFXTIM register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	GFXTIM_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LCCOE	FCCOE	Res.	Res.	Res.	Res.	Res.	Res.	SYNCS [1:0]		Res.	Res.	Res.	TEPOL	Res.	Res.	TES [1:0]	
	Reset value															0	0							0	0				0			0	0
0x004	GFXTIM_CGCR	Res.	FCCHRS [2:0]			Res.	Res.	Res.	FCCFR	Res.	FCCCS [2:0]			Res.	FCS [2:0]			Res.	LCCHRS [2:0]			Res.	Res.	Res.	LCCFR	Res.	Res.	Res.	LCCCS	Res.	LCS[2:0]		
	Reset value		0	0	0				0		0	0	0		0	0	0		0	0	0				0				0		0	0	0

Table 165. GFXTIM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x008	GFXTIM_TCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRFC2R	RFC2CM	RFC2EN	Res.	FRFC1R	RFC1CM	RFC1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FALCR	ALCEN	Res.	Res.	FAFCR	AFCEN
	Reset value										0	0	0		0	0	0											0	0			0	0
0x00C	GFXTIM_TDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFC2DIS	Res.	Res.	Res.	RFC1DIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALCDIS	Res.	Res.	Res.	AFCDIS
	Reset value												0				0												0				0
0x010	GFXTIM_EVCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EV4EN	EV3EN	EV2EN	EV1EN
	Reset value																													0	0	0	0
0x014	GFXTIM_EVSR	Res.	FES4[2:0]			Res.	LES4[2:0]			Res.	FES3[2:0]			Res.	LES3[2:0]			Res.	FES2[2:0]			Res.	LES2[2:0]			Res.	FES1[2:0]			Res.	LES1[2:0]		
	Reset value		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0
0x018-0x01C	Reserved	Reserved																															
0x020	GFXTIM_WDGTCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FWDGR	Res.	Res.	Res.	Res.	WDGCS[3:0]				Res.	Res.	WDGHRC[1:0]		Res.	WDGS	WDGDIS	WDGEN
	Reset value																0					0	0	0	0			0	0		0	0	0
0x024-0x02C	Reserved	Reserved																															
0x030	GFXTIM_ISR	Res.	Res.	Res.	Res.	Res.	Res.	WDGPF	WDGAF	Res.	Res.	Res.	Res.	EV4F	EV3F	EV2F	EV1F	Res.	Res.	RFC2RF	RFC1RF	Res.	Res.	ALCC2F	ALCC1F	Res.	Res.	Res.	AFCC1F	Res.	TEF	ALCOF	AFCOF
	Reset value							0	0					0	0	0	0			0	0			0	0				0		0	0	0
0x034	GFXTIM_ICR	Res.	Res.	Res.	Res.	Res.	Res.	CWDGPF	CWDGAF	Res.	Res.	Res.	Res.	CEV4F	CEV3F	CEV2F	CEV1F	Res.	Res.	CRFC2RF	CRFC1RRF	Res.	Res.	CALCC2F	CALCC1F	Res.	Res.	Res.	CAFCC1F	Res.	CTEF	CALCOF	CAFCOF
	Reset value							0	0					0	0	0	0			0	0			0	0				0		0	0	0
0x038	GFXTIM_IER	Res.	Res.	Res.	Res.	Res.	Res.	WDGPIE	WDGAIE	Res.	Res.	Res.	Res.	EV4IE	EV3IE	EV2IE	EV1IE	Res.	Res.	RFC2RIE	RFC1RIE	Res.	Res.	ALCC2IE	ALCC1IE	Res.	Res.	Res.	AFCC1IE	Res.	TEIE	ALCOIE	AFCOIE
	Reset value							0	0					0	0	0	0			0	0			0	0				0		0	0	0
0x03C	GFXTIM_TSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFC2S	Res.	Res.	Res.	RFC1S	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALCS	Res.	Res.	Res.	AFCS
	Reset value												0				0												0				0
0x040	GFXTIM_LCCRR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RELOAD[21:0]																					
	Reset value											0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x044	GFXTIM_FCCRR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RELOAD[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x048-0x04C	Reserved	Reserved																															
0x050	GFXTIM_ATR	FRAME[19:0]																				LINE[11:0]											
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x054	GFXTIM_AFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRAME[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x058	GFXTIM_ALCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x05C	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Table 165. GFXTIM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x060	GFXTIM_ AFCC1R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRAME[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x064-0x06C	Reserved	Reserved																															
0x070	GFXTIM_ ALCC1R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x074	GFXTIM_ ALCC2R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x078-0x07C	Reserved	Reserved																															
0x080	GFXTIM_RFC1R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRAME[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x084	GFXTIM_ RFC1RR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRAME[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x088	GFXTIM_RFC2R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRAME[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x08C	GFXTIM_ RFC2RR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRAME[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x090-0x09C	Reserved	Reserved																															
0x0A0	GFXTIM_ WDGCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VALUE[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A4	GFXTIM_ WDGRR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RELOAD[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A8	GFXTIM_ WDGPAR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREALARM[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

19 Nested vectored interrupt controller (NVIC)

19.1 NVIC main features

- 162 maskable interrupt channels (not including the 16 Cortex-M33 with FPU interrupt lines)
- 16 programmable priority levels (four bits of interrupt priority used)
- Low-latency exception and interrupt handling
- Power management control
- Implementation of system control registers

The NVIC and the processor core interface are closely coupled, enabling low-latency interrupt processing and efficient processing of late arriving interrupts.

The NVIC registers are banked across secure and nonsecure states.

All interrupts. including the core exceptions, are managed by the NVIC.

19.2 SysTick calibration value register

The Cortex-M33 with TrustZone mainline security extension embeds two SysTick timers.

When TrustZone is activated, the following SysTick timers are available:

- SysTick, secure instance
- SysTick, nonsecure instance

When TrustZone is disabled, only one SysTick timer is available.

The SysTick timer calibration value (STCALIB) is 0x3E8. It gives a reference time base of 1 ms based on a SysTick clock frequency of 1 MHz. To match the 1 ms time base for an application running at a given frequency, the SysTick reload value must be programmed as follows in the SYST_RVR register:

- When SysTick clock source is CPU, clock HCLK reload value = (HCLK x STCALIB) - 1
- When SysTick clock source is external, clock (HCLK/8) reload value = ((HCLK / 8) x STCALIB) - 1

The HCLK refers to the AHB frequency value in MHz.

Example: SysTick clock source is CPU clock HCLK of 100 MHz, to match a time base of 1 ms: SysTick reload value = (100 x STCALIB) - 1 = 0x1869F.

19.3 Interrupt and exception vectors

The mapping is defined in *Table 166*. Gray rows indicate vectors without specific position.

Table 166. Interrupt vector mapping

Position	Priority	Type of priority	Acronym	Description	Address
-	-	-	-	Reserved	0x0000 0000
-	-4	Fixed	Reset	Reset	0x0000 0004
-	-2	Fixed	NMI	Nonmaskable interrupt. The RCC clock security system (CSS) is linked to the NMI vector.	0x0000 0008
-	-3 or -1	Fixed	Secure HardFault	Secure HardFault	0x0000 000C
-	-1	Fixed	Nonsecure HardFault	Nonsecure HardFault, all classes of fault	0x0000 000C
-	0	Settable	MemManage	Memory management	0x0000 0010
-	1	Settable	BusFault	Prefetch fault, memory access fault	0x0000 0014
-	2	Settable	UsageFault	Undefined instruction or illegal state	0x0000 0018
-	3	Settable	SecureFault	SecureFault	0x0000 001C
-	-	-	-	Reserved	0x0000 0020 - 0x0000 0028
-	4	-	SVC	System service call via SWI instruction	0x0000 002C
-	5	-	Debug Monitor	Monitor	0x0000 0030
-	-	-	-	Reserved	0x0000 0034
-	6	Settable	PendSV	Pendable request for system service	0x0000 0038
-	7	Settable	SysTick	System tick timer	0x0000 003C
0	8	Settable	WWDG	Window watchdog interrupt	0x0000 0040
1	9	Settable	PVD_AVD_UVM_IO2VM	Power voltage monitor, analog voltage monitor, UVM, and IO2VM voltage monitors	0x0000 0044
2	10	Settable	RTC	RTC global nonsecure interrupts	0x0000 0048
3	11	Settable	RTC_S	RTC global secure interrupts	0x0000 004C
4	12	Settable	TAMP	Tamper global interrupts	0x0000 0050
5	13	Settable	RAMCFG	RAM configuration global interrupt	0x0000 0054
6	14	Settable	FLASH	Flash nonsecure global interrupt	0x0000 0058
7	15	Settable	FLASH_S	Flash secure global interrupt	0x0000 005C
8	16	Settable	GTZC	GTZC global interrupt	0x0000 0060
9	17	Settable	RCC	RCC nonsecure global interrupt	0x0000 0064
10	18	Settable	RCC_S	RCC secure global interrupt	0x0000 0068
11	19	Settable	EXTI0	EXTI line0 interrupt	0x0000 006C
12	20	Settable	EXTI1	EXTI line1 interrupt	0x0000 0070

Table 166. Interrupt vector mapping (continued)

Position	Priority	Type of priority	Acronym	Description	Address
13	21	Settable	EXTI2	EXTI line2 interrupt	0x0000 0074
14	22	Settable	EXTI3	EXTI line3 interrupt	0x0000 0078
15	23	Settable	EXTI4	EXTI line4 interrupt	0x0000 007C
16	24	Settable	EXTI5	EXTI line5 interrupt	0x0000 0080
17	25	Settable	EXTI6	EXTI line6 interrupt	0x0000 0084
18	26	Settable	EXTI7	EXTI line7 interrupt	0x0000 0088
19	27	Settable	EXTI8	EXTI line8 interrupt	0x0000 008C
20	28	Settable	EXTI9	EXTI line9 interrupt	0x0000 0090
21	29	Settable	EXTI10	EXTI line10 interrupt	0x0000 0094
22	30	Settable	EXTI11	EXTI line11 interrupt	0x0000 0098
23	31	Settable	EXTI12	EXTI line12 interrupt	0x0000 009C
24	32	Settable	EXTI13	EXTI line13 interrupt	0x0000 00A0
25	33	Settable	EXTI14	EXTI line14 interrupt	0x0000 00A4
26	34	Settable	EXTI15	EXTI line15 interrupt	0x0000 00A8
27	35	Settable	GPDMA1_CH0	GPDMA1 channel 0 global interrupt	0x0000 00AC
28	36	Settable	GPDMA1_CH1	GPDMA1 channel 1 global interrupt	0x0000 00B0
29	37	Settable	GPDMA1_CH2	GPDMA1 channel 2 global interrupt	0x0000 00B4
30	38	Settable	GPDMA1_CH3	GPDMA1 channel 3 global interrupt	0x0000 00B8
31	39	Settable	GPDMA1_CH4	GPDMA1 channel 4 global interrupt	0x0000 00BC
32	40	Settable	GPDMA1_CH5	GPDMA1 channel 5 global interrupt	0x0000 00C0
33	41	Settable	GPDMA1_CH6	GPDMA1 channel 6 global interrupt	0x0000 00C4
34	42	Settable	GPDMA1_CH7	GPDMA1 channel 7 global interrupt	0x0000 00C8
35	43	Settable	IWDG	Independent watchdog interrupt	0x0000 00CC
36	44	Settable	SAES	Secure AES	0x0000 00D0
37	45	Settable	ADC	ADC global interrupt	0x0000 00D4
38	46	Settable	DAC1	DAC1 global interrupt	0x0000 00D8
39	47	Settable	FDCAN1_IT0	FDCAN1 Interrupt 0	0x0000 00DC
40	48	Settable	FDCAN1_IT1	FDCAN1 Interrupt 1	0x0000 00E0
41	49	Settable	TIM1_BRK/TIM1_TERR/ TIM1_IERR	TIM1 break/TIM1 transition error/ TIM1 index error	0x0000 00E4
42	50	Settable	TIM1_UP	TIM1 update	0x0000 00E8
43	51	Settable	TIM1_TRG_COM/ TIM1_DIR/TIM1_IDX	TIM1 trigger and commutation/ TIM1 direction change interrupt/TIM1 index	0x0000 00EC
44	52	Settable	TIM1_CC	TIM1 capture compare interrupt	0x0000 00F0

Table 166. Interrupt vector mapping (continued)

Position	Priority	Type of priority	Acronym	Description	Address
45	53	Settable	TIM2	TIM2 global interrupt	0x0000 00F4
46	54	Settable	TIM3	TIM3 global interrupt	0x0000 00F8
47	55	Settable	TIM4	TIM4 global interrupt	0x0000 00FC
48	56	Settable	TIM5	TIM5 global interrupt	0x0000 0100
49	57	Settable	TIM6	TIM6 global interrupt	0x0000 0104
50	58	Settable	TIM7	TIM7 global interrupt	0x0000 0108
51	59	Settable	I2C1_EV	I2C1 event interrupt	0x0000 010C
52	60	Settable	I2C1_ER	I2C1 error interrupt	0x0000 0110
53	61	Settable	I2C2_EV	I2C2 event interrupt	0x0000 0114
54	62	Settable	I2C2_ER	I2C2 error interrupt	0x0000 0118
55	63	Settable	SPI1	SPI1 global interrupt	0x0000 011C
56	64	Settable	SPI2	SPI2 global interrupt	0x0000 0120
57	65	Settable	SPI3	SPI3 global interrupt	0x0000 0124
58	66	Settable	USART1	USART1 global interrupt	0x0000 0128
59	67	Settable	USART2	USART2 global interrupt	0x0000 012C
60	68	Settable	USART3	USART3 global interrupt	0x0000 0130
61	69	Settable	UART4	UART4 global interrupt	0x0000 0134
62	70	Settable	UART5	UART5 global interrupt	0x0000 0138
63	71	Settable	LPUART1	LPUART1 global interrupt OR LPUART1 wake-up OR LPUART1 T wake-up through EXTI line	0x0000 013C
64	72	Settable	LPTIM1 OR LPTIM1_AIT	LPTIM1 global interrupt OR LPTIM1 AIT through EXTI line	0x0000 0140
65	73	Settable	TIM8_BRK/TIM8_TERR/ TIM8_IERR	TIM8 break interrupt/TIM8 transition error/ TIM8 index error	0x0000 0144
66	74	Settable	TIM8_UP	TIM8 update interrupt	0x0000 0148
67	75	Settable	TIM8_TRG_COM/ TIM8_DIR/TIM8_IDX	TIM8 trigger and commutation interrupt/ TIM8 direction change interrupt/TIM8 index	0x0000 014C
68	76	Settable	TIM8_CC	TIM8 capture compare interrupt	0x0000 0150
69	77	Settable	ADC2	ADC2 global interrupt	0x0000 0154
70	78	Settable	LPTIM2 OR LPTIM2_AIT	LPTIM2 global interrupt OR LPTimer2 AIT through EXTI line	0x0000 0158
71	79	Settable	TIM15	TIM15 global interrupt	0x0000 015C
72	80	Settable	TIM16	TIM16 global interrupt	0x0000 0160
73	81	Settable	TIM17	TIM17 global interrupt	0x0000 0164
74	82	Settable	USB_FS	USB OTG_FS global interrupt	0x0000 0168

Table 166. Interrupt vector mapping (continued)

Position	Priority	Type of priority	Acronym	Description	Address
75	83	Settable	CRS	CRS global interrupt	0x0000 016C
76	84	Settable	UCPD1	UCPD1 global interrupt	0x0000 0170
77	85	Settable	FMC	FMC global interrupt	0x0000 0174
78	86	Settable	OCTOSPI1	OCTOSPI1 global interrupt	0x0000 0178
79	87	Settable	SDMMC1	SDMMC1 global interrupt	0x0000 017C
80	88	Settable	I2C3_EV	I2C3 event interrupt	0x0000 0180
81	89	Settable	I2C3_ER	I2C3 error interrupt	0x0000 0184
82	90	Settable	SPI4	SPI4 global interrupt	0x0000 0188
83	91	Settable	SPI5	SPI5 global interrupt	0x0000 018C
84	92	Settable	SPI6	SPI6 global interrupt	0x0000 0190
85	93	Settable	USART6	USART6 global interrupt	0x0000 0194
86	94	Settable	USART10	USART10 global interrupt	0x0000 0198
87	95	Settable	USART11	USART11 global interrupt	0x0000 019C
88	96	Settable	SAI1	SAI1 global interrupt	0x0000 01A0
89	97	Settable	SAI2	SAI2 global interrupt	0x0000 01A4
90	98	Settable	GPDMA2_CH0	GPDMA2 channel0 global interrupt	0x0000 01A8
91	99	Settable	GPDMA2_CH1	GPDMA2 channel1 global interrupt	0x0000 01AC
92	100	Settable	GPDMA2_CH2	GPDMA2 channel2 global interrupt	0x0000 01B0
93	101	Settable	GPDMA2_CH3	GPDMA2 channe3 global interrupt	0x0000 01B4
94	102	Settable	GPDMA2_CH4	GPDMA2 channel4 global interrupt	0x0000 01B8
95	103	Settable	GPDMA2_CH5	GPDMA2 channel5 global interrupt	0x0000 01BC
96	104	Settable	GPDMA2_CH6	GPDMA2 channel6 global interrupt	0x0000 01C0
97	105	Settable	GPDMA2_CH7	GPDMA2 channel7 global interrupt	0x0000 01C4
98	106	Settable	UART7	UART7 global interrupt	0x0000 01C8
99	107	Settable	UART8	UART8 global interrupt	0x0000 01CC
100	108	Settable	UART9	UART9 global interrupt	0x0000 01D0
101	109	Settable	UART12	UART12 global interrupt	0x0000 01D4
102	110	Settable	SDMMC2	SDMMC2 global interrupt	0x0000 01D8
103	111	Settable	FPU	Floating point interrupt	0x0000 01DC
104	112	Settable	ICACHE	Instruction cache global interrupt	0x0000 01E0
105	113	Settable	DCACHE	Data cache global interrupt	0x0000 01E4
106	114	Settable	ETH	Ethernet interrupt	0x0000 01E8
107	115	Settable	ETH_WKUP	ETHERNET wake-up interrupt through EXTI line	0x0000 01EC

Table 166. Interrupt vector mapping (continued)

Position	Priority	Type of priority	Acronym	Description	Address
108	116	Settable	DCMI_PSSI	DCMI/PSSI global interrupt	0x0000 01F0
109	117	Settable	FDCAN2_IT0	FDCAN2 Interrupt 0	0x0000 01F4
110	118	Settable	FDCAN2_IT1	FDCAN2 Interrupt 1	0x0000 01F8
111	119	Settable	CORDIC	CORDIC interrupt	0x0000 01FC
112	120	Settable	FMAC	FMAC interrupt	0x0000 0200
113	121	Settable	DTS OR DTS_WKUP	DTS interrupt OR DTS AIT through EXTI line	0x0000 0204
114	122	Settable	RNG	RNG global interrupt	0x0000 0208
115	123	Settable	OTFDEC1	OTFDEC1 secure global interrupt	0x0000 020C
116	124	Settable	AES	AES global interrupt	0x0000 0210
117	125	Settable	HASH	HASH interrupt	0x0000 0214
118	126	Settable	PKA	PKA global interrupt	0x0000 0218
119	127	Settable	CEC	HDMI-CEC global interrupt	0x0000 021C
120	128	Settable	TIM12	TIM12 global interrupt	0x0000 0220
121	129	Settable	TIM13	TIM13 global interrupt	0x0000 0224
122	130	Settable	TIM14	TIM14 global interrupt	0x0000 0228
123	131	Settable	I3C1_EV	I3C1 event interrupt	0x0000 022C
124	132	Settable	I3C1_ER	I3C1 error interrupt	0x0000 0230
125	133	Settable	I2C4_EV	I2C4 event interrupt	0x0000 0234
126	134	Settable	I2C4_ER	I2C4 error interrupt	0x0000 0238
127	135	Settable	LPTIM3 OR LPTIM3_AIT	LPTIM3 global interrupt OR LPTIM3 AIT through EXTI line	0x0000 023C
128	136	Settable	LPTIM4 OR LPTIM4_AIT	LPTIM4 global interrupt OR LPTIM4 AIT through EXTI line	0x0000 0240
129	137	Settable	LPTIM5 OR LPTIM5_AIT	LPTIM5 global interrupt OR LPTIM5 AIT through EXTI line	0x0000 0244
130	138	Settable	LPTIM6 OR LPTIM6_AIT	LPTIM6 global interrupt OR LPTIM6 AIT through EXTI line	0x0000 0248
131	139	Settable	I3C2_EV	I3C2 event interrupt	0x0000 024C
132	140	Settable	I3C2_ER	I3C2 error interrupt	0x0000 0250
133	141	Settable	COMP	Comparator global interrupt	0x0000 0254
134	142	Settable	DMA2D	DMA2D interrupt	0x0000 0258
135	143	Settable	JPEG	JPEG interrupt	0x0000 025C
136	144	Settable	GPDMA1_CH8	GPDMA1 channel 8 global interrupt	0x0000 0260
137	145	Settable	GPDMA1_CH9	GPDMA1 channel 9 global interrupt	0x0000 0264

Table 166. Interrupt vector mapping (continued)

Position	Priority	Type of priority	Acronym	Description	Address
138	146	Settable	GPDMA1_CH10	GPDMA1 channel 10 global interrupt	0x0000 0268
139	147	Settable	GPDMA1_CH11	GPDMA1 channel 11 global interrupt	0x0000 026C
140	148	Settable	GPDMA2_CH8	GPDMA2 channel 8 global interrupt	0x0000 0270
141	149	Settable	GPDMA2_CH9	GPDMA2 channel 9 global interrupt	0x0000 0274
142	150	Settable	GPDMA2_CH10	GPDMA2 channel 10 global interrupt	0x0000 0278
143	151	Settable	GPDMA2_CH11	GPDMA2 channel 11 global interrupt	0x0000 027C
144	152	Settable	GFXTIM	GFXTIM interrupt	0x0000 0280
145	153	Settable	LCD_IRQ	LCD interrupt	0x0000 0284
146	154	Settable	LCD_GBL_ERROR	LCD global error	0x0000 0288
147	155	Settable	PLAY1	PLA global nonsecure interrupt	0x0000 028C
148	156	Settable	PLAY1_S	PLA global secure interrupt	0x0000 0290
149	157	Settable	ADC3	ADC3 global interrupt	0x0000 0294
150	158	Settable	OCTOSPI2	OCTOSPI2 global interrupt	0x0000 0298
151	159	Settable	OTFDEC2	OTFDEC2 secure global interrupt	0x0000 029C
152	160	Settable	FDCAN3_IT0	FDCAN3 Interrupt 0	0x0000 02A0
153	161	Settable	FDCAN3_IT1	FDCAN3 Interrupt 1	0x0000 02A4
154	162	Settable	MDF1_FLT0	MDF1 Filter 0 global interrupt	0x0000 02A8
155	163	Settable	MDF1_FLT1	MDF1 Filter 1 global interrupt	0x0000 02AC
156	164	Settable	MDF1_FLT2	MDF1 Filter 2 global interrupt	0x0000 02B0
157	165	Settable	MDF1_FLT3	MDF1 Filter 3 global interrupt	0x0000 02B4
158	166	Settable	MDF1_FLT4	MDF1 Filter 4 global interrupt	0x0000 02B8
159	167	Settable	MDF1_FLT5	MDF1 Filter 5 global interrupt	0x0000 02BC
160	168	Settable	ADF1	ADF1 interrupt	0x0000 02C0
161	169	Settable	OTG_HS	USB OTG HS global interrupt	0x0000 02C4

20 Extended interrupts and event controller (EXTI)

The extended interrupts and event controller (EXTI) manages the individual CPU and system wake-up through configurable and direct event inputs. It provides wake-up requests to the power control and generates an interrupt request to the CPU NVIC and events to the CPU event input. For the CPU, an additional event generation block (EVG) is needed to generate the CPU event signal.

The EXTI wake-up requests allow the system to be woken up from Stop modes.

The interrupt request and event request generation can be used also in Run modes.

The EXTI also includes the EXTI multiplexer IO port selection.

20.1 EXTI main features

The EXTI main features are the following:

- 67 input events supported
- All event inputs allow the possibility to wake up the system.
- Events that do not have an associated wake-up flag in the peripheral, have a flag in the EXTI, and generate an interrupt to the CPU from the EXTI.
- Events can be used to generate a CPU wake-up event.

The asynchronous event inputs are classified in two groups:

- Configurable events (signals from I/Os or peripherals able to generate a pulse), with the following features
  - Selectable active trigger edge
  - Interrupt pending status register bits independent for the rising and falling edge
  - Individual interrupt and event generation mask, used for conditioning the CPU wake-up, interrupt, and event generation
  - Software trigger possibility
  - Secure events: The access to control and configuration bits of secure input events can be made secure and or privilege.
  - EXTI IO port selection
- Direct events (interrupt and wake-up sources from peripherals having an associated flag, which requires to be cleared in the peripheral), with the following features:
  - Fixed rising edge active trigger
  - No interrupt pending status register bit in the EXTI (the interrupt pending status flag is provided by the peripheral generating the event)
  - Individual interrupt and event generation mask, used to condition the CPU wake-up and event generation
  - No software trigger possibility

20.2 EXTI block diagram

The EXTI consists of a register block accessed via an AHB interface, the event input trigger block, the masking block, and the EXTI multiplexer as shown in *Figure 116*.

The register block contains all the EXTI registers.

The event input trigger block provides event input edge trigger logic.

The masking block provides the event input distribution to the different wake-up, interrupt and event outputs, and their masking.

The EXTI multiplexer provides the IO port selection on to the EXTI event signal.

Figure 116. EXTI block diagram

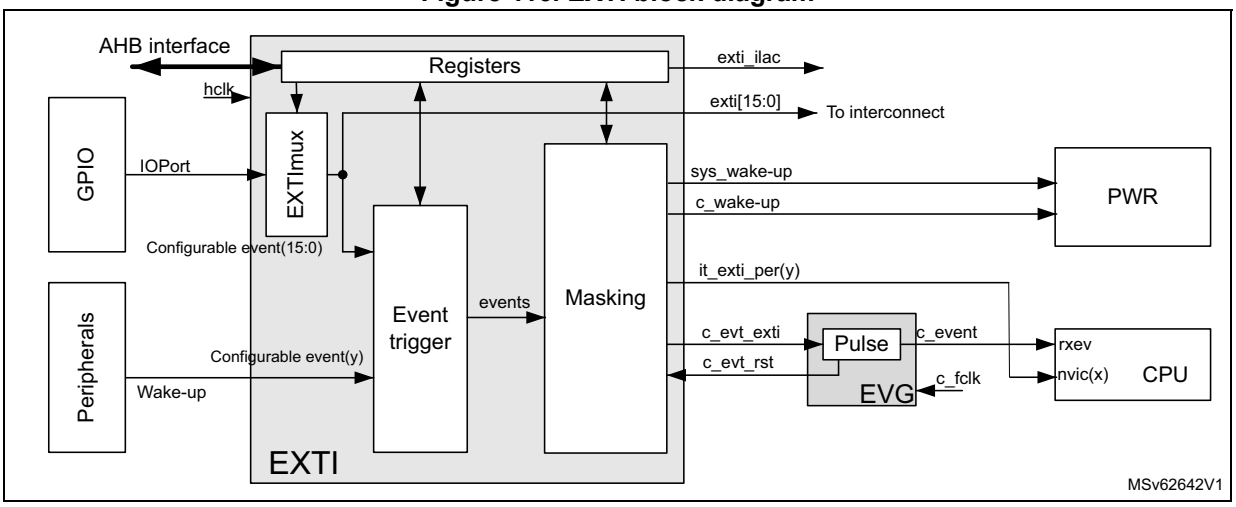


Table 167. EXTI signals

Pin name	I/O	Description
AHB interface	I/O	EXTI register bus interface. When one event is configured to enable security, the AHB interface supports secure accesses.
hclk	I	AHB bus clock and EXTI system clock
Configurable event(y)	I	Asynchronous wake-up events from peripherals without an associated interrupt and flag
Direct event(x)	I	Synchronous and asynchronous wake-up events from peripherals with an associated interrupt and flag
exti_ilac	O	Illegal access event
IOPort(n)	I	GPIOs block IO ports[15:0]
exti[15:0]	O	EXTI GPIO output port to trigger other peripherals
it_exti_per (y)	O	Interrupts to the CPU associated with configurable event (y)
c_evt_exti	O	High-level sensitive event output for CPU, synchronous to hclk
c_evt_rst	I	Asynchronous reset input to clear c_evt_exti
sys_wakeup	O	Asynchronous system wake-up request to PWR for ck_sys and hclk
c_wakeup	O	Wake-up request to PWR for CPU, synchronous to hclk

Table 168. EVG signals

Pin name	I/O	Description
c_fclk	I	CPU free running clock
c_evt_in	I	High-level sensitive events input from EXTI, asynchronous to CPU clock
c_event	O	Event pulse, synchronous to CPU clock
c_evt_rst	O	Event reset signal, synchronous to CPU clock

20.2.1 EXTI connections between peripherals and CPU

Some peripherals able to generate wake-up or interrupt events when the system is in Stop mode, are connected to the EXTI.

- Peripheral wake-up signals that generate a pulse or do not have an interrupt status bits in the peripheral are connected to an EXTI configurable event input. For these events, the EXTI provides a status pending bit to be cleared. It is the EXTI interrupt, associated with the status bit, that interrupts the CPU.
- Peripheral interrupt and wake-up signals with a status bit in the peripheral to be cleared are connected to an EXTI direct event input. There is no status pending bit within the EXTI. The interrupt or wake-up is cleared by the CPU in the peripheral. It is the peripheral interrupt that interrupts the CPU directly.
- All GPIO ports input to the EXTI multiplexer allow the selection of a port pin to wake up the system via a configurable event.

The EXTI configurable event interrupts are connected to the NVIC.

The dedicated EXTI/EVG CPU event is connected to the CPU rxev input.

The EXTI CPU wake-up signals are connected to the PWR and are used to wake up the system and the CPU subsystem bus clocks.

20.2.2 EXTI interrupt/event mapping

The EXTI lines are connected as shown in the table below.

Table 169. EXTI line connections

EXTI Line	Line source	Line type
0-15	GPIO	Configurable
16	PVD/AVD output	Configurable
17	RTC nonsecure	-
18	RTC secure	-
19	TAMP nonsecure	-
20	TAMP secure	-
21	I2C1 wake-up	-
22	I2C2 wake-up	-
23	I2C3 wake-up	-
24	I3C1 wake-up	-

Table 169. EXTI line connections (continued)

EXTI Line	Line source	Line type
25	USART1 wake-up	-
26	USART2 wake-up	-
27	USART3 wake-up	-
28	UART4 wake-up	-
29	UART5 wake-up	-
30	USART6 wake-up	-
31	UART7 wake-up	-
32	UART8 wake-up	-
33	UART9 wake-up	-
34	USART10 wake-up	-
35	USART11 wake-up	-
36	UART12 wake-up	-
37	LPUART1 wake-up	-
38	LPTIM1	-
39	LPTIM2	-
40	SPI1 wake-up	-
41	SPI2 wake-up	-
42	SPI3 wake-up	-
43	SPI4 wake-up	-
44	SPI5 wake-up	-
45	SPI6 wake-up	-
46	ETH wake-up	Configurable
47	OTGFS wake-up	-
48	UCPD1 wake-up	-
49	LPTIM2 CH1	Configurable
50	DTS wake-up	Configurable
51	HDMI-CEC wake-up	-
52	I2C4 wake-up	-
53	UVM output	Configurable
54	LPTIM3	-
55	LPTIM4	-
56	LPTIM5	-
57	LPTIM6	-
58	COMP1 output	Configurable
59	COMP2 output	Configurable

Table 169. EXTI line connections (continued)

EXTI Line	Line source	Line type
60	OTGHS wake-up	-
61	I3C2 wake-up	-
62	ADF1	-
63	MDF1	-
64	play1_out14	Configurable
65	IWDG	-
66	V_{DDIO2} voltage monitor	Configurable

20.3 EXTI functional description

The events features are controlled from the register bits as follows:

- Active trigger edge enable
  - by rising edge selection in the *EXTI rising trigger selection register (EXTI_RTSR1)* and *EXTI rising trigger selection register 2 (EXTI_RTSR2)*
  - by falling edge selection in the *EXTI falling trigger selection register (EXTI_FTSR1)* and *EXTI falling trigger selection register 2 (EXTI_FTSR2)*
- Software trigger in the *EXTI software interrupt event register (EXTI_SWIER1)* and *EXTI software interrupt event register 2 (EXTI_SWIER2)*
- Interrupt pending flag in the

  EXTI rising edge pending register (EXTI_RPR1) and *EXTI rising edge pending register 2 (EXTI_RPR2)*

  EXTI falling edge pending register (EXTI_FPR1) and *EXTI falling edge pending register 2 (EXTI_FPR2)*
- CPU wake-up and interrupt enable in the

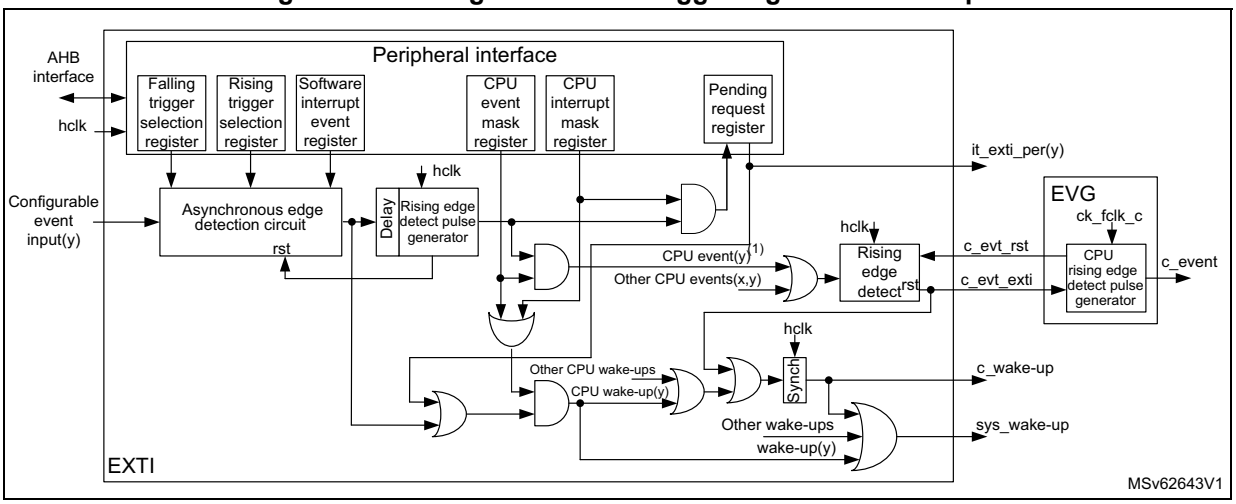
  EXTI CPU wake-up with interrupt mask register (EXTI_IMR1), *EXTI CPU wake-up with interrupt mask register 2 (EXTI_IMR2)*, and *EXTI CPU wake-up with interrupt mask register 3 (EXTI_IMR3)*
- CPU wake-up and event enable

  EXTI CPU wake-up with event mask register (EXTI_EMR1), *EXTI CPU wake-up with event mask register 2 (EXTI_EMR2)*, and *EXTI CPU wake-up with event mask register 3 (EXTI_EMR3)*

20.3.1 EXTI configurable event input wake-up

The figure below is a detailed representation of the logic associated with configurable event inputs that wake up the CPU subsystem bus clocks and generate an EXTI pending flag and interrupt to the CPU, and/or a CPU wake-up event.

Figure 117. Configurable event trigger logic CPU wake-up



1. Only for the input events that support the CPU rxev generation c_event.

The software interrupt event register allows configurable events to be triggered by software, writing the corresponding register bit, whatever the edge selection setting.

The configurable event active trigger edge (or both edges) is selected and enabled in the rising/falling edge selection registers.

The CPU has its dedicated wake-up (interrupt) mask register and a dedicated event mask registers. When the event is enabled, it is generated to the CPU. All events for the CPU are ORed together into a single CPU event signal. The event pending registers (EXTI_RPR and EXTI_FPR) are not set for an unmasked CPU event.

The configurable events have unique interrupt pending request registers. The pending register is only set for an unmasked interrupt. Each configurable event provides a common interrupt to the CPU. The configurable event interrupts must be acknowledged by software in the EXTI_RPR and/or EXTI_FPR registers.

When a CPU wake-up (interrupt) or CPU event is enabled, the asynchronous edge detection circuit is reset by the clocked delay and rising edge detect pulse generator. This guarantees that the EXTI hclk clock is woken up before the asynchronous edge detection circuit is reset.

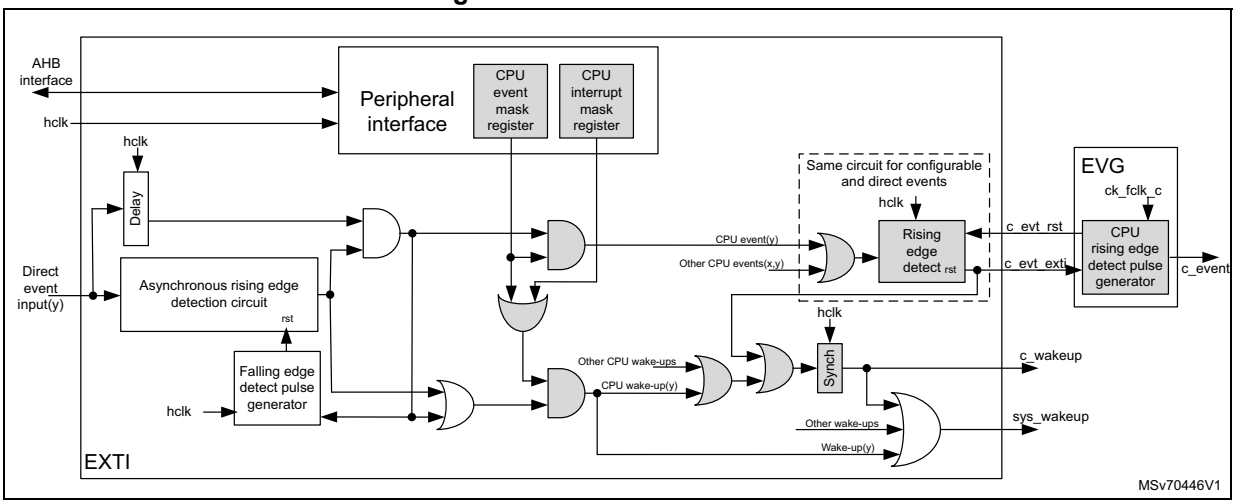
Note: A detected configurable event interrupt pending request can be cleared by the CPU with the correct access permission. The system is not able to enter into low-power modes as long as an interrupt pending request is active.

20.3.2 EXTI direct event input wake-up

The direct events do not have an associated EXTI interrupt. The EXTI only wakes up the system and CPU subsystem clocks, and can generate a CPU wake-up event. The peripheral synchronous interrupt, associated with the direct wake-up event, wakes up the CPU.

The EXTI direct event is able to generate a CPU event that wakes up the CPU. The CPU event may occur before the associated peripheral interrupt flag is set.

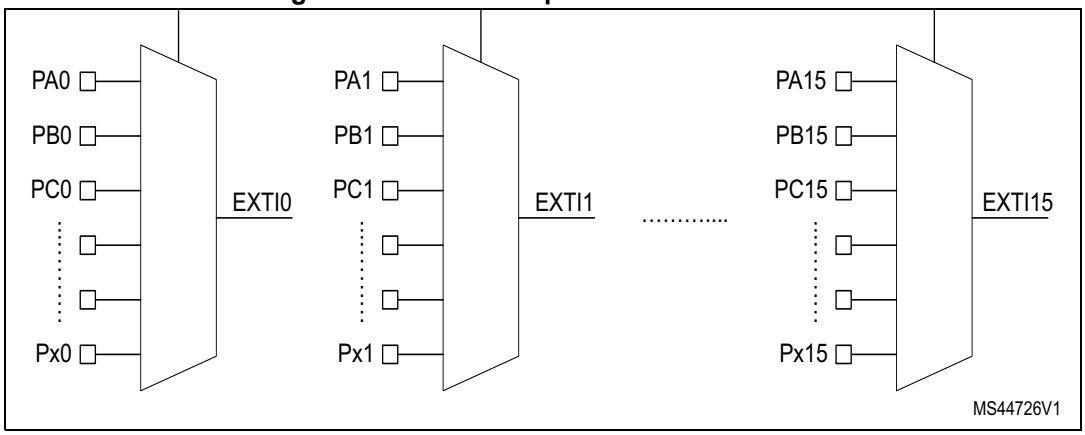
Figure 118. EXTI direct events



20.3.3 EXTI multiplexer selection

The EXTI multiplexer allows the selection of GPIOs as interrupts and wake-up. GPIOs are connected via 16 EXTI multiplexer lines to the first 16 EXTI events as configurable event. The selection of GPIO port as EXTI multiplexer output is controlled in the .

Figure 119. EXTI multiplexer GPIO selection



The EXTI multiplexer outputs are available as output signals from the EXTI to trigger other peripherals, whatever the masking in EXTI_IMR and EXTI_EMR registers.

20.4 EXTI functional behavior

The configurable events are enabled by enabling at least one of the trigger edges.

Once an event input is enabled, the CPU wake-up generation is conditioned by the CPU interrupt mask and CPU event mask.

Table 170. Masking functionality

CPU interrupt enable (in EXTI_IMR.IMn)	CPU event enable (in EXTI_EMR.EMn)	Configurable event inputs (in EXTI_RPR.RPIFn and EXTI_FPR.FPIFn)	Exti(n) interrupt(1)	CPU event	CPU wake-up
0	0	No	Masked	Masked	Masked
	1	No	Masked	Yes	Yes
1	0	Status latched	Yes	Masked	Yes(2)
	1	Status latched	Yes	Yes	Yes

1. The single exti(n) interrupt goes to the CPU. If no interrupt is required for CPU(m), the exti(n) interrupt must be masked in the CPU NVIC.
2. Only if the CPU interrupt is enabled in EXTI_IMR.IMn.

For configurable event inputs, when the enabled edges occur on the event input, an event request is generated. When the associated CPU interrupt is unmasked, the corresponding pending bits EXTI_RPR.RPIFn and/or EXTI_FPR.FPIFn is/are set: the CPU subsystem is woken up and the CPU interrupt signal is activated. The EXTI_RPR.RPIFn and/or EXTI_FPR.FPIFn pending bits must be cleared by software writing it to 1. This action clears the CPU interrupt.

For the configurable event inputs, an event request can be generated by software when writing a 1 in the software interrupt/event register EXTI_SWIER, allowing the generation of a rising edge on the event. The rising edge event pending bit is set in EXTI_RPR, whatever the setting in EXTI_RTSR.

20.5 EXTI event protection

The EXTI is able to protect event register bits from being modified by nonsecure and unprivileged accesses. The protection is individually activated per input event via the register bits in EXTI_SECCFGR and EXTI_PRIVCFGR. At EXTI level, the protection consists in preventing the following unauthorized write access:

- Change the settings of the secure and/or privileged configurable events.
- Change the masking of the secure and/or privileged input events.
- Clear pending status of the secure and/or privileged input events.

Table 171. Register protection overview

Register name	Access type	Protection[1][2]
EXTI_RTSR	RW	Security and privilege can be bit-wise enabled in EXTI_SECCFGR and EXTI_PRIVCFGR.
EXTI_FTSR	RW	
EXTI_SWIER	RW	
EXTI_RPR	RW	
EXTI_FPR	RW	
EXTI_SECCFGR	RW	Always secure. Privilege can be bit-wise enabled in EXTI_PRIVCFGR.
EXTI_PRIVCFGR	RW	Always privilege. Security can be bit-wise enabled in EXTI_SECCFGR.
EXTI_EXTICRn	RW	Security and privilege can be bit-wise enabled in EXTI_SECCFGR and EXTI_PRIVCFGR.
EXTI_LOCKR	RW	Always secure
EXTI_IM	RW	Security and privilege can be bit-wise enabled in EXTI_SECCFGR and EXTI_PRIVCFGR.
EXTI_EMR	RW	

1. Security is enabled with the individual input event (EXTI_SECCFGR register).
2. Privilege is enabled with the individual input event (EXTI_PRIVCFGR register).

20.5.1 EXTI security protection

When security is enabled for an input event, the associated input event configuration and control bits can only be modified and read by a secure access. A nonsecure write access is discarded and a read returns 0.

When input events are nonsecure, the security is disabled. The associated input event configuration and control bits can be modified and read by a secure access and nonsecure access.

The security configuration in registers EXTI_SECCFGR can be globally locked after reset by EXTI_LOCKR.LOCK.

20.5.2 EXTI privilege protection

When privilege is enabled for an input event, the associated input event configuration and control bits can only be modified and read by a privileged access. An unprivileged write access is discarded and a read returns 0.

When input events are unprivileged, the privilege is disabled. The associated input event configuration and control bits can be modified and read by a privileged access and unprivileged access.

The privileged configuration in registers EXTI_PRIVCFGR can be globally locked after reset by EXTI_LOCKR.LOCK.

20.6 EXTI registers

The EXTI register map is divided in the following sections:

Table 172. EXTI register map sections

Address offset	Description
0x000 - 0x01C	General configurable event [31:0] configuration
0x020 - 0x03C	General configurable event [63:32] configuration
0x040 - 0x05C	General configurable event [66:64] configuration
0x060 - 0x06C	EXTI IO port multiplexer selection
0x070	EXTI protection lock configuration
0x080 - 0x0A4	CPU input event configuration

All the registers can be accessed with word (32-bit), half-word (16-bit) and byte (8-bit) access.

20.6.1 EXTI rising trigger selection register (EXTI_RTSR1)

Address offset: 0x000

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RT16
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RT15	RT14	RT13	RT12	RT11	RT10	RT9	RT8	RT7	RT6	RT5	RT4	RT3	RT2	RT1	RT0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bits 16:0 **RTx:** Rising trigger event configuration bit of configurable event input x[(1)] (x = 16 to 0)

When EXTI_SECCFGR.SECx is disabled, RTx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, RTx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, RTx can be accessed with unprivileged and privileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, RTx can only be accessed with privileged access. Unprivileged write to this bit x is discarded, unprivileged read returns 0.

0: Rising trigger disabled (for event and interrupt) for input line

1: Rising trigger enabled (for event and interrupt) for input line

1. The configurable event inputs are edge triggered. No glitch must be generated on these inputs.
If a rising edge on the configurable event input occurs during writing of the register, the associated pending bit is not set.
Rising and falling edge triggers can be set for the same configurable event input. In this case, both edges generate a trigger.

20.6.2 EXTI falling trigger selection register (EXTI_FTSR1)

Address offset: 0x004

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FT16
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FT15	FT14	FT13	FT12	FT11	FT10	FT9	FT8	FT7	FT6	FT5	FT4	FT3	FT2	FT1	FT0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bits 16:0 **FTx:** Falling trigger event configuration bit of configurable event input x [(1)] (x = 16 to 0)

When EXTI_SECCFGR.SECx is disabled, FTx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, FTx can only be accessed with secure access. Nonsecure write to this FTx is discarded, nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, FTx can be accessed with unprivileged and privileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, FTx can only be accessed with privileged access. Unprivileged write to this FTx is discarded, unprivileged read returns 0.

0: Falling trigger disabled (for event and Interrupt) for input line

1: Falling trigger enabled (for event and Interrupt) for input line.

1. The configurable event inputs are edge triggered. No glitch must be generated on these inputs.
If a falling edge on the configurable event input occurs during writing of the register, the associated pending bit is not set.
Rising and falling edge triggers can be set for the same configurable event input. In this case, both edges generate a trigger.

20.6.3 EXTI software interrupt event register (EXTI_SWIER1)

Address offset: 0x008

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWI16
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SWI15	SWI14	SWI13	SWI12	SWI11	SWI10	SWI9	SWI8	SWI7	SWI6	SWI5	SWI4	SWI3	SWI2	SWI1	SWI0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bits 16:0 **SWIx:** Software interrupt on event x (x = 16 to 0)

When EXTI_SECCFGR.SECx is disabled, SWIx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, SWIx can only be accessed with secure access. Nonsecure write to this SWI x is discarded, nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, SWIx can be accessed with unprivileged and privileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, SWIx can only be accessed with privileged access. Unprivileged write to this SWIx is discarded, unprivileged read returns 0.

A software interrupt is generated independent from the setting in EXTI_RTSR and EXTI_FTSR. It always returns 0 when read.

0: Writing 0 has no effect.

1: Writing 1 triggers a rising edge event on event x. This bit is auto cleared by hardware.

20.6.4 EXTI rising edge pending register (EXTI_RPR1)

Address offset: 0x00C

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RPIF16
															rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RPIF15	RPIF14	RPIF13	RPIF12	RPIF11	RPIF10	RPIF9	RPIF8	RPIF7	RPIF6	RPIF5	RPIF4	RPIF3	RPIF2	RPIF1	RPIF0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bits 16:0 **RPIFx:** configurable event inputs x rising edge pending bit (x = 16 to 0)

When EXTI_SECCFGR.SECx is disabled, RPIFx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, RPIFx can only be accessed with secure access. Nonsecure write to this RPIFx is discarded, nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, RPIFx can be accessed with unprivileged and privileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, RPIFx can only be accessed with privileged access. Unprivileged write to this RPIFx is discarded, unprivileged read returns 0.

0: No rising edge trigger request occurred

1: Rising edge trigger request occurred

This bit is set when the rising edge event or an EXTI_SWIER software trigger arrives on the configurable event line. This bit is cleared by writing 1 to it.

20.6.5 EXTI falling edge pending register (EXTI_FPR1)

Address offset: 0x010

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FPIF16
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FPIF15	FPIF14	FPIF13	FPIF12	FPIF11	FPIF10	FPIF9	FPIF8	FPIF7	FPIF6	FPIF5	FPIF4	FPIF3	FPIF2	FPIF1	FPIF0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bits 16:0 **FPIFx:** configurable event inputs x falling edge pending bit (x = 16 to 0)

When EXTI_SECCFGR.SECx is disabled, FPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FPIFx can only be accessed with secure access. Nonsecure write to this FPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FPIFx can only be accessed with privileged access. Unprivileged write to this FPIFx is discarded, unprivileged read returns 0.
0: No falling edge trigger request occurred
1: Falling edge trigger request occurred
This bit is set when the falling edge event arrives on the configurable event line. This bit is cleared by writing 1 to it.

20.6.6 EXTI security configuration register (EXTI_SECCFGR1)

Address offset: 0x014

Reset value: 0x0000 0000

This register provides write access security. A nonsecure write access is ignored and causes the generation of an illegal access event. A nonsecure read returns the register data.

It contains only register bits for security capable input events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SEC31	SEC30	SEC29	SEC28	SEC27	SEC26	SEC25	SEC24	SEC23	SEC22	SEC21	SEC20	SEC19	SEC18	SEC17	SEC16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEC15	SEC14	SEC13	SEC12	SEC11	SEC10	SEC9	SEC8	SEC7	SEC6	SEC5	SEC4	SEC3	SEC2	SEC1	SEC0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SECx:** Security enable on event input x (x = 31 to 0)

When EXTI_PRIVCFGR.PRIVx is disabled, SECx can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, SECx can only be written with privileged access. Unprivileged write to this SECx is discarded.
0: Event security disabled (nonsecure)
1: Event security enabled (secure)

20.6.7 EXTI privilege configuration register (EXTI_PRIVCFGR1)

Address offset: 0x018

Reset value: 0x0000 0000

This register provides privileged write access protection. An unprivileged read returns the register data.

It contains only register bits for privilege capable input events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRIV31	PRIV30	PRIV29	PRIV28	PRIV27	PRIV26	PRIV25	PRIV24	PRIV23	PRIV22	PRIV21	PRIV20	PRIV19	PRIV18	PRIV17	PRIV16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRIV15	PRIV14	PRIV13	PRIV12	PRIV11	PRIV10	PRIV9	PRIV8	PRIV7	PRIV6	PRIV5	PRIV4	PRIV3	PRIV2	PRIV1	PRIV0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PRIVx:** Security enable on event input x (x = 31 to 0)

When EXTI_SECCFGR.SECx is disabled, PRIVx can be accessed with secure and nonsecure access.
When EXTI_SECCFGR.SECx is enabled, PRIVx can only be written with secure access. Nonsecure write to this PRIVx is discarded.
0: Event privilege disabled (unprivileged)
1: Event privilege enabled (privileged)

20.6.8 EXTI rising trigger selection register 2 (EXTI_RTSR2)

Address offset: 0x020

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	RT59	RT58	Res.	Res.	Res.	Res.	RT53	Res.	Res.	RT50	RT49	Res.
				rw	rw					rw			rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RT46	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw														

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **RT59:** Rising trigger event configuration bit of configurable event input x[(1)]
When EXTI_SECCFGR.SECx is disabled, RTx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RTx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RTx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RTx can only be accessed with privileged access. Unprivileged write to this bit x is discarded, unprivileged read returns 0.
0: Rising trigger disabled (for event and interrupt) for input line
1: Rising trigger enabled (for event and interrupt) for input line

Bit 26 **RT58:** Rising trigger event configuration bit of configurable event input x[(1)]
When EXTI_SECCFGR.SECx is disabled, RTx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RTx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RTx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RTx can only be accessed with privileged access. Unprivileged write to this bit x is discarded, unprivileged read returns 0.
0: Rising trigger disabled (for event and interrupt) for input line
1: Rising trigger enabled (for event and interrupt) for input line

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **RT53:** Rising trigger event configuration bit of configurable event input x[(1)]
When EXTI_SECCFGR.SECx is disabled, RTx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RTx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RTx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RTx can only be accessed with privileged access. Unprivileged write to this bit x is discarded, unprivileged read returns 0.
0: Rising trigger disabled (for event and interrupt) for input line
1: Rising trigger enabled (for event and interrupt) for input line

Bits 20:19 Reserved, must be kept at reset value.

Bit 18 **RT50:** Rising trigger event configuration bit of configurable event input x[(1)]
When EXTI_SECCFGR.SECx is disabled, RTx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RTx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RTx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RTx can only be accessed with privileged access. Unprivileged write to this bit x is discarded, unprivileged read returns 0.
0: Rising trigger disabled (for event and interrupt) for input line
1: Rising trigger enabled (for event and interrupt) for input line

Bit 17 **RT49:** Rising trigger event configuration bit of configurable event input x[1]

When EXTI_SECCFGR.SECx is disabled, RTx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, RTx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, RTx can be accessed with unprivileged and privileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, RTx can only be accessed with privileged access. Unprivileged write to this bit x is discarded, unprivileged read returns 0.

0: Rising trigger disabled (for event and interrupt) for input line

1: Rising trigger enabled (for event and interrupt) for input line

Bits 16:15 Reserved, must be kept at reset value.

Bit 14 **RT46:** Rising trigger event configuration bit of configurable event input x[1]

When EXTI_SECCFGR.SECx is disabled, RTx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, RTx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, RTx can be accessed with unprivileged and privileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, RTx can only be accessed with privileged access. Unprivileged write to this bit x is discarded, unprivileged read returns 0.

0: Rising trigger disabled (for event and interrupt) for input line

1: Rising trigger enabled (for event and interrupt) for input line

Bits 13:0 Reserved, must be kept at reset value.

1. The configurable event inputs are edge triggered. No glitch must be generated on these inputs.
If a rising edge on the configurable event input occurs during writing of the register, the associated pending bit is not set.
Rising and falling edge triggers can be set for the same configurable event input. In this case, both edges generate a trigger.

20.6.9 EXTI falling trigger selection register 2 (EXTI_FTSR2)

Address offset: 0x024

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	FT59	FT58	Res.	Res.	Res.	Res.	FT53	Res.	Res.	FT50	FT49	Res.
				rw	rw					rw			rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	FT46	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw														

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **FT59:** Falling trigger event configuration bit of configurable event input x[1]
When EXTI_SECCFGR.SECx is disabled, FTx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FTx can only be accessed with secure access. Nonsecure write to this FTx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FTx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FTx can only be accessed with privileged access. Unprivileged write to this FTx is discarded, unprivileged read returns 0.
0: Falling trigger disabled (for event and Interrupt) for input line
1: Falling trigger enabled (for event and Interrupt) for input line.

Bit 26 **FT58:** Falling trigger event configuration bit of configurable event input x[1]
When EXTI_SECCFGR.SECx is disabled, FTx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FTx can only be accessed with secure access. Nonsecure write to this FTx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FTx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FTx can only be accessed with privileged access. Unprivileged write to this FTx is discarded, unprivileged read returns 0.
0: Falling trigger disabled (for event and Interrupt) for input line
1: Falling trigger enabled (for event and Interrupt) for input line.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **FT53:** Falling trigger event configuration bit of configurable event input x[1]
When EXTI_SECCFGR.SECx is disabled, FTx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FTx can only be accessed with secure access. Nonsecure write to this FTx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FTx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FTx can only be accessed with privileged access. Unprivileged write to this FTx is discarded, unprivileged read returns 0.
0: Falling trigger disabled (for event and Interrupt) for input line
1: Falling trigger enabled (for event and Interrupt) for input line.

Bits 20:19 Reserved, must be kept at reset value.

Bit 18 **FT50:** Falling trigger event configuration bit of configurable event input x[1]
When EXTI_SECCFGR.SECx is disabled, FTx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FTx can only be accessed with secure access. Nonsecure write to this FTx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FTx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FTx can only be accessed with privileged access. Unprivileged write to this FTx is discarded, unprivileged read returns 0.
0: Falling trigger disabled (for event and Interrupt) for input line
1: Falling trigger enabled (for event and Interrupt) for input line.

Bit 17 **FT49:** Falling trigger event configuration bit of configurable event input x(1)

When EXTI_SECCFGR.SECx is disabled, FTx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, FTx can only be accessed with secure access. Nonsecure write to this FTx is discarded, nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, FTx can be accessed with unprivileged and privileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, FTx can only be accessed with privileged access. Unprivileged write to this FTx is discarded, unprivileged read returns 0.

0: Falling trigger disabled (for event and Interrupt) for input line

1: Falling trigger enabled (for event and Interrupt) for input line.

Bits 16:15 Reserved, must be kept at reset value.

Bit 14 **FT46:** Falling trigger event configuration bit of configurable event input x(1)

When EXTI_SECCFGR.SECx is disabled, FTx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, FTx can only be accessed with secure access. Nonsecure write to this FTx is discarded, nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, FTx can be accessed with unprivileged and privileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, FTx can only be accessed with privileged access. Unprivileged write to this FTx is discarded, unprivileged read returns 0.

0: Falling trigger disabled (for event and Interrupt) for input line

1: Falling trigger enabled (for event and Interrupt) for input line.

Bits 13:0 Reserved, must be kept at reset value.

1. The configurable event inputs are edge triggered. No glitch must be generated on these inputs.
If a falling edge on the configurable event input occurs during writing of the register, the associated pending bit is not set.
Rising and falling edge triggers can be set for the same configurable event input. In this case, both edges generate a trigger.

20.6.10 EXTI software interrupt event register 2 (EXTI_SWIER2)

Address offset: 0x028

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	SWI59	SWI58	Res.	Res.	Res.	Res.	SWI53	Res.	Res.	SWI50	SWI49	Res.
				rw	rw					rw			rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	SWI46	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw														

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **SWI59:** Software interrupt on event x
When EXTI_SECCFGR.SECx is disabled, SWIx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, SWIx can only be accessed with secure access. Nonsecure write to this SWI x is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, SWIx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, SWIx can only be accessed with privileged access. Unprivileged write to this SWIx is discarded, unprivileged read returns 0.
A software interrupt is generated independent from the setting in EXTI_RTSR and EXTI_FTSR. It always returns 0 when read.
0: Writing 0 has no effect.
1: Writing 1 triggers a rising edge event on event x. This bit is auto cleared by hardware.

Bit 26 **SWI58:** Software interrupt on event x
When EXTI_SECCFGR.SECx is disabled, SWIx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, SWIx can only be accessed with secure access. Nonsecure write to this SWI x is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, SWIx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, SWIx can only be accessed with privileged access. Unprivileged write to this SWIx is discarded, unprivileged read returns 0.
A software interrupt is generated independent from the setting in EXTI_RTSR and EXTI_FTSR. It always returns 0 when read.
0: Writing 0 has no effect.
1: Writing 1 triggers a rising edge event on event x. This bit is auto cleared by hardware.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **SWI53:** Software interrupt on event x
When EXTI_SECCFGR.SECx is disabled, SWIx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, SWIx can only be accessed with secure access. Nonsecure write to this SWI x is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, SWIx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, SWIx can only be accessed with privileged access. Unprivileged write to this SWIx is discarded, unprivileged read returns 0.
A software interrupt is generated independent from the setting in EXTI_RTSR and EXTI_FTSR. It always returns 0 when read.
0: Writing 0 has no effect.
1: Writing 1 triggers a rising edge event on event x. This bit is auto cleared by hardware.

Bits 20:19 Reserved, must be kept at reset value.

Bit 18 **SWI50:** Software interrupt on event x

When EXTI_SECCFGR.SECx is disabled, SWIx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, SWIx can only be accessed with secure access. Nonsecure write to this SWI x is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, SWIx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, SWIx can only be accessed with privileged access. Unprivileged write to this SWIx is discarded, unprivileged read returns 0.
A software interrupt is generated independent from the setting in EXTI_RTSR and EXTI_FTSR. It always returns 0 when read.
0: Writing 0 has no effect.
1: Writing 1 triggers a rising edge event on event x. This bit is auto cleared by hardware.

Bit 17 **SWI49:** Software interrupt on event x

When EXTI_SECCFGR.SECx is disabled, SWIx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, SWIx can only be accessed with secure access. Nonsecure write to this SWI x is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, SWIx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, SWIx can only be accessed with privileged access. Unprivileged write to this SWIx is discarded, unprivileged read returns 0.
A software interrupt is generated independent from the setting in EXTI_RTSR and EXTI_FTSR. It always returns 0 when read.
0: Writing 0 has no effect.
1: Writing 1 triggers a rising edge event on event x. This bit is auto cleared by hardware.

Bits 16:15 Reserved, must be kept at reset value.

Bit 14 **SWI46:** Software interrupt on event x

When EXTI_SECCFGR.SECx is disabled, SWIx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, SWIx can only be accessed with secure access. Nonsecure write to this SWI x is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, SWIx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, SWIx can only be accessed with privileged access. Unprivileged write to this SWIx is discarded, unprivileged read returns 0.
A software interrupt is generated independent from the setting in EXTI_RTSR and EXTI_FTSR. It always returns 0 when read.
0: Writing 0 has no effect.
1: Writing 1 triggers a rising edge event on event x. This bit is auto cleared by hardware.

Bits 13:0 Reserved, must be kept at reset value.

20.6.11 EXTI rising edge pending register 2 (EXTI_RPR2)

Address offset: 0x02C

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	RPIF59	RPIF58	Res.	Res.	Res.	Res.	RPIF53	Res.	Res.	RPIF50	RPIF49	Res.
				rw	rw					rw			rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RPIF46	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw														

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **RPIF59:** configurable event inputs x rising edge pending bit

When EXTI_SECCFGR.SECx is disabled, RPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RPIFx can only be accessed with secure access. Nonsecure write to this RPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RPIFx can only be accessed with privileged access. Unprivileged write to this RPIFx is discarded, unprivileged read returns 0.
0: No rising edge trigger request occurred
1: Rising edge trigger request occurred
This bit is set when the rising edge event or an EXTI_SWIER software trigger arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bit 26 **RPIF58:** configurable event inputs x rising edge pending bit

When EXTI_SECCFGR.SECx is disabled, RPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RPIFx can only be accessed with secure access. Nonsecure write to this RPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RPIFx can only be accessed with privileged access. Unprivileged write to this RPIFx is discarded, unprivileged read returns 0.
0: No rising edge trigger request occurred
1: Rising edge trigger request occurred
This bit is set when the rising edge event or an EXTI_SWIER software trigger arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **RPIF53:** configurable event inputs x rising edge pending bit
When EXTI_SECCFGR.SECx is disabled, RPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RPIFx can only be accessed with secure access. Nonsecure write to this RPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RPIFx can only be accessed with privileged access. Unprivileged write to this RPIFx is discarded, unprivileged read returns 0.
0: No rising edge trigger request occurred
1: Rising edge trigger request occurred
This bit is set when the rising edge event or an EXTI_SWIER software trigger arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bits 20:19 Reserved, must be kept at reset value.

Bit 18 **RPIF50:** configurable event inputs x rising edge pending bit
When EXTI_SECCFGR.SECx is disabled, RPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RPIFx can only be accessed with secure access. Nonsecure write to this RPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RPIFx can only be accessed with privileged access. Unprivileged write to this RPIFx is discarded, unprivileged read returns 0.
0: No rising edge trigger request occurred
1: Rising edge trigger request occurred
This bit is set when the rising edge event or an EXTI_SWIER software trigger arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bit 17 **RPIF49:** configurable event inputs x rising edge pending bit
When EXTI_SECCFGR.SECx is disabled, RPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RPIFx can only be accessed with secure access. Nonsecure write to this RPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RPIFx can only be accessed with privileged access. Unprivileged write to this RPIFx is discarded, unprivileged read returns 0.
0: No rising edge trigger request occurred
1: Rising edge trigger request occurred
This bit is set when the rising edge event or an EXTI_SWIER software trigger arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bits 16:15 Reserved, must be kept at reset value.

Bit 14 **RPIF46:** configurable event inputs x rising edge pending bit
When EXTI_SECCFGR.SECx is disabled, RPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RPIFx can only be accessed with secure access. Nonsecure write to this RPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RPIFx can only be accessed with privileged access. Unprivileged write to this RPIFx is discarded, unprivileged read returns 0.
0: No rising edge trigger request occurred
1: Rising edge trigger request occurred
This bit is set when the rising edge event or an EXTI_SWIER software trigger arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bits 13:0 Reserved, must be kept at reset value.

20.6.12 EXTI falling edge pending register 2 (EXTI_FPR2)

Address offset: 0x030

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	FPIF59	FPIF58	Res.	Res.	Res.	Res.	FPIF53	Res.	Res.	FPIF50	FPIF49	Res.
				rw	rw					rw			rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	FPIF46	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw														

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **FPIF59:** configurable event inputs x falling edge pending bit
When EXTI_SECCFGR.SECx is disabled, FPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FPIFx can only be accessed with secure access. Nonsecure write to this FPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FPIFx can only be accessed with privileged access. Unprivileged write to this FPIFx is discarded, unprivileged read returns 0.
0: No falling edge trigger request occurred
1: Falling edge trigger request occurred
This bit is set when the falling edge event arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bit 26 **FPIF58:** configurable event inputs x falling edge pending bit

When EXTI_SECCFGR.SECx is disabled, FPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FPIFx can only be accessed with secure access. Nonsecure write to this FPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FPIFx can only be accessed with privileged access. Unprivileged write to this FPIFx is discarded, unprivileged read returns 0.
0: No falling edge trigger request occurred
1: Falling edge trigger request occurred
This bit is set when the falling edge event arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **FPIF53:** configurable event inputs x falling edge pending bit

When EXTI_SECCFGR.SECx is disabled, FPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FPIFx can only be accessed with secure access. Nonsecure write to this FPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FPIFx can only be accessed with privileged access. Unprivileged write to this FPIFx is discarded, unprivileged read returns 0.
0: No falling edge trigger request occurred
1: Falling edge trigger request occurred
This bit is set when the falling edge event arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bits 20:19 Reserved, must be kept at reset value.

Bit 18 **FPIF50:** configurable event inputs x falling edge pending bit

When EXTI_SECCFGR.SECx is disabled, FPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FPIFx can only be accessed with secure access. Nonsecure write to this FPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FPIFx can only be accessed with privileged access. Unprivileged write to this FPIFx is discarded, unprivileged read returns 0.
0: No falling edge trigger request occurred
1: Falling edge trigger request occurred
This bit is set when the falling edge event arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bit 17 **FPIF49:** configurable event inputs x falling edge pending bit

When EXTI_SECCFGR.SECx is disabled, FPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FPIFx can only be accessed with secure access. Nonsecure write to this FPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FPIFx can only be accessed with privileged access. Unprivileged write to this FPIFx is discarded, unprivileged read returns 0.
0: No falling edge trigger request occurred
1: Falling edge trigger request occurred
This bit is set when the falling edge event arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bits 16:15 Reserved, must be kept at reset value.

Bit 14 **FPIF46:** configurable event inputs x falling edge pending bit

When EXTI_SECCFGR.SECx is disabled, FPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FPIFx can only be accessed with secure access. Nonsecure write to this FPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FPIFx can only be accessed with privileged access. Unprivileged write to this FPIFx is discarded, unprivileged read returns 0.
0: No falling edge trigger request occurred
1: Falling edge trigger request occurred
This bit is set when the falling edge event arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bits 13:0 Reserved, must be kept at reset value.

20.6.13 EXTI security configuration register 2 (EXTI_SECCFGR2)

Address offset: 0x034

Reset value: 0x0000 0000

This register provides write access security. A nonsecure write access is ignored and causes the generation of an illegal access event. A nonsecure read returns the register data.

It contains only register bits for privilege capable input events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SEC63	SEC62	SEC61	SEC60	SEC59	SEC58	SEC57	SEC56	SEC55	SEC54	SEC53	SEC52	SEC51	SEC50	SEC49	SEC48
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEC47	SEC46	SEC45	SEC44	SEC43	SEC42	SEC41	SEC40	SEC39	SEC38	SEC37	SEC36	SEC35	SEC34	SEC33	SEC32
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SECx:** Security enable on event input x (x = 63 to 32)

When EXTI_PRIVCFGR.PRIVx is disabled, SECx can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, SECx can only be written with privileged access. Unprivileged write to this SECx is discarded.
0: Event security disabled (nonsecure)
1: Event security enabled (secure)

20.6.14 EXTI privilege configuration register 2 (EXTI_PRIVCFGR2)

Address offset: 0x038

Reset value: 0x0000 0000

This register provides privileged write access protection. An unprivileged read returns the register data.

It contains only register bits for security capable input events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRIV63	PRIV62	PRIV61	PRIV60	PRIV59	PRIV58	PRIV57	PRIV56	PRIV55	PRIV54	PRIV53	PRIV52	PRIV51	PRIV50	PRIV49	PRIV48
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRIV47	PRIV46	PRIV45	PRIV44	PRIV43	PRIV42	PRIV41	PRIV40	PRIV39	PRIV38	PRIV37	PRIV36	PRIV35	PRIV34	PRIV33	PRIV32
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PRIVx:** Security enable on event input x (x = 63 to 32)

When EXTI_SECCFGR.SECx is disabled, PRIVx can be accessed with secure and nonsecure access.
When EXTI_SECCFGR.SECx is enabled, PRIVx can only be written with secure access. Nonsecure write to this PRIVx is discarded.
0: Event privilege disabled (unprivileged)
1: Event privilege enabled (privileged)

20.6.15 EXTI rising trigger selection register 3 (EXTI_RTSR3)

Address offset: 0x040

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RT66	Res.	RT64
													rw		rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **RT66:** Rising trigger event configuration bit of configurable event input x[1]
When EXTI_SECCFGR.SECx is disabled, RTx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RTx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RTx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RTx can only be accessed with privileged access. Unprivileged write to this bit x is discarded, unprivileged read returns 0.
0: Rising trigger disabled (for event and interrupt) for input line
1: Rising trigger enabled (for event and interrupt) for input line

Bit 1 Reserved, must be kept at reset value.

Bit 0 **RT64:** Rising trigger event configuration bit of configurable event input x[1]
When EXTI_SECCFGR.SECx is disabled, RTx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RTx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RTx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RTx can only be accessed with privileged access. Unprivileged write to this bit x is discarded, unprivileged read returns 0.
0: Rising trigger disabled (for event and interrupt) for input line
1: Rising trigger enabled (for event and interrupt) for input line

1. The configurable event inputs are edge triggered. No glitch must be generated on these inputs.
If a rising edge on the configurable event input occurs during writing of the register, the associated pending bit is not set.
Rising and falling edge triggers can be set for the same configurable event input. In this case, both edges generate a trigger.

20.6.16 EXTI falling trigger selection register 3 (EXTI_FTSR3)

Address offset: 0x044

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FT66	Res.	FT64
													rw		rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **FT66:** Falling trigger event configuration bit of configurable event input x(1)

When EXTI_SECCFGR.SECx is disabled, FTx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, FTx can only be accessed with secure access. Nonsecure write to this FTx is discarded, nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, FTx can be accessed with unprivileged and privileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, FTx can only be accessed with privileged access. Unprivileged write to this FTx is discarded, unprivileged read returns 0.

0: Falling trigger disabled (for event and Interrupt) for input line

1: Falling trigger enabled (for event and Interrupt) for input line.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **FT64:** Falling trigger event configuration bit of configurable event input x(1)

When EXTI_SECCFGR.SECx is disabled, FTx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, FTx can only be accessed with secure access. Nonsecure write to this FTx is discarded, nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, FTx can be accessed with unprivileged and privileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, FTx can only be accessed with privileged access. Unprivileged write to this FTx is discarded, unprivileged read returns 0.

0: Falling trigger disabled (for event and Interrupt) for input line

1: Falling trigger enabled (for event and Interrupt) for input line.

1. The configurable event inputs are edge triggered. No glitch must be generated on these inputs.
If a falling edge on the configurable event input occurs during writing of the register, the associated pending bit is not set.
Rising and falling edge triggers can be set for the same configurable event input. In this case, both edges generate a trigger.

20.6.17 EXTI software interrupt event register 3 (EXTI_SWIER3)

Address offset: 0x048

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWI66	Res.	SWI64
													rw		rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **SWI66:** Software interrupt on event x
When EXTI_SECCFGR.SECx is disabled, SWIx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, SWIx can only be accessed with secure access. Nonsecure write to this SWI x is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, SWIx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, SWIx can only be accessed with privileged access. Unprivileged write to this SWIx is discarded, unprivileged read returns 0.
A software interrupt is generated independent from the setting in EXTI_RTSR and EXTI_FTSR. It always returns 0 when read.
0: Writing 0 has no effect.
1: Writing 1 triggers a rising edge event on event x. This bit is auto cleared by hardware.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **SWI64:** Software interrupt on event x
When EXTI_SECCFGR.SECx is disabled, SWIx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, SWIx can only be accessed with secure access. Nonsecure write to this SWI x is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, SWIx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, SWIx can only be accessed with privileged access. Unprivileged write to this SWIx is discarded, unprivileged read returns 0.
A software interrupt is generated independent from the setting in EXTI_RTSR and EXTI_FTSR. It always returns 0 when read.
0: Writing 0 has no effect.
1: Writing 1 triggers a rising edge event on event x. This bit is auto cleared by hardware.

20.6.18 EXTI rising edge pending register 3 (EXTI_RPR3)

Address offset: 0x04C

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RPIF66	Res.	RPIF64
													rw		rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **RPIF66:** configurable event inputs x rising edge pending bit
When EXTI_SECCFGR.SECx is disabled, RPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RPIFx can only be accessed with secure access. Nonsecure write to this RPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RPIFx can only be accessed with privileged access. Unprivileged write to this RPIFx is discarded, unprivileged read returns 0.
0: No rising edge trigger request occurred
1: Rising edge trigger request occurred
This bit is set when the rising edge event or an EXTI_SWIER software trigger arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **RPIF64:** configurable event inputs x rising edge pending bit
When EXTI_SECCFGR.SECx is disabled, RPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, RPIFx can only be accessed with secure access. Nonsecure write to this RPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, RPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, RPIFx can only be accessed with privileged access. Unprivileged write to this RPIFx is discarded, unprivileged read returns 0.
0: No rising edge trigger request occurred
1: Rising edge trigger request occurred
This bit is set when the rising edge event or an EXTI_SWIER software trigger arrives on the configurable event line. This bit is cleared by writing 1 to it.

20.6.19 EXTI falling edge pending register 3 (EXTI_FPR3)

Address offset: 0x050

Reset value: 0x0000 0000

It contains only register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FPIF66	Res.	FPIF64
													rw		rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **FPIF66:** configurable event inputs x falling edge pending bit
When EXTI_SECCFGR.SECx is disabled, FPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FPIFx can only be accessed with secure access. Nonsecure write to this FPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FPIFx can only be accessed with privileged access. Unprivileged write to this FPIFx is discarded, unprivileged read returns 0.
0: No falling edge trigger request occurred
1: Falling edge trigger request occurred
This bit is set when the falling edge event arrives on the configurable event line. This bit is cleared by writing 1 to it.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **FPIF64:** configurable event inputs x falling edge pending bit
When EXTI_SECCFGR.SECx is disabled, FPIFx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, FPIFx can only be accessed with secure access. Nonsecure write to this FPIFx is discarded, nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, FPIFx can be accessed with unprivileged and privileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, FPIFx can only be accessed with privileged access. Unprivileged write to this FPIFx is discarded, unprivileged read returns 0.
0: No falling edge trigger request occurred
1: Falling edge trigger request occurred
This bit is set when the falling edge event arrives on the configurable event line. This bit is cleared by writing 1 to it.

20.6.20 EXTI security configuration register 3 (EXTI_SECCFGR3)

Address offset: 0x054

Reset value: 0x0000 0000

This register provides write access security. A nonsecure write access is ignored and causes the generation of an illegal access event. A nonsecure read returns the register data.

It contains only register bits for privilege capable input events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEC66	SEC65	SEC64
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **SECx:** Security enable on event input x (x = 66 to 64)
When EXTI_PRIVCFGR.PRIVx is disabled, SECx can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, SECx can only be written with privileged access. Unprivileged write to this SECx is discarded.
0: Event security disabled (nonsecure)
1: Event security enabled (secure)

20.6.21 EXTI privilege configuration register 3 (EXTI_PRIVCFGR3)

Address offset: 0x058

Reset value: 0x0000 0000

This register provides privileged write access protection. An unprivileged read returns the register data.

It contains only register bits for security capable input events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV66	PRIV65	PRIV64
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **PRIVx:** Security enable on event input x (x = 66 to 64)
When EXTI_SECCFGR.SECx is disabled, PRIVx can be accessed with secure and nonsecure access.
When EXTI_SECCFGR.SECx is enabled, PRIVx can only be written with secure access. Nonsecure write to this PRIVx is discarded.
0: Event privilege disabled (unprivileged)
1: Event privilege enabled (privileged)

20.6.22 EXTI external interrupt selection register (EXTI_EXTICR1)

Address offset: 0x060 EXTI multiplexer 0, 1, 2, 3

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EXTI3[7:0]								EXTI2[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTI1[7:0]								EXTI0[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **EXTI3[7:0]:** EXTI3 GPIO port selection

These bits are written by software to select the source input for EXTI3 external interrupt.
When EXTI_SECCFGR1.SEC3 is disabled, EXTI3 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC3 is enabled, EXTI3 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV3 is disabled, EXTI3 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV3 is enabled, EXTI3 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA3 pin
0x01: PB3 pin
0x02: PC3 pin
0x03: PD3 pin
0x04: PE3 pin
0x05: PF3 pin
0x06: PG3 pin
0x07: PH3 pin
0x08: PI3 pin
0x09: PJ3 pin
0x0A: PK3 pin
Others: reserved

Bits 23:16 **EXTI2[7:0]:** EXTI2 GPIO port selection

These bits are written by software to select the source input for EXTI2 external interrupt.
When EXTI_SECCFGR1.SEC2 is disabled, EXTI2 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC2 is enabled, EXTI2 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV2 is disabled, EXTI2 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV2 is enabled, EXTI2 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA2 pin
0x01: PB2 pin
0x02: PC2 pin
0x03: PD2 pin
0x04: PE2 pin
0x05: PF2 pin
0x06: PG2 pin
0x07: PH2 pin
0x08: PI2 pin
0x09: PJ2 pin
0x0A: PK2 pin
Others: reserved

Bits 15:8 **EXTI1[7:0]:** EXTI1 GPIO port selection

These bits are written by software to select the source input for EXTI1 external interrupt.
When EXTI_SECCFGR1.SEC1 is disabled, EXTI1 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC1 is enabled, EXTI1 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV1 is disabled, EXTI1 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV1 is enabled, EXTI1 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA1 pin
0x01: PB1 pin
0x02: PC1 pin
0x03: PD1 pin
0x04: PE1 pin
0x05: PF1 pin
0x06: PG1 pin
0x07: PH1 pin
0x08: PI1 pin
0x09: PJ1 pin
0x0A: PK1 pin
Others: reserved

Bits 7:0 **EXTI0[7:0]:** EXTI0 GPIO port selection

These bits are written by software to select the source input for EXTI0 external interrupt.
When EXTI_SECCFGR1.SEC0 is disabled, EXTI0 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC0 is enabled, EXTI0 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV0 is disabled, EXTI0 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV0 is enabled, EXTI0 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA0 pin
0x01: PB0 pin
0x02: PC0 pin
0x03: PD0 pin
0x04: PE0 pin
0x05: PF0 pin
0x06: PG0 pin
0x07: PH0 pin
0x08: PI0 pin
0x09: PJ0 pin
0x0A: PK0 pin
Others: reserved

20.6.23 EXTI external interrupt selection register (EXTI_EXTICR2)

Address offset: 0x064 EXTI multiplexer 4, 5, 6, 7

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EXTI7[7:0]								EXTI6[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTI5[7:0]								EXTI4[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **EXTI7[7:0]:** EXTI7 GPIO port selection

These bits are written by software to select the source input for EXTI7 external interrupt.
When EXTI_SECCFGR1.SEC7 is disabled, EXTI7 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC7 is enabled, EXTI7 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV7 is disabled, EXTI7 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV7 is enabled, EXTI7 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA7 pin
0x01: PB7 pin
0x02: PC7 pin
0x03: PD7 pin
0x04: PE7 pin
0x05: PF7 pin
0x06: PG7 pin
0x07: PH7 pin
0x08: PI7 pin
0x09: PJ7 pin
0x0A: PK7 pin
Others: reserved

Bits 23:16 **EXTI6[7:0]:** EXTI6 GPIO port selection

These bits are written by software to select the source input for EXTI6 external interrupt.
When EXTI_SECCFGR1.SEC6 is disabled, EXTI6 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC6 is enabled, EXTI6 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV6 is disabled, EXTI6 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV6 is enabled, EXTI6 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA6 pin
0x01: PB6 pin
0x02: PC6 pin
0x03: PD6 pin
0x04: PE6 pin
0x05: PF6 pin
0x06: PG6 pin
0x07: PH6 pin
0x08: PI6 pin
0x09: PJ6 pin
0x0A: PK6 pin
Others: reserved

Bits 15:8 **EXTI5[7:0]:** EXTI5 GPIO port selection

These bits are written by software to select the source input for EXTI5 external interrupt.
When EXTI_SECCFGR1.SEC5 is disabled, EXTI5 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC5 is enabled, EXTI5 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV5 is disabled, EXTI5 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV5 is enabled, EXTI5 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA5 pin
0x01: PB5 pin
0x02: PC5 pin
0x03: PD5 pin
0x04: PE5 pin
0x05: PF5 pin
0x06: PG5 pin
0x07: PH5 pin
0x08: PI5 pin
0x09: PJ5 pin
0x0A: PK5 pin
Others: reserved

Bits 7:0 **EXTI4[7:0]:** EXTI4 GPIO port selection

These bits are written by software to select the source input for EXTI4 external interrupt.
When EXTI_SECCFGR1.SEC4 is disabled, EXTI4 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC4 is enabled, EXTI4 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV4 is disabled, EXTI4 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV4 is enabled, EXTI4 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA4 pin
0x01: PB4 pin
0x02: PC4 pin
0x03: PD4 pin
0x04: PE4 pin
0x05: PF4 pin
0x06: PG4 pin
0x07: PH4 pin
0x08: PI4 pin
0x09: PJ4 pin
0x0A: PK4 pin
Others: reserved

20.6.24 EXTI external interrupt selection register (EXTI_EXTICR3)

Address offset: 0x068 EXTI multiplexer 8, 9, 10, 11

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EXTI11[7:0]								EXTI10[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTI9[7:0]								EXTI8[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **EXTI11[7:0]:** EXTI11 GPIO port selection

These bits are written by software to select the source input for EXTI11 external interrupt.
When EXTI_SECCFGR1.SEC11 is disabled, EXTI11 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC11 is enabled, EXTI11 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV11 is disabled, EXTI11 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV11 is enabled, EXTI11 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA11 pin
0x01: PB11 pin
0x02: PC11 pin
0x03: PD11 pin
0x04: PE11 pin
0x05: PF11 pin
0x06: PG11 pin
0x07: PH11 pin
0x08: PI11 pin
0x09: PJ11 pin
0x0A: PK11 pin
Others: reserved

Bits 23:16 **EXTI10[7:0]:** EXTI10 GPIO port selection

These bits are written by software to select the source input for EXTI10 external interrupt.
When EXTI_SECCFGR1.SEC10 is disabled, EXTI10 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC10 is enabled, EXTI10 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV10 is disabled, EXTI10 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV10 is enabled, EXTI10 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA10 pin
0x01: PB10 pin
0x02: PC10 pin
0x03: PD10 pin
0x04: PE10 pin
0x05: PF10 pin
0x06: PG10 pin
0x07: PH10 pin
0x08: PI10 pin
0x09: PJ10 pin
0x0A: PK10 pin
Others: reserved

Bits 15:8 **EXTI9[7:0]:** EXTI9 GPIO port selection

These bits are written by software to select the source input for EXTI9 external interrupt.
When EXTI_SECCFGR1.SEC9 is disabled, EXTI9 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC9 is enabled, EXTI9 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV9 is disabled, EXTI9 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV9 is enabled, EXTI9 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA9 pin
0x01: PB9 pin
0x02: PC9 pin
0x03: PD9 pin
0x04: PE9 pin
0x05: PF9 pin
0x06: PG9 pin
0x07: PH9 pin
0x08: PI9 pin
0x09: PJ9 pin
0x0A: PK9 pin
Others: reserved

Bits 7:0 **EXTI8[7:0]:** EXTI8 GPIO port selection

These bits are written by software to select the source input for EXTI8 external interrupt.
When EXTI_SECCFGR1.SEC8 is disabled, EXTI8 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC8 is enabled, EXTI8 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV8 is disabled, EXTI8 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV8 is enabled, EXTI8 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA8 pin
0x01: PB8 pin
0x02: PC8 pin
0x03: PD8 pin
0x04: PE8 pin
0x05: PF8 pin
0x06: PG8 pin
0x07: PH8 pin
0x08: PI8 pin
0x09: PJ8 pin
0x0A: PK8 pin
Others: reserved

20.6.25 EXTI external interrupt selection register (EXTI_EXTICR4)

Address offset: 0x06C EXTI multiplexer 12, 13, 14, 15

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EXTI15[7:0]								EXTI14[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTI13[7:0]								EXTI12[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **EXTI15[7:0]:** EXTI15 GPIO port selection

These bits are written by software to select the source input for EXTI15 external interrupt.
When EXTI_SECCFGR1.SEC15 is disabled, EXTI15 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC15 is enabled, EXTI15 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV15 is disabled, EXTI15 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV15 is enabled, EXTI15 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA15 pin
0x01: PB15 pin
0x02: PC15 pin
0x03: PD15 pin
0x04: PE15 pin
0x05: PF15 pin
0x06: PG15 pin
0x07: PH15 pin
0x08: PI15 pin
0x09: PJ15 pin
0x0A: PK15 pin
Others: reserved

Bits 23:16 **EXTI14[7:0]:** EXTI14 GPIO port selection

These bits are written by software to select the source input for EXTI14 external interrupt.
When EXTI_SECCFGR1.SEC14 is disabled, EXTI14 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC14 is enabled, EXTI14 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV14 is disabled, EXTI14 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV14 is enabled, EXTI14 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA14 pin
0x01: PB14 pin
0x02: PC14 pin
0x03: PD14 pin
0x04: PE14 pin
0x05: PF14 pin
0x06: PG14 pin
0x07: PH14 pin
0x08: PI14 pin
0x09: PJ14 pin
0x0A: PK14 pin
Others: reserved

Bits 15:8 **EXTI13[7:0]:** EXTI13 GPIO port selection

These bits are written by software to select the source input for EXTI13 external interrupt.
When EXTI_SECCFGR1.SEC13 is disabled, EXTI13 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC13 is enabled, EXTI13 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV13 is disabled, EXTI13 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV13 is enabled, EXTI13 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA13 pin
0x01: PB13 pin
0x02: PC13 pin
0x03: PD13 pin
0x04: PE13 pin
0x05: PF13 pin
0x06: PG13 pin
0x07: PH13 pin
0x08: PI13 pin
0x09: PJ13 pin
0x0A: PK13 pin
Others: reserved

Bits 7:0 **EXTI12[7:0]:** EXTI12 GPIO port selection

These bits are written by software to select the source input for EXTI12 external interrupt.
When EXTI_SECCFGR1.SEC12 is disabled, EXTI12 can be accessed with nonsecure and secure access.
When EXTI_SECCFGR1.SEC12 is enabled, EXTI12 can only be accessed with secure access. Nonsecure write is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR1.PRIV12 is disabled, EXTI12 can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR1.PRIV12 is enabled, EXTI12 can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0x00: PA12 pin
0x01: PB12 pin
0x02: PC12 pin
0x03: PD12 pin
0x04: PE12 pin
0x05: PF12 pin
0x06: PG12 pin
0x07: PH12 pin
0x08: PI12 pin
0x09: PJ12 pin
0x0A: PK12 pin
Others: reserved

20.6.26 EXTI lock register (EXTI_LOCKR)

Address offset: 0x070

Reset value: 0x0000 0000

This register provides write access security: a nonsecure write access is ignored and a read access returns zero data, and both generates an illegal access event.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCK
															rs

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **LOCK**: Global security and privilege configuration registers (EXTI_SECCFGR and EXTI_PRIVCFGR) lock

This bit is written once after reset.
0: Security and privilege configuration open, can be modified.
1: Security and privilege configuration locked, can no longer be modified.

20.6.27 EXTI CPU wake-up with interrupt mask register (EXTI_IMR1)

Address offset: 0x080

Reset value: 0xFFFE 0000

Contains register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IM31	IM30	IM29	IM28	IM27	IM26	IM25	IM24	IM23	IM22	IM21	IM20	IM19	IM18	IM17	IM16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IM15	IM14	IM13	IM12	IM11	IM10	IM9	IM8	IM7	IM6	IM5	IM4	IM3	IM2	IM1	IM0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IMx:** CPU wake-up with interrupt mask on event input x [1] (x = 31 to 0)

When EXTI_SECCFGR.SECx is disabled, IMx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, IMx can only be accessed with secure access. Nonsecure write to this bit is discarded and nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, IMx can be accessed with privileged and unprivileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, IMx can only be accessed with privileged access. Unprivileged write to this bit is discarded.

0: Wake-up with interrupt request from input event x is masked.

1: Wake-up with interrupt request from input event x is unmasked.

1. The reset value for configurable event inputs is set to 0 in order to disable the interrupt by default.

20.6.28 EXTI CPU wake-up with event mask register (EXTI_EMR1)

Address offset: 0x084

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EM16
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EM15	EM14	EM13	EM12	EM11	EM10	EM9	EM8	EM7	EM6	EM5	EM4	EM3	EM2	EM1	EM0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bits 16:0 **EMx:** CPU wake-up with event generation mask on event input x (x = 16 to 0)

When EXTI_SECCFGR.SECx is disabled, EMx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, EMx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, EMx can be accessed with privileged and unprivileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, EMx can only be accessed with privileged access. Unprivileged write to this bit is discarded.

0: Wake-up with event generation from Line x is masked.

1: Wake-up with event generation from Line x is unmasked.

20.6.29 EXTI CPU wake-up with interrupt mask register 2 (EXTI_IMR2)

Address offset: 0x090

Reset value: 0xF3D9 BFFF

Contains register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IM63	IM62	IM61	IM60	IM59	IM58	IM57	IM56	IM55	IM54	IM53	IM52	IM51	IM50	IM49	IM48
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IM47	IM46	IM45	IM44	IM43	IM42	IM41	IM40	IM39	IM38	IM37	IM36	IM35	IM34	IM33	IM32
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IMx:** CPU wake-up with interrupt mask on event input x [(1)] (x = 63 to 0)

When EXTI_SECCFGR.SECx is disabled, IMx can be accessed with nonsecure and secure access.

When EXTI_SECCFGR.SECx is enabled, IMx can only be accessed with secure access. Nonsecure write to this bit is discarded and nonsecure read returns 0.

When EXTI_PRIVCFGR.PRIVx is disabled, IMx can be accessed with privileged and unprivileged access.

When EXTI_PRIVCFGR.PRIVx is enabled, IMx can only be accessed with privileged access. Unprivileged write to this bit is discarded.

0: Wake-up with interrupt request from input event x is masked.

1: Wake-up with interrupt request from input event x is unmasked.

1. The reset value for configurable event inputs is set to 0 to disable the interrupt by default.

20.6.30 EXTI CPU wake-up with event mask register 2 (EXTI_EMR2)

Address offset: 0x094

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	EM59	EM58	Res.	Res.	Res.	Res.	EM53	Res.	Res.	EM50	EM49	Res.
				rw	rw					rw			rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	EM46	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw														

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:26 **EMx:** CPU wake-up with event generation mask on event input x (x = 59 to 58)

When EXTI_SECCFGR.SECx is disabled, EMx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, EMx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, EMx can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, EMx can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0: Wake-up with event generation from Line x is masked.
1: Wake-up with event generation from Line x is unmasked.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **EM53:** CPU wake-up with event generation mask on event input

When EXTI_SECCFGR.SECx is disabled, EMx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, EMx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, EMx can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, EMx can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0: Wake-up with event generation from Line x is masked.
1: Wake-up with event generation from Line x is unmasked.

Bits 20:19 Reserved, must be kept at reset value.

Bits 18:17 **EMx:** CPU wake-up with event generation mask on event input x (x = 50 to 49)

When EXTI_SECCFGR.SECx is disabled, EMx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, EMx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, EMx can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, EMx can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0: Wake-up with event generation from Line x is masked.
1: Wake-up with event generation from Line x is unmasked.

Bits 16:15 Reserved, must be kept at reset value.

Bit 14 **EM46:** CPU wake-up with event generation mask on event input
When EXTI_SECCFGR.SECx is disabled, EMx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, EMx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, EMx can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, EMx can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0: Wake-up with event generation from Line x is masked.
1: Wake-up with event generation from Line x is unmasked.

Bits 13:0 Reserved, must be kept at reset value.

20.6.31 EXTI CPU wake-up with interrupt mask register 3 (EXTI_IMR3)

Address offset: 0x0A0

Reset value: 0x0000 0002

Contains register bits for configurable events.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IM66	IM65	IM64
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **IMx:** CPU wake-up with interrupt mask on event input x [1] (x = 66 to 64)
When EXTI_SECCFGR.SECx is disabled, IMx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, IMx can only be accessed with secure access. Nonsecure write to this bit is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, IMx can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, IMx can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0: Wake-up with interrupt request from input event x is masked.
1: Wake-up with interrupt request from input event x is unmasked.

1. The reset value for configurable event inputs is set to 0 to disable the interrupt by default.

20.6.32 EXTI CPU wake-up with event mask register 3 (EXTI_EMR3)

Address offset: 0x0A4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EM66	Res.	EM64
													rw		rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **EM66:** CPU wake-up with event generation mask on event input
When EXTI_SECCFGR.SECx is disabled, EMx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, EMx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, EMx can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, EMx can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0: Wake-up with event generation from Line x is masked.
1: Wake-up with event generation from Line x is unmasked.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **EM64:** CPU wake-up with event generation mask on event input
When EXTI_SECCFGR.SECx is disabled, EMx can be accessed with nonsecure and secure access.
When EXTI_SECCFGR.SECx is enabled, EMx can only be accessed with secure access. Nonsecure write to this bit x is discarded and nonsecure read returns 0.
When EXTI_PRIVCFGR.PRIVx is disabled, EMx can be accessed with privileged and unprivileged access.
When EXTI_PRIVCFGR.PRIVx is enabled, EMx can only be accessed with privileged access. Unprivileged write to this bit is discarded.
0: Wake-up with event generation from Line x is masked.
1: Wake-up with event generation from Line x is unmasked.

20.6.33 EXTI register map

Table 173. EXTI register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**EXTI_RTSR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RT16	RT15	RT14	RT13	RT12	RT11	RT10	RT9	RT8	RT7	RT6	RT5	RT4	RT3	RT2	RT1	RT0
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x004	**EXTI_FTSR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FT16	FT15	FT14	FT13	FT12	FT11	FT10	FT9	FT8	FT7	FT6	FT5	FT4	FT3	FT2	FT1	FT0
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 173. EXTI register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x008	**EXTI_SWIER1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWI16	SWI15	SWI14	SWI13	SWI12	SWI11	SWI10	SWI9	SWI8	SWI7	SWI6	SWI5	SWI4	SWI3	SWI2	SWI1	SWI0
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C	**EXTI_RPR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RPIF1	RPIF1	RPIF1	RPIF1	RPIF1	RPIF1	RPIF1	RPIF9	RPIF8	RPIF7	RPIF6	RPIF5	RPIF4	RPIF3	RPIF2	RPIF1	RPIF0
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x010	**EXTI_FPR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FPIF16	FPIF15	FPIF14	FPIF13	FPIF12	FPIF11	FPIF10	FPIF9	FPIF8	FPIF7	FPIF6	FPIF5	FPIF4	FPIF3	FPIF2	FPIF1	FPIF0
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	**EXTI_ SECCFGR1**	SEC31	SEC30	SEC29	SEC28	SEC27	SEC26	SEC25	SEC24	SEC23	SEC22	SEC21	SEC20	SEC19	SEC18	SEC17	SEC16	SEC15	SEC14	SEC13	SEC12	SEC11	SEC10	SEC9	SEC8	SEC7	SEC6	SEC5	SEC4	SEC3	SEC2	SEC1	SEC0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x018	**EXTI_ PRIVCFGR1**	PRIV31	PRIV30	PRIV29	PRIV28	PRIV27	PRIV26	PRIV25	PRIV24	PRIV23	PRIV22	PRIV21	PRIV20	PRIV19	PRIV18	PRIV17	PRIV16	PRIV15	PRIV14	PRIV13	PRIV12	PRIV11	PRIV10	PRIV9	PRIV8	PRIV7	PRIV6	PRIV5	PRIV4	PRIV3	PRIV2	PRIV1	PRIV0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x01C	**Reserved**	Reserved																															
0x020	**EXTI_RTSR2**	Res.	Res.	Res.	Res.	RT59	RT58	Res.	Res.	Res.	Res.	RT53	Res.	Res.	RT50	RT49	Res.	Res.	RT46	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0					0			0	0			0															
0x024	**EXTI_FTSR2**	Res.	Res.	Res.	Res.	FT59	FT58	Res.	Res.	Res.	Res.	FT53	Res.	Res.	FT50	FT49	Res.	Res.	FT46	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0					0			0	0			0															
0x028	**EXTI_SWIER2**	Res.	Res.	Res.	Res.	SWI59	SWI58	Res.	Res.	Res.	Res.	SWI53	Res.	Res.	SWI50	SWI49	Res.	Res.	SWI46	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0					0			0	0			0															
0x02C	**EXTI_RPR2**	Res.	Res.	Res.	Res.	RPIF59	RPIF58	Res.	Res.	Res.	Res.	RPIF53	Res.	Res.	RPIF50	RPIF49	Res.	Res.	RPIF46	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0					0			0	0			0															
0x030	**EXTI_FPR2**	Res.	Res.	Res.	Res.	FPIF59	FPIF58	Res.	Res.	Res.	Res.	FPIF53	Res.	Res.	FPIF50	FPIF49	Res.	Res.	FPIF46	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0					0			0	0			0															
0x034	**EXTI_ SECCFGR2**	SEC63	SEC62	SEC61	SEC60	SEC59	SEC58	SEC57	SEC56	SEC55	SEC54	SEC53	SEC52	SEC51	SEC50	SEC49	SEC48	SEC47	SEC46	SEC45	SEC44	SEC43	SEC42	SEC41	SEC40	SEC39	SEC38	SEC37	SEC36	SEC35	SEC34	SEC33	SEC32
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x038	**EXTI_ PRIVCFGR2**	PRIV63	PRIV62	PRIV61	PRIV60	PRIV59	PRIV58	PRIV57	PRIV56	PRIV55	PRIV54	PRIV53	PRIV52	PRIV51	PRIV50	PRIV49	PRIV48	PRIV47	PRIV46	PRIV45	PRIV44	PRIV43	PRIV42	PRIV41	PRIV40	PRIV39	PRIV38	PRIV37	PRIV36	PRIV35	PRIV34	PRIV33	PRIV32
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x03C	**Reserved**	Reserved																															
0x040	**EXTI_RTSR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RT66	Res.	RT64
	Reset value																														0		0
0x044	**EXTI_FTSR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FT66	Res.	FT64
	Reset value																														0		0
0x048	**EXTI_SWIER3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWI66	Res.	SWI64
	Reset value																														0		0

Table 173. EXTI register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x04C	**EXTI_RPR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RPIF66	Res.	RPIF64
	Reset value																														0		0
0x050	**EXTI_FPR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FPIF66	Res.	FPIF64
	Reset value																														0		0
0x054	**EXTI_ SECCFGR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEC66	SEC65	SEC64
	Reset value																														0	0	0
0x058	**EXTI_ PRIVCFGR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV66	PRIV65	PRIV64
	Reset value																														0	0	0
0x05C	**Reserved**	Reserved																															
0x060	**EXTI_EXTICR1**	EXTI3[7:0]								EXTI2[7:0]								EXTI1[7:0]								EXTI0[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x064	**EXTI_EXTICR2**	EXTI7[7:0]								EXTI6[7:0]								EXTI5[7:0]								EXTI4[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x068	**EXTI_EXTICR3**	EXTI11[7:0]								EXTI10[7:0]								EXTI9[7:0]								EXTI8[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x06C	**EXTI_EXTICR4**	EXTI15[7:0]								EXTI14[7:0]								EXTI13[7:0]								EXTI12[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x070	**EXTI_LOCKR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCK
	Reset value																																0
0x074 to 0x07C	**Reserved**	Reserved																															
0x080	**EXTI_IMR1**	IM31	IM30	IM29	IM28	IM27	IM26	IM25	IM24	IM23	IM22	IM21	IM20	IM19	IM18	IM17	IM16	IM15	IM14	IM13	IM12	IM11	IM10	IM9	IM8	IM7	IM6	IM5	IM4	IM3	IM2	IM1	IM0
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x084	**EXTI_EMR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EM16	EM15	EM14	EM13	EM12	EM11	EM10	EM9	EM8	EM7	EM6	EM5	EM4	EM3	EM2	EM1	EM0
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x090	**EXTI_IMR2**	IM63	IM62	IM61	IM60	IM59	IM58	IM57	IM56	IM55	IM54	IM53	IM52	IM51	IM50	IM49	IM48	IM47	IM46	IM45	IM44	IM43	IM42	IM41	IM40	IM39	IM38	IM37	IM36	IM35	IM34	IM33	IM32
	Reset value	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x094	**EXTI_EMR2**	Res.	Res.	Res.	Res.	EM59	EM58	Res.	Res.	Res.	Res.	EM53	Res.	Res.	EM50	EM49	Res.	Res.	EM46	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0					0			0	0			0															
0x0A0	**EXTI_IMR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IM66	IM65	IM64
	Reset value																														0	1	0

Table 173. EXTI register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0A4	**EXTI_EMR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EM66	Res.	EM64
	Reset value																														0		0

Refer to *Section 2.3* for the register boundary addresses.

21 Cyclic redundancy check calculation unit (CRC)

21.1 CRC introduction

The CRC (cyclic redundancy check) calculation unit is used to get a CRC code from 8-, 16- or 32-bit data word and a generator polynomial.

Among other applications, CRC-based techniques are used to verify data transmission or storage integrity. In the scope of the functional safety standards, they offer a means of verifying the flash memory integrity. The CRC calculation unit helps compute a signature of the software during runtime, to be compared with a reference signature generated at link time and stored at a given memory location.

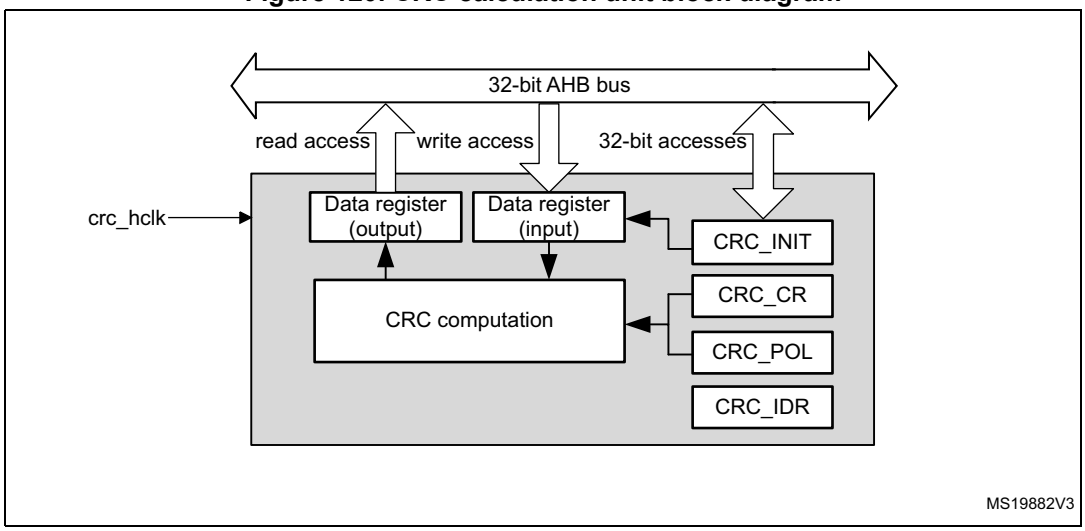
21.2 CRC main features

- Uses CRC-32 (Ethernet) polynomial: 0x4C11DB7
  $X^{32} + X^{26} + X^{23} + X^{22} + X^{16} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^5 + X^4 + X^2 + X + 1$
- Alternatively, uses fully programmable polynomial with programmable size (7, 8, 16, 32 bits)
- Handles 8-,16-, 32-bit data size
- Programmable CRC initial value
- Single input/output 32-bit data register
- Input buffer to avoid bus stall during calculation
- CRC computation done in 4 AHB clock cycles (HCLK) for the 32-bit data size
- General-purpose 8-bit register (can be used for temporary storage)
- Reversibility options on I/O data
- Accessed through AHB slave peripheral by 32-bit words only, with the exception of CRC_DR register that can be accessed by words, right-aligned half-words and right-aligned bytes

21.3 CRC functional description

21.3.1 CRC block diagram

Figure 120. CRC calculation unit block diagram



21.3.2 CRC internal signals

Table 174. CRC internal input/output signals

Signal name	Signal type	Description
crc_hclk	Digital input	AHB clock

21.3.3 CRC operation

The CRC calculation unit has a single 32-bit read/write data register (CRC_DR). It is used to input new data (write access), and holds the result of the previous CRC calculation (read access).

Each write operation to the data register creates a combination of the previous CRC value (stored in CRC_DR) and the new one. CRC computation is done on the whole 32-bit data word or byte by byte depending on the format of the data being written.

The CRC_DR register can be accessed by word, right-aligned half-word and right-aligned byte. When the RTYPE_IN bit is set in CRC_CR, non-word accesses to CRC_DR register are ignored. For the other registers only 32-bit accesses are allowed.

The duration of the computation depends on input data width:

- 4 AHB clock cycles for 32 bits
- 2 AHB clock cycles for 16 bits
- 1 AHB clock cycles for 8 bits

An input buffer allows a second data to be immediately written without waiting for any wait-states due to the previous CRC calculation.

The data size can be dynamically adjusted to minimize the number of write accesses for a given number of bytes. For instance, a CRC for 5 bytes can be computed with a word write followed by a byte write.

The input data can be reversed to manage the various endianness schemes. The reversing operation can be performed on 8 bits, 16 bits and 32 bits depending on the REV_IN[1:0] bits in the CRC_CR register. If RTYPE_IN bit is set in this register, the input reversing operation can be performed with a byte or half-word granularity, but not with single bit granularity.

For example, with RTYPE_IN cleared, 0x1A2B3C4D input data are used for CRC calculation as:

- 0x58D43CB2 with bit-reversal done by byte (REV_IN[1:0] = 01)
- 0xD458B23C with bit-reversal done by half-word (REV_IN[1:0] = 10)
- 0xB23CD458 with bit-reversal done on the full word (REV_IN[1:0] = 11)

With RTYPE_IN set, 0x1A2B3C4D input data are used for CRC calculation as:

- 0x3C4D1A2B with half-word reversal done by word (REV_IN[1:0] = 01)
- 0x4D3C2B1A with byte-reversal done by word (REV_IN[1:0] = 10)

The output data can also be reversed by setting the REV_OUT[1:0] bits in the CRC_CR register. If RTYPE_OUT is set in this register, the output reversing operation is performed with a byte or half-word granularity, but not with single bit granularity.

With RTYPE_OUT cleared, the operation is done at bit level. For example, 0x11223344 output data are converted to 0x22CC4488.

With RTYPE_OUT set, 0x11223344 output data are converted as:

- 0x33441122 with half-word reversal done by word (REV_IN[1:0] = 01)
- 0x44332211 with byte-reversal done by word (REV_IN[1:0] = 10)

The CRC calculator can be initialized to a programmable value using the RESET control bit in the CRC_CR register (the default value is 0xFFFFFFFF).

The initial CRC value can be programmed with the CRC_INIT register. The CRC_DR register is automatically initialized upon CRC_INIT register write access.

The CRC_IDR register can be used to hold a temporary value related to CRC 7-, 8-, 16-, and 32-bit calculations. It is not affected by the RESET bit in the CRC_CR register.

Polynomial programmability

The polynomial coefficients are fully programmable through the CRC_POL register, and the polynomial size can be configured to be 7-, 8-, 16-, or 32-bits by programming the POLYSIZE[1:0] bits in the CRC_CR register. Even polynomials are not supported.

Note: The type of an even polynomial is $X+X^2+..+X^n$, while the type of an odd polynomial is $1+X+X^2+..+X^n$.

If the CRC data is less than 32-bit, its value can be read from the least significant bits of the CRC_DR register.

To obtain a reliable CRC calculation, the change on-fly of the polynomial value or size can not be performed during a CRC calculation. As a result, if a CRC calculation is ongoing, the application must either reset it or perform a CRC_DR read before changing the polynomial.

The default polynomial value is the CRC-32 (Ethernet) polynomial: 0x4C11DB7.

21.4 CRC registers

The CRC_DR register can be accessed by words, right-aligned half-words and right-aligned bytes when RTYPE bit is cleared in CRC_CR. When RTYPE is set, only word accesses are allowed. For the other registers only 32-bit accesses are allowed.

21.4.1 CRC data register (CRC_DR)

Address offset: 0x00

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DR[31:0]:** Data register bits

This register is used to write new data to the CRC calculator.

It holds the previous CRC calculation result when it is read.

If the data size is less than 32 bits, the least significant bits are used to write/read the correct value.

21.4.2 CRC independent data register (CRC_IDR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IDR[31:0]**: General-purpose 32-bit data register bits

These bits can be used as a temporary storage location for four bytes.

This register is not affected by CRC resets generated by the RESET bit in the CRC_CR register

21.4.3 CRC control register (CRC_CR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	RTYPE_OUT	RTYPE_IN	REV_OUT[1:0]		REV_IN[1:0]		POLYSIZE[1:0]		Res.	Res.	RESET
					rw	rw	rw	rw	rw	rw	rw	rw			rs

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **RTYPE_OUT**: Reverse type output
This bit controls the reversal granularity of the output data.
0: Bit level output
1: Byte or half-word level output

Bit 9 **RTYPE_IN**: Reverse type input
This bit controls the reversal granularity of the input data.
0: Bit level input
1: Byte or half-word level input

Bits 8:7 **REV_OUT[1:0]**: Reverse output data
This bitfield controls the reversal of the bit order of the output data.
00: Bit order not affected (RTYPE_OUT = 0 or 1)
01: Bit-reversed output format (RTYPE_OUT = 0) or half-word reversal done by word (RTYPE_OUT = 1)
10: Bit order not affected (RTYPE_OUT = 0) or byte reversal done by word (RTYPE_OUT = 1)
11: Bit order not affected (RTYPE_OUT = 0 or 1)

Bits 6:5 **REV_IN[1:0]**: Reverse input data
This bitfield controls the reversal of the bit order of the input data
00: Bit order not affected (RTYPE_IN = 0 or 1)
01: Bit reversal done by byte (RTYPE_IN = 0) or half-word reversal done by word (RTYPE_IN = 1)
10: Bit reversal done by half-word (RTYPE_IN = 0) or byte reversal done by word (RTYPE_IN = 1)
11: Bit reversal done by word (RTYPE_IN = 0) or bit order is not affected (RTYPE_IN = 1)

Bits 4:3 **POLYSIZE[1:0]**: Polynomial size

These bits control the size of the polynomial.

00: 32 bit polynomial

01: 16 bit polynomial

10: 8 bit polynomial

11: 7 bit polynomial

Bits 2:1 Reserved, must be kept at reset value.

Bit 0 **RESET**: RESET bit

This bit is set by software to reset the CRC calculation unit and set the data register to the value stored in the CRC_INIT register. This bit can only be set, it is automatically cleared by hardware.

21.4.4 CRC initial value (CRC_INIT)

Address offset: 0x10

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CRC_INIT[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CRC_INIT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CRC_INIT[31:0]**: Programmable initial CRC value

This register is used to write the CRC initial value.

21.4.5 CRC polynomial (CRC_POL)

Address offset: 0x14

Reset value: 0x04C1 1DB7

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
POL[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
POL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **POL[31:0]**: Programmable polynomial

This register is used to write the coefficients of the polynomial to be used for CRC calculation.

If the polynomial size is less than 32 bits, the least significant bits have to be used to program the correct value.

21.4.6 CRC register map

Table 175. CRC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	CRC_DR	DR[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x04	CRC_IDR	IDR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	CRC_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RTYPE_OUT	RTYPE_IN	REV_OUT[1:0]		REV_IN[1:0]		POLYSIZE[1:0]		Res.	Res.	RESET
	Reset value																						0	0	0	0	0	0	0	0			0
0x10	CRC_INIT	CRC_INIT[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x14	CRC_POL	POL[31:0]																															
	Reset value	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	0	1	1	1	0	1	1	0	1	1	0	1	1	1

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

22 CORDIC coprocessor (CORDIC)

22.1 CORDIC introduction

The CORDIC coprocessor provides hardware acceleration of mathematical functions (mainly trigonometric ones) commonly used in motor control, metering, signal processing, and many other applications.

It speeds up the calculation of these functions compared to a software implementation, making possible the use of a lower operating frequency, or freeing up processor cycles to perform other tasks.

22.2 CORDIC main features

- 24-bit CORDIC rotation engine
- Circular and Hyperbolic modes
- Rotation and Vectoring modes
- Functions: sine, cosine, sinh, cosh, atan, atan2, atanh, modulus, square root, natural logarithm
- Programmable precision
- Low latency AHB slave interface
- Results can be read as soon as ready, without polling or interrupt
- DMA read and write channels
- Multiple register read/write by DMA

22.3 CORDIC functional description

22.3.1 General description

The CORDIC is a cost-efficient successive approximation algorithm for evaluating trigonometric and hyperbolic functions.

In trigonometric (circular) mode, the sine and cosine of an angle θ are determined by rotating the unit vector [1, 0] through decreasing angles until the cumulative sum of the rotation angles equals the input angle θ. The x and y cartesian components of the rotated vector then correspond, respectively, to the cosine and sine of θ. Inversely, the angle of a vector [x, y] corresponding to arctangent (y / x), is determined by rotating [x, y] through successively decreasing angles to obtain the unit vector [1, 0]. The cumulative sum of the rotation angles gives the angle of the original vector.

The CORDIC algorithm can also be used for calculating hyperbolic functions (sinh, cosh, atanh), by replacing the successive circular rotations by steps along a hyperbole.

Other functions can be derived from the basic functions described above.

22.3.2 CORDIC functions

The first step when using the coprocessor is to select the required function, by programming the FUNC field of the CORDIC_CR register.

Table 176 lists the functions supported by the CORDIC coprocessor.

Table 176. CORDIC functions

Function	Primary argument (ARG1)	Secondary argument (ARG2)	Primary result (RES1)	Secondary result (RES2)
Cosine	angle θ	modulus m	$m \cdot \cos\theta$	$m \cdot \sin\theta$
Sine	angle θ	modulus m	$m \cdot \sin\theta$	$m \cdot \cos\theta$
Phase	x	y	atan2(y,x)	$\sqrt{x^2+y^2}$
Modulus	x	y	$\sqrt{x^2+y^2}$	atan2(y,x)
Arctangent	x	none	$\tan^{-1} x$	none
Hyperbolic cosine	x	none	cosh x	sinh x
Hyperbolic sine	x	none	sinh x	cosh x
Hyperbolic arctangent	x	none	$\tanh^{-1} x$	none
Natural logarithm	x	none	ln x	none
Square root	x	none	$\sqrt{x}$	none

Several functions take two input arguments (ARG1 and ARG2), and some generate two results (RES1 and RES2) simultaneously. This is a side-effect of the algorithm and means that only one operation is needed to obtain two values. This is the case, for example, when performing polar-to-rectangular conversion: sin θ also generates cos θ, and cos θ also generates sin θ. Similarly for rectangular-to-polar conversion (phase(x,y), modulus(x,y)) and for hyperbolic functions (cosh θ, sinh θ).

Note: The exponential function, exp x, can be obtained as the sum of sinh x and cosh x. Furthermore, base N logarithms, $\log_N x$, can be derived by multiplying ln x by a constant K, where K = 1/ln N.

For certain functions (atan, log, sqrt) a scaling factor (see *Section 22.3.4*) can be applied to extend the range beyond the maximum [-1, 1] supported by the q1.31 fixed point format. The scaling factor must be set to 0 for all other circular functions, and to 1 for hyperbolic functions.

Cosine

Table 177. Cosine parameters

Parameter	Description	Range
ARG1	Angle θ in radians, divided by π	[-1, 1]
ARG2	Modulus m	[0, 1]
RES1	m • cos θ	[-1, 1]

Table 177. Cosine parameters (continued)

Parameter	Description	Range
RES2	m • sin θ	[-1, 1]
SCALE	Not applicable	0

This function calculates the cosine of an angle in the range -π to π. It can also be used to perform polar to rectangular conversion.

The primary argument is the angle θ in radians. It must be divided by π before programming ARG1.

The secondary argument is the modulus m. If m is greater than 1, a scaling must be applied in software to adapt it to the q1.31 range of ARG2.

The primary result, RES1, is the cosine of the angle, multiplied by the modulus.

The secondary result, RES2, is the sine of the angle, multiplied by the modulus.

Sine

Table 178. Sine parameters

Parameter	Description	Range
ARG1	Angle θ in radians, divided by π	[-1, 1]
ARG2	Modulus m	[0, 1]
RES1	m • sin θ	[-1, 1]
RES2	m • cos θ	[-1, 1]
SCALE	Not applicable	0

This function calculates the sine of an angle in the range -π to π. It can also be used to perform polar to rectangular conversion.

The primary argument is the angle θ in radians. It must be divided by π before programming ARG1.

The secondary argument is the modulus m. If m is greater than 1, a scaling must be applied in software to adapt it to the q1.31 range of ARG2.

The primary result, RES1, is the sine of the angle, multiplied by the modulus.

The secondary result, RES2, is the cosine of the angle, multiplied by the modulus.

Phase

Table 179. Phase parameters

Parameter	Description	Range
ARG1	x coordinate	[-1, 1]
ARG2	y coordinate	[-1, 1]
RES1	Phase angle θ in radians, divided by π	[-1, 1]

Table 179. Phase parameters (continued)

Parameter	Description	Range
RES2	Modulus m	[0, 1]
SCALE	Not applicable	0

This function calculates the phase angle in the range -π to π of a vector **v** = [x y] (also known as atan2(y,x). It can also be used to perform rectangular to polar conversion.

The primary argument is the x coordinate, that is, the magnitude of the vector in the direction of the x axis. If |x| > 1, a scaling must be applied in software to adapt it to the q1.31 range of ARG1.

The secondary argument is the y coordinate, that is, the magnitude of the vector in the direction of the y axis. If |y| > 1, a scaling must be applied in software to adapt it to the q1.31 range of ARG2.

The primary result, RES1, is the phase angle θ of the vector **v**. RES1 must be multiplied by π to obtain the angle in radians. Note that values close to π may sometimes wrap to -π due to the circular nature of the phase angle.

The secondary result, RES2, is the modulus, given by: $|v| = \sqrt{x^2 + y^2}$. If |**v**| > 1 the result in RES2 is saturated to 1.

Modulus

Table 180. Modulus parameters

Parameter	Description	Range
ARG1	x coordinate	[-1, 1]
ARG2	y coordinate	[-1, 1]
RES1	Modulus m	[0, 1]
RES2	Phase angle θ	[-1, 1]
SCALE	Not applicable	0

This function calculates the magnitude, or modulus, of a vector **v** = [x y]. It can also be used to perform rectangular to polar conversion.

The primary argument is the x coordinate, that is, the magnitude of the vector in the direction of the x axis. If |x| > 1, a scaling must be applied in software to adapt it to the q1.31 range of ARG1.

The secondary argument is the y coordinate, that is, the magnitude of the vector in the direction of the y axis. If |y| > 1, a scaling must be applied in software to adapt it to the q1.31 range of ARG2.

The primary result, RES1, is the modulus, given by: $|v| = \sqrt{x^2 + y^2}$. If |**v**| > 1 the result in RES1 is saturated to 1.

The secondary result, RES2, is the phase angle θ of the vector **v**. RES2 must be multiplied by π to obtain the angle in radians. Note that values close to π may sometimes wrap to -π due to the circular nature of the phase angle.

Arctangent

Table 181. Arctangent parameters

Parameter	Description	Range
ARG1	$x \cdot 2^{-n}$	[-1, 1]
ARG2	Not applicable	-
RES1	$2^{-n} \cdot \tan^{-1} x$, in radians, divided by p	[-1, 1]
RES2	Not applicable	-
SCALE	n	[0 7]

This function calculates the arctangent, or inverse tangent, of the input argument x.

The primary argument, ARG1, is the input value, $x = \tan \theta$. If $|x| > 1$, a scaling factor of 2^{-n} must be applied in software such that $-1 < x \cdot 2^{-n} < 1$. The scaled value $x \cdot 2^{-n}$ is programmed in ARG1 and the scale factor n must be programmed in the SCALE parameter.

Note that the maximum input value allowed is $\tan \theta = 128$, which corresponds to an angle $\theta = 89.55$ degrees. For $|x| > 128$, a software method must be used to find $\tan^{-1} x$.

The secondary argument, ARG2, is unused.

The primary result, RES1, is the angle $\theta = \tan^{-1} x$. RES1 must be multiplied by $2^n \cdot \pi$ to obtain the angle in radians.

The secondary result, RES2, is unused.

Hyperbolic cosine

Table 182. Hyperbolic cosine parameters

Parameter	Description	Range
ARG1	$x \cdot 2^{-n}$	[-0.559 0.559]
ARG2	Not applicable	-
RES1	$2^{-n} \cdot \cosh x$	[0.5 0.846]
RES2	$2^{-n} \cdot \sinh x$	[-0.683 0.683]
SCALE	n	1

This function calculates the hyperbolic cosine of a hyperbolic angle x. It can also be used to calculate the exponential functions $e^x = \cosh x + \sinh x$, and $e^{-x} = \cosh x - \sinh x$.

The primary argument is the hyperbolic angle x. Only values of x in the range -1.118 to +1.118 are supported. Since the minimum value of cosh x is 1, which is beyond the range of the q1.31 format, a scaling factor of 2^{-n} must be applied in software. The factor n = 1 must be programmed in the SCALE parameter.

The secondary argument is not used.

The primary result, RES1, is the hyperbolic cosine, cosh x. RES1 must be multiplied by 2 to obtain the correct result.

The secondary result, RES2, is the hyperbolic sine, sinh x. RES2 must be multiplied by 2 to obtain the correct result.

Hyperbolic sine

Table 183. Hyperbolic sine parameters

Parameter	Description	Range
ARG1	$x \cdot 2^{-n}$	[-0.559, 0.559]
ARG2	Not applicable	-
RES1	$2^{-n} \cdot \sinh x$	[-0.683, 0.683]
RES2	$2^{-n} \cdot \cosh x$	[0.5, 0.846]
SCALE	n	1

This function calculates the hyperbolic sine of a hyperbolic angle x. It can also be used to calculate the exponential functions e^x = cosh x + sinh x, and e^{-x} = cosh x- sinh x.

The primary argument is the hyperbolic angle x. Only values of x in the range -1.118 to +1.118 are supported. For all input values, a scaling factor of 2^{-n} must be applied in software, where n = 1. The scaled value x • 0.5 is programmed in ARG1 and the factor n = 1 must be programmed in the SCALE parameter.

The secondary argument is not used.

The primary result, RES1, is the hyperbolic sine, sinh x. RES1 must be multiplied by 2 to obtain the correct result.

The secondary result, RES2, is the hyperbolic cosine, cosh x. RES2 must be multiplied by 2 to obtain the correct result.

Hyperbolic arctangent

Table 184. Hyperbolic arctangent parameters

Parameter	Description	Range
ARG1	$x \bullet 2^{-n}$	[-0.403 0.403]
ARG2	Not applicable	-
RES1	$2^{-n} \bullet$atanh x	[-0.559 0.559]
RES2	Not applicable	-
SCALE	n	1

This function calculates the hyperbolic arctangent of the input argument x.

The primary argument is the input value x. Only values of x in the -0.806 to +0.806 range are supported. The value x must be scaled by a factor 2^{-n}, where n = 1. The scaled value

x • 0.5 is programmed in ARG1 and the factor n = 1 must be programmed in the SCALE parameter.

The secondary argument is not used.

The primary result is the hyperbolic arctangent, atanh x. RES1 must be multiplied by 2 to obtain the correct value.

The secondary result is not used.

Natural logarithm

Table 185. Natural logarithm parameters

Parameter	Description	Range
ARG1	$x \cdot 2^{-n}$	[0.054 0.875]
ARG2	Not applicable	-
RES1	$2^{-(n+1)}.\ln x$	[-0.279 0.137]
RES2	Not applicable	-
SCALE	n	[1 4]

This function calculates the natural logarithm of the input argument x.

The primary argument is the input value x. Only values of x in the range 0.107 to 9.35 are supported. The value x must be scaled by a factor 2^{-n}, such that $x < 2^{-n} < 1\text{-}2^{-n}$. The scaled value $x \cdot 2^{-n}$ is programmed in ARG1 and the factor n must be programmed in the SCALE parameter.

Table 186 lists the valid scaling factors, n, and the corresponding ranges of x and ARG1.

Table 186. Natural log scaling factors and corresponding ranges

n	x range	ARG1 range
1	$0.107 \le x < 1$	$0.0535 \le ARG1 < 0.5$
2	$1 \le x < 3$	$0.25 \le ARG1 < 0.75$
3	$3 \le x < 7$	$0.375 \le ARG1 < 0.875$
4	$7 \le x \le 9.35$	$0.4375 \le ARG1 < 0.584$

The secondary argument is not used.

The primary result is the natural logarithm, ln x. RES1 must be multiplied by $2^{(n+1)}$ to obtain the correct value.

The secondary result is not used.

Square root

Table 187. Square root parameters

Parameter	Description	Range
ARG1	$x \cdot 2^{-n}$	[0.027 0.875]
ARG2	Not applicable	-
RES1	$2^{-n}\sqrt{x}$	[0.04 1]
RES2	Not applicable	-
SCALE	n	[0 2]

This function calculates the square root of the input argument x.

The primary argument is the input value x. Only values of x in the range 0.027 to 2.34 are supported. The value x must be scaled by a factor 2^{-n}, such that $x \cdot 2^{-n} < (1 - 2^{(-n-2)})$.

The scaled value $x \cdot 2^{-n}$ is programmed in ARG1 and the factor n must be programmed in the SCALE parameter.

Table 188 lists the valid scaling factors, n, and the corresponding ranges of x and ARG1.

Table 188. Square root scaling factors and corresponding ranges

n	x range	ARG1 range
0	$0.027 \leq x < 0.75$	$0.027 \leq ARG1 < 0.75$
1	$0.75 \leq x < 1.75$	$0.375 \leq ARG1 < 0.875$
2	$1.75 \leq x \leq 2.341$	$0.4375 \leq ARG1 \leq 0.585$

The secondary argument is not used.

The primary result is the square root of x. RES1 must be multiplied by 2^n to obtain the correct value.

The secondary result is not used.

22.3.3 Fixed point representation

The CORDIC operates in fixed point signed integer format. Input and output values can be either q1.31 or q1.15.

In q1.31 format, numbers are represented by one sign bit and 31 fractional bits (binary decimal places). The numeric range is therefore -1 (0x80000000) to $1 - 2^{-31}$ (0x7FFFFFFF).

In q1.15 format, the numeric range is 1 (0x8000) to $1 - 2^{-15}$ (0x7FFF). This format has the advantage that two input arguments can be packed into a single 32-bit write, and two results can be fetched in one 32-bit read.

22.3.4 Scaling factor

Several of the functions listed in *Section 22.3.2* specify a scaling factor, SCALE. This allows the function input range to be extended to cover the full range of values supported by the CORDIC, without saturating the input, output, or internal registers. If the scaling factor is

required, it must be calculated by software and programmed into the SCALE field of the CORDIC_CSR register. The input arguments must be scaled accordingly before programming the scaled values in the CORDIC_WDATA register. The scaling must also be undone on the results read from the CORDIC_RDATA register.

Note: The scaling factor entails a loss of precision due to truncation of the scaled value.

22.3.5 Precision

The precision of the result is dependent on the number of CORDIC iterations. The algorithm converges at a constant rate of one binary digit per iteration for trigonometric functions (sine, cosine, phase, modulus), see *Figure 121*.

For hyperbolic functions (hyperbolic sine, hyperbolic cosine, natural logarithm), the convergence rate is less constant due to the peculiarities of the CORDIC algorithm (see *Figure 122*). The square root function converges at roughly twice the speed of the hyperbolic functions (see *Figure 123*).

Figure 121. CORDIC convergence for trigonometric functions

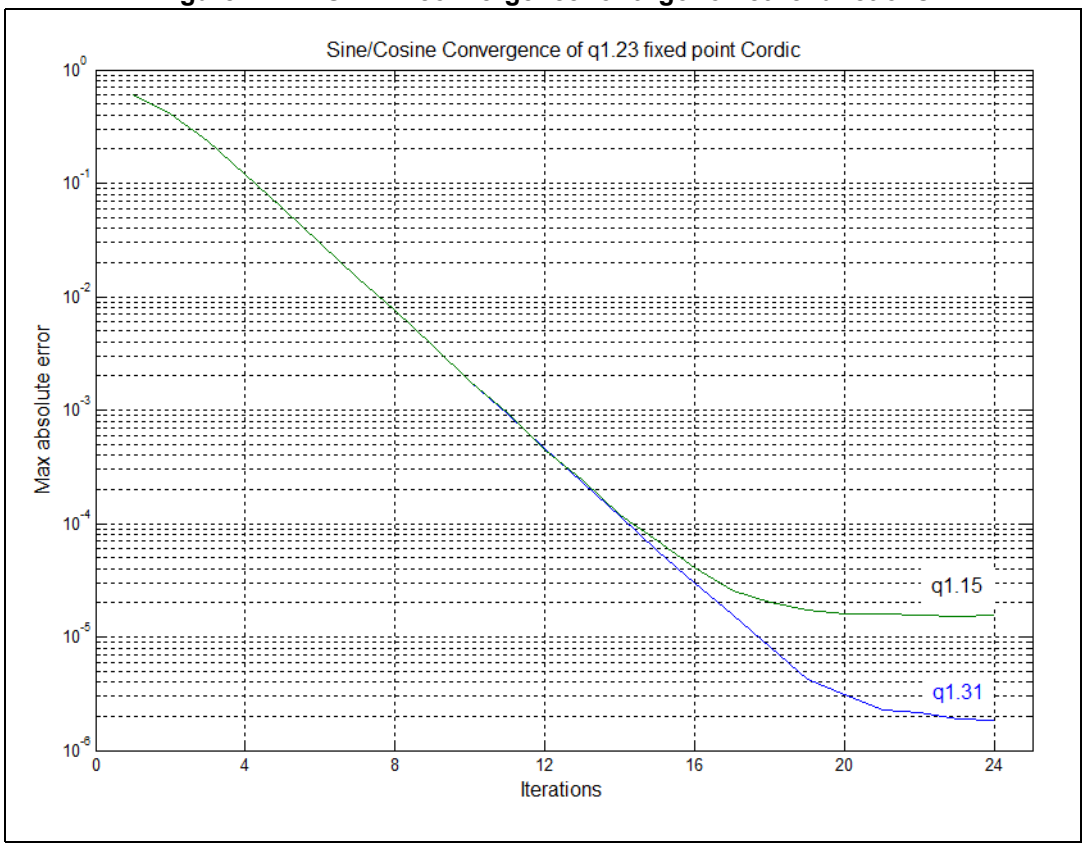


Figure 122. CORDIC convergence for hyperbolic functions

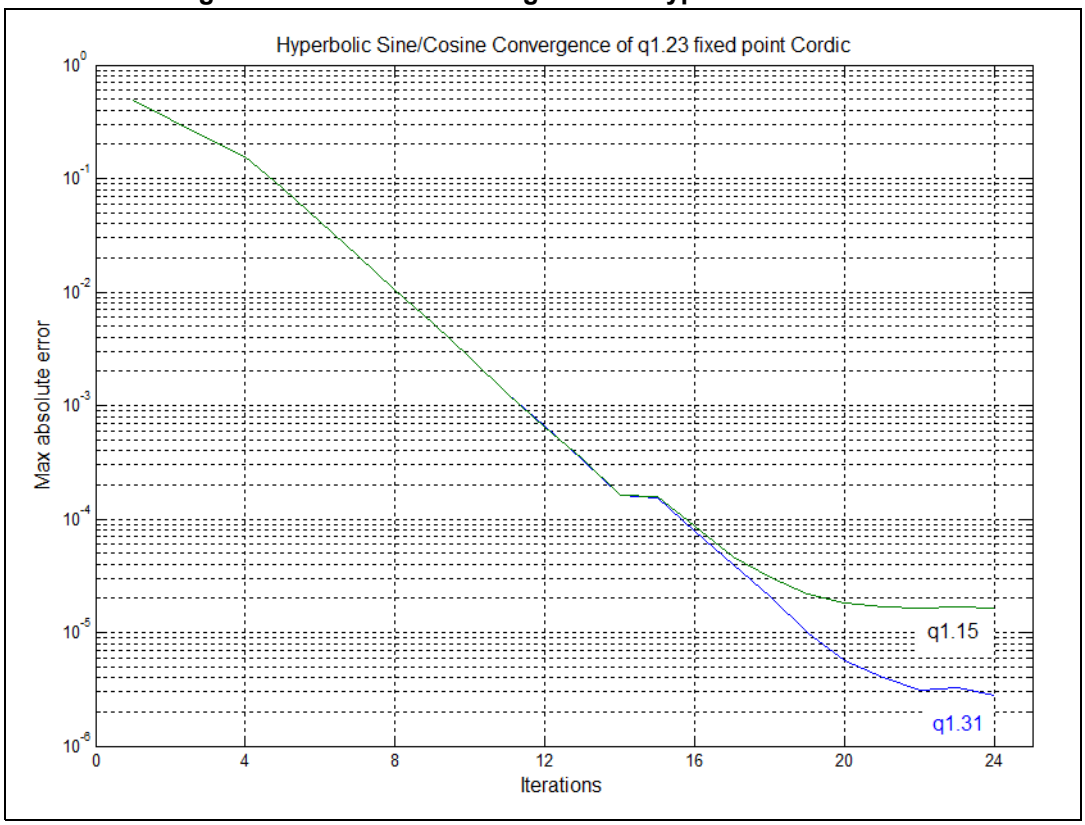
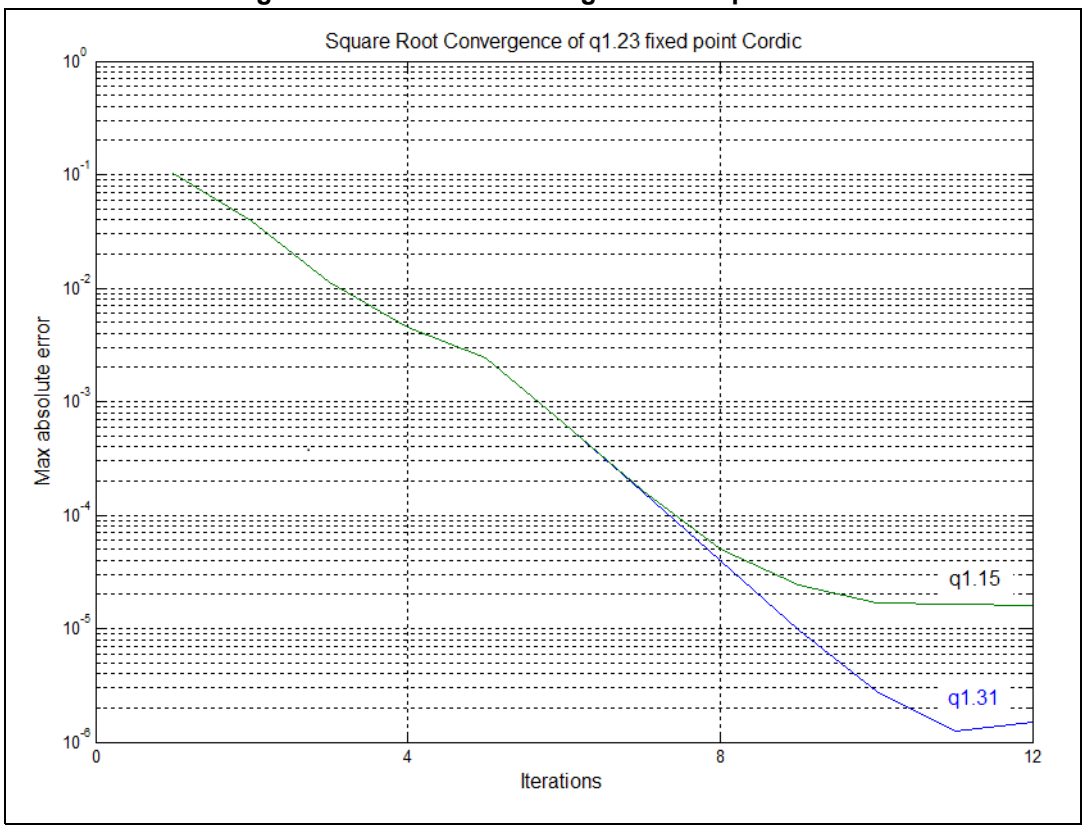


Figure 123. CORDIC convergence for square root



Note: The convergence rate decreases as the quantization error starts to become significant.

The CORDIC can perform four iterations per clock cycle. For each function, the maximum error remaining after every four iterations is shown in *Table 189*, together with the number of clock cycles required to reach that precision. From this table, the desired number of cycles can be determined and programmed in the PRECISION field of the CORDIC_CR register. The coprocessor stops as soon as the programmed number of iterations is completed, and the result can be read immediately.

Table 189. Precision vs. number of iterations

Function	Number of iterations	Number of cycles	Max residual error(1)	
			q1.31 format	q1.15 format
Sin, Cos, Phase(2), Mod, Atan(4)	4	1	2^{-3}	2^{-3}
	8	2	2^{-7}	2^{-7}
	12	3	2^{-11}	2^{-11}
	16	4	2^{-15}	2^{-15}
	20	5	2^{-18}	2^{-16}
	24	6	2^{-19}	2^{-16}

Table 189. Precision vs. number of iterations (continued)

Function	Number of iterations	Number of cycles	Max residual error(1)	
			q1.31 format	q1.15 format
Sinh, Cosh, Atanh, Ln(3)	4	1	2^{-2}	2^{-2}
	8	2	2^{-6}	2^{-6}
	12	3	2^{-10}	2^{-10}
	16	4	2^{-13}	2^{-13}
	20	5	2^{-17}	2^{-15}
	24	6	2^{-18}	2^{-15}
Sqrt(4)	4	1	2^{-7}	2^{-7}
	8	2	2^{-14}	2^{-14}
	12	3	2^{-19}	2^{-15}

1. Max residual error is the maximum error remaining after the given number of iterations, compared to the identical calculation performed in double precision floating point. An additional rounding error may be incurred, of up to 2^{-16} for q15 format or 2^{-20} for q31 format.
2. For modulus > 0.5. The achievable precision reduces proportionally to the magnitude of the modulus, as quantization error becomes significant.
3. SCALE = 1. If a higher scaling factor is used, the achievable precision is reduced proportionally.
4. SCALE = 0. If a higher scaling factor is used, the achievable precision is reduced proportionally.

22.3.6 Zero-overhead mode

The fastest way to use the coprocessor is to preprogram the CORDIC_CSR register with the function to be performed (FUNC), the desired number of clock cycles (PRECISION), the size of the input and output values (ARGSIZE, RESSIZE), the number of input arguments (NARGS) and/or results (NRES), and the scaling factor (SCALE), if applicable.

The calculation is triggered by writing the input arguments to the CORDIC_WDATA register. As soon as the correct number of input arguments has been written (and any ongoing calculation has finished), a new calculation is launched using these input arguments and the current CORDIC_CSR settings. There is no need to reprogram the CORDIC_CSR register if there is no change.

If a dual 32-bit input argument is needed (ARGSIZE = 0, NARGS = 1), the primary input argument (ARG1) must be written first, followed by the secondary argument (ARG2). If the secondary argument remains unchanged for a series of calculations, the second write can be avoided, by reprogramming the number of arguments to one (NARGS = 0), once the first calculation has started. The secondary argument retains its programmed value as long as the function is not changed.

Note: ARG2 is set to +1 (0x7FFFFFFF) after a reset.

If two 16-bit arguments are used (ARGSIZE = 1) they must be packed into a 32-bit word, with ARG1 in the least significant half-word and ARG2 in the most significant half-word. The packed 32-bit word is then written to the CORDIC_WDATA register. Only one write is needed in this case (NARGS = 0).

For functions taking only one input argument, ARG1, it is recommended to set NARGS = 0. If NARGS = 1, a second write to CORDIC_WDATA must be performed to trigger the calculation. The ARG2 data in this case is not used.

Once the calculation starts, any attempt to read the CORDIC_RDATA register inserts bus wait-states until the calculation is completed, before returning the result. It is then possible for the software to write the input and immediately read the result without polling to see if it is valid. Alternatively, the processor can wait for the appropriate number of clock cycles before reading the result. This time can be used to program the CORDIC_CSR register for the next calculation, and prepare the next input data, if needed. The CORDIC_CSR register can be reprogrammed while a calculation is in progress, without affecting the result of the ongoing calculation. In the same way, the CORDIC_WDATA register can be updated with the next argument(s) once the previous ones have been taken into account. The next arguments and settings remain pending until the previous calculation has completed.

When a calculation is finished, the result(s) can be read from the CORDIC_RDATA register. If two 32-bit results are expected (NRES = 1, RESSIZE = 0), the primary result (RES1) is read out first, followed by the secondary result (RES2). If only one 32-bit result is expected (NRES = 0, RESSIZE = 0), then RES1 is output on the first read.

If 16-bit results are expected (RESSIZE = 1), a single read to CORDIC_RDATA fetches both results packed into a 32-bit word. RES1 is in the lower half-word, and RES2 in the upper half-word. In this case, it is recommended to program NRES = 0. IF NRES = 1, a second read of CORDIC_RDATA must be performed to free up the CORDIC for the next operation. The data from this second read must be discarded.

The next calculation starts when the expected number of results has been read, provided the expected number of arguments has been written. This means that at any time, there can be a calculation in progress, or waiting for the results to be read, and an operation pending. Any further access to CORDIC_WDATA while an operation is pending cancels it and overwrites the data.

The following sequence summarizes the use of the CORDIC_IP in zero-overhead mode:

1. Program the CORDIC_CSR register with the appropriate settings
2. Program the argument(s) for the first calculation in the CORDIC_WDATA register. This launches the first calculation.
3. If needed, update the CORDIC_CSR register settings for the next calculation.
4. Program the argument(s) for the next calculation in the CORDIC_WDATA register.
5. Read the result(s) from the CORDIC_RDATA register. This triggers the next calculation.
6. Go to step *3*.

22.3.7 Polling mode

When a new result is available in the CORDIC_RDATA register, the RRDY flag is set in the CORDIC_CSR register. The flag can be polled by reading the register. It is reset by reading the CORDIC_RDATA register (once or twice, depending on the NRES field of the CORDIC_CSR register).

Polling the RRDY flag takes slightly longer than reading the CORDIC_RDATA register directly, since the result is not read as soon as it is available. The processor and bus interface are not stalled while reading the CORDIC_CSR register, so this mode may be of interest if stalling the processor is not acceptable (for example, if low latency interrupts must be serviced).

22.3.8 Interrupt mode

By setting the interrupt enable (IE) bit in the CORDIC_CSR register, an interrupt is generated whenever the RRDY flag is set. The interrupt is cleared when the flag is reset.

This mode allows the result of the calculation to be read under interrupt service routine, and hence given a priority relative to other tasks. However, it is slower than directly reading the result, or polling the flag, due to the interrupt handling delays.

22.3.9 DMA mode

If the DMA write enable (DMAWEN) bit is set in the CORDIC_CSR register, and no operation is pending, a DMA write channel request is generated. The DMA controller can transfer a primary input argument (ARG1) from memory into the CORDIC_WDATA register. Writing into the register deasserts the DMA request. If NARGS = 1 in the CORDIC_CSR register, a second DMA write channel request is generated to transfer the secondary input argument (ARG2) into the CORDIC_WDATA register. When all input arguments have been written, and any ongoing calculation has been completed (by reading the results), a new calculation is started and another DMA write channel request is generated.

If the DMA read enable (DMAREN) bit is set in the CORDIC_CSR register, the RRDY flag going active generates a DMA read channel request. The DMA controller can then transfer the primary result (RES1) from the CORDIC_RDATA register to memory. Reading the register deasserts the DMA request. If NRES = 1 in the CORDIC_CSR register, a second DMA request is generated to read out the secondary result (RES2). When all results have been read, the RRDY flag is deasserted.

The DMA read and write channels can be enabled separately. If both channels are enabled, the CORDIC can autonomously perform repeated calculations on a buffer of data without processor intervention. This allows the processor to perform other tasks. The DMA controller is operating in memory-to-peripheral mode for the write channel, and peripheral-to-memory mode for the read channel. The sequence is started by the processor setting the DMAWEN flag, the DMA read and write requests are generated as fast as the CORDIC can process the data.

In some cases, the input data may be stored in memory, and the output is transferred at regular intervals to another peripheral, such as a digital-to-analog converter. In this case, the destination peripheral generates a DMA request each time it needs a new data. The DMA controller can directly fetch the next sample from the CORDIC_RDATA register (in this case the DMA controller is operating in memory-to-peripheral mode, even though the source is a peripheral register). The act of reading the result allows the CORDIC to start a new calculation, which in turn generates a DMA write channel request, and the DMA controller transfers the next input value to the CORDIC_WDATA register. The DMA write channel is enabled (DMAWEN = 1), but the read channel must not be enabled.

In a similar way, data coming from another peripheral, such as an ADC, can be transferred directly to the CORDIC_WDATA register (in peripheral-to-memory mode). The DMA write channel must not be enabled. The CORDIC processes the input data and generates a DMA read request when complete, if DMAREN = 1. The DMA controller then transfers the result from CORDIC_RDATA register to memory (peripheral-to-memory mode).

Note: No DMA request is generated to program the CORDIC_CSR register. DMA mode is therefore useful only when repeatedly performing the same function with the same settings. The scale factor cannot be changed during a series of DMA transfers.

Note: Each DMA request must be acknowledged, as a result of the DMA performing an access to the CORDIC_WDATA or CORDIC_RDATA register. If an extraneous access to the relevant register occurs before this, the acknowledge is asserted prematurely, and may block the DMA channel. Therefore, when the DMA read channel is enabled, CPU access to the CORDIC_RDATA register must be avoided. Similarly, the processor must avoid accessing the CORDIC_WDATA register when the DMA write channel is enabled.

22.4 CORDIC registers

The CORDIC registers can be accessed only in 32-bit word format

22.4.1 CORDIC control/status register (CORDIC_CSR)

Address offset: 0x00

Reset value: 0x0000 0050

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RRDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARG SIZE	RES SIZE	N ARGS	NRES	DMA WEN	DMA REN	IEN
r									rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	SCALE[2:0]			PRECISION[3:0]				FUNC[3:0]			
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **RRDY**: Result ready flag

0: No new data in output register

1: CORDIC_RDATA register contains new data.

This bit is set by hardware when a CORDIC operation completes. It is reset by hardware when the CORDIC_RDATA register is read (NRES+1) times.

When this bit is set, if the IEN bit is also set, the CORDIC interrupt is asserted. If the DMAREN bit is set, a DMA read channel request is generated. While this bit is set, no new calculation is started.

Bits 30:23 Reserved, must be kept at reset value.

Bit 22 **ARGSIZE**: Width of input data

0: 32-bit

1: 16-bit

ARGSIZE selects the number of bits used to represent input data.

If 32-bit data is selected, the CORDIC_WDATA register expects arguments in q1.31 format.

If 16-bit data is selected, the CORDIC_WDATA register expects arguments in q1.15 format. The primary argument (ARG1) is written to the least significant half-word, and the secondary argument (ARG2) to the most significant half-word.

Bit 21 **RESSIZE**: Width of output data

0: 32-bit

1: 16-bit

RESSIZE selects the number of bits used to represent output data.

If 32-bit data is selected, the CORDIC_RDATA register contains results in q1.31 format.

If 16-bit data is selected, the least significant half-word of CORDIC_RDATA contains the primary result (RES1) in q1.15 format, and the most significant half-word contains the secondary result (RES2), also in q1.15 format.

Bit 20 **NARGS**: Number of arguments expected by the CORDIC_WDATA register

0: Only one 32-bit write (or two 16-bit values if ARGSIZE = 1) is needed for the next calculation.

1: Two 32-bit values must be written to the CORDIC_WDATA register to trigger the next calculation.

Reads return the current state of the bit.

Bit 19 **NRES**: Number of results in the CORDIC_RDATA register

0: Only one 32-bit value (or two 16-bit values if RESSIZE = 1) is transferred to the CORDIC_RDATA register on completion of the next calculation. One read from CORDIC_RDATA resets the RRDY flag.

1: Two 32-bit values are transferred to the CORDIC_RDATA register on completion of the next calculation. Two reads from CORDIC_RDATA are necessary to reset the RRDY flag.

Reads return the current state of the bit.

Bit 18 **DMAWEN**: Enable DMA write channel

0: Disabled. No DMA write requests are generated.

1: Enabled. Requests are generated on the DMA write channel whenever no operation is pending

This bit is set and cleared by software. A read returns the current state of the bit.

Bit 17 **DMAREN**: Enable DMA read channel

0: Disabled. No DMA read requests are generated.

1: Enabled. Requests are generated on the DMA read channel whenever the RRDY flag is set.

This bit is set and cleared by software. A read returns the current state of the bit.

Bit 16 **IEN**: Enable interrupt.

0: Disabled. No interrupt requests are generated.

1: Enabled. An interrupt request is generated whenever the RRDY flag is set.

This bit is set and cleared by software. A read returns the current state of the bit.

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:8 **SCALE[2:0]**: Scaling factor

The value of this field indicates the scaling factor applied to the arguments and/or results. A value n implies that the arguments have been multiplied by a factor 2^{-n}, and/or the results need to be multiplied by 2^{n}. Refer to *Section 22.3.2* for the applicability of the scaling factor for each function and the appropriate range.

Bits 7:4 **PRECISION[3:0]**: Precision required (number of iterations)

0: reserved

1 to 15: (Number of iterations)/4

To determine the number of iterations needed for a given accuracy refer to *Table 189*.

Note that for most functions, the recommended range for this field is 3 to 6.

Bits 3:0 **FUNC[3:0]**: Function

0: Cosine
1: Sine
2: Phase
3: Modulus
4: Arctangent
5: Hyperbolic cosine
6: Hyperbolic sine
7: Arctanh
8: Natural logarithm
9: Square root
10 to 15: Reserved

22.4.2 CORDIC argument register (CORDIC_WDATA)

Address offset: 0x04

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARG[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARG[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **ARG[31:0]**: Function input arguments

This register is programmed with the input arguments for the function selected in the CORDIC_CSR register FUNC field.

If 32-bit format is selected (CORDIC_CSR.ARGSIZE = 0) and two input arguments are required (CORDIC_CSR.NARGS = 1), two successive writes are required to this register. The first writes the primary argument (ARG1), the second writes the secondary argument (ARG2).

If 32-bit format is selected and only one input argument is required (NARGS = 0), only one write is required to this register, containing the primary argument (ARG1).

If 16-bit format is selected (CORDIC_CSR.ARGSIZE = 1), one write to this register contains both arguments. The primary argument (ARG1) is in the lower half, ARG[15:0], and the secondary argument (ARG2) is in the upper half, ARG[31:16]. In this case, NARGS must be set to 0.

Refer to *Section 22.3.2* for the arguments required by each function, and their permitted range.

When the required number of arguments has been written, the CORDIC evaluates the function designated by CORDIC_CSR.FUNC using the supplied input arguments, provided any previous calculation has completed. If a calculation is ongoing, the ARG1 and ARG 2 values are held pending until the calculation is completed and the results read. During this time, a write to the register cancels the pending operation and overwrite the argument data.

22.4.3 CORDIC result register (CORDIC_RDATA)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RES[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RES[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RES[31:0]**: Function result

If 32-bit format is selected (CORDIC_CSR.RESSIZE = 0) and two output values are expected (CORDIC_CSR.NRES = 1), this register must be read twice when the RRDY flag is set. The first read fetches the primary result (RES1). The second read fetches the secondary result (RES2) and resets RRDY.

If 32-bit format is selected and only one output value is expected (NRES = 0), only one read of this register is required to fetch the primary result (RES1) and reset the RRDY flag.

If 16-bit format is selected (CORDIC_CSR.RESSIZE = 1), this register contains the primary result (RES1) in the lower half, RES[15:0], and the secondary result (RES2) in the upper half, RES[31:16]. In this case, NRES must be set to 0, and only one read performed.

A read from this register resets the RRDY flag in the CORDIC_CSR register.

22.4.4 CORDIC register map

Table 190. CORDIC register map and reset value

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	CORDIC_CSR	RRDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARGSIZE	RESSIZE	NARGS	NRES	DMAWEN	DMAREN	IEN	Res.	Res.	Res.	Res.	SCALE [2:0]				PRECISION [3:0]				FUNC [3:0]			
	Reset value	0									0	0	0	0	0	0	0					0	0	0	0	0	1	0	1	0	0	0	0
0x04	CORDIC_WDATA	ARG[31:0]																															
	Reset value	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
0x08	CORDIC_RDATA	RES[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

23 Filter math accelerator (FMAC)

23.1 FMAC introduction

The filter math accelerator unit performs arithmetic operations on vectors. It comprises a multiplier/accumulator (MAC) unit, together with address generation logic which allows it to index vector elements held in local memory.

The unit includes support for circular buffers on input and output, which allows digital filters to be implemented. Both finite and infinite impulse response filters can be realized.

The unit allows frequent or lengthy filtering operations to be offloaded from the CPU, freeing up the processor for other tasks. In many cases it can accelerate such calculations compared to a software implementation, resulting in a speed-up of time critical tasks.

23.2 FMAC main features

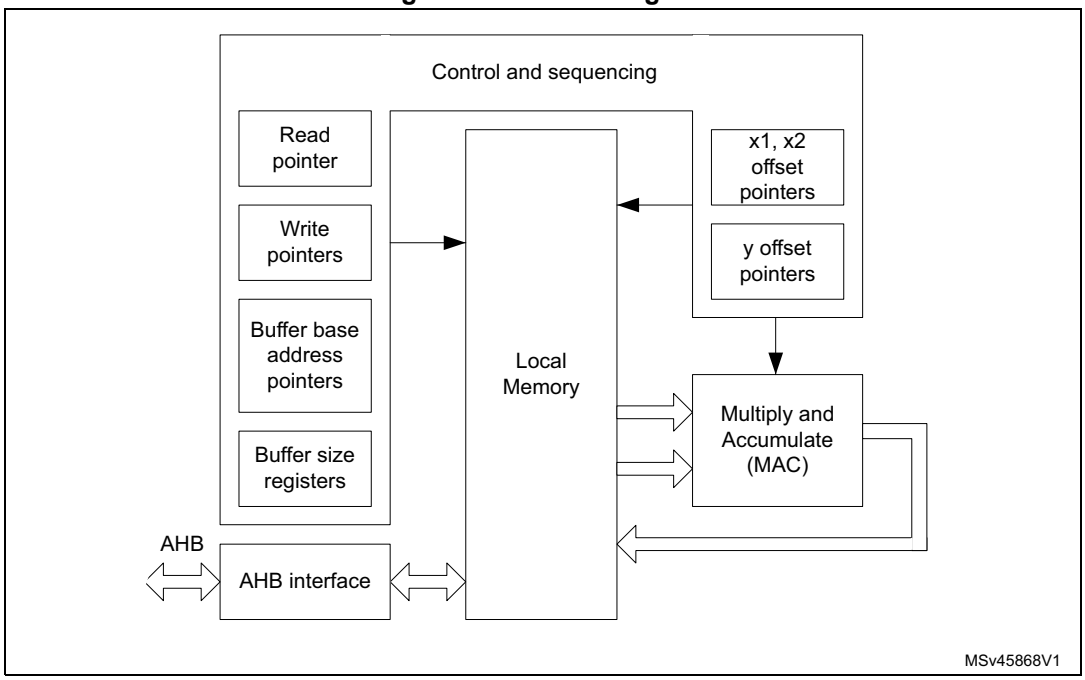
- 16 x 16-bit multiplier
- 24 + 2-bit accumulator with addition and subtraction
- 16-bit input and output data
- 256 x 16-bit local memory
- Up to three areas can be defined in memory for data buffers (two input, one output), defined by programmable base address pointers and associated size registers
- Input and output buffers can be circular
- Filter functions: FIR, IIR (direct form 1)
- Vector functions: Dot product, convolution, correlation
- AHB slave interface
- DMA read and write data channels

23.3 FMAC functional description

23.3.1 General description

The FMAC is shown in *Figure 124*.

Figure 124. Block diagram



The unit is built around a fixed point multiplier and accumulator (MAC). The MAC can take two 16-bit input signed values from memory, multiply them together and add them to the contents of the accumulator. The address of the input values in memory is determined using a set of pointers. These pointers can be loaded, incremented, decremented or reset by the internal hardware. The pointer and MAC operations are controlled by a built-in sequencer in order to execute the requested operation.

To calculate a dot product, the two input vectors are loaded into the local memory by the processor or DMA controller, and the requested operation is selected and started. Each pair of input vector elements is fetched from memory, multiplied together and accumulated. When all the vector elements have been processed, the contents of the accumulator are stored in the local memory, from where they can be read out by the processor or DMA.

The finite impulse response (FIR) filter operation (also known as convolution) consists in repeatedly calculating the dot product of the coefficient vector and a vector of input samples, the latter being shifted by one sample delay, with the least recent sample being discarded and a new sample added, at each repetition.

The infinite impulse response (IIR) filter operation is the convolution of the feedback coefficients with the previous output samples, added to the result of the FIR convolution.

A more detailed description of the filter operations is given in *Section 23.3.6: Filter functions*.

23.3.2 Local memory and buffers

The unit contains a 256 x 16-bit read/write memory which is used for local storage:

- Input values (the elements of the input vectors) are stored in two buffers, X1 and X2.
- Output values (the results of the operations) are stored in another buffer, Y.
- The locations and sizes of the buffers are designated as follows:
  - x1_base: the base address of the X1 buffer
  - x2_base: the base address of the X2 buffer
  - y_base: the base address of the Y buffer
  - x1_buf_size: the number of 16-bit addresses allocated to the X1 buffer
  - x2_buf_size: the number of 16-bit addresses allocated to the X2 buffer
  - y_buf_size: the number of 16-bit addresses allocated to the Y buffer.

These parameters are programmed in the corresponding registers when configuring the unit.

The CPU (or DMA controller) can initialize the contents of each buffer using the Initialization functions (*Section 23.3.5: Initialization functions*) and writing to the write data register. The data is transferred to the location within the target buffer indicated by a write pointer. After each new write, the write pointer is incremented. When the write pointer reaches the end of the allocated buffer space, it wraps back to the base address. This feature is used to load the elements of a vector prior to an operation, or to initialize a filter and load filter coefficients.

Buffer configuration

The buffer sizes and base address offsets must be configured in the X1, X2 and Y buffer configuration registers. For each function, the required buffer size is specified in the function description in *Section 23.3.6: Filter functions*. The base addresses can be chosen anywhere in internal memory, provided that all buffers fit within the internal memory address range (0x00 to 0xFF), that is, base address + buffer size must be less than 256.

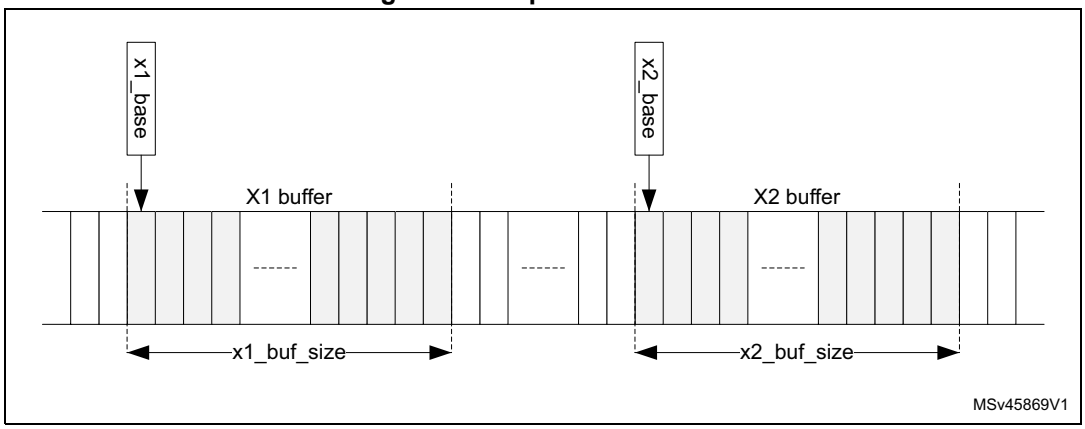
There is no constraint on the size and location of the buffers (they can overlap or even coincide exactly). For filter functions it is recommended not to overlap buffers as this can lead to erroneous behavior.

When circular buffer operation is required, an optional “headroom”, d, can be added to the buffer size. Furthermore, a watermark level can be set, to regulate the CPU or DMA activity. The value of d and the watermark level must be chosen according to the application performance requirements. For maximum throughput, the input buffer must never go empty, so d must be somewhat greater than the watermark level, allowing for any interrupt or DMA latency. On the other hand, if the input data can not be provided as fast as the unit can process them, the buffer can be allowed to empty waiting for the next data to be written, so d can be equal to the watermark level (to ensure that no overflow occurs on the input).

23.3.3 Input buffers

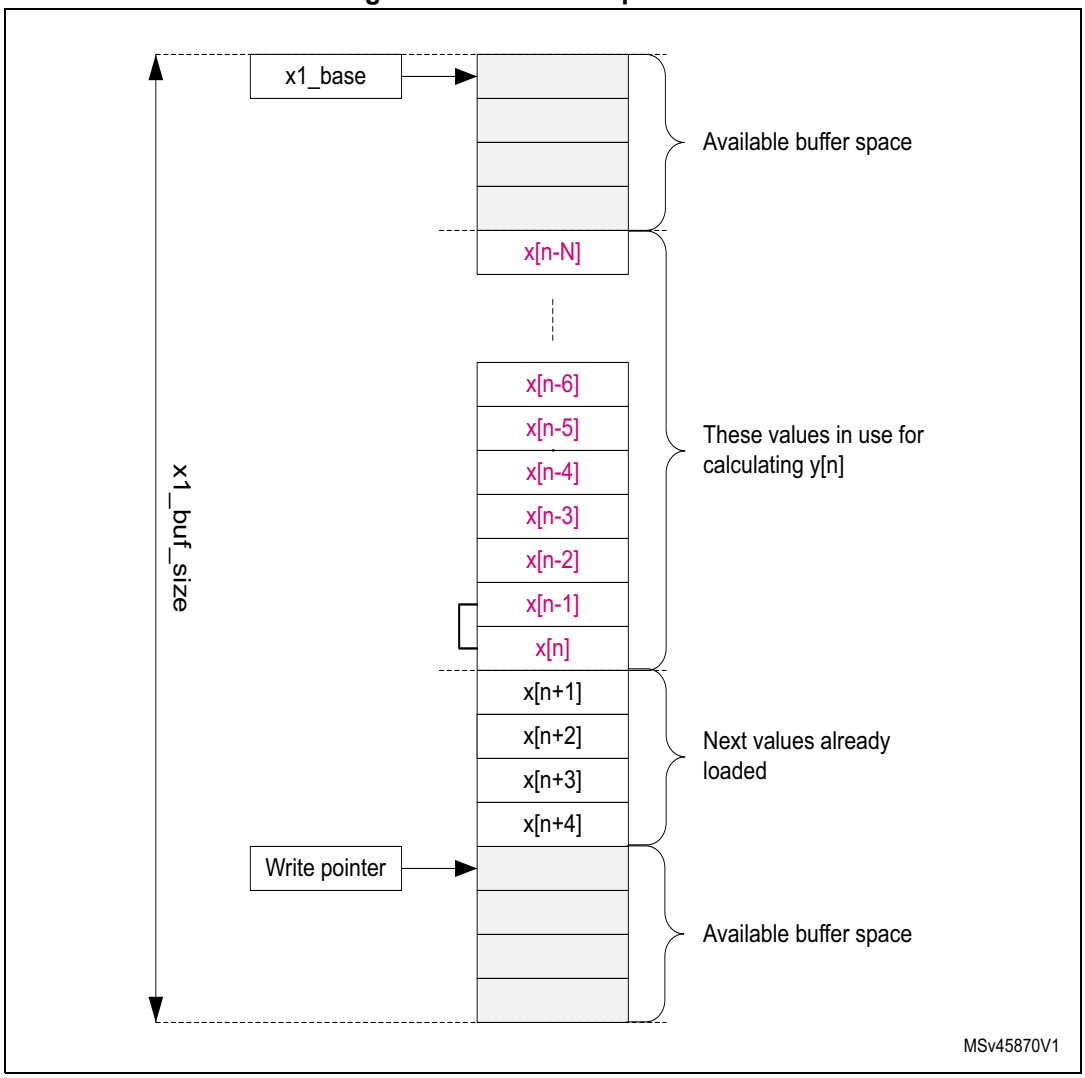
The X1 and X2 buffers are used to store data for input to the MAC. Each multiplication takes a value from the X1 buffer and a value from the X2 buffer and multiplies them together. A pointer in the control unit generates the read address offset (relative to the buffer base address) for each value. The pointers are managed by hardware according to the current function.

Figure 125. Input buffer areas



The X1 buffer can be used as a circular buffer, in which case new data are continually transferred into the input buffer whenever space is available. Pre-loading this buffer is optional for digital filters, since if no input samples have been written in the buffer when the operation is started, it is flagged as empty, which triggers the CPU or DMA to load new samples until there are enough to begin operation. Pre-loading is nevertheless useful in the case of a vector operation, that is, the input data is already available in system memory and circular operation is not required.

Figure 126. Circular input buffer



The X2 buffer can only be used in vector mode (that is not circular), and needs to be pre-loaded, except if the contents of the buffer do not change from one operation to the next. For filter functions, the X2 buffer is used to store the filter coefficients.

When operating as a circular buffer, the space allocated to the buffer (x1_buf_size) must generally be bigger than the number of elements in use for the current calculation, so that there are always new values available in the buffer. *Figure 126* illustrates the layout of the buffer for a filter operation. While calculating an output sample y[n], the unit uses a set of N+1 input samples, x[n-N] to x[n]. When this is finished, the unit starts the calculation of y[n+1], using the set of input samples x[n-N+1] to x[n+1]. The least-recent input sample, x[n-N], drops out of the input set, and a new sample, x[n+1], is added to it.

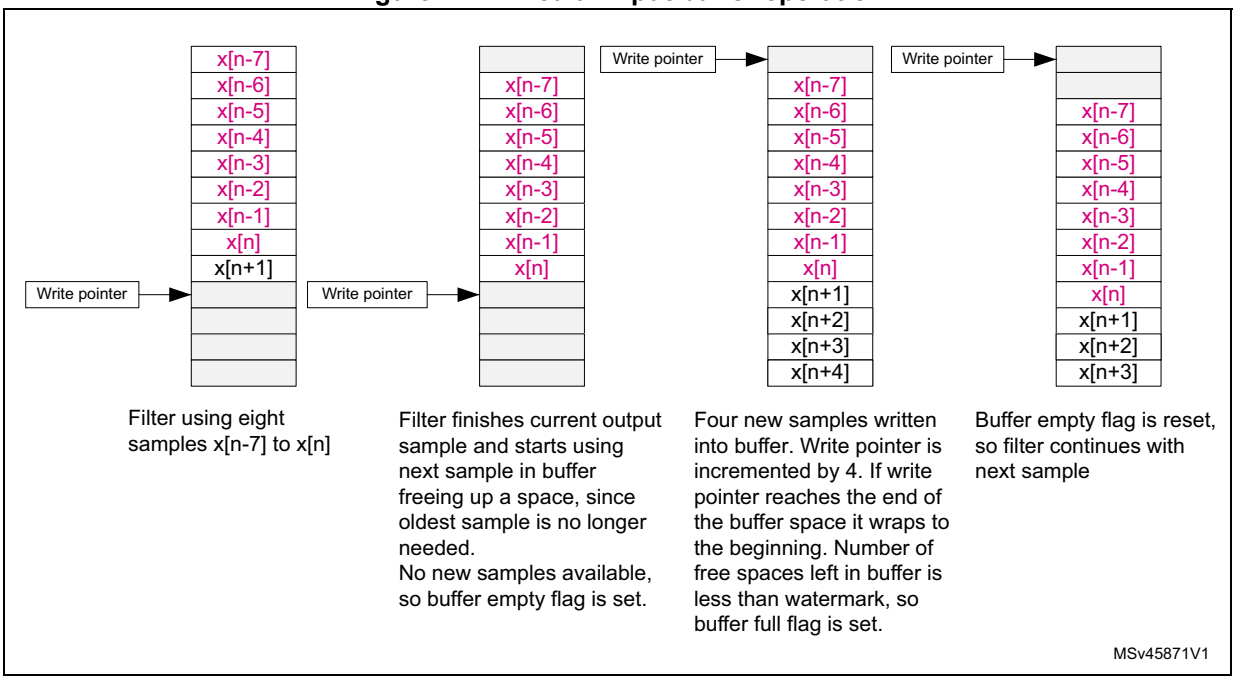
The processor, or DMA controller, must ensure that the new sample x[n+1] is available in the buffer space when required. If not, the buffer is flagged as empty, which stalls the execution of the unit until a new sample is added. No underflow condition is signaled on the X1 buffer.

Note: If the flow of samples is controlled by a timer or other peripheral such as an ADC, the buffer regularly goes empty, since the filter processes each new sample faster than the source can provide it. This is an essential feature of filter operation.

If the number of free spaces in the buffer is less than the watermark threshold programmed in the FULL_WM bitfield of the FMAC_X1BUFCFG register, the buffer is flagged as full. As long as the full flag is not set, interrupts are generated, if enabled, to request more data for the buffer. The watermark allows several data to be transferred under one interrupt, without danger of overflow. Nevertheless, if an overflow does occur, the OVFL error flag is set and the write data is ignored. The write pointer is not incremented in the event of an overflow.

The operation of the X1 buffer during a filtering operation is illustrated in *Figure 127*. This example shows an 8-tap FIR filter with a watermark set to four.

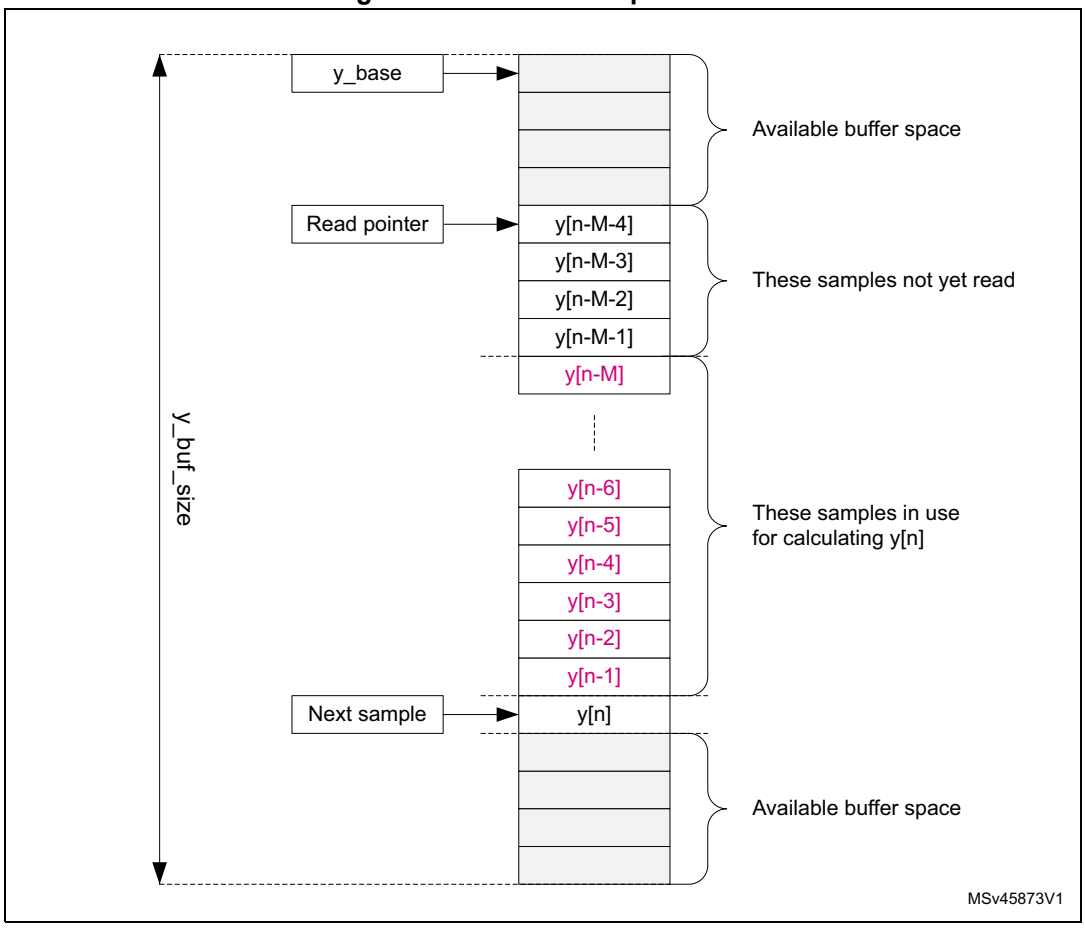
Figure 127. Circular input buffer operation



23.3.4 Output buffer

The Y (output) buffer is used to store the output of an accumulation. Each new output value is stored in the buffer until it is read by the processor or DMA controller. Each time a read access is made to the read data register, the read data is fetched from the address indicated by the read pointer. This pointer is incremented after each read, and wraps back to the base address when it reaches the end of the allocated Y buffer space.

Figure 128. Circular output buffer



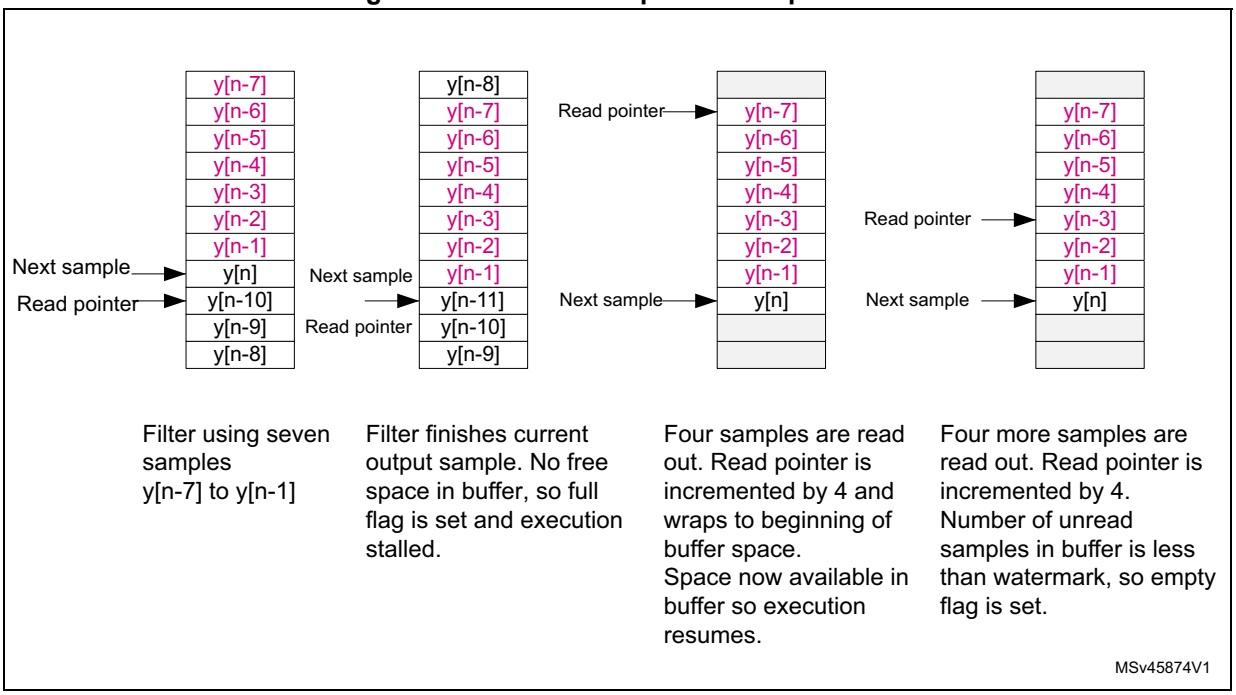
The Y buffer can also operate as a circular buffer. If the address for the next output value is the same as that indicated by the read pointer (an unread sample), then the buffer is flagged as full and execution stalled until the sample is read.

In the case of IIR filters, the Y buffer is used to store the set of M previous output samples, y[n-M] to y[n-1], used for calculating the next output sample y[n]. Each time a new sample is added to the set, the least recent sample y[n-M] drops out.

If the number of unread data in the buffer is less than the watermark threshold programmed in the EMPTY_WM bitfield of the FMAC_YBUFCFG register, the buffer is flagged as empty. As long as the empty flag is not set, interrupts or DMA requests are generated, if enabled, to request reads from the buffer. The watermark allows several data to be transferred under one interrupt, without danger of underflow. Nevertheless, if an underflow does occur, the UNFL error flag is set. In this case, the read pointer is not incremented and the read operation returns the content of the memory at the read pointer address.

The operation of the Y buffer in circular mode is illustrated in *Figure 129*. This example shows a 7-tap IIR filter with a watermark set to four.

Figure 129. Circular output buffer operation



23.3.5 Initialization functions

The following functions initialize the FMAC unit. They are triggered by writing the appropriate value in the FUNC bitfield of the FMAC_PARAM register, with the START bit set. The P and Q bitfields must also contain the appropriate parameter values for each function as detailed below. The R bitfield is not used. When the function completes, the START bit is automatically reset by hardware.

During initialization, it is recommended that the DMA requests and interrupts be disabled. The transfer of data into the FMAC memory can be done by software or by memory-to-memory DMA transfers, since no flow control is required.

Load X1 buffer

This function pre-loads the X1 buffer with N values, starting from the address in X1_BASE. Successive writes to the FMAC_WDATA register load the write data into the X1 buffer and increment the write address. The write pointer points to the address X1_BASE + N when the function completes.

The function can be used to pre-load the buffer with the elements of a vector, or to initialize the input storage elements of a filter.

Parameters

- The parameter P contains the number of values, N, to be loaded into the X1 buffer.
- The parameters Q and R are not used.

The function completes when N writes have been performed to the FMAC_WDATA register.

Load X2 buffer

This function pre-loads the X2 buffer with N + M values, starting from the address in X2_BASE. Successive writes to the FMAC_WDATA register load the write data into the X2 buffer and increment the write address.

The function can be used to pre-load the buffer with the elements of a vector, or the coefficients of a filter. In the case of an IIR, the N feed-forward and M feed-back coefficients are concatenated and loaded together into the X2 buffer. The total number of coefficients is equal to N + M. For an FIR, there are no feedback coefficients, so M = 0.

Parameters

- The parameter P contains the number of values, N, to be loaded into the X2 buffer starting from address X2_BASE.
- The parameter Q contains the number of values, M, to be loaded into the X2 buffer starting from address X2_BASE + N.
- The parameter R is not used.

The function completes when N + M writes have been performed to the FMAC_WDATA register.

Load Y buffer

This function pre-loads the Y buffer with N values, starting from the address in Y_BASE. Successive writes to the FMAC_WDATA register load the write data into the Y buffer and increment the write address. The read pointer points to the address Y_BASE + N when the function completes.

The function can be used to pre-load the feedback storage elements of an IIR filter.

Parameters

- The parameter P contains the number of values to be loaded into the Y buffer.
- The parameters Q and R are not used.

The function completes when N writes have been performed to the FMAC_WDATA register.

23.3.6 Filter functions

The following filter functions are supported by the FMAC unit. These functions are triggered by writing the corresponding value in the FUNC bitfield of the FMAC_PARAM register with the START bit set. The P, Q and R bitfields must also contain the appropriate parameter values for each function as detailed below. The filter functions continue to run until the START bit is reset by software.

Convolution (FIR filter)

Y = **B***__X__

$$y_n = 2^R \cdot \sum_{k=0}^{N} b_k x_{n-k}$$

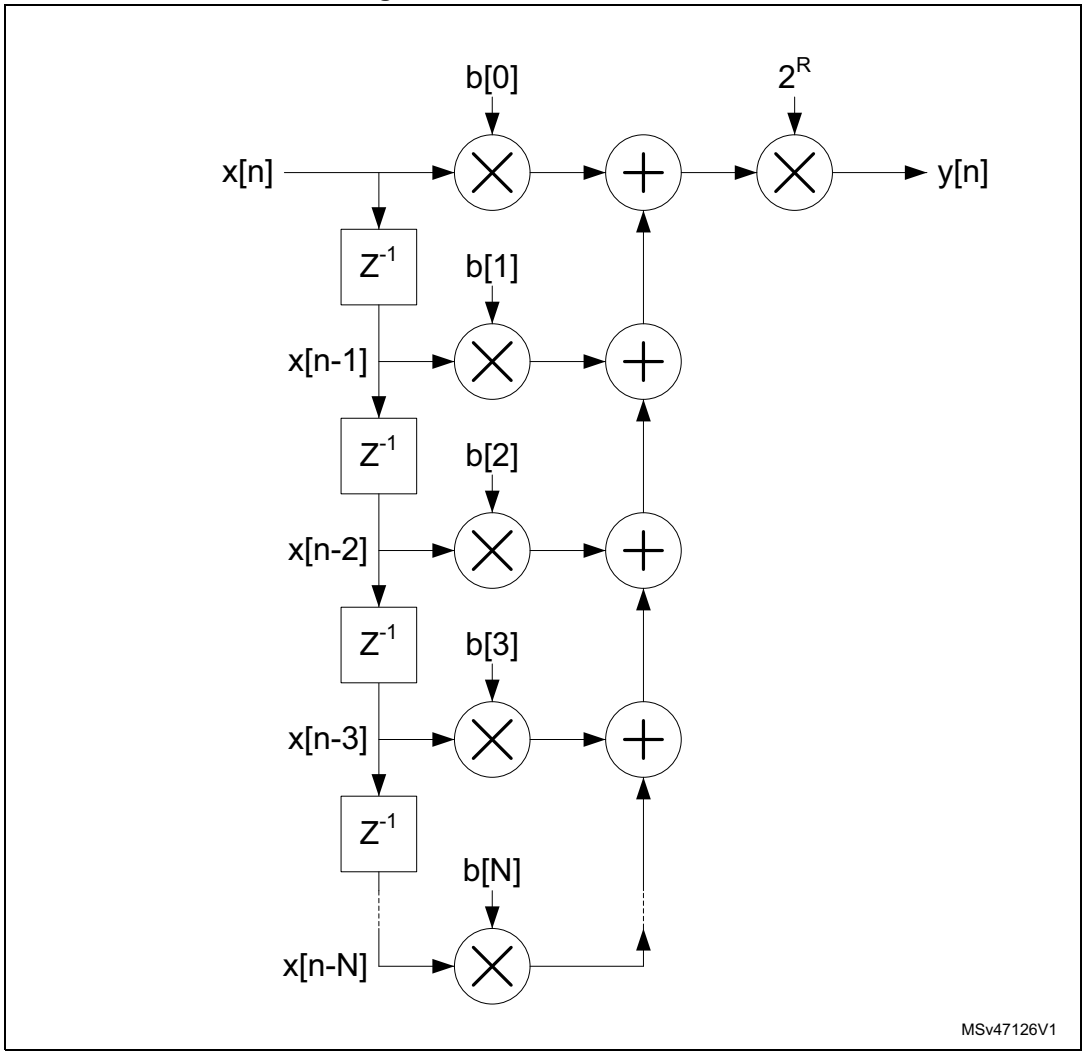
This function performs a convolution of a vector **B** of length N+1 and a vector **X** of indefinite length. The elements of **Y** for incrementing values of n are calculated as the dot product,

$y_n = \underline{\mathbf{B}}.\underline{\mathbf{X}}_{\mathbf{n}}$, where $\underline{\mathbf{X}}_{\mathbf{n}} = [x_{n-N},...,x_n]$ is composed of the N+1 elements of **X** at indexes n - N to n.

This function corresponds to a finite impulse response (FIR) filter, where vector **B** contains the filter coefficients and vector **X** the sampled data.

The structure of the filter (direct form) is shown in *Figure 130*.

Figure 130. FIR filter structure



Note that the cross correlation vector can be calculated by reversing the order of the coefficient vector **B**.

Input:

- X1 buffer contains the elements of vector **X**. It is a circular buffer of length N + 1 + d.
- X2 buffer contains the elements of vector **B**. It is a fixed buffer of length N + 1.

Output:

- Y buffer contains the output values, y_n. It is a circular buffer of length d.

Parameters:

- The parameter P contains the length, N+1, of the coefficient vector **B** in the range [2:127].
- The parameter R contains the gain to be applied to the accumulator output. The value output to the Y buffer is multiplied by 2^R, where R is in the range [0:7]
- The parameter Q is not used.

The function completes when the START bit in the FMAC_PARAM register is reset by software.

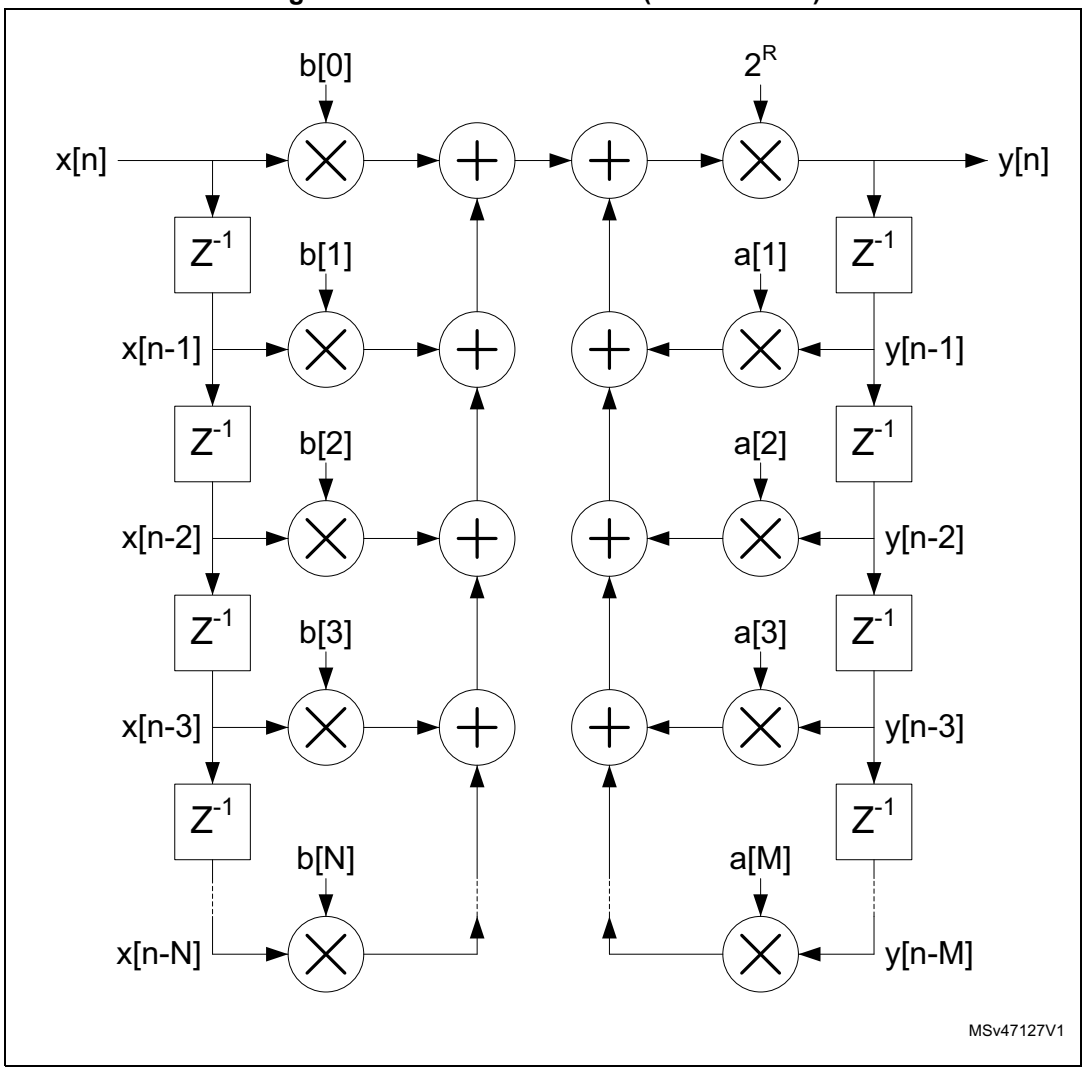
IIR filter

Y = **B*****X**+**A*****Y'**

$$y_n = 2^R \cdot \left(\sum_{k=0}^{N} b_k x_{n-k} + \sum_{k=1}^{M} a_k y_{n-k} \right)$$

This function implements an infinite impulse response (IIR) filter. The filter output vector **Y** is the convolution of a coefficient vector **B** of length N+1 and a vector **X** of indefinite length, plus the convolution of the delayed output vector **Y'** with a second coefficient vector **A**, of length M. The elements of **Y** for incrementing values of n are calculated as y_n = **B**.$\mathbf{X_n}$ + **A**.$\mathbf{Y_{n-1}}$, where $\mathbf{X_n}$ = $[x_{n-N},...,x_n]$ comprises the N+1 elements of **X** at indexes n - N to n, while $\mathbf{Y_{n-1}}$ = $[y_{n-M},...,y_{n-1}]$ comprises the M elements of **Y** at indexes n - M to n - 1. The structure of the filter (direct form 1) is shown in *Figure 131*.

Figure 131. IIR filter structure (direct form 1)



Input:

- X1 buffer contains the elements of vector **X**. It is a circular buffer of length N + 1+ d.
- X2 buffer contains the elements of coefficient vectors **B** and **A** concatenated (b_0, b_1, b_2..., b_N, a_1, a_2, ..., a_M). It is a fixed buffer of length M+N+1.

Output:

- Y buffer contains the output values, y_n. It is a circular buffer of length M + d.

Parameters

- The parameter P contains the length, N + 1, of the coefficient vector **B** in the range [2:64].
- The parameter Q contains the length, M, of the coefficient vector **A** in the range [1:63].
- The parameter R contains the gain to be applied to the accumulator output. The value output to the Y buffer is multiplied by 2^R, where R is in the range [0:7].

The function completes when the START bit in the FMAC_PARAM register is reset by software.

23.3.7 Fixed point representation

The FMAC operates in fixed point signed integer format. Input and output values are q1.15.

In q1.15 format, numbers are represented by one sign bit and 15 fractional bits (binary decimal places). The numeric range is therefore -1 (0x8000) to 1 - 2^{-15} (0x7FFF).

The accumulator has 26 bits, of which 22 are fractional and 4 are integer/sign (q4.22). This allows it to support partial accumulation sums in the range -8 (0x2000000) to +7.99999976 (0x1FFFFFF). A programmable gain from 0dB to 42dB in steps of 6dB can be applied at the output of the accumulator.

Note that the content of the accumulator is not saturated if the numeric range is exceeded. Partial sums whose value is greater than +7.99999976 or less than -8, wrap but this is harmless provided subsequent accumulations undo the wrapping. Nevertheless, the SAT flag in the FMAC_SR register is set if wrapping occurs, and generates an interrupt if the SATIEN bit is set in the FMAC_CR register. This helps in debugging the filter.

The data output by the accumulator can optionally be saturated, after application of the programmable gain, by setting the CLIPEN bit in the FMAC_CR register. If this bit is set, then any value which exceeds the numeric range of the q1.15 output, is set to 1 - 2^{-15} or -1, according to the sign. If clipping is not enabled, the unused accumulator bits after applying the gain is simply truncated.

23.3.8 Implementing FIR filters with the FMAC

The FMAC supports FIR filters of length N, where N is the number of taps or coefficients. The minimum local memory requirement for a FIR filter of length N is 2N + 1:

– N coefficients
– N input samples
– 1 output sample

Since the local memory size is 256, the maximum value for N is 127.

If maximum throughput is required, it may be necessary to allocate a small amount of extra space, d1 and d2, to the input and output sample buffers respectively, to ensure that the filter never stalls waiting for a new input sample, or waiting for the output sample to be read. In this case, the local memory requirement is 2N + d1 + d2.

The buffers must be configured as follows:

- X1_BUF_SIZE = N + d1;
- X2_BUF_SIZE = N;
- Y_BUF_SIZE = d2 (or 1 if no extra space is required)

The buffer base addresses can be allocated anywhere, but the X2 buffer must not overlap with the others, or else the coefficients are overwritten. An example configuration is:

- X2_BASE = 0;
- X1_BASE = N;
- Y_BASE = 2N + d1

However, if the memory space is limited, the X1 and Y buffer areas can be overlapped, such that each output sample takes the place of the oldest input sample, which is no longer required:

- X2_BASE = 0;
- X1_BASE = N;
- Y_BASE = N

In this case, Y_BUF_SIZE = X1_BUF_SIZE = N + d1, so that the buffers remain in sync.

Note: The FULL_WM bitfield of X1 buffer configuration register must be programmed with a value less than or equal to $log_2(d1)$, otherwise the buffer is flagged full before N input samples have been written, and no more samples are requested. Similarly, the EMPTY_WM bitfield of the Y buffer configuration register must be less than or equal to $log_2(d2)$.

The filter coefficients **must** be pre-loaded into the X2 buffer, using the Load X2 Buffer function. The X1 buffer can optionally be pre-loaded with any number of samples up to a maximum of N. There is no point in pre-loading the Y buffer, since for the FIR filter there is no feedback path.

After configuring and initializing the buffers, the FMAC_CR register must be programmed according to the method used for writing and reading data to and from the FMAC memory.

Three methods are supported:

- Polling: No DMA request or Interrupt request is generated. Software must check that the X1_FULL flag is low before writing to WDATA, or that the Y_EMPTY flag is low before reading from RDATA.
- Interrupt: The interrupt request is asserted while the X1_FULL flag is low, for writes, or when the Y_EMPTY flag is low, for reads.
- DMA: DMA requests are asserted on the DMA write channel while the X1_FULL flag is low, and on the read channel while the Y_EMPTY flag is low.

Different methods can be used for read and for write. However it is not recommended to use both interrupts and DMA requests for the same operation[(a)]. The valid combinations are listed in *Table 191*.

Table 191. Valid combinations for read and write methods

WIEN	RIEN	DMAWEN	DMAREN	Write	Read
0	0	0	0	Polling	Polling
0	1	0	0	Polling	Interrupt
1	0	0	0	Interrupt	Polling
1	1	0	0	Interrupt	Interrupt
0	0	0	1	Polling	DMA
0	0	1	0	DMA	Polling
0	0	1	1	DMA	DMA
0	1	1	0	DMA	Interrupt
1	0	0	1	Interrupt	DMA

a. If both interrupts and DMA requests are enabled then only DMA must perform the transfer.

The filter is started by writing to the FMAC_PARAM register with the following bitfield values:

- FUNC = 8 (FIR filter);
- P = N (number of coefficients);
- Q = “Don’t care”;
- R = Gain;
- START = 1;

If less than N + d - 2^{FULL_WM} values have been pre-loaded in the X1 buffer, the X1FULL flag remains low. If the WIEN bit is set in the FMAC_CR register, then the interrupt request is asserted immediately to request the processor to write 2^{FULL_WM} additional samples into the buffer, via the FMAC_WDATA register. It remains asserted until the X1FULL flag goes high in the FMAC_SR register. The interrupt service routine must check the X1FULL flag after every 2^{FULL_WM} writes to the FMAC_WDATA register, and repeat the transfer until the flag goes high. Similarly, if the DMAWEN bit is set in the FMAC_CR register, DMA write channel requests are generated until the X1FULL flag goes high.

The filter calculates the first output sample when at least N samples have been written into the X1 buffer (including any pre-loaded samples).

When 2^{EMPTY_WM} output samples have been written into the Y buffer, the YEMPTY flag in the FMAC_SR register goes low. If the RIEN bit is set in the FMAC_CR register, the interrupt request is asserted to request the processor to read 2^{EMPTY_WM} samples from the buffer, via the FMAC_RDATA register. It remains asserted until the YEMPTY flag goes high. The interrupt service routine must check the YEMPTY flag after every 2^{EMPTY_WM} reads from the FMAC_RDATA register, and repeat the transfer until the flag goes high. If the DMAREN bit is set in the FMAC_CR, DMA read channel requests are generated until the YEMPTY flag goes high.

The filter continues to operate in this fashion until it is stopped by the software resetting the START bit.

23.3.9 Implementing IIR filters with the FMAC

The FMAC supports IIR filters of length N, where N is the number of feed-forward taps or coefficients. The number of feedback coefficients, M, can be any value from 1 to N-1. Only direct form 1 implementations can be realized, so filters designed for other forms need to be converted.

The minimum memory requirement for an IIR filter with N feed-forward coefficients and M feed-back coefficients is 2N + 2M:

- N + M coefficients
- N input samples
- M output samples

If M = N-1, then the maximum filter length that can be implemented is N = 64.

As for the FIR, for maximum throughput, a small amount of additional space, d1 and d2, is allowed in the input and output buffer size respectively, making the total memory requirement 2M + 2N + d1 + d2.

The buffers must be configured as follows:

- X1_BUF_SIZE = N + d1;
- X2_BUF_SIZE = N + M;
- Y_BUF_SIZE = M + d2;

The buffer base addresses can be allocated anywhere, but must not overlap. An example configuration is given below:

- X2_BASE = 0;
- X1_BASE = N + M;
- Y_BASE = 2N + M + d1;

Note: The FULL_WM bitfield of X1 buffer configuration register must be programmed with a value less than or equal to $log_2(d1)$, otherwise the buffer is flagged full before N input samples have been written, and no more samples are requested. Similarly, the EMPTY_WM bitfield of the Y buffer configuration register must be less than or equal to $log_2(d2)$.

The filter coefficients (N feed-forward followed by M feedback) **must** be pre-loaded into the X2 buffer, using the Load X2 Buffer function. The X1 buffer can optionally be pre-loaded with any number of samples up to a maximum of N. The Y buffer can optionally be pre-loaded with any number of values up to a maximum of M. This has the effect of initializing the feedback delay line.

After configuring the buffers, the FMAC_CR register must be programmed in the same way as for the FIR filter (see *Section 23.3.8: Implementing FIR filters with the FMAC*).

The filter is started by writing to the FMAC_PARAM register with the following bitfield values:

- FUNC = 9 (IIR filter);
- P = N (number of feed-forward coefficients);
- Q = M (number of feed-back coefficients);
- R = Gain;
- START = 1;

If less than N + d - 2^{FULL_WM} values have been pre-loaded in the X1 buffer, the X1FULL flag remains low. If the WIEN bit is set in the FMAC_CR register, then the interrupt request is asserted immediately to request the processor to write 2^{FULL_WM} additional samples into the buffer, via the FMAC_WDATA register. It remains asserted until the X1FULL flag goes high in the FMAC_SR register. The interrupt service routine must check the X1FULL flag after every 2^{FULL_WM} writes to the FMAC_WDATA register, and repeat the transfer until the flag goes high. Similarly, if the DMAWEN bit is set in the FMAC_CR register, DMA write channel requests are generated until the X1FULL flag goes high.

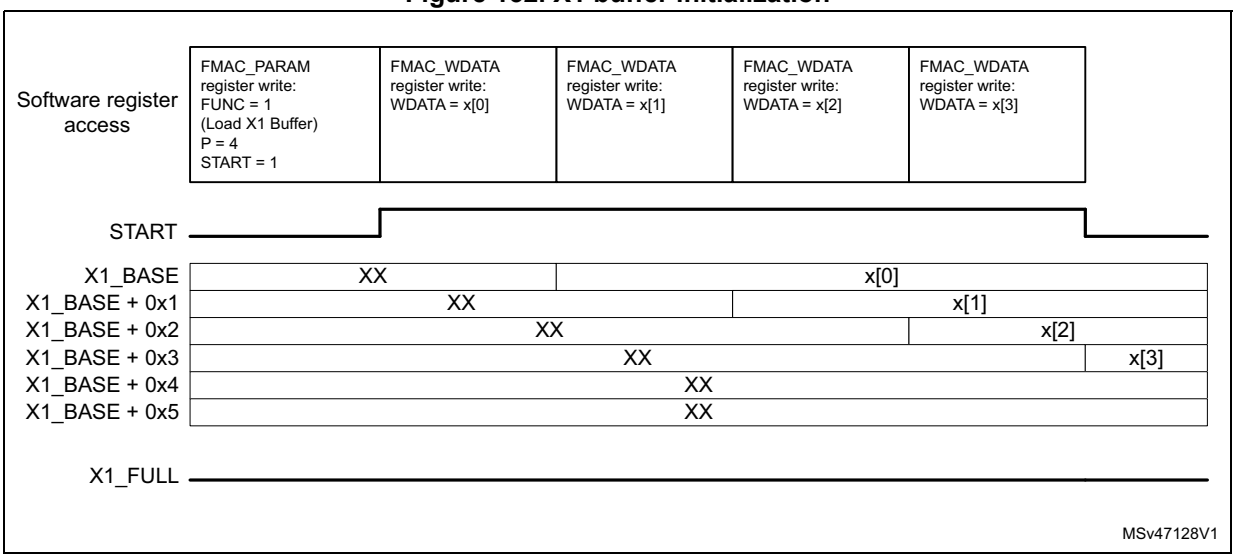
The filter calculates the first output sample when at least N samples have been written into the X1 buffer (including any pre-loaded samples). The first sample is calculated using the first N samples in the X1 buffer, and the first M samples in the Y buffer (whether or not they are preloaded. The first output sample is written into the Y buffer at Y_BASE + M.

When 2^{EMPTY_WM} new output samples have been written into the Y buffer, the YEMPTY flag in the FMAC_SR register goes low. If the RIEN bit is set in the FMAC_CR register, the interrupt request is asserted to request the processor to read 2^{EMPTY_WM} samples from the buffer, via the FMAC_RDATA register. It remains asserted until the YEMPTY flag goes high. The interrupt service routine must check the YEMPTY flag after every 2^{EMPTY_WM} reads from the FMAC_RDATA register, and repeat the transfer until the flag goes high. If the DMAREN bit is set in the FMAC_CR, DMA read channel requests are generated until the YEMPTY flag goes high

The filter continues to operate in this fashion until it is stopped by the software resetting the START bit.

23.3.10 Examples of filter initialization

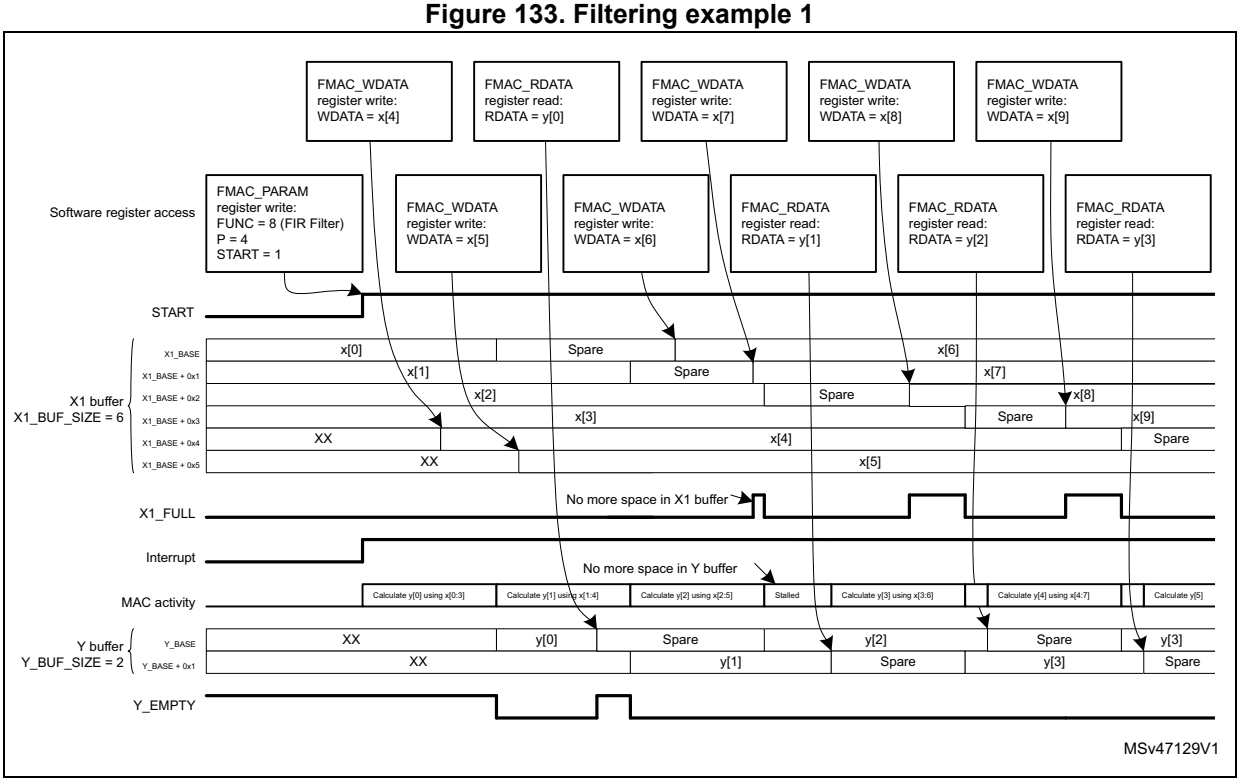
Figure 132. X1 buffer initialization



The example in *Figure 132* illustrates an X1 buffer pre-load with four samples (P = 4). The buffer size is six (X1_BUF_SIZE = 6). The initialization is launched by programming the FMAC_PARAM register with the START bit set. The four samples are then written to FMAC_WDATA, and transferred into local memory from X1_BASE onwards. The START bit resets after the fourth sample has been written. At this point, the X1 buffer contains the four samples, in order of writing, and the write pointer (next empty space) is at X1_BASE + 0x4.

23.3.11 Examples of filter operation

Figure 133. Filtering example 1



The example in *Figure 133* illustrates the beginning of a filter operation. The filter has four taps (P=4). The X1 buffer size is six and the Y buffer size is two. The FULL_WM and EMPTY_WM bitfields are both set to 0. Prior to starting the filter, the X1 buffer has been pre-loaded with four samples, x[0:3] as in *Figure 132*. So the filter starts calculating the first output sample, y[0], immediately after the START bit is set. Since the X1FULL flag is not set (due to two uninitialized spaces in the X1 buffer), the interrupt is asserted straight away, to request new data. The processor writes two new samples, x[4] and x[5], to the FMAC_WDATA register, which are transferred to the empty locations in the X1 buffer.

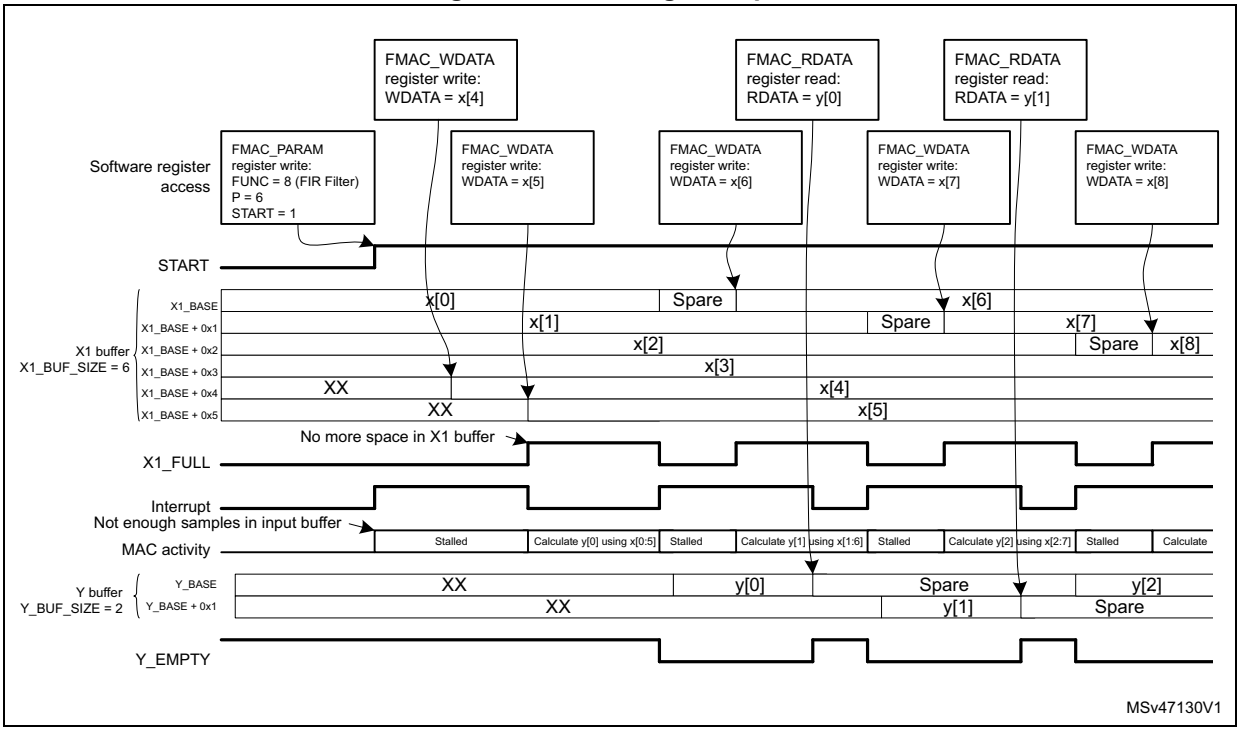
In the mean time, the FMAC finishes calculating the first output sample, y[0], and writes it into the Y buffer, causing the Y_EMPTY flag to go low. At the same time, the x[0] sample is discarded, as it is no longer required, freeing up its location in memory (at X1_BASE). The FMAC can immediately start work on the second output sample, y[1], since all the required input samples x[1:5] are present in the X1 buffer.

Since the Y_EMPTY flag is low, the interrupt remains active after the processor finishes writing x[5]. The processor reads y[0] from the FMAC_RDATA register, freeing up its location in the Y buffer. There are now no samples in the output buffer since y[1] is still being calculated, so the Y_EMPTY flag goes high. Nevertheless, the interrupt remains active, because there is still free space in the X1 buffer, which the processor next fills with x[6], and so on.

Note: In this example, the processor can fill the input buffer more quickly than the FMAC can process them, so the X1_full flag regularly goes active. However, it struggles to read the Y buffer fast enough, so the FMAC stalls regularly waiting for space to be freed up in the Y buffer. This means the filter is not executing at maximum throughput. The reason is that the

filter length is small and the processor relatively slow, in this example. So increasing the Y buffer size does not help.

Figure 134. Filtering example 2



The example in *Figure 134* illustrates the beginning of the same filter operation, but this time the filter has six taps (P=6). The X1 buffer size is six and the Y buffer size is two. The FULL_WM and EMPTY_WM bitfields are both set to 0. Prior to starting the filter, the X1 buffer has been pre-loaded with four samples, x[0:3] as in *Figure 132*. Because there are not enough samples in the input buffer, the X1FULL flag is not set, so the interrupt is asserted straight away, to request new data. The FMAC is stalled.

The processor writes two new samples, x[4] and x[5], to the FMAC_WDATA register, which are transferred to the empty locations in the X1 buffer. As soon as there are six unused samples in the X1 buffer, the X1_FULL flag goes active (since the buffer size is six), causing the interrupt to go inactive. The FMAC starts calculating the first output sample, y[0]. Since this requires all six input samples, there are no free spaces in the X1 buffer and so the X1_FULL flag remains active. Only when the FMAC finishes calculating y[0] and writes it into the Y buffer, can x[0] be discarded, freeing up a space in the X1 buffer, and deasserting X1_FULL. At the same time, the Y_EMPTY flag goes inactive. Both these flag states cause the interrupt to be asserted, requesting the processor to write a new input sample, first of all, and then read the output sample just calculated. The FMAC remains stalled until a new input sample is written.

In this example, the processor has to wait for the FMAC to finish calculating the current output sample, before it can write a new input sample, and therefore the X1 buffer regularly goes empty, stalling the FMAC. This can be avoided by allowing some extra space in the input buffer.

23.3.12 Filter design tips

The FMAC architecture imposes some constraints detailed below, on the design of digital filters.

1. Implementation of direct form 2, or transposed forms, is not efficient. Filters which have been designed for such forms must be converted to direct form 1.
2. Cascaded filters must either be combined into a single stage, or implemented as separate filters. In the latter case, multiple sets of filter coefficients can be pre-loaded into the memory, one set per stage, and only the X2_BASE address changed to select which set is used. The most efficient method of implementing a multi-stage filter is to pre-load a large X1 buffer with input samples, run the IIR filter function on it using the first stage coefficients, and store the output samples back in memory. Then change the X2_BASE pointer to point to the 2nd stage coefficients, and reload the input buffer with the output of the first stage (with a gain if required), before running the IIR function again. The procedure is repeated for all stages. Once the final stage samples have been transferred back into system memory, the input buffer can be loaded with the next set of input samples, and a new round of calculations started. Note that the N sample input buffer of each stage must be pre-loaded first of all with the N-1 last inputs from the previous round, plus one new sample, in order to keep continuity between each round. Similarly, the output buffer of each stage must be loaded with the last M samples from the previous round, for the same reason.
3. The use of direct form 1 for IIR designs can lead to large positive or negative partial sums in the accumulator, if for example a large step occurs on the input, or some of the filter coefficients' absolute values are >1. Since the accumulator is limited to 26 bits, the biggest value that it can handle without wrapping (changing sign) is 0x1FFFFFF positive or 0x2000000 negative. This corresponds to 3.99999988 and -4 respectively in q3.23 fixed point format. Wrapping does not represent a problem provided the wrapping is "undone" before the end of the accumulation. However this is not always the case when a filter is starting up and can lead to unexpected results. Consider pre-loading the output buffer with suitable values to avoid this.
4. The IIR filter has feed-forward (numerator) coefficients $[b_0, b_1, ..., b_{N-1}]$, and feed-back (denominator) coefficients $[1, a_1, ..., a_M]$. Many IIR filters require some of the denominator coefficients to have an absolute value greater than 1 to achieve a steep roll-off in the frequency response. Given that the coefficients are coded in fixed point q1.15 format, this is not possible. Nevertheless, by scaling the denominator coefficients by a factor 2^{-R}, such that $2^{-R}.[1, a_1, ..., a_M]$ are all less than 1, such filters can be implemented. However an inverse gain of 2^R must be applied at the output of the accumulator to compensate the scaling. This has an adverse effect on the signal-to-noise ratio.

23.4 FMAC registers

23.4.1 FMAC X1 buffer configuration register (FMAC_X1BUFCFG)

Address offset: 0x00

Reset value: 0x0000 0000

Access: word access

This register can only be modified if START = 0 in the FMAC_PARAM register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	FULL_WM[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw	rw								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
X1_BUF_SIZE[7:0]								X1_BASE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:24 **FULL_WM[1:0]**: Watermark for buffer full flag

Defines the threshold for setting the X1 buffer full flag when operating in circular mode. The flag is set if the number of free spaces in the buffer is less than 2^{FULL_WM}.

0: Threshold = 1

1: Threshold = 2

2: Threshold = 4

3: Threshold = 8

Setting a threshold greater than 1 allows several data to be transferred into the buffer under one interrupt.

Threshold must be set to 1 if DMA write requests are enabled (DMAWEN = 1 in FMAC_CR register).

Bits 23:16 Reserved, must be kept at reset value.

Bits 15:8 **X1_BUF_SIZE[7:0]**: Allocated size of X1 buffer in 16-bit words

The minimum buffer size is the number of feed-forward taps in the filter (+ the watermark threshold - 1).

Bits 7:0 **X1_BASE[7:0]**: Base address of X1 buffer

23.4.2 FMAC X2 buffer configuration register (FMAC_X2BUFCFG)

Address offset: 0x04

Reset value: 0x0000 0000

Access: word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
X2_BUF_SIZE[7:0]								X2_BASE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **X2_BUF_SIZE[7:0]**: Size of X2 buffer in 16-bit words
This bitfield can not be modified when a function is ongoing (START = 1).

Bits 7:0 **X2_BASE[7:0]**: Base address of X2 buffer
The X2 buffer base address can be modified while START=1, for example to change coefficient values. The filter must be stalled when doing this, since changing the coefficients while a calculation is ongoing affects the result.

23.4.3 FMAC Y buffer configuration register (FMAC_YBUFCFG)

Address offset: 0x08

Reset value: 0x0000 0000

Access: word access

This register can only be modified if START = 0 in the FMAC_PARAM register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	EMPTY_WM[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw	rw								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Y_BUF_SIZE[7:0]								Y_BASE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:24 **EMPTY_WM[1:0]**: Watermark for buffer empty flag
Defines the threshold for setting the Y buffer empty flag when operating in circular mode. The flag is set if the number of unread values in the buffer is less than 2^{EMPTY_WM}.
0: Threshold = 1
1: Threshold = 2
2: Threshold = 4
3: Threshold = 8
Setting a threshold greater than 1 allows several data to be transferred from the buffer under one interrupt.
Threshold must be set to 1 if DMA read requests are enabled (DMAREN = 1 in FMAC_CR register).

Bits 23:16 Reserved, must be kept at reset value.

Bits 15:8 **Y_BUF_SIZE[7:0]**: Size of Y buffer in 16-bit words
For FIR filters, the minimum buffer size is 1 (+ the watermark threshold). For IIR filters the minimum buffer size is the number of feedback taps (+ the watermark threshold).

Bits 7:0 **Y_BASE[7:0]**: Base address of Y buffer

23.4.4 FMAC parameter register (FMAC_PARAM)

Address offset: 0x0C

Reset value: 0x0000 0000

Access: word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
START	FUNC[6:0]							R[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Q[7:0]								P[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **START**: Enable execution
0: Stop execution
1: Start execution
Setting this bit triggers the execution of the function selected in the FUNC bitfield. Resetting it by software stops any ongoing function. For initialization functions, this bit is reset by hardware.

Bits 30:24 **FUNC[6:0]**: Function
0: Reserved
1: Load X1 buffer
2: Load X2 buffer
3: Load Y buffer
4 to 7: Reserved
8: Convolution (FIR filter)
9: IIR filter (direct form 1)
10 to 127: Reserved
This bitfield can not be modified when a function is ongoing (START = 1)

Bits 23:16 **R[7:0]**: Input parameter R.
The value of this parameter is dependent on the function.
This bitfield can not be modified when a function is ongoing (START = 1)

Bits 15:8 **Q[7:0]**: Input parameter Q.
The value of this parameter is dependent on the function.
This bitfield can not be modified when a function is ongoing (START = 1)

Bits 7:0 **P[7:0]**: Input parameter P.
The value of this parameter is dependent on the function
This bitfield can not be modified when a function is ongoing (START = 1)

23.4.5 FMAC control register (FMAC_CR)

Address offset: 0x10

Reset value: 0x0000 0000

Access: word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RESET
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CLIP EN	Res.	Res.	Res.	Res.	Res.	DMA WEN	DMA REN	Res.	Res.	Res.	SAT IEN	UNFL IEN	OVFL IEN	WIEN	RIEN
rw						rw	rw				rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **RESET**: Reset FMAC unit

This resets the write and read pointers, the internal control logic, the FMAC_SR register and the FMAC_PARAM register, including the START bit if active. Other register settings are not affected. This bit is reset by hardware.

0: Reset inactive

1: Reset active

Bit 15 **CLIPEN**: Enable clipping

0: Clipping disabled. Values at the output of the accumulator which exceed the q1.15 range, wrap.

1: Clipping enabled. Values at the output of the accumulator which exceed the q1.15 range are saturated to the maximum positive or negative value (+1 or -1) according to the sign.

Bits 14:10 Reserved, must be kept at reset value.

Bit 9 **DMAWEN**: Enable DMA write channel requests

0: Disable. No DMA requests are generated

1: Enable. DMA requests are generated while the X1 buffer is not full.

This bit can only be modified when START= 0 in the FMAC_PARAM register. A read returns the current state of the bit.

Bit 8 **DMAREN**: Enable DMA read channel requests

0: Disable. No DMA requests are generated

1: Enable. DMA requests are generated while the Y buffer is not empty.

This bit can only be modified when START= 0 in the FMAC_PARAM register. A read returns the current state of the bit.

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **SATIEN**: Enable saturation error interrupts

0: Disabled. No interrupts are generated upon saturation detection.

1: Enabled. An interrupt request is generated if the SAT flag is set

This bit is set and cleared by software. A read returns the current state of the bit.

Bit 3 **UNFLIEN**: Enable underflow error interrupts

0: Disabled. No interrupts are generated upon underflow detection.

1: Enabled. An interrupt request is generated if the UNFL flag is set

This bit is set and cleared by software. A read returns the current state of the bit.

Bit 2 **OVFLIEN**: Enable overflow error interrupts
0: Disabled. No interrupts are generated upon overflow detection.
1: Enabled. An interrupt request is generated if the OVFL flag is set
This bit is set and cleared by software. A read returns the current state of the bit.

Bit 1 **WIEN**: Enable write interrupt
0: Disabled. No write interrupt requests are generated.
1: Enabled. An interrupt request is generated while the X1 buffer FULL flag is not set.
This bit is set and cleared by software. A read returns the current state of the bit.

Bit 0 **RIEN**: Enable read interrupt
0: Disabled. No read interrupt requests are generated.
1: Enabled. An interrupt request is generated while the Y buffer EMPTY flag is not set.
This bit is set and cleared by software. A read returns the current state of the bit.

23.4.6 FMAC status register (FMAC_SR)

Address offset: 0x14

Reset value: 0x0000 0001

Access: word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	SAT	UNFL	OVFL	Res.	Res.	Res.	Res.	Res.	Res.	X1 FULL	Y EMPTY
					r	r	r							r	r

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **SAT**: Saturation error flag
Saturation occurs when the result of an accumulation exceeds the numeric range of the accumulator.
0: No saturation detected
1: Saturation detected. If the SATIEN bit is set, an interrupt is generated.
This flag is cleared by a reset of the unit.

Bit 9 **UNFL**: Underflow error flag
An underflow occurs when a read is made from FMAC_RDATA when no valid data is available in the Y buffer.
0: No underflow detected
1: Underflow detected. If the UNFLIEN bit is set, an interrupt is generated.
This flag is cleared by a reset of the unit.

Bit 8 **OVFL**: Overflow error flag
An overflow occurs when a write is made to FMAC_WDATA when no free space is available in the X1 buffer.
0: No overflow detected
1: Overflow detected. If the OVFLIEN bit is set, an interrupt is generated.
This flag is cleared by a reset of the unit.

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **X1FULL**: X1 buffer full flag

The buffer is flagged as full if the number of available spaces is less than the FULL_WM threshold. The number of available spaces is the difference between the write pointer and the least recent sample currently in use.

0: X1 buffer not full. If the WIEN bit is set, the interrupt request is asserted until the flag is set. If DMAWEN is set, DMA write channel requests are generated until the flag is set.

1: X1 buffer full.

This flag is set and cleared by hardware, or by a reset.

Note: after the last available space in the X1 buffer is filled there is a delay of 3 clock cycles before the X1FULL flag goes high. To avoid any risk of overflow it is recommended to insert a software delay after writing to the X1 buffer before reading the FMAC_SR. Alternatively, a FULL_WM threshold of 2 can be used.

Bit 0 **YEMPTY**: Y buffer empty flag

The buffer is flagged as empty if the number of unread data is less than the EMPTY_WM threshold. The number of unread data is the difference between the read pointer and the current output destination address.

0: Y buffer not empty. If the RIEN bit is set, the interrupt request is asserted until the flag is set. If DMAREN is set, DMA read channel requests are generated until the flag is set.

1: Y buffer empty.

This flag is set and cleared by hardware, or by a reset.

Note: after the last sample is read from the Y buffer there is a delay of 3 clock cycles before the YEMPTY flag goes high. To avoid any risk of underflow it is recommended to insert a software delay after reading from the Y buffer before reading the FMAC_SR. Alternatively, an EMPTY_WM threshold of 2 can be used.

23.4.7 FMAC write data register (FMAC_WDATA)

Address offset: 0x18

Reset value: 0x0000 0000

Access: word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WDATA[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **WDATA[15:0]**: Write data

When a write access to this register occurs, the write data are transferred to the address offset indicated by the write pointer. The pointer address is automatically incremented after each write access.

23.4.8 FMAC read data register (FMAC_RDATA)

Address offset: 0x1C

Reset value: 0x0000 0000

Access: word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **RDATA[15:0]**: Read data

When a read access to this register occurs, the read data are the contents of the Y output buffer at the address offset indicated by the READ pointer. The pointer address is automatically incremented after each read access.

23.4.9 FMAC register map

Table 192.FMAC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	FMAC_X1BUFCFG	Res.	Res.	Res.	Res.	Res.	Res.	FULL_WM[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	X1_BUF_SIZE[7:0]								X1_BASE[7:0]							
	Reset value							0	0									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	FMAC_X2BUFCFG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	X2_BUF_SIZE[7:0]								X2_BASE[7:0]							
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	FMAC_YBUFCFG	Res.	Res.	Res.	Res.	Res.	Res.	EMPTY_WM[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Y_BUF_SIZE[7:0]								Y_BASE[7:0]							
	Reset value							0	0									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	FMAC_PARAM	START	FUNC[6:0]							R[7:0]								Q[7:0]								P[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	FMAC_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RESET	CLIPEN	Res.	Res.	Res.	Res.	Res.	DMAWEN	DMAREN	Res.	Res.	Res.	SATIEN	UNFLIEN	OVFLIEN	WIEN	RIEN
	Reset value																0	0						0	0				0	0	0	0	0
0x14	FMAC_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SAT	UNFL	OVFL	Res.	Res.	Res.	Res.	Res.	Res.	X1FULL	YEMPTY
	Reset value																						0	0	0							0	1
0x18	FMAC_WDATA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDATA[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	FMAC_RDATA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDATA[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

24 Programmable logic array (PLAY)

24.1 PLAY introduction

The programmable logic array allows the user to create custom logic and state machines without the need for external programmable logic devices, such as FPGAs. The PLAY provides a number of programmable logic elements, in the form of look-up tables (LUTs), each of which have four inputs and one output. The output can be programmed to be any logical function of the four inputs. More complex functions can be created by cascading logic elements.

Inputs to and outputs from the logic array can be selected from a choice of external I/Os, internal signals or software programmable register bits. External inputs can be synchronized to the internal clock and filtered to remove short pulses, or connected directly to the logic array if purely combinatorial or asynchronous functions are required.

Each logic element output can be registered using the internal clock, or another signal. Registered outputs can be fed back to the logic array inputs to create finite state machines. Transitions on the outputs can set flags, which can generate interrupts to the processor. The state of the flags can be read and reset by software. The raw states of the logic element outputs can also be read by software or by an external debugger. This provides visibility of the logic array state to simplify debugging of the programmed logic functions.

The array is configured via memory-mapped registers. Configuration is simple and intuitive. Configuration registers are protected against accidental programming by a lock bit. The configuration is maintained in case of a warm system reset.

24.2 PLAY main features

- Glitch-free programmable logic elements each comprising a 4-input look-up table and a register
- Configurable input and output interconnects
- Optional synchronization of inputs, with programmable glitch filters and edge detection/pulse extension feature.
- Software programmable inputs
- Flags with interrupt capability for communication with software
- Simple register-based configuration interface, protected by software lock

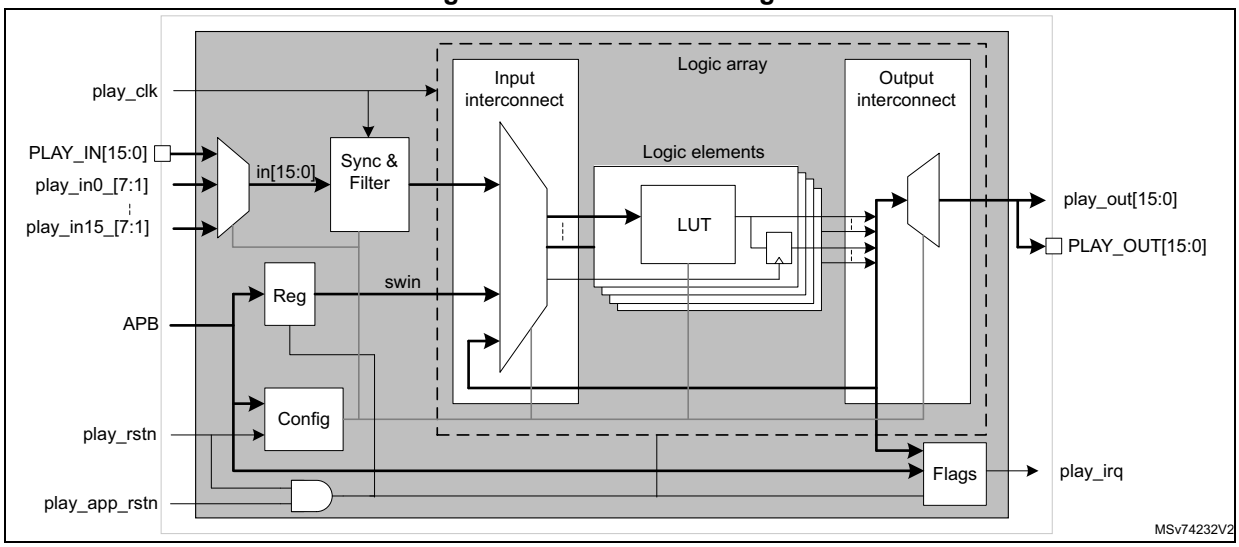
24.3 PLAY functional description

- a logic array, including
  - 16 logic elements
  - an input interconnect
  - an output interconnect
- a synchronization and filter unit
- a configuration unit
- a flag and interrupt unit
- an APB bus slave interface

These are shown in *Figure 135*.

24.3.1 PLAY block diagram

Figure 135. PLAY block diagram



24.3.2 PLAY pins and internal signals

Table 193. PLAY pins

Pin name	Pin type	Description
PLAY_IN[15:0]	Digital inputs	External inputs to the PLAY
PLAY_OUT[15:0]	Digital outputs	External outputs from the PLAY

Table 194. PLAY internal signals

Signal name	Signal type	Description
play_in[15:0]_[7:1]	Digital inputs	PLAY internal inputs
play_out[15:0]	Digital outputs	PLAY internal outputs
play_clk	Clock input	PLAY clock from RCC
pclk	Clock input	APB bus clock
play_irq	Interrupt request	Global interrupt
play_rstn	Reset input	Global reset (includes config)
play_app_rstn	Reset input	Application reset (excludes config)
play_priv0, play_priv1	Digital outputs	Privilege attribute indicators

Table 195 lists the signals connected to the PLAY inputs. Up to 16 inputs can be selected for connection to the logic array, one from each row. See *Section 24.3.4: Input selection* for details.

Table 195. PLAY logic array input *n* signal selection

input *n*	PLAY_FILT*n*CFG.PREMUXSEL[2:0]							
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
0	**play_in0_0**	**play_in0_1**	**play_in0_2**	**play_in0_3**	**play_in0_4**	**play_in0_5**	**play_in0_6**	**play_in0_7**
	PLAY_IN0	tim2_trgo	tim3_trgo	SPI1_MOSI	EVENTOUT	adc1_awd2	lptim2_ch2	lptim1_ch2
1	**play_in1_0**	**play_in1_1**	**play_in1_2**	**play_in1_3**	**play_in1_4**	**play_in1_5**	**play_in1_6**	**play_in1_7**
	PLAY_IN1	tim2_oc3	tim3_oc3	SPI1_SCLK	SPI2_NSS	USART1_TX	comp2_out	comp1_out
2	**play_in2_0**	**play_in2_1**	**play_in2_2**	**play_in2_3**	**play_in2_4**	**play_in2_5**	**play_in2_6**	**play_in2_7**
	PLAY_IN2	tim2_oc4	tim3_oc4	tim2_trgo	SPI2_MOSI	USART1_CK	rcc_mco2	rcc_mco1
3	**play_in3_0**	**play_in3_1**	**play_in3_2**	**play_in3_3**	**play_in3_4**	**play_in3_5**	**play_in3_6**	**play_in3_7**
	PLAY_IN3	lptim1_ch1	lptim2_ch1	tim2_oc3	SPI2_SCLK	NMI	adc2_awd1	adc1_awd1
4	**play_in4_0**	**play_in4_1**	**play_in4_2**	**play_in4_3**	**play_in4_4**	**play_in4_5**	**play_in4_6**	**play_in4_7**
	PLAY_IN4	lptim1_ch2	lptim2_ch2	tim2_oc4	tim3_trgo	LOCKUP	adc2_awd2	adc1_awd2
5	**play_in5_0**	**play_in5_1**	**play_in5_2**	**play_in5_3**	**play_in5_4**	**play_in5_5**	**play_in5_6**	**play_in5_7**
	PLAY_IN5	comp1_out	comp2_out	lptim1_ch1	tim3_oc3	SPI1_NSS	USART2_TX	USART1_TX
6	**play_in6_0**	**play_in6_9**	**play_in6_2**	**play_in6_3**	**play_in6_4**	**play_in6_5**	**play_in6_6**	**play_in6_7**
	PLAY_IN6	rcc_mco1	rcc_mco2	lptim1_ch2	tim3_oc4	SPI1_MOSI	USART2_CK	USART1_CK
7	**play_in7_0**	**play_in7_1**	**play_in7_2**	**play_in7_3**	**play_in7_4**	**play_in7_5**	**play_in7_6**	**play_in7_7**
	PLAY_IN7	adc1_awd1	adc2_awd1	comp1_out	lptim2_ch1	SPI1_SCLK	0	NMI
8	**play_in8_0**	**play_in8_1**	**play_in8_2**	**play_in8_3**	**play_in8_4**	**play_in8_5**	**play_in8_6**	**play_in8_7**
	PLAY_IN8	adc1_awd2	adc2_awd2	rcc_mco1	lptim2_ch2	tim2_trgo	EVENTOUT	LOCKUP
9	**play_in9_0**	**play_in9_1**	**play_in9_2**	**play_in9_3**	**play_in9_4**	**play_in9_5**	**play_in9_6**	**play_in9_7**
	PLAY_IN9	USART1_TX	USART2_TX	adc1_awd1	comp2_out	tim2_oc3	SPI2_NSS	SPI1_NSS
10	**play_in10_0**	**play_in10_1**	**play_in10_2**	**play_in10_3**	**play_in10_4**	**play_in10_5**	**play_in10_6**	**play_in10_7**
	PLAY_IN10	USART1_CK	USART2_CK	adc1_awd2	rcc_mco2	tim2_oc4	SPI2_MOSI	SPI1_MOSI
11	**play_in11_0**	**play_in11_1**	**play_in11_2**	**play_in11_3**	**play_in11_4**	**play_in11_5**	**play_in11_6**	**play_in11_7**
	PLAY_IN11	NMI	0	USART1_TX	adc2_awd1	lptim1_ch1	SPI2_SCLK	SPI1_SCLK
12	**play_in12_0**	**play_in12_1**	**play_in12_2**	**play_in12_3**	**play_in12_4**	**play_in12_5**	**play_in12_6**	**play_in12_7**
	PLAY_IN12	LOCKUP	EVENTOUT	USART1_CK	adc2_awd2	lptim1_ch2	tim3_trgo	tim2_trgo
13	**play_in13_0**	**play_in13_1**	**play_in13_2**	**play_in13_3**	**play_in13_4**	**play_in13_5**	**play_in13_6**	**play_in13_7**
	PLAY_IN13	SPI1_NSS	SPI2_NSS	NMI	USART2_TX	comp1_out	tim3_oc3	tim2_oc3
14	**play_in14_0**	**play_in14_1**	**play_in14_2**	**play_in14_3**	**play_in14_4**	**play_in14_5**	**play_in14_6**	**play_in14_7**
	PLAY_IN14	SPI1_MOSI	SPI2_MOSI	LOCKUP	USART2_CK	rcc_mco1	tim3_oc4	tim2_oc4
15	**play_in15_0**	**play_in15_1**	**play_in15_2**	**play_in15_3**	**play_in15_4**	**play_in15_5**	**play_in15_6**	**play_in15_7**
	PLAY_IN15	SPI1_SCLK	SPI2_SCLK	SPI1_NSS	0	adc1_awd1	lptim2_ch1	lptim1_ch1

Table 196. PLAY output connections

Signal name	External pins	Internal signals
play_out0	PLAY_OUT0	TIM2_etr16 TIM3_etr16 lptim1_ext_trig7 lptim2_ext_trig7
play_out1	PLAY_OUT1	TIM1_brk[3] TIM8_brk[3]
play_out2	PLAY_OUT2	TIM1_brk2[3] TIM8_brk2[3]
play_out3	PLAY_OUT3	TIM2_ti1_4 TIM3_ti1_4 lptim1_in1_mux2 lptim2_in1_mux2
play_out4	PLAY_OUT4	TIM2_ti2_3 TIM3_ti2_3 lptim1_in2_mux2 lptim2_in2_mux2
play_out5	PLAY_OUT5	TIM2_ti3_1 TIM3_ti3_1 lptim1_ic1_mux3 lptim2_ic1_mux3
play_out6	PLAY_OUT6	TIM2_ti4_1 TIM3_ti4_1
play_out7	PLAY_OUT7	adc1_ext_trg20 adc2_ext_trg20 adc3_ext_trg20
play_out8	PLAY_OUT8	-
play_out9	PLAY_OUT9	adc1_jext_trg20 adc2_jext_trg20 adc3_jext_trg20
play_out10	PLAY_OUT10	-
play_out11	PLAY_OUT11	dac_trg14
play_out12	PLAY_OUT12	dac_trg15
play_out13	PLAY_OUT13	dts_ts1_trg4
play_out14	PLAY_OUT14	EXTI_event_64
play_out15	PLAY_OUT15	GPDMA_trig_72

24.3.3 PLAY reset and clocks

The PLAY has two reset inputs:

- play_rstn: connected to the power reset
- play_app_rstn: connected to the system reset

The PLAY configuration registers are reset by:

- play_rstn

All other registers, including the PLAY logic element output registers, are reset by:

- play_rstn
- play_app_rstn

The PLAY configuration and control registers are clocked by:

- pclk (APB bus clock)

The synchronisation and filters are clocked by:

- play_clk

The PLAY logic element output registers are clocked by:

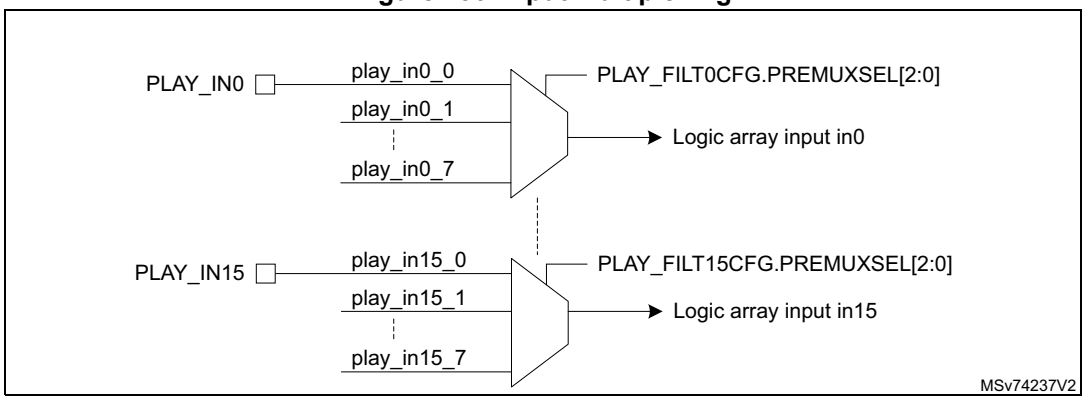
- play_clk, optionally conditioned by any of the PLAY inputs or logic element registered outputs

24.3.4 Input selection

There are 16 inputs to the logic array, in0 to in15, which can be connected to external I/Os or internal signals coming from other functional units.

Each logic array input can connect to one of eight signals. A pre-multiplexer selects which signal is connected to an input. The pre-multiplexer for logic array input *n* is configured by the PLAY_FILT*n*CFG.PREMUXSEL[2:0] register field (see *Figure 136*). Only one signal can be chosen per input.

Figure 136. Input multiplexing

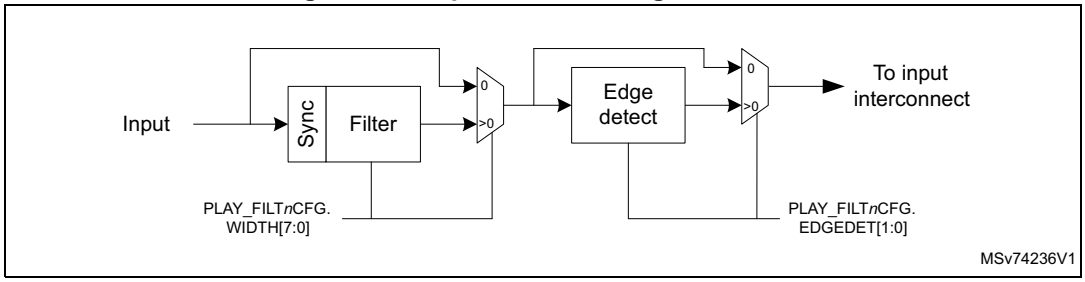


The mapping of signals to logic array inputs is shown in *Table 195*. The left hand column contains the logic array input number. The columns to the right show the play_in signal name as well as the source signal to which it is connected, for each setting of PLAY_FILT*n*CFG.PREMUXSEL[2:0]. Some source signal names appear more than once in the table, which means they can be mapped to more than one input. This offers more flexibility when mapping source signals to logic array inputs.

24.3.5 Input filtering and edge detection

Inputs pass through a filter stage, which can be configured to remove short pulses or glitches and generate a pulse if an edge is detected (see *Figure 137*).

Figure 137. Input filter and edge detection



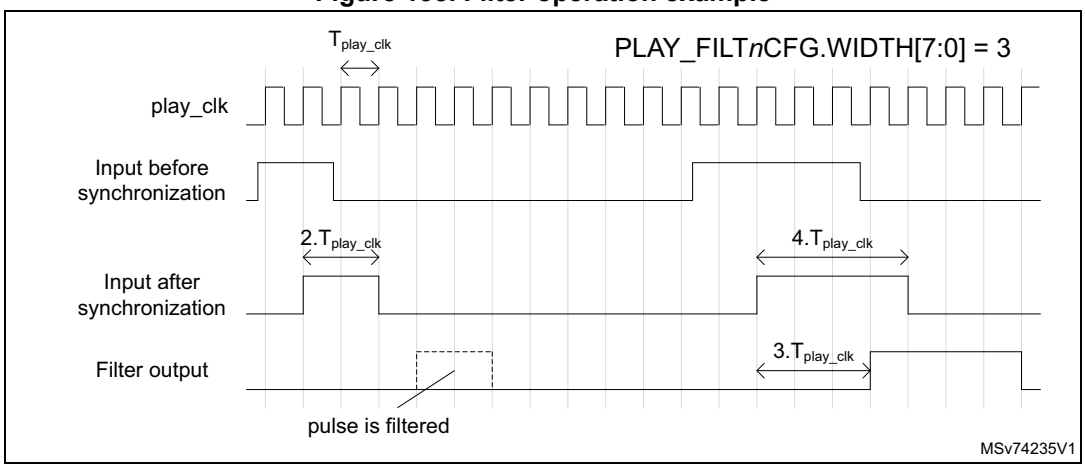
Filtering

Every input has a filter which removes pulses shorter than a programmable number of play_clk clock cycles (after synchronization). The filter samples the input at the play_clk clock frequency and starts a counter if it detects a change in state. If the input transitions again before the counter reaches zero, the counter is stopped and reloaded, and the filter output state remains unchanged. If the counter reaches zero, it is reloaded and the filter output state toggles.

The minimum pulse width for input *n* can be programmed from 1 to 255 cycles in register bits PLAY_FILTCFG*n*.WIDTH[7:0]. Note that the filter introduces a delay equal to the programmed minimum pulse width.

Figure 138 illustrates the operation of the filter for PLAY_FILTCFG*n*.WIDTH[7:0] = 3. Pulses whose width is less than three periods of play_clk (T_{play_clk}) are filtered. Pulses whose width is three periods or more propagate through the filter, with a delay of three T_{play_clk} periods.

Figure 138. Filter operation example



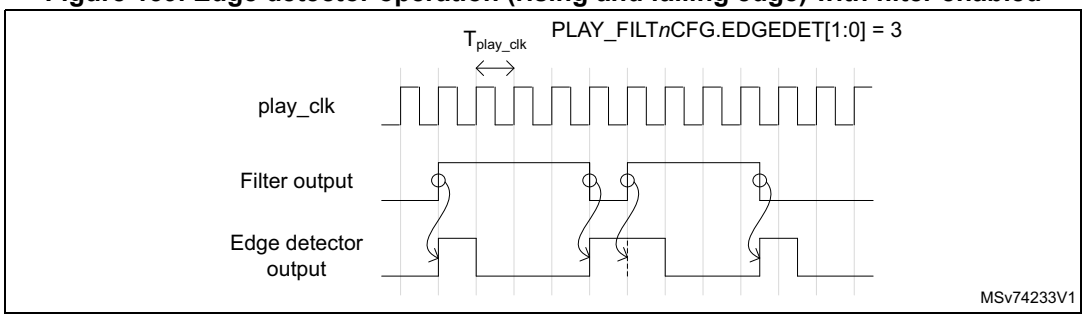
The filter can be bypassed by setting PLAY_FILT*n*CFG.WIDTH[7:0] = 0.

Edge detection and pulse generation

For all inputs there is an optional edge detection feature which detects a transition and generates a positive pulse of one play_clk clock period. This can be used to detect and lengthen pulses which are shorter than the play_clk clock period, or to trigger actions on an edge rather than a level. The edge detection feature is enabled for input *n* by programming the PLAY_FILTCFG*n*.EDGEDET[1:0] field with direction of the transition (rising, falling or both edges). Setting the field to 0 disables and bypasses the edge detection.

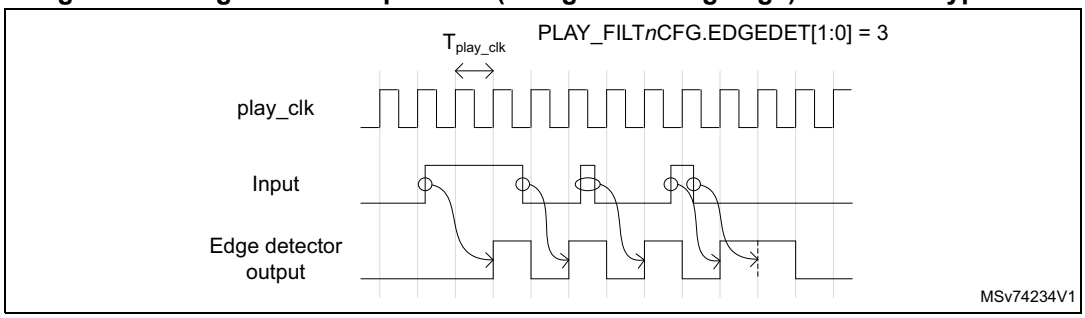
If the filter is enabled (PLAY_FILTCFG*n*.WIDTH[7:0] > 0), the edge detector generates a pulse when an edge is detected at the output of the filter (see *Figure 139*). Note that if both rising and falling edges are programmed, back-to-back transitions on successive clocks generate a double length pulse.

Figure 139. Edge detector operation (rising and falling edge) with filter enabled



To lengthen a pulse shorter than one play_clk period, the filter must be bypassed. This is done by setting PLAY_FILTCFG*n*.WIDTH[7:0] = 0. The synchronization is done by the edge detection unit. When an edge is detected on the input signal, a positive pulse is generated after a delay of between one and two play_clk periods (see *Figure 140*).

Figure 140. Edge detector operation (rising and falling edge) with filter bypassed



If both rising and falling edges are programmed, and the input pulse width is less than one play_clk period, only one output pulse is generated. Note however that if two transitions occur either side of a clock edge, a double length pulse is generated.

Synchronization

All input signals are considered to be asynchronous to the play_clk clock. If any synchronous logic is connected downstream, it is mandatory to synchronize the inputs to

the play_clk clock, to avoid meta-stability. Synchronization introduces a delay of 1 to 2 play_clk periods.

Synchronization is performed by enabling the filter or the edge detector. If both the filter and edge detector are bypassed (PLAY_FILT*n*CFG.WIDTH[7:0] = 0 and PLAY_FILT*n*CFG.EDGEDET[1:0] = 0), the input signal is propagated directly to the logic array without synchronization.

Caution: If both edge detector and filter are bypassed, the input must only be used to drive purely combinatorial logic.

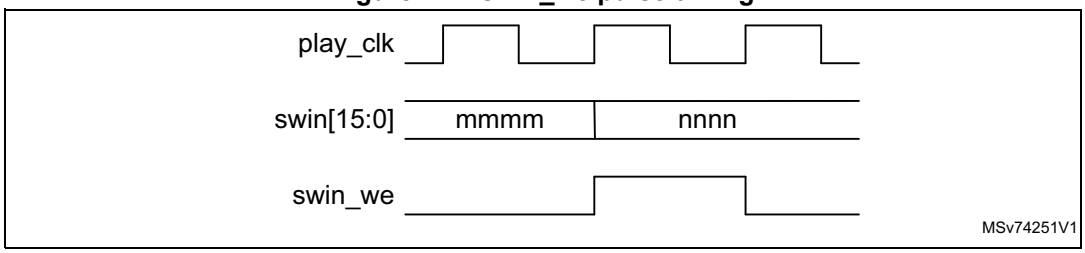
24.3.6 Software programmable inputs

The PLAY_SWIN register contains 16 bits which are connected to inputs swin0 to swin15. This allows software programmable functionality to be included in the logic expression. This can be used for example to enable or disable functionality, or to trigger state transitions, by software. These inputs also allow testing of the programmed logic array functionality.

The PLAY_SWIN register bits can be set independently by writing a 1 to the corresponding bits in the PLAY_SWIN_SET register. In the same way they can be reset by writing a 1 to the corresponding bits in the PLAY_SWIN_CLR register. It is also possible to read and write the bits directly in the PLAY_SWIN register.

Every time there is a write to the PLAY_SWIN, PLAY_SWIN_SET or PLAY_SWIN_CLR register, a positive pulse is generated on the swin_we signal. The pulse lasts one play_clk cycle, starting from the moment the register value is updated (see *Figure 141*). The swin_we signal is connected to the input interconnect and can be used as a clock enable for any of the logic element output registers. This means that writing to the PLAY_SWIN register can trigger a state transition conditioned by the new values on swin0 to swin15, for example.

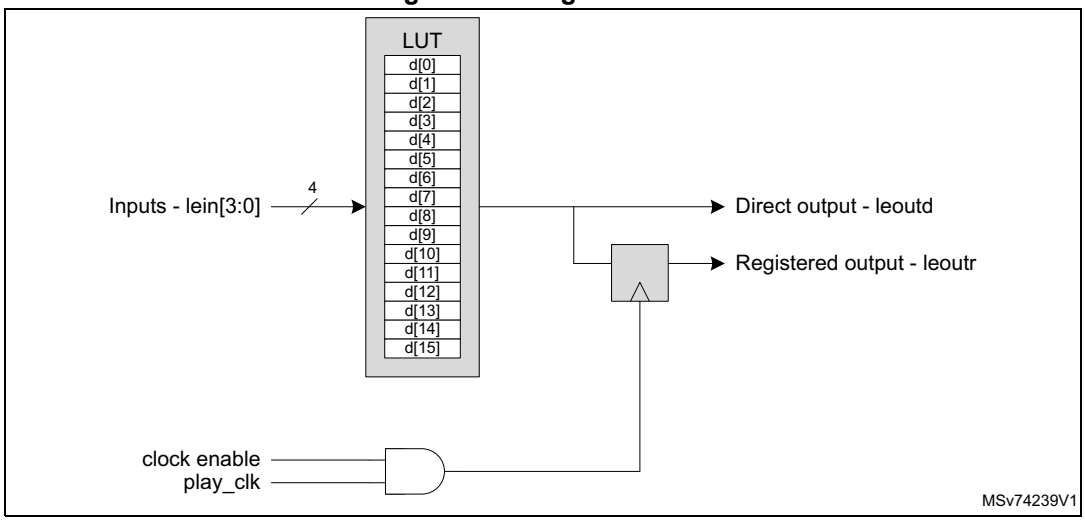
Figure 141. swin_we pulse timing



24.3.7 Logic elements

The logic array provides 16 logic elements (LEs), each containing a 4-input, single output look-up table (LUT) and a register (*Figure 142*).

Figure 142. Logic element



Look-up table (LUT)

The LUT is a 16 x 1-bit memory which generates a single output, leoutd, whose value is a function of the four LUT inputs, lein[3:0] which make up the address. The LUT is programmed at configuration time with the required state of the output for every possible combination of lein[3:0].

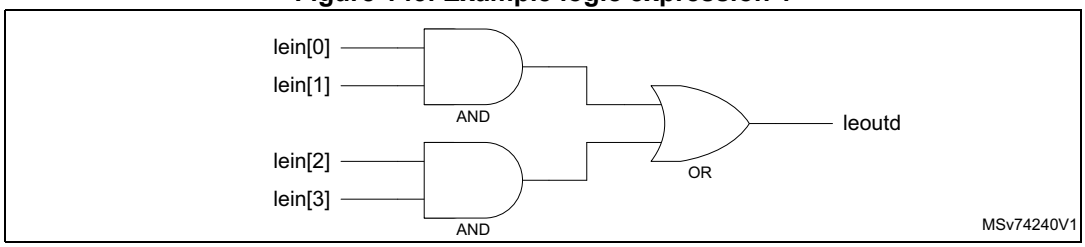
To implement a Boolean logic expression, the full truth table for the expression must be detailed.

This is demonstrated using the following logic expression as an example:

leoutd = lein[0] AND lein[1] OR lein[2] AND lein[3]

This expression corresponds to the diagram in *Figure 143*.

Figure 143. Example logic expression 1



The truth table is given in *Table 197*.

Table 197. Truth table example 1

Inputs - lein[3:0]	Output - leoutd
0000	0
0001	0
0010	0
0011	1
0100	0

Table 197. Truth table example 1 (continued)

Inputs - lein[3:0]	Output - leoutd
0101	0
0110	0
0111	1
1000	0
1001	0
1010	0
1011	1
1100	1
1101	1
1110	1
1111	1

The left hand column lists the address formed by the combination of the four LUT inputs, lein[3:0], and the right hand column lists the required output value on leoutd for each input combination.

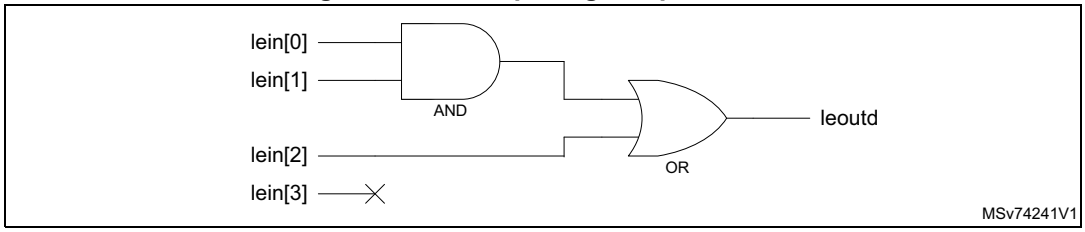
During configuration, the LUT is programmed as a single 16-bit register, with the data read from the output column of the truth table, read from bottom (MSB) to top (LSB). In this example the LUT configuration register would be programmed with 1111 1000 1000 1000 (0xF888).

If any of the inputs are unused or “don’t care”, the output must be the same for both possible values of the unused input. In other words, the contents of address 0bxnnn must be the same for x = 0 or x = 1.

For example, in the following logic expression, lein[3] is unused:

leoutd = lein[0] AND lein[1] OR lein[2]

Figure 144. Example logic expression 2



The truth table for this expression is shown in *Table 198*. To obtain the full LUT, each row containing an ‘x’ is split into two identical rows. Then the ‘x’ is replaced by ‘0’ and ‘1’ respectively.

In this example the configuration register is programmed with 1111 1000 1111 1000 (0xF8F8).

Table 198. Truth table example 2

lein[3:0]	leoutd
x000	0
x001	0
x010	0
x011	1
x100	1
x101	1
x110	1
x111	1

Alternatively, the unused input can be connected to an unused input with value 0 (see *Table 199*), so that addresses with x = 1 are never accessed and can be left at 0.

The LUT configuration registers are directly mapped in the PLAY APB address space. The LUT configuration for logic element *n* is programmed in the register bit field PLAY_LE*n*CFG1.LUT[15:0].

LE output register

The LUT output can be direct or registered. Output registers are clocked by the play_clk, optionally qualified by a clock enable signal. When the clock enable signal is high, the register is updated with the LUT output every play_clk cycle. A clock enable must be high for at least one play_clk cycle. This constraint is guaranteed for input signals using edge detection or filtering (see *Section 24.3.5: Input filtering and edge detection*). It is also guaranteed for the synchronous feedback signals leoutr[15:0].

Caution: Asynchronous signals must not be selected as clock enables.

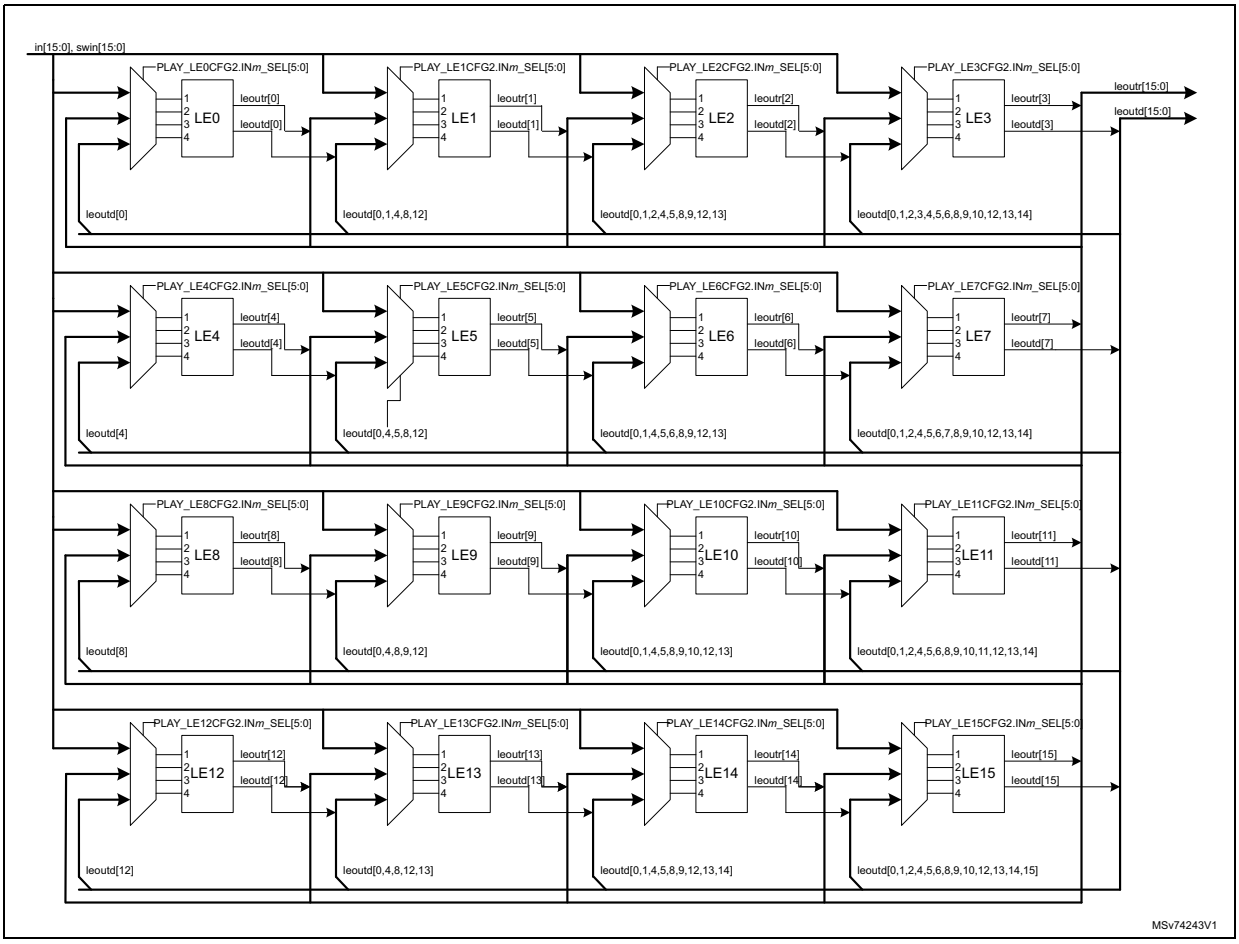
During configuration (when PLAY_CFGCR.UNLOCK = 1), the logic element registers are held in reset.

Logic element registers are also reset by play_rstn and play_app_rstn.

24.3.8 Input interconnect

The input interconnect selects which signals are connected to each logic element, as shown in *Figure 145*.

Figure 145. Input interconnect



LUT input selection

For each logic element, up to four input signals can be configured as LUT inputs, and one as a clock enable for the LE register. The LUT inputs can be selected from among the following signals:

- in[15:0] - 16 inputs from I/Os or other functional blocks, via the filter and edge detection unit
- swin[15:0] - 16 register bits (PLAY_SWIN register)
- leoutr[15:0] - 16 feedback signals from LE registered outputs
- logic 0

Each logic element's direct output can be fed back to one of its inputs. This allows implementation of asynchronous latches.

It is also possible to connect the direct outputs of certain logic elements to the inputs of others - see *Combining logic elements*.

For logic element *n* (0 to 15), the signals connected to input *m* (0 to 3), are selected by configuration register PLAY_LE*n*CFG2, bit field IN*m*_SEL[5:0].

The selection of the LUT input signals is summarized in *Table 199*.

For example, to connect input signal in15 to input 2 of logic element 0, program PLAY_LE0CFG2.IN2_SEL[5:0] = 47. To connect input 3 of logic element 1 to the direct output of logic element 0, leoutd0, program PLAY_LE1CFG2.IN3_SEL[5:0] = 0.

Table 199. Logic element *n* LUT input selection

PLAY_LE*n*CFG2.IN*m*_SEL [5:0]	Signal connected to LUT input *m*	Source
0	For *n* = 4,8,12: 0	-
	For *n* = 0,1,2,3,5,6,7,9,10,11,13,14,15: leoutd[*0*]	LE 0 direct output
1	For *n* = 0,4,5,8,9,12,13: 0	-
	For *n* = 1,2,3,6,7,10,11,14,15: leoutd[*1*]	LE 1 direct output
2	For *n* = 0,1,4,5,6,8,9,10,12,13,14: 0	-
	For *n* = 2,3,7,11,15: leoutd[*2*]	LE 2 direct output
3	For *n* = 0,1,2,4,5,6,7,8,9,10,11,12,13,14,15: 0	-
	For *n* = 3: leoutd[*3*]	LE 3 direct output
4	For *n* = 0,8,12: 0	-
	For *n* = 1,2,3,4,5,6,7,9,10,11,13,14,15: leoutd[*4*]	LE 4 direct output
5	For *n* = 0,1,4,8,9,12,13: 0	-
	For *n* = 2,3,5,6,7,10,11,14,15: leoutd[*5*]	LE 5 direct output
6	For *n* = 0,1,2,4,5,8,9,10,12,13,14: 0	-
	For *n* = 3,6,7,11,15: leoutd[*6*]	LE 6 direct output
7	For *n* = 0,1,2,3,4,5,6,8,9,10,11,12,13,14,15: ’0’	-
	For *n* = 7: leoutd[*7*]	LE 7 direct output
8	For *n* = 0,4,12: 0	-
	For *n* = 1,2,3,5,6,7,8,9,10,11,13,14,15: leoutd[*8*]	LE 8 direct output
9	For *n* = 0,1,4,5,8,12,13: 0	-
	For *n* = 2,3,6,7,9,10,11,14,15: leoutd[*9*]	LE 9 direct output
10	For *n* = 0,1,2,4,5,6,8,9,12,13,14,15: 0	-
	For *n* = 3,7,10,11: leoutd[*10*]	LE 10 direct output
11	For *n* = 0,1,2,3,4,5,6,7,8,9,10,12,13,14,15: 0	-
	For *n* = 11: leoutd[*11*]	LE 11 direct output
12	For *n* = 0,4,8: 0	-
	For *n* = 1,2,3,5,6,7,9,10,11,12,13,14,15: leoutd[*12*]	LE 12 direct output
13	For *n* = 0,1,4,5,8,9,12: 0	-
	For *n* = 2,3,6,7,10,11,13,14,15: leoutd[*13*]	LE 13 direct output

Table 199. Logic element *n* LUT input selection (continued)

PLAY_LE*n*CFG2.IN*m*_SEL [5:0]	Signal connected to LUT input *m*	Source
14	For *n* = 0,1,2,4,5,6,8,9,10,12,13: 0	-
	For *n* = 3,7,11,14,15: leoutd[*14*]	LE 14 direct output
15	For *n* = 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14: 0	-
	For *n* = 15: leoutd[*15*]	LE 15 direct output
16 to 31	leoutr[0] to leoutr[15]	LE registered outputs
32 to 47	in0 to in15	input signals
48 to 63	swin0 to swin15	PLAY_SWIN

LE clock enable selection

The LE register clock enable can be selected from any of these signals:

- in[15:0] - 16 inputs from I/Os or other functional blocks, via the filter and edge detection
- swin[15:0] - 16 register bits (PLAY_SWIN register)
- swin_we - pulse indicating that a write to the PLAY_SWIN register has taken place
- leoutr[15:0] - 16 feedback signals from LE registered outputs
- 0- clock disabled
- 1- always enabled

For logic element n the clock enable is selected by configuration register bits PLAY_LE*n*CFG2.CK_SEL[5:0].

The selection of the LE register clock is summarized in *Table 200*.

Table 200. Logic element *n* register clock selection

PLAY_LE*n*CFG2.CK_SEL[5:0]	Clock enable signal[(1)]	Source
0	0 (clock disabled)	-
1	1 (always enabled)	-
2	swin_we	APB interface
3 to 15	reserved	-
16 to 31	leoutr0 to leoutr15 (excluding leoutr*n*)	LE registered outputs
32 to 47	in0 to in15	input signals
48 to 63	swin0 to swin15	PLAY_SWIN

1. Reserved values select 0

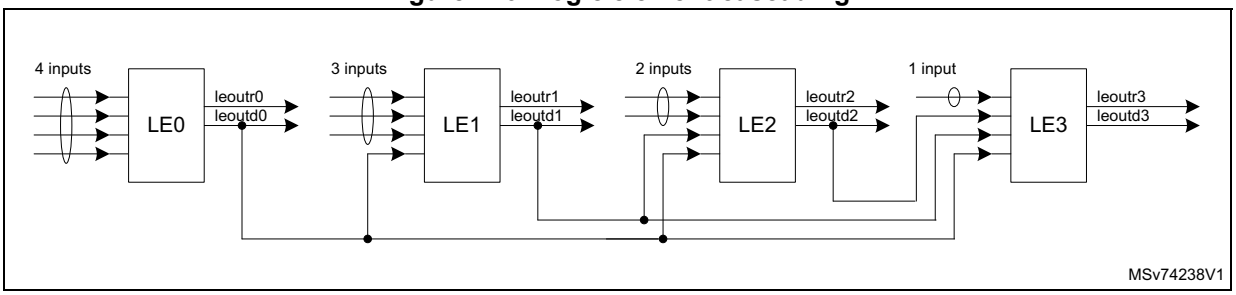
Combining logic elements

LE 0-3 form a group which can be cascaded combinatorially from left to right (see *Figure 146*):

- LE0 direct output can be connected to LE1-3 inputs
- LE1 direct output can be connected to LE2-3 inputs
- LE2 direct output can be connected to LE3 inputs

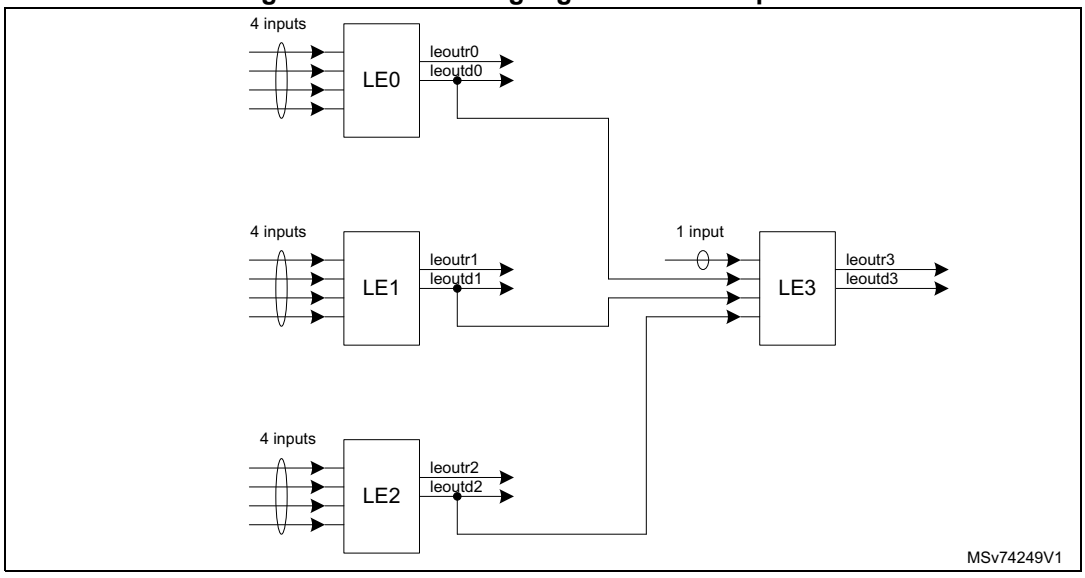
The other groups of four (LE 4-7, LE 8-11, LE12-15) can be cascaded in the same way. Furthermore, logic elements from different groups can be connected together, provided the left to right logic flow is respected. For example, LE4 direct output can be connected to LE1 input, but not to LE0 input.

Figure 146. Logic element cascading



It is also possible to use one logic element to combine the outputs of up to three others, as shown in *Figure 147*. In this example, the direct outputs of LE0-2 are connected to the inputs of LE3. This allows up to 13 different inputs to be combined in a single logic expression.

Figure 147. Combining logic elements in parallel



Note that combining logic elements in this way requires the logic expression to be split into partial expressions, with up to four inputs each.

For example, consider the following expression:

Y = (X1 AND X2) OR (X3 AND X4) OR (X5 AND X6).

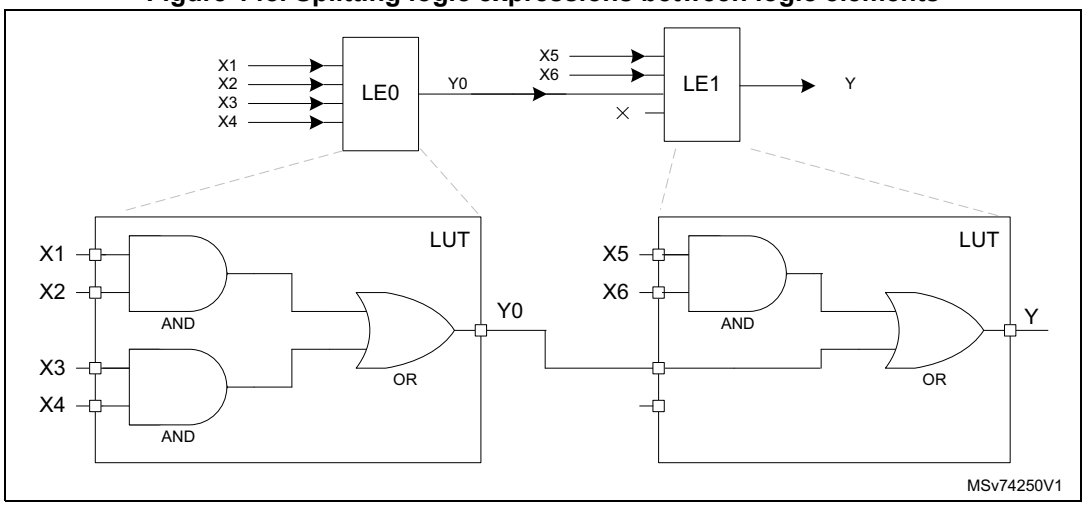
This expression has six inputs (X1 to X6) and one output (Y). It therefore requires at least two logic elements, for example LE0 and LE1, as illustrated in *Figure 148*. The expression for Y can be split into two expressions:

a) Y0 = (X1 AND X2) OR (X3 AND X4)

b) Y = Y0 OR (X5 AND X6)

Then LE0 is configured with expression ‘a’, and LE1 with expression ‘b’. Inputs X1 to X4 are connected to LE0. Inputs X5 and X6, are connected to LE1, together with Y0, the direct output of LE0.

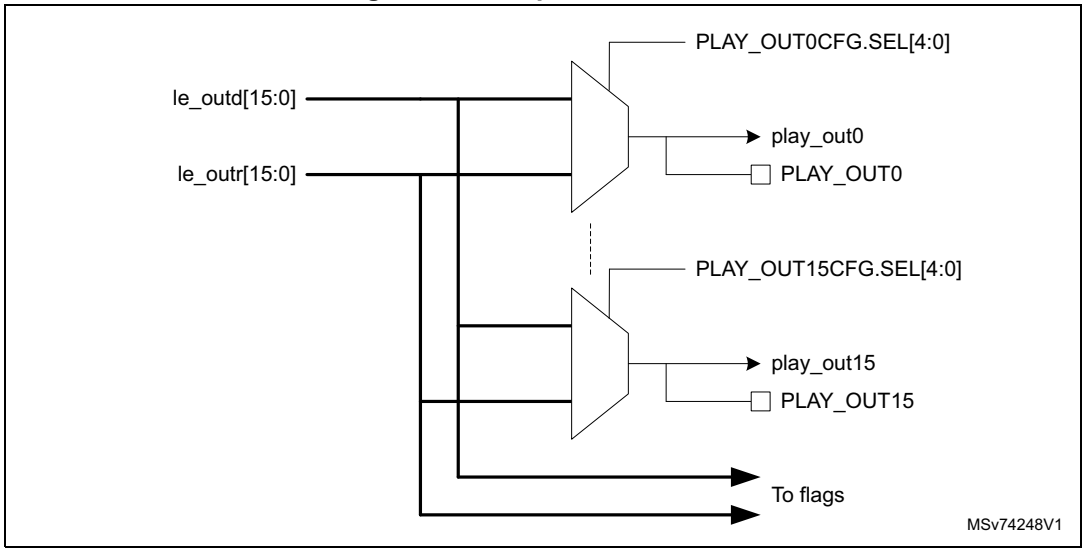
Figure 148. Splitting logic expressions between logic elements



24.3.9 Output interconnect

The output interconnect selects which logic element or eFPGA outputs are connected to which PLAY outputs, as shown in *Figure 149*.

Figure 149. Output interconnect



The PLAY outputs include the following signals:

- play_out[15:0] - 16 outputs to I/Os or other functional blocks

Each output can be connected to any one of the logic element outputs, registered or direct. The signal connected to output *n* is selected by configuration register bits PLAY_OUT*n*CFG.SEL[4:0].

The output selection is summarized in *Table 201*.

Table 201. Output n source selection

PLAY_OUT*n*CFG.SEL[4:0]	Source
0	leoutd0 - LE0 direct output
1	leoutd1 - LE1 direct output
2	leoutd2 - LE2 direct output
3	leoutd3 - LE3 direct output
4	leoutd4 - LE4 direct output
5	leoutd5 - LE5 direct output
6	leoutd6 - LE6 direct output
7	leoutd7 - LE7 direct outpu
8	leoutd8 - LE8 direct output
9	leoutd9 - LE9 direct output
10	leoutd10 - LE10 direct output

Table 201. Output n source selection (continued)

PLAY_OUT*n*CFG.SEL[4:0]	Source
11	leoutd11 - LE11 direct output
12	leoutd12 - LE12 direct output
13	leoutd13 - LE13 direct output
14	leoutd14 - LE14 direct output
15	leoutd15 - LE15 direct output
16	leoutr0 - LE0 register output
17	leoutr1 - LE1 register output
18	leoutr2 - LE2 register output
19	leoutr3 - LE3 register output
20	leoutr4 - LE4 register output
21	leoutr5 - LE5 register output
22	leoutr6 - LE6 register output
23	leoutr7 - LE7 register output
24	leoutr8 - LE8 register output
25	leoutr9 - LE9 register output
26	leoutr10 - LE10 register output
27	leoutr11 - LE11 register output
28	leoutr12 - LE12 register output
29	leoutr13 - LE13 register output
30	leoutr14 - LE14 register output
31	leoutr15 - LE15 register output

24.3.10 Flags

A transition on any of the logic element outputs leoutd[15:0] or leoutr[15:0] can set the corresponding flag in the PLAY_FLSTAT register.

The direction of the transition (rising or falling) can be selected in the PLAY_FLCTL register. Once set, the flag can only be reset by software writing to the PLAY_FLCLR register (or by a reset). Setting a flag generates an interrupt to the CPU on the play_irq signal, if the enable bit for the flag is set in the PLAY_FLIER register. To clear the interrupt the software must reset the flag, or mask it by resetting the enable.

Due to the asynchronous relationship between play_clk and the pclk, a resynchronisation delay is incurred between a transition on the logic element output and the setting of the corresponding flag. The maximum delay is approximately one period of play_clk plus three periods of pclk. The play_irq interrupt is not asserted until the flag goes high. Note that if successive transitions occur on the same output before the flag is cleared, they are not taken into account. However if a subsequent transition on another logic element output occurs during the resynchronization delay, a second resynchronization starts as soon as the first is finished, at the end of which the second flag is set.

The raw state of the signals can also be read by software via the PLAY_OSR register. This is primarily intended for debugging the programmed logic. The user must be aware that the logic element outputs can change asynchronously and the value that is read from PLAY_OSR may not correspond to the actual state of the outputs at the moment of reading.

24.3.11 Miscellaneous status bits

The software input register (PLAY_SWIN), and the flag edge control register (PLAY_FLCTL) are in the play_clk domain. When a write occurs to one of these registers (including to PLAY_SWINSET/CLR), the write data is stored temporarily in the APB bus clock (pclk) domain until the next play_clk pulse at which point the data is transferred to the target register. If play_clk is slow compared to pclk, or if it is inactive, the update could take an indefinitely long time to complete. To avoid stalling the processor, any subsequent writes to the same register before the target register update has completed, are ignored.

To ensure that updates are not lost, the PLAY_MSR register contains two read-only status bits, SWIN write busy flag (SWIN_WBFS) and FLCTL write busy flag (FLCTL_WBFS). When one of these bits is set to 1, it indicates that an update is pending to the corresponding register, PLAY_SWIN or PLAY_FLCTL. The busy flags are automatically reset to 0 when the update completes.

If play_clk is significantly slower than pclk, it is recommended to poll the busy flag in the PLAY_MSR prior to writing to the corresponding register, to be sure that it has reset to 0 indicating that the previous update has completed.

Alternatively, software can enable the write complete interrupts in the PLAY_IER register to generate an interrupt request when a pending write completes (see *Section 24.5*).

24.4 PLAY in low-power modes

The play_clk can be maintained when the system is in low-power mode (Stop mode). The full functionality of the logic array is available, but the memory-mapped registers are not accessible and the flags are not updated.

When the play_clk is stopped, the logic element output registers do not operate, neither does the edge detection and filtering. However combinatorial logic continues to function as programmed.

If a logic element direct output is mapped to an asynchronous wake-up event, a transition on the output can wake the system from Stop mode. It is recommended to configure one of the software programmable inputs to reset the output so that software can deassert the wake-up event, if it is not otherwise deasserted.

In Standby mode, the PLAY is powered down and no longer functional. It must be reconfigured on exit from Standby.

24.5 PLAY interrupts

There is one interrupt request, play_irq, which can be configured to interrupt the processor when any of the following conditions occurs:

1. One or more of the flags are set, as indicated by the PLAY_FLSTAT register
2. An outstanding write to the PLAY_FLCTL register has completed, as indicated by the FLCTLWBFS bit in the PLAY_MSR register.
3. An outstanding write to the PLAY_SWIN register has completed, as indicated by the SWINWBFS bit in the PLAY_MSR register.

An interrupt handler must first read the PLAY interrupt status register (PLAY_ISR) to determine the source of the interrupt.

If the FLCTL write complete (FLCTLWC) or SWIN write complete (SWINWC) bits are set, it means that a previous write respectively to the PLAY_FLCTL or PLAY_SWIN register has completed. The write complete status bits can be cleared by writing a one to the corresponding bit in the interrupt clear (PLAY_ICR) register. The write complete interrupts are enabled and disabled by writing to the PLAY_IER register.

If the PLAY_ISR.FLAGS bit is set, the interrupt handler must read the PLAY_FLSTAT register to determine which flag(s) caused the interrupt. The FLAGS bit is reset by hardware when all the flags are inactive or masked. See *Section 24.3.10* for more details.

24.6 PLAY registers

There are three types of PLAY registers:

- Access control registers:

  PLAY_SECCFGR

  PLAY_PRIVCFGR

  These registers control software access rights to the PLAY registers.
- Configuration registers: PLAY_CFGCR, PLAY_FILTxCFGR, PLAY_LExCFG1, PLAY_LExCFG2, PLAY_OUTxCFG

  These registers configure the logic elements, input and output interconnects, input multiplexers and filters.
- Functional registers: PLAY_SWIN, PLAY_SWINSET, PLAY_SWINCLR, PLAY_OSR, PLAY_FLSTAT, PLAY_FLSET, PLAY_FLCLR, PLAY_FLIER, PLAY_FLCTL, PLAY_MSR, PLAY_ISR, PLAY_IER, PLAY_ICR

  These registers are used by the application software to interact with the logic array during operation.

24.6.1 PLAY configuration control register (PLAY_CFGCR)

Address offset: 0x000

Reset value: 0x0000 0001

This register contains miscellaneous configuration bits. It is a configuration register and is reset by play_rstn.

If PLAY_SECCFGR.SEC[0] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[0] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UNLOCK
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **UNLOCK**: Unlock configuration

When configuration is complete, it must be set to 0 to prevent accidental corruption of the configuration registers and enable operation of the logic element registers.

0: Configuration is locked. All configuration registers are write protected.

1: Configuration is unlocked. Configuration registers can be programmed.

24.6.2 PLAY security attributes configuration register (PLAY_SECCFGR)

Address offset: 0x004

Reset value: 0x0000 0000

This register controls the security attributes of the PLAY registers. It is an access control register and is reset by play_rstn.

The register can only be modified by a secure, privileged write access. It can be read by any access. A nonsecure write access is ignored. An unprivileged write access is ignored.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEC[1:0]	
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bits 1:0 **SEC**[1:0]: Secure access control

0: All registers are accessible in nonsecure or secure state

1: Configuration registers can only be accessed in secure state. All other registers can be accessed in secure or nonsecure state.

2: Reserved

3: All registers are accessible in secure state only.

24.6.3 PLAY privilege attributes configuration register (PLAY_PRIVCFGR)

Address offset: 0x008

Reset value: 0x0000 0000

This register controls the privilege attributes of the PLAY registers. It is an access control register and is reset by play_rstn. It can only be modified by a privileged write access. It can be read by any access.

If PLAY_SECFGR.SEC[n] = 1, PLAY_PRIVCFG.PRIV[n] can only be modified by a secure write access. A nonsecure write access to PLAY_PRIVCFG.PRIV[n] is ignored.

If PLAY_SECCFGR.SEC[n] = 0, PLAY_PRIVCFG.PRIV[n] can be modified by secure or nonsecure write access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV[1:0]	
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bits 1:0 **PRIV**[1:0]: Privilege access control

0: All registers are accessible in unprivileged or privileged state

1: Configuration registers can only be accessed in privileged state. All other registers can be accessed in privileged or unprivileged state.

2: Reserved

3: All registers are accessible in privileged state only.

24.6.4 PLAY filter x configuration register (PLAY_FILTxCFG)

Address offset: 0x020 + 0x04 * x, (x = 0 to 15)

Reset value: 0x0000 0000

This register configures the filter, edge detector and premultiplexer for logic array input x. It is a configuration register and is reset by play_rstn. Write accesses to this register are ignored if PLAY_CFGCR.UNLOCK = 0.

If PLAY_SECCFGR.SEC[0] = 1, the register requires secure access (nonsecure accesses are ignored, and signaled on play_sec_ilac).

If PLAY_PRIVCFGR.PRIV[0] = 1, the register requires privileged access (unprivileged accesses are ignored, and signaled on play_priv_ilac).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREMUXSEL[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	EDGEDET[1:0]		WIDTH[7:0]							
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **PREMUXSEL[2:0]**: Input pre-multiplexer select

Selects the signal to be connected to the input. See *Table 195* for details.

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **EDGEDET[1:0]**: Edge detection mode.

0: Edge detection is bypassed

1: A rising edge transition on the input is converted into a positive pulse of 1 play_clk cycle.

2: A falling edge transition on the input is converted into a positive pulse of 1 play_clk cycle.

3: A rising or falling edge transition on the input is converted into a positive pulse of 1 play_clk cycle.

Bits 7:0 **WIDTH[7:0]**: Minimum pulse width

0: Filter is bypassed.

1 to 255: Minimum pulse width, in play_clk cycles. Any pulse on the input shorter than this is ignored.

24.6.5 PLAY logic element x configuration register 1 (PLAY_LExCFG1)

Address offset: 0x060 + 0x04 * x, (x = 0 to 15)

Reset value: 0x0000 0000

This register configures the look-up table contents for logic element x. It is a configuration register and is reset by play_rstn. Write accesses to this register are ignored if PLAY_CFGCR.UNLOCK = 0.

If PLAY_SECCFGR.SEC[0] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[0] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LUT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **LUT[15:0]**: Look-up table contents.
Truth table output for the logic element.

24.6.6 PLAY logic element x configuration register 2 (PLAY_LExCFG2)

Address offset: 0x0A0 + 0x04 * x, (x = 0 to 15)

Reset value: 0x00FF FFFF

This register configures the input source and the register clock source for logic element x. It is a configuration register and is reset by play_rstn. Write accesses to this register are ignored if PLAY_CFGCR.UNLOCK = 0.

If PLAY_SECCFGR.SEC[0] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[0] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	CK_SEL[5:0]						IN3_SEL[5:0]						IN2_SEL[5:4]	
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IN2_SEL[3:0]				IN1_SEL[5:0]						IN0_SEL[5:0]					
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:24 **CK_SEL[5:0]**: Clock enable selection
Selects source to be used as the clock enable for the logic element register. See *Table 200* for details.
After reset, this bit field is set to 0x0 (disabled)

Bits 23:18 **IN3_SEL[5:0]**: Logic element input 3 selection
Selects source for LUT input 3. See *Table 199* for details.
After reset, this bit field is set to 0x1F: PLAY_SWIN[15]

Bits 17:12 **IN2_SEL[5:0]**: Logic element input 2 selection
Selects source for LUT input 2. See *Table 199* for details.
After reset, this bit field is set to 0x1F: PLAY_SWIN[15]

Bits 11:6 **IN1_SEL[5:0]**: Logic element input 1 selection
Selects source for LUT input 1. See *Table 199* for details.
After reset, this bit field is set to 0x1F: PLAY_SWIN[15]

Bits 5:0 **IN0_SEL[5:0]**: Logic element input 0 selection
Selects source for LUT input 0. See *Table 199* for details.
After reset, this bit field is set to 0x1F: PLAY_SWIN[15]

24.6.7 PLAY output x configuration register (PLAY_OUTxCFG)

Address offset: 0x100 + 0x04 * x, (x = 0 to 15)

Reset value: 0x0000 0000

This register selects the source for play_out[x]. It is a configuration register and is reset by play_rstn. Write accesses to this register are ignored if PLAY_CFGCR.UNLOCK = 0.

If PLAY_SECCFGR.SEC[0] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[0] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEL[4:0]				
											rw	rw	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bits 4:0 **SEL[4:0]**: Output source selection.
The value of this field selects which LE output is connected to the output. See *Table 201* for details.

24.6.8 PLAY software input status register (PLAY_SWIN)

Address offset: 0x200

Reset value: 0x0000 0000

This register is used to read and write the state of the software programmable inputs. It is a functional register and is reset by play_rstn and play_app_rstn.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored, and signaled on play_sec_ilac).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

Caution: play_clk must be active when writing to this register. Any subsequent write access to this register (or PLAY_SWINSET or PLAY_SWINCLR) is ignored until the write completes. Software must poll the PLAY_SWIN write busy flag in the *PLAY miscellaneous status register (PLAY_MSR)* to make sure that no writes are pending. If play_clk is slow compared to the bus clock, pclk, a write may take a long time to complete. In this case, the PLAY_SWIN register write complete interrupt - see *PLAY interrupt status register (PLAY_ISR)* - can be used to signal to the software when the registers can be accessed again.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SWIN15	SWIN14	SWIN13	SWIN12	SWIN11	SWIN10	SWIN9	SWIN8	SWIN7	SWIN6	SWIN5	SWIN4	SWIN3	SWIN2	SWIN1	SWIN0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **SWINy**: Input swiny state (y = 15 to 0)
0: Input low
1: Input high

24.6.9 PLAY software input set register (PLAY_SWINSET)

Address offset: 0x204

Reset value: 0x0000 0000

This register is used to set the state of the software programmable inputs. It is a functional register and is reset automatically by hardware.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

Caution: play_clk must be active when writing to this register. Any subsequent write access to this register (or PLAY_SWIN or PLAY_SWINCLR) is ignored until the write completes. Software must poll the PLAY_SWIN write busy flag in the *PLAY miscellaneous status register (PLAY_MSR)* to make sure that no writes are pending. If play_clk is slow compared to the

bus clock, pclk, a write may take a long time to complete. In this case, the PLAY_SWIN register write complete interrupt - see *PLAY interrupt status register (PLAY_ISR)* - can be used to signal to the software when the register can be accessed again.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SWIN15	SWIN14	SWIN13	SWIN12	SWIN11	SWIN10	SWIN9	SWIN8	SWIN7	SWIN6	SWIN5	SWIN4	SWIN3	SWIN2	SWIN1	SWIN0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **SWINy**: Set PLAY_SWIN.SWINy (y = 15 to 0)
0: Input low
1: Input high

24.6.10 PLAY software input clear register (PLAY_SWINCLR)

Address offset: 0x208

Reset value: 0x0000 0000

This register is used to reset the state of the software programmable inputs. It is a functional register and is reset automatically by hardware.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

Caution: play_clk must be active when writing to this register. Any subsequent write access to this register (or PLAY_SWIN or PLAY_SWINSET) is ignored until the write completes. Software must poll the PLAY_SWIN write busy flag in the *PLAY miscellaneous status register (PLAY_MSR)* to make sure that no writes are pending. If play_clk is slow compared to the bus clock, pclk, a write may take a long time to complete. In this case, the PLAY_SWIN register write complete interrupt - see *PLAY interrupt status register (PLAY_ISR)* - can be used to signal to the software when the registers can be accessed again.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SWIN15	SWIN14	SWIN13	SWIN12	SWIN11	SWIN10	SWIN9	SWIN8	SWIN7	SWIN6	SWIN5	SWIN4	SWIN3	SWIN2	SWIN1	SWIN0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **SWINy**: Reset PLAY_SWIN.SWINy (y = 15 to 0)
0: Input low
1: Input high

24.6.11 PLAY output status register (PLAY_OSR)

Address offset: 0x210

Reset value: 0x0000 0000

This register allows software to read the state of the LE direct and registered outputs. It is a functional register and is reset by play_rstn and play_app_rstn.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LEOUTR15	LEOUTR14	LEOUTR13	LEOUTR12	LEOUTR11	LEOUTR10	LEOUTR9	LEOUTR8	LEOUTR7	LEOUTR6	LEOUTR5	LEOUTR4	LEOUTR3	LEOUTR2	LEOUTR1	LEOUTR0
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LEOUTD15	LEOUTD14	LEOUTD13	LEOUTD12	LEOUTD11	LEOUTD10	LEOUTD9	LEOUTD8	LEOUTD7	LEOUTD6	LEOUTD5	LEOUTD4	LEOUTD3	LEOUTD2	LEOUTD1	LEOUTD0
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **LEOUTRy**: State of LE registered output leoutry (y = 15 to 0)

Bits 15:0 **LEOUTDy**: State of LE direct outputs leoutdy (y = 15 to 0)

24.6.12 PLAY flag status register (PLAY_FLSTAT)

Address offset: 0x220

Reset value: 0x0000 0000

This register allows software to read the state of the LE output flags. It is a functional register and is reset by play_rstn and play_app_rstn.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FLAGR15	FLAGR14	FLAGR13	FLAGR12	FLAGR11	FLAGR10	FLAGR9	FLAGR8	FLAGR7	FLAGR6	FLAGR5	FLAGR4	FLAGR3	FLAGR2	FLAGR1	FLAGR0
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLAGD15	FLAGD14	FLAGD13	FLAGD12	FLAGD11	FLAGD10	FLAGD9	FLAGD8	FLAGD7	FLAGD6	FLAGD5	FLAGD4	FLAGD3	FLAGD2	FLAGD1	FLAGD0
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **FLAGRy**: Flag state for LEy registered output (y = 15 to 0)

0: Flag reset

1: Flag set

Bits 15:0 **FLAGDy**: Flag state for LEy direct output (y = 15 to 0)
0: Flag reset
1: Flag set

24.6.13 PLAY flag set register (PLAY_FLSET)

Address offset: 0x224

Reset value: 0x0000 0000

This register allows software to set the LE output flags. It is a functional register and is reset automatically by hardware.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FLAGR_SET15	FLAGR_SET14	FLAGR_SET13	FLAGR_SET12	FLAGR_SET11	FLAGR_SET10	FLAGR_SET9	FLAGR_SET8	FLAGR_SET7	FLAGR_SET6	FLAGR_SET5	FLAGR_SET4	FLAGR_SET3	FLAGR_SET2	FLAGR_SET1	FLAGR_SET0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLAGD_SET15	FLAGD_SET14	FLAGD_SET13	FLAGD_SET12	FLAGD_SET11	FLAGD_SET10	FLAGD_SET9	FLAGD_SET8	FLAGD_SET7	FLAGD_SET6	FLAGD_SET5	FLAGD_SET4	FLAGD_SET3	FLAGD_SET2	FLAGD_SET1	FLAGD_SET0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 **FLAGR_SETy**: Flag set for LEy registered output (y = 15 to 0)
0: No effect
1: Set flag

Bits 15:0 **FLAGD_SETy**: Flag set for LEy direct output (y = 15 to 0)
0: No effect
1: Set flag

24.6.14 PLAY flag clear register (PLAY_FLCLR)

Address offset: 0x228

Reset value: 0x0000 0000

This register allows software to clear the state of the LE output flags. It is a functional register and is reset automatically by hardware.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FLAGR_CLR15	FLAGR_CLR14	FLAGR_CLR13	FLAGR_CLR12	FLAGR_CLR11	FLAGR_CLR10	FLAGR_CLR9	FLAGR_CLR8	FLAGR_CLR7	FLAGR_CLR6	FLAGR_CLR5	FLAGR_CLR4	FLAGR_CLR3	FLAGR_CLR2	FLAGR_CLR1	FLAGR_CLR0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLAGD_CLR15	FLAGD_CLR14	FLAGD_CLR13	FLAGD_CLR12	FLAGD_CLR11	FLAGD_CLR10	FLAGD_CLR9	FLAGD_CLR8	FLAGD_CLR7	FLAGD_CLR6	FLAGD_CLR5	FLAGD_CLR4	FLAGD_CLR3	FLAGD_CLR2	FLAGD_CLR1	FLAGD_CLR0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 **FLAGR_CLRy**: Flag clear for LEy registered output (y = 15 to 0)
0: No effect
1: Clear flag

Bits 15:0 **FLAGD_CLRy**: Flag clear for LEy direct output (y = 15 to 0)
0: No effect
1: Clear flag

24.6.15 PLAY flag interrupt enable register (PLAY_FLIER)

Address offset: 0x22C

Reset value: 0x0000 0000

This register enables interrupt requests based on LE output flag state. It is a functional register and is reset by play_rstn and play_app_rstn.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FLAGR_IEN15	FLAGR_IEN14	FLAGR_IEN13	FLAGR_IEN12	FLAGR_IEN11	FLAGR_IEN10	FLAGR_IEN9	FLAGR_IEN8	FLAGR_IEN7	FLAGR_IEN6	FLAGR_IEN5	FLAGR_IEN4	FLAGR_IEN3	FLAGR_IEN2	FLAGR_IEN1	FLAGR_IEN0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLAGD_IEN15	FLAGD_IEN14	FLAGD_IEN13	FLAGD_IEN12	FLAGD_IEN11	FLAGD_IEN10	FLAGD_IEN9	FLAGD_IEN8	FLAGD_IEN7	FLAGD_IEN6	FLAGD_IEN5	FLAGD_IEN4	FLAGD_IEN3	FLAGD_IEN2	FLAGD_IEN1	FLAGD_IEN0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **FLAGR_IENy**: Flag interrupt enable for LEy registered output (y = 15 to 0)
0: No interrupt is generated on play_irq
1: An interrupt is generated on play_irq if PLAY_FLSTAT.FLAGRy = 1

Bits 15:0 **FLAGD_IENy**: Flag interrupt enable for LEy direct output (y = 15 to 0)
0: No interrupt is generated on play_irq
1: An interrupt is generated on play_irq if PLAY_FLSTAT.FLAGDy = 1

24.6.16 PLAY flag control register (PLAY_FLCTL)

Address offset: 0x230

Reset value: 0x0000 0000

This register selects the direction of signal transition to set the corresponding LE output flag. It is a functional register and is reset by play_rstn and play_app_rstn.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

Caution: play_clk must be active when writing to this register. Any subsequent write access to this register is ignored until the write completes. Software must poll the PLAY_FLCTL write busy flag in the *PLAY miscellaneous status register (PLAY_MSR)* to make sure that no writes are pending. If play_clk is slow compared to the bus clock, pclk, a write may take a long time to complete. In this case, the PLAY_FLCTL register write complete interrupt - see *PLAY interrupt status register (PLAY_ISR)* - can be used to signal to the software when the register can be accessed again.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FLAGR_EDGE15	FLAGR_EDGE14	FLAGR_EDGE13	FLAGR_EDGE12	FLAGR_EDGE11	FLAGR_EDGE10	FLAGR_EDGE9	FLAGR_EDGE8	FLAGR_EDGE7	FLAGR_EDGE6	FLAGR_EDGE5	FLAGR_EDGE4	FLAGR_EDGE3	FLAGR_EDGE2	FLAGR_EDGE1	FLAGR_EDGE0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLAGD_EDGE15	FLAGD_EDGE14	FLAGD_EDGE13	FLAGD_EDGE12	FLAGD_EDGE11	FLAGD_EDGE10	FLAGD_EDGE9	FLAGD_EDGE8	FLAGD_EDGE7	FLAGD_EDGE6	FLAGD_EDGE5	FLAGD_EDGE4	FLAGD_EDGE3	FLAGD_EDGE2	FLAGD_EDGE1	FLAGD_EDGE0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **FLAGR_EDGEy**: Edge direction for LEy registered output (y = 15 to 0)
0: FLAGRy is set by a falling edge on leoutry
1: FLAGRy is set by a rising edge on leoutry

Bits 15:0 **FLAGD_EDGEy**: Edge direction for LEy direct output (y = 15 to 0)
0: FLAGDy is set by a falling edge on leoutdy
1: FLAGDy is set by a rising edge on leoutdy

24.6.17 PLAY miscellaneous status register (PLAY_MSR)

Address offset: 0x234

Reset value: 0x0000 0000

This register allows software to read the state of miscellaneous status flags (not including LE output flags). It is a functional register and is reset by play_rstn and play_app_rstn.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLCTL WBFS	SWIN WBFS
														r	r

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **FLCTLWBFS**: PLAY_FLCTL register write busy flag status
0: PLAY_FLCTL register can be written
1: Write is pending, any new write access to PLAY_FLCTL register is ignored

Bit 0 **SWINWBFS**: PLAY_SWIN register write busy flag status
0: PLAY_SWIN register can be written
1: Write is pending, any new write access to PLAY_SWIN, PLAY_SWINCLR or PLAY_SWINSET registers is ignored

24.6.18 PLAY interrupt status register (PLAY_ISR)

Address offset: 0x238

Reset value: 0x0000 0000

This register allows software to read the state of the interrupt request sources. The PLAY_ISR register must be read first of all when the play_irq is asserted, to identify the source(s) of the interrupt request. It is a functional register and is reset by play_rstn and play_app_rstn.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLAGS	FLCTL WC	SWIN WC
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **FLAGS**: Flag interrupts status
0: No flag interrupts active
1: One or more bits in PLAY_FLSTAT register is active and has generated an interrupt request

Bit 1 **FLCTLWC**: PLAY_FLCTL register write complete interrupt status
0: Interrupt request is not pending
1: Interrupt request is pending

Bit 0 **SWINWC**: PLAY_SWIN register write complete interrupt status
0: Interrupt request is not pending
1: Interrupt request is pending

24.6.19 PLAY interrupt clear register (PLAY_ICR)

Address offset: 0x23C

Reset value: 0xXXXX XXXX

This register allows software to clear active interrupt requests, except for those generated by flags - see *Section 24.6.14: PLAY flag clear register (PLAY_FLCLR)*. It is a functional register.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLCTL WC_CLR	SWIN WC_CLR
														w	w

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **FLCTLWC_CLR**: PLAY_FLCTL register write complete interrupt clear
0: No action
1: Clear interrupt request

Bit 0 **SWINWC_CLR**: PLAY_SWIN register write complete interrupt clear
0: No action
1: Clear interrupt request

24.6.20 PLAY interrupt enable register (PLAY_IER)

Address offset: 0x240

Reset value: 0x0000 0000

This register allows software to enable or disable interrupt requests, except for those generated by flags - see *Section 24.6.15: PLAY flag interrupt enable register (PLAY_FLIER)*. It is a functional register and is reset by play_rstn and play_app_rstn.

If PLAY_SECCFGR.SEC[1] = 1, the register requires secure access (nonsecure accesses are ignored).

If PLAY_PRIVCFGR.PRIV[1] = 1, the register requires privileged access (unprivileged accesses are ignored).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLCTLWC_IEN	SWINWC_IEN
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **FLCTLWC_IEN**: PLAY_FLCTL register write complete interrupt enable
0: Interrupt disabled
1: Interrupt enabled. An interrupt is generated when a write to the PLAY_FCTL register completes

Bit 0 **SWINWC_IEN**: PLAY_SWIN register write complete interrupt enable
0: Interrupt disabled
1: Interrupt enabled. An interrupt is generated when a write to the PLAY_SWIN register completes

24.7 PLAY register map

Table 202. PLAY register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	PLAY_CFGCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UNLOCK
	Reset value																																1
0x004	Reserved	Res.																															

Table 202. PLAY register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x004	PLAY_SECCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEC[1:0]	
	Reset value																															0	0
0x008	Reserved	Res.																															
0x008	PLAY_PRIVCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV[1:0]	
	Reset value																															0	0
0x00C to 0x01C	Reserved	Res.																															
0x020 + 0x4 * x, (x=0 to 15) Last address: 0x05C	PLAY_FILTxCFG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREMUXSEL [2:0]			Res.	Res.	Res.	Res.	Res.	Res.	EDGEDET [1:0]		WIDTH [7:0]							
	Reset value														0	0	0							0	0	0	0	0	0	0	0	0	0
0x060 + 0x4 * x, (x=0 to 15) Last address: 0x09C	PLAY_LExCFG1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LUT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A0 + 0x4 * x, (x=0 to 15) Last address: 0x0DC	PLAY_LExCFG2	Res.	Res.	CK_SEL[4:0]						IN3_SEL[5:0]						IN2_SEL[5:0]						IN1_SEL[5:0]					IN0_SEL[5:0]						
	Reset value			0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0E0 - 0x0FC	Reserved	Res.																															
0x100 + 0x4 * x, (x=0 to 15) Last address: 0x13C	PLAY_OUTxCFG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEL[4:0]				
	Reset value																												0	0	0	0	0
0x140 - 0x1FC	Reserved	Res.																															
0x200	PLAY_SWIN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWIN15	SWIN14	SWIN13	SWIN12	SWIN11	SWIN10	SWIN9	SWIN8	SWIN7	SWIN6	SWIN5	SWIN4	SWIN3	SWIN2	SWIN1	SWIN0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x204	PLAY_SWINSET	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWIN15	SWIN14	SWIN13	SWIN12	SWIN11	SWIN10	SWIN9	SWIN8	SWIN7	SWIN6	SWIN5	SWIN4	SWIN3	SWIN2	SWIN1	SWIN0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x208	PLAY_SWINCLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWIN15	SWIN14	SWIN13	SWIN12	SWIN11	SWIN10	SWIN9	SWIN8	SWIN7	SWIN6	SWIN5	SWIN4	SWIN3	SWIN2	SWIN1	SWIN0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20C	Reserved	Res.																															
0x210	PLAY_OSR	LEOUTR15	LEOUTR14	LEOUTR13	LEOUTR12	LEOUTR11	LEOUTR10	LEOUTR9	LEOUTR8	LEOUTR7	LEOUTR6	LEOUTR5	LEOUTR4	LEOUTR3	LEOUTR2	LEOUTR1	LEOUTR0	LEOUTD15	LEOUTD14	LEOUTD13	LEOUTD12	LEOUTD11	LEOUTD10	LEOUTD9	LEOUTD8	LEOUTD7	LEOUTD6	LEOUTD5	LEOUTD4	LEOUTD3	LEOUTD2	LEOUTD1	LEOUTD0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x214 - 0x21C	Reserved	Res.																															

Table 202. PLAY register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x220	PLAY_FLSTAT	FLAGR15	FLAGR14	FLAGR13	FLAGR12	FLAGR11	FLAGR10	FLAGR9	FLAGR8	FLAGR7	FLAGR6	FLAGR5	FLAGR4	FLAGR3	FLAGR2	FLAGR1	FLAGR0	FLAGD15	FLAGD14	FLAGD13	FLAGD12	FLAGD11	FLAGD10	FLAGD9	FLAGD8	FLAGD7	FLAGD6	FLAGD5	FLAGD4	FLAGD3	FLAGD2	FLAGD1	FLAGD0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x224	PLAY_FLSET	FLAGR_SET15	FLAGR_SET14	FLAGR_SET13	FLAGR_SET12	FLAGR_SET11	FLAGR_SET10	FLAGR_SET9	FLAGR_SET8	FLAGR_SET7	FLAGR_SET6	FLAGR_SET5	FLAGR_SET4	FLAGR_SET3	FLAGR_SET2	FLAGR_SET1	FLAGR_SET0	FLAGD_SET15	FLAGD_SET14	FLAGD_SET13	FLAGD_SET12	FLAGD_SET11	FLAGD_SET10	FLAGD_SET9	FLAGD_SET8	FLAGD_SET7	FLAGD_SET6	FLAGD_SET5	FLAGD_SET4	FLAGD_SET3	FLAGD_SET2	FLAGD_SE1	FLAGD_SET0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x228	PLAY_FLCLR	FLAGR_CLR15	FLAGR_CLR14	FLAGR_CLR13	FLAGR_CLR12	FLAGR_CLR11	FLAGR_CLR10	FLAGR_CLR9	FLAGR_CLR8	FLAGR_CLR7	FLAGR_CLR6	FLAGR_CLR5	FLAGR_CLR4	FLAGR_CLR3	FLAGR_CLR2	FLAGR_CLR1	FLAGR_CLR0	FLAGD_CLR15	FLAGD_CLR14	FLAGD_CLR13	FLAGD_CLR12	FLAGD_CLR11	FLAGD_CLR10	FLAGD_CLR9	FLAGD_CLR8	FLAGD_CLR7	FLAGD_CLR6	FLAGD_CLR5	FLAGD_CLR4	FLAGD_CLR3	FLAGD_CLR2	FLAGD_CLR1	FLAGD_CLR0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x22C	PLAY_FLIER	FLAGR_IEN15	FLAGR_IE14	FLAGR_IEN13	FLAGR_IEN12	FLAGR_IEN11	FLAGR_IEN10	FLAGR_IEN9	FLAGR_IEN8	FLAGR_IEN7	FLAGR_IEN6	FLAGR_IEN5	FLAGR_IEN4	FLAGR_IEN3	FLAGR_IEN2	FLAGR_IEN1	FLAGR_IEN0	FLAGD_IEN15	FLAGD_IEN14	FLAGD_IEN13	FLAGD_IEN12	FLAGD_IEN11	FLAGD_IEN10	FLAGD_IEN9	FLAGD_IEN8	FLAGD_IEN7	FLAGD_IEN6	FLAGD_IEN5	FLAGD_IEN4	FLAGD_IEN3	FLAGD_IEN2	FLAGD_IEN1	FLAGD_IEN0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x230	PLAY_FLCTL	FLAGR_EDGE15	FLAGR_EDGE14	FLAGR_EDGE13	FLAGR_EDGE12	FLAGR_EDGE11	FLAGR_EDGE10	FLAGR_EDGE9	FLAGR_EDGE8	FLAGR_EDGE7	FLAGR_EDGE6	FLAGR_EDGE5	FLAGR_EDGE4	FLAGR_EDGE3	FLAGR_EDGE2	FLAGR_EDGE1	FLAGR_EDGE0	FLAGD_EDGE15	FLAGD_EDGE14	FLAGD_EDGE13	FLAGD_EDGE12	FLAGD_EDGE11	FLAGD_EDGE10	FLAGD_EDGE9	FLAGD_EDGE8	FLAGD_EDGE7	FLAGD_EDGE6	FLAGD_EDGE5	FLAGD_EDGE4	FLAGD_EDGE3	FLAGD_EDGE2	FLAGD_EDGE1	FLAGD_EDGE0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x234	PLAY_MSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLCTLWBFS	SWINWBFS
	Reset value																															0	0
0x238	PLAY_ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLAGS	FLCTLWC	SWINWC
	Reset value																														0	0	0
0x23C	PLAY_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLCTLWC_CLR	SWINWC_CLR
	Reset value																															X	X
0x240	PLAY_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLCTLWC_IEN	SWINWC_IEN
	Reset value																															0	0
0x244 - 0x3EC	Reserved	Res.																															

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

25 Flexible memory controller (FMC)

25.1 FMC introduction

The flexible memory controller (FMC) includes three memory controllers:

- The NOR/PSRAM memory controller
- The NAND memory controller
- The Synchronous DRAM (SDRAM/Mobile LPSDR SDRAM) controller

25.2 FMC main features

The FMC functional block makes the interface with: synchronous and asynchronous static memories, SDRAM memories, and NAND flash memory. Its main purposes are:

- to translate AHB transactions into the appropriate external device protocol
- to meet the access time requirements of the external memory devices

All external memories share the addresses, data and control signals with the controller. Each external device is accessed by means of a unique chip select. The FMC performs only one access at a time to an external device.

The main features of the FMC controller are the following:

- Interface with static-memory mapped devices including:
  - Static random access memory (SRAM)
  - NOR flash memory/OneNAND flash memory
  - PSRAM (4 memory banks)
  - Ferroelectric RAM (FRAM)
  - NAND flash memory with ECC hardware to check up to 8 Kbytes of data
- Interface with synchronous DRAM (SDRAM/Mobile LPSDR SDRAM) memories
- Interface with parallel LCD modules, supporting Intel 8080 and Motorola 6800 modes.
- Burst mode support for faster access to synchronous devices such as NOR flash memory, PSRAM and SDRAM)
- Programmable continuous clock output for asynchronous and synchronous accesses
- 8-,16- or 32-bit wide data bus
- Independent chip select control for each memory bank
- Independent configuration for each memory bank
- Write enable and byte lane select outputs for use with PSRAM, SRAM and SDRAM devices
- External asynchronous wait control
- Write FIFO with 16 x32-bit depth
- Cacheable Read FIFO with 6 x32-bit depth (6 x14-bit address tag) for SDRAM controller.

The Write FIFO is common to all memory controllers and consists of:

- a Write Data FIFO which stores the AHB data to be written to the memory (up to 32 bits) plus one bit for the AHB transfer (burst or not sequential mode)
- a Write Address FIFO which stores the AHB address (up to 28 bits) plus the AHB data size (up to 2 bits). When operating in burst mode, only the start address is stored except when crossing a page boundary (for PSRAM and SDRAM). In this case, the AHB burst is broken into two FIFO entries.

At startup the FMC pins must be configured by the user application. The FMC I/O pins which are not used by the application can be used for other purposes.

The FMC registers that define the external device type and associated characteristics are usually set at boot time and do not change until the next reset or power-up.

However, only a few bits can be changed on-the-fly:

- MBKEN, FMCEN, WEN bits in FMC_BCRx register
- ECCEN and PBKEN bits in the FMC_PCR register
- IFS, IRS and ILS bits in the FMC_SR register

Follow the below sequence to modify parameters while the FMC is enabled:

1. First disable the FMC controller to prevent further accesses to any memory controller while the register is modified.
2. Update all required configurations.
3. Enable the FMC controller again.

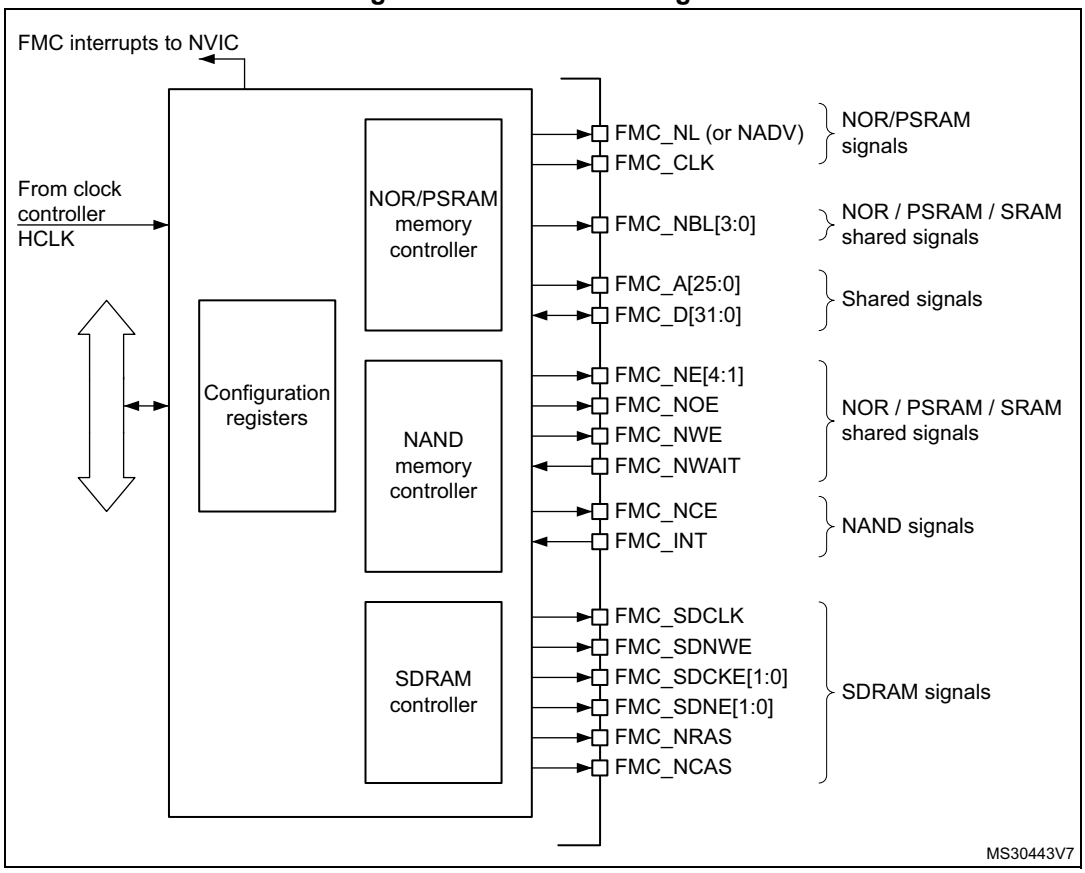
25.3 FMC block diagram

The FMC consists of the following main blocks:

- The AHB interface (including the FMC configuration registers)
- The NOR flash/PSRAM/SRAM controller
- The SDRAM controller

The block diagram is shown in the figure below.

Figure 150. FMC block diagram



25.4 AHB interface

The AHB slave interface allows internal CPUs and other bus master peripherals to access the external memories.

AHB transactions are translated into the external device protocol. In particular, if the selected external memory is 16- or 8-bit wide, 32-bit wide transactions on the AHB are split into consecutive 16- or 8-bit accesses. The FMC chip select (FMC_NEx) does not toggle between the consecutive accesses except in case of Access mode D when the Extended mode is enabled.

The FMC generates an AHB error in the following conditions:

- When reading or writing to a FMC bank (Bank 1 to 4) which is not enabled.
- When reading or writing to the NOR flash bank while the FACCEN bit is reset in the FMC_BCRx register.
- When writing to a write protected SDRAM bank (WP bit set in the SDRAM_SDCRx register).
- When the SDRAM address range is violated (access to reserved address range)

The effect of an AHB error depends on the AHB master which has attempted the R/W access:

- If the access has been attempted by the Cortex®-M33 CPU, a hard fault interrupt is generated.
- If the access has been performed by a DMA controller, a DMA transfer error is generated and the corresponding DMA channel is automatically disabled.

The AHB clock (HCLK) is the reference clock for the FMC.

25.4.1 Supported memories and transactions

General transaction rules

The requested AHB transaction data size can be 8-, 16- or 32-bit wide whereas the accessed external device has a fixed data width. This may lead to inconsistent transfers.

Therefore, some simple transaction rules must be followed:

- AHB transaction size and memory data size are equal

  There is no issue in this case.
- AHB transaction size is greater than the memory size:

  In this case, the FMC splits the AHB transaction into smaller consecutive memory accesses to meet the external data width. The FMC chip select (FMC_NEx) does not toggle between the consecutive accesses. If the bus turnaround timings is configured to any other value than 0, the FMC chip select (FMC_NEx) toggles between the consecutive accesses. This feature is required when interfacing with FRAM memory.
- AHB transaction size is smaller than the memory size:

  The transfer may or not be consistent depending on the type of external device:
  - Accesses to devices that have the byte select feature (SRAM, ROM, PSRAM, SDRAM)

    In this case, the FMC allows read/write transactions and accesses to the right data through its byte lanes NBL[3:0].

    Bytes to be written are addressed by NBL[3:0].

    All memory bytes are read (NBL[3:0] are driven low during read transaction) and the useless ones are discarded.
  - Accesses to devices that do not have the byte select feature (NOR and NAND flash memories)

    This situation occurs when a byte access is requested to a 16-bit wide flash memory. Since the device cannot be accessed in Byte mode (only 16-bit words can be read/written from/to the flash memory), Write transactions and Read transactions are allowed (the controller reads the entire 16-bit memory word and uses only the required byte).

Wrap support for NOR flash/PSRAM and SDRAM

Wrap burst mode for synchronous memories is not supported. The memories must be configured in Linear burst mode of undefined length.

Configuration registers

The FMC can be configured through a set of registers. Refer to *Section 25.6.6*, for a detailed description of the NOR flash/PSRAM controller registers. Refer to *Section 25.7.7*,

for a detailed description of the NAND flash registers and to *Section 25.8.5* for a detailed description of the SDRAM controller registers.

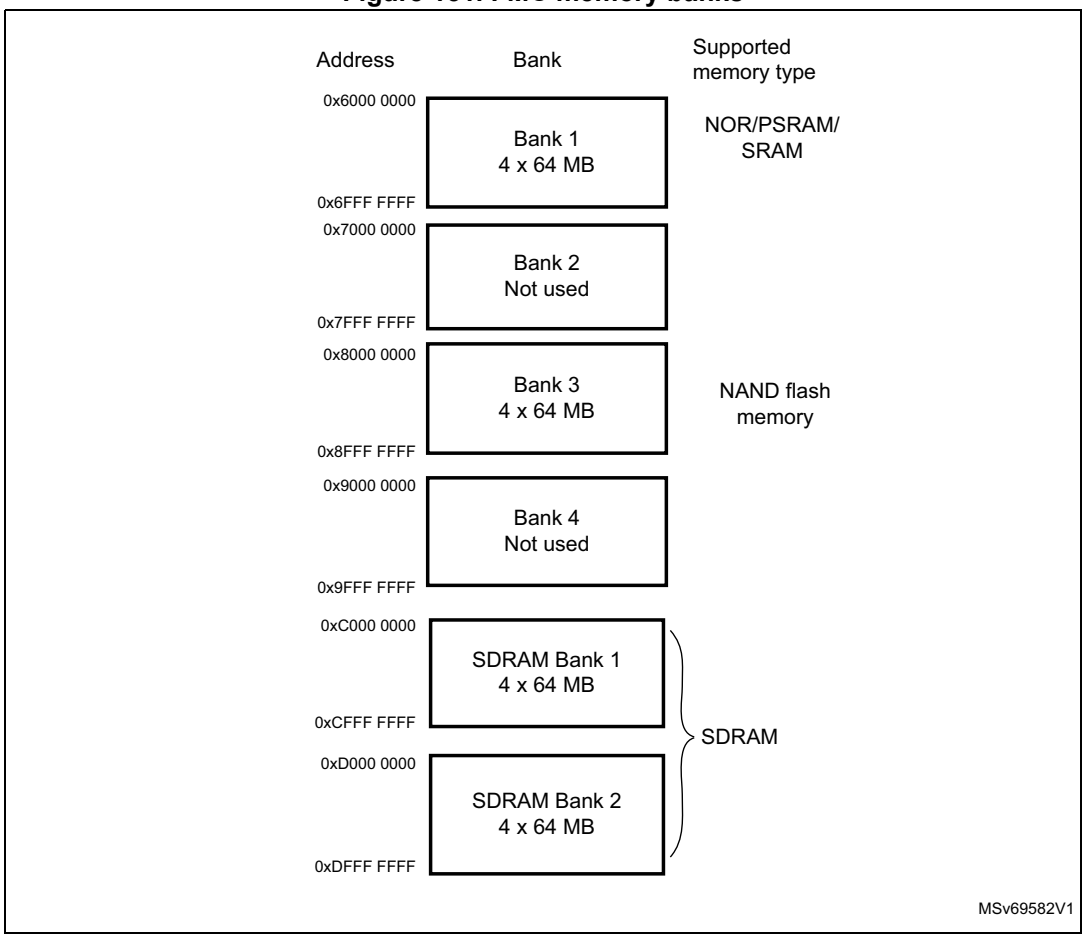
25.5 External device address mapping

From the FMC point of view, the external memory is divided into fixed-size banks of 256 Mbytes each (see *Figure 151*):

- Bank 1 used to address up to 4 NOR flash memory or PSRAM devices. This bank is split into 4 NOR/PSRAM subbanks with 4 dedicated chip selects, as follows:
  - Bank 1 - NOR/PSRAM 1
  - Bank 1 - NOR/PSRAM 2
  - Bank 1 - NOR/PSRAM 3
  - Bank 1 - NOR/PSRAM 4
- Bank 3 used to address NAND flash memory devices.The MPU memory attribute for this space must be reconfigured by software to Device.
- Bank 4 and 5 used to address SDRAM devices (1 device per bank).

For each bank the type of memory to be used can be configured by the user application through the Configuration register.

Figure 151. FMC memory banks



25.5.1 NOR/PSRAM address mapping

HADDR[27:26] bits are used to select one of the four memory banks as shown in *Table 203*.

Table 203. NOR/PSRAM bank selection

HADDR[27:26](1)	Selected bank
00	Bank 1 - NOR/PSRAM 1
01	Bank 1 - NOR/PSRAM 2
10	Bank 1 - NOR/PSRAM 3
11	Bank 1 - NOR/PSRAM 4

1. HADDR are internal AHB address lines that are translated to external memory.

The HADDR[25:0] bits contain the external memory address. Since HADDR is a byte address whereas the memory is addressed at word level, the address actually issued to the memory varies according to the memory data width, as shown in the following table.

Table 204. NOR/PSRAM External memory address

Memory width(1)	Data address issued to the memory	Maximum memory capacity (bits)
8-bit	HADDR[25:0]	64 Mbytes x 8 = 512 Mbits
16-bit	HADDR[25:1] >> 1	64 Mbytes/2 x 16 = 512 Mbits
32-bit	HADDR[25:2] >> 2	64 Mbytes/4 x 32 = 512 Mbits

1. In case of a 16-bit external memory width, the FMC internally uses HADDR[25:1] to generate the address for external memory FMC_A[24:0]. In case of a 32-bit memory width, the FMC internally uses HADDR[25:2] to generate the external address.
Whatever the external memory width, FMC_A[0] must be connected to external memory address A[0].

25.5.2 NAND flash memory address mapping

The NAND bank is divided into memory areas as indicated in *Table 205*.

Table 205. NAND memory mapping and timing registers

Start address	End address	FMC bank	Memory space	Timing register
0x8800 0000	0x8BFF FFFF	Bank 3 - NAND flash	Attribute	FMC_PATT (0x8C)
0x8000 0000	0x83FF FFFF		Common	FMC_PMEM (0x88)

For NAND flash memory, the common and attribute memory spaces are subdivided into three sections (see in *Table 206* below) located in the lower 256 Kbytes:

- Data section (first 64 Kbytes in the common/attribute memory space)
- Command section (second 64 Kbytes in the common / attribute memory space)
- Address section (next 128 Kbytes in the common / attribute memory space)

Table 206. NAND bank selection

Section name	HADDR[17:16]	Address range
Address section	1X	0x020000-0x03FFFF
Command section	01	0x010000-0x01FFFF
Data section	00	0x000000-0x0FFFF

The application software uses the 3 sections to access the NAND flash memory:

- **To sending a command to NAND flash memory**, the software must write the command value to any memory location in the command section.
- **To specify the NAND flash address that must be read or written**, the software must write the address value to any memory location in the address section. Since an address can be 4 or 5 bytes long (depending on the actual memory size), several consecutive write operations to the address section are required to specify the full address.
- **To read or write data,** the software reads or writes the data from/to any memory location in the data section.

Since the NAND flash memory automatically increments addresses, there is no need to increment the address of the data section to access consecutive memory locations.

25.5.3 SDRAM address mapping

The HADDR[28] bit (internal AHB address line 28) is used to select one of the two memory banks as indicated in *Table 207*.

Table 207. SDRAM bank selection

HADDR[28]	Selected bank	Control register	Timing register
0	SDRAM Bank1	FMC_SDCR1	FMC_SDTR1
1	SDRAM Bank2	FMC_SDCR2	FMC_SDTR2

The following table shows SDRAM mapping for a 13-bit row, a 11-bit column and a 4 internal bank configuration.

Table 208. SDRAM address mapping

Memory width(1)	Internal bank	Row address	Column address(2)	Maximum memory capacity (Mbytes)
8-bit	HADDR[25:24]	HADDR[23:11]	HADDR[10:0]	64 Mbytes: 4 x 8K x 2K
16-bit	HADDR[26:25]	HADDR[24:12]	HADDR[11:1]	128 Mbytes: 4 x 8K x 2K x 2
32-bit	HADDR[27:26]	HADDR[25:13]	HADDR[12:2]	256 Mbytes: 4 x 8K x 2K x 4

1. When interfacing with a 16-bit memory, the FMC internally uses the HADDR[11:1] internal AHB address lines to generate the external address. Whatever the memory width, FMC_A[0] has to be connected to the external memory address A[0].

2. The AutoPrecharge is not supported. FMC_A[10] must be connected to the external memory address A[10] but it is always driven low.

The HADDR[27:0] bits are translated to external SDRAM address depending on the SDRAM controller configuration:

- Data size:8, 16 or 32 bits
- Row size:11, 12 or 13 bits
- Column size: 8, 9, 10 or 11 bits
- Number of internal banks: two or four internal banks

The following tables show the SDRAM address mapping versus the SDRAM controller configuration.

Table 209. SDRAM address mapping with 8-bit data bus width(1)(2)

Row size configuration	HADDR(AHB Internal Address Lines)																										
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
11-bit row size configuration	Res.							Bank [1:0]		Row[10:0]											Column[7:0]							
	Res.							Bank [1:0]		Row[10:0]											Column[8:0]							
	Res.							Bank [1:0]		Row[10:0]											Column[9:0]							
	Res.							Bank [1:0]		Row[10:0]											Column[10:0]							
12-bit row size configuration	Res.							Bank [1:0]		Row[11:0]											Column[7:0]							
	Res.							Bank [1:0]		Row[11:0]											Column[8:0]							
	Res.							Bank [1:0]		Row[11:0]											Column[9:0]							
	Res.							Bank [1:0]		Row[11:0]											Column[10:0]							
13-bit row size configuration	Res.							Bank [1:0]		Row[12:0]											Column[7:0]							
	Res.							Bank [1:0]		Row[12:0]											Column[8:0]							
	Res.							Bank [1:0]		Row[12:0]											Column[9:0]							
	Res.							Bank [1:0]		Row[12:0]											Column[10:0]							

1. BANK[1:0] are the Bank Address BA[1:0]. When only 2 internal banks are used, BA1 must always be set to ‘0’.
2. Access to Reserved (Res.) address range generates an AHB error.

Table 210. SDRAM address mapping with 16-bit data bus width(1)(2)

Row size Configuration	HADDR(AHB address Lines)																										
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
11-bit row size configuration	Res.						Bank [1:0]		Row[10:0]											Column[7:0]								BM0(3)
	Res.						Bank [1:0]		Row[10:0]											Column[8:0]								BM0
	Res.						Bank [1:0]		Row[10:0]											Column[9:0]								BM0
	Res.						Bank [1:0]		Row[10:0]											Column[10:0]								BM0
12-bit row size configuration	Res.						Bank [1:0]		Row[11:0]											Column[7:0]								BM0
	Res.						Bank [1:0]		Row[11:0]											Column[8:0]								BM0
	Res.						Bank [1:0]		Row[11:0]											Column[9:0]								BM0
	Res.						Bank [1:0]		Row[11:0]											Column[10:0]								BM0
13-bit row size configuration	Res.						Bank [1:0]		Row[12:0]											Column[7:0]								BM0
	Res.						Bank [1:0]		Row[12:0]											Column[8:0]								BM0
	Res.						Bank [1:0]		Row[12:0]											Column[9:0]								BM0
	Res.						Bank [1:0]		Row[12:0]											Column[10:0]								BM0

1. BANK[1:0] are the Bank Address BA[1:0]. When only 2 internal banks are used, BA1 must always be set to ‘0’.
2. Access to Reserved space (Res.) generates an AHB error.
3. BM0: is the byte mask for 16-bit access.

Table 211. SDRAM address mapping with 32-bit data bus width(1)(2)

Row size configuration	HADDR(AHB address Lines)																										
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
11-bit row size configuration	Res.					Bank [1:0]		Row[10:0]											Column[7:0]								BM[1:0](3)	
	Res.					Bank [1:0]		Row[10:0]											Column[8:0]								BM[1:0]	
	Res.					Bank [1:0]		Row[10:0]											Column[9:0]								BM[1:0]	
	Res.					Bank [1:0]		Row[10:0]											Column[10:0]								BM[1:0]	

Table 211. SDRAM address mapping with 32-bit data bus width(1)(2) (continued)

Row size configuration	HADDR(AHB address Lines)																											
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
12-bit row size configuration	Res.				Bank [1:0]		Row[11:0]												Column[7:0]								BM[1:0]	
	Res.			Bank [1:0]			Row[11:0]												Column[8:0]								BM[1:0]	
	Res.		Bank [1:0]				Row[11:0]												Column[9:0]								BM[1:0]	
	Res.	Bank [1:0]					Row[11:0]												Column[10:0]								BM[1:0]	
13-bit row size configuration	Res.			Bank [1:0]			Row[12:0]												Column[7:0]								BM[1:0	
	Res.		Bank [1:0]				Row[12:0]												Column[8:0]								BM[1:0	
	Res.	Bank [1:0]					Row[12:0]												Column[9:0]								BM[1:0	
	Bank [1:0]						Row[12:0]												Column[10:0]								BM[1:0	

1. BANK[1:0] are the Bank Address BA[1:0]. When only 2 internal banks are used, BA1 must always be set to ‘0’.
2. Access to Reserved space (Res.) generates an AHB error.
3. BM[1:0]: is the byte mask for 32-bit access.

25.6 NOR flash/PSRAM controller

The FMC generates the appropriate signal timings to drive the following types of memories:

- Asynchronous SRAM, FRAM and ROM
  - 8 bits
  - 16 bits
  - 32 bits
- PSRAM (CellularRAM™)
  - Asynchronous mode
  - Burst mode for synchronous accesses
  - Multiplexed or non-multiplexed
- NOR flash memory
  - Asynchronous mode
  - Burst mode for synchronous accesses
  - Multiplexed or non-multiplexed

The FMC outputs a unique chip select signal, NE[4:1], per bank. All the other signals (addresses, data and control) are shared.

The FMC supports a wide range of devices through a programmable timings among which:

- Programmable wait states (up to 15)
- Programmable bus turnaround cycles (up to 15)
- Programmable output enable and write enable delays (up to 15)
- Independent read and write timings and protocol to support the widest variety of memories and timings
- Programmable continuous clock (FMC_CLK) output.

The FMC Clock (FMC_CLK) is a submultiple of the HCLK clock. It can be delivered to the selected external device either during synchronous accesses only or during asynchronous and synchronous accesses depending on the CCKEN bit configuration in the FMC_BCR1 register:

- If the CCLKEN bit is reset, the FMC generates the clock (CLK) only during synchronous accesses (Read/write transactions).
- If the CCLKEN bit is set, the FMC generates a continuous clock during asynchronous and synchronous accesses. To generate the FMC_CLK continuous clock, Bank 1 must be configured in Synchronous mode (see *Section 25.6.6: NOR/PSRAM controller registers*). Since the same clock is used for all synchronous memories, when a continuous output clock is generated and synchronous accesses are performed, the AHB data size has to be the same as the memory data width (MWID) otherwise the FMC_CLK frequency is changed depending on AHB data transaction (refer to *Section 25.6.5: Synchronous transactions* for FMC_CLK divider ratio formula).

The size of each bank is fixed and equal to 64 Mbytes. Each bank is configured through dedicated registers (see *Section 25.6.6: NOR/PSRAM controller registers*).

The programmable memory parameters include access times (see *Table 212*) and support for wait management (for PSRAM and NOR flash accessed in Burst mode).

Table 212. Programmable NOR/PSRAM access parameters

Parameter	Function	Access mode	Unit	Min.	Max.
Address setup	Duration of the address setup phase	Asynchronous	AHB clock cycle (HCLK)	0	15
Address hold	Duration of the address hold phase	Asynchronous, muxed I/Os	AHB clock cycle (HCLK)	1	15
NBL setup	Duration of the byte lanes setup phase	Asynchronous	AHB clock cycle (HCLK)	0	3
Data setup	Duration of the data setup phase	Asynchronous	AHB clock cycle (HCLK)	1	256
Data hold	Duration of the data hold phase	Asynchronous	AHB clock cycle (HCLK)	0	3
Bust turn	Duration of the bus turnaround phase	Asynchronous and synchronous read / write	AHB clock cycle (HCLK)	0	15

Table 212. Programmable NOR/PSRAM access parameters (continued)

Parameter	Function	Access mode	Unit	Min.	Max.
Clock divide ratio	Number of AHB clock cycles (HCLK) to build one memory clock cycle (CLK)	Synchronous	AHB clock cycle (HCLK)	2	16
Data latency	Number of clock cycles to issue to the memory before the first data of the burst	Synchronous	Memory clock cycle (CLK)	2	17

25.6.1 External memory interface signals

Table 213, *Table 214* and *Table 215* list the signals that are typically used to interface with NOR flash memory, SRAM and PSRAM.

Note: The prefix "N" identifies the signals that are active low.

NOR flash memory, non-multiplexed I/Os

Table 213. Non-multiplexed I/O NOR flash memory

FMC signal name	I/O	Function
CLK	O	Clock (for synchronous access)
A[25:0]	O	Address bus
D[31:0]	I/O	Bidirectional data bus
NE[x]	O	Chip select, x = 1..4
NOE	O	Output enable
NWE	O	Write enable
NL(=NADV)	O	Latch enable (this signal is called address valid, NADV, by some NOR flash devices)
NWAIT	I	NOR flash wait input signal to the FMC

The maximum capacity is 512 Mbits (26 address lines).

NOR flash memory, 16-bit multiplexed I/Os

Table 214. 16-bit multiplexed I/O NOR flash memory

FMC signal name	I/O	Function
CLK	O	Clock (for synchronous access)
A[25:16]	O	Address bus
AD[15:0]	I/O	16-bit multiplexed, bidirectional address/data bus (the 16-bit address A[15:0] and data D[15:0] are multiplexed on the databus)
NE[x]	O	Chip select, x = 1..4
NOE	O	Output enable
NWE	O	Write enable

Table 214. 16-bit multiplexed I/O NOR flash memory (continued)

FMC signal name	I/O	Function
NL(=NADV)	O	Latch enable (this signal is called address valid, NADV, by some NOR flash devices)
NWAIT	I	NOR flash wait input signal to the FMC

The maximum capacity is 512 Mbits.

PSRAM/FRAM/SRAM, non-multiplexed I/Os

Table 215. Non-multiplexed I/Os PSRAM/SRAM

FMC signal name	I/O	Function
CLK	O	Clock (only for PSRAM synchronous access)
A[25:0]	O	Address bus
D[31:0]	I/O	Data bidirectional bus
NE[x]	O	Chip select, x = 1..4 (called NCE by PSRAM (CellularRAM™ i.e. CRAM))
NOE	O	Output enable
NWE	O	Write enable
NL(= NADV)	O	Address valid only for PSRAM input (memory signal name: NADV)
NWAIT	I	PSRAM wait input signal to the FMC
NBL[3:0]	O	Byte lane output. Byte 0 to Byte 3 control (Upper and lower byte enable)

The maximum capacity is 512 Mbits.

PSRAM, 16-bit multiplexed I/Os

Table 216. 16-Bit multiplexed I/O PSRAM

FMC signal name	I/O	Function
CLK	O	Clock (for synchronous access)
A[25:16]	O	Address bus
AD[15:0]	I/O	16-bit multiplexed, bidirectional address/data bus (the 16-bit address A[15:0] and data D[15:0] are multiplexed on the databus)
NE[x]	O	Chip select, x = 1..4 (called NCE by PSRAM (CellularRAM™ i.e. CRAM))
NOE	O	Output enable
NWE	O	Write enable
NL(= NADV)	O	Address valid PSRAM input (memory signal name: NADV)
NWAIT	I	PSRAM wait input signal to the FMC
NBL[1:0]	O	Byte lane output. Byte 0 and Byte 1 control (upper and lower byte enable)

The maximum capacity is 512 Mbits (26 address lines).

25.6.2 Supported memories and transactions

Table 217 below shows an example of the supported devices, access modes and transactions when the memory data bus is 16-bit wide for NOR flash memory, PSRAM and SRAM. The transactions not allowed (or not supported) by the FMC are shown in gray in this example.

Table 217. NOR flash/PSRAM: example of supported memories and transactions

Device	Mode	R/W	AHB data size	Memory data size	Allowed/ not allowed	Comments
NOR flash (muxed I/Os and nonmuxed I/Os)	Asynchronous	R	8	16	Y	-
	Asynchronous	W	8	16	N	-
	Asynchronous	R	16	16	Y	-
	Asynchronous	W	16	16	Y	-
	Asynchronous	R	32	16	Y	Split into 2 FMC accesses
	Asynchronous	W	32	16	Y	Split into 2 FMC accesses
	Asynchronous page	R	-	16	N	Mode is not supported
	Synchronous	R	8	16	N	-
	Synchronous	R	16	16	Y	-
	Synchronous	R	32	16	Y	-
PSRAM (multiplexed I/Os and non-multiplexed I/Os)	Asynchronous	R	8	16	Y	-
	Asynchronous	W	8	16	Y	Use of byte lanes NBL[1:0]
	Asynchronous	R	16	16	Y	-
	Asynchronous	W	16	16	Y	-
	Asynchronous	R	32	16	Y	Split into 2 FMC accesses
	Asynchronous	W	32	16	Y	Split into 2 FMC accesses
	Asynchronous page	R	-	16	N	Mode is not supported
	Synchronous	R	8	16	N	-
	Synchronous	R	16	16	Y	-
	Synchronous	R	32	16	Y	-
	Synchronous	W	8	16	Y	Use of byte lanes NBL[1:0]
	Synchronous	W	16/32	16	Y	-
SRAM and ROM	Asynchronous	R	8 / 16	16	Y	-
	Asynchronous	W	8 / 16	16	Y	Use of byte lanes NBL[1:0]
	Asynchronous	R	32	16	Y	Split into 2 FMC accesses
	Asynchronous	W	32	16	Y	Split into 2 FMC accesses Use of byte lanes NBL[1:0]

25.6.3 General timing rules

Signals synchronization

- All controller output signals change on the rising edge of the internal clock (HCLK)
- In Synchronous mode (read or write), all output signals change on the rising edge of HCLK. Whatever the CLKDIV value, all outputs change as follows:
  - NOEL/NWEL/ NEL/NADVL/ NADVH /NBLL/ Address valid outputs change on the falling edge of FMC_CLK clock.
  - NOEH/ NWEH / NEH/ NOEH/NBLH/ Address invalid outputs change on the rising edge of FMC_CLK clock.

25.6.4 NOR flash/PSRAM controller asynchronous transactions

Asynchronous static memories (NOR flash, PSRAM, SRAM, FRAM)

- Signals are synchronized by the internal clock HCLK. This clock is not issued to the memory
- The FMC always samples the data before de-asserting the NOE signal. This guarantees that the memory data hold timing constraint is met (minimum Chip Enable high to data transition is usually 0 ns)
- If the Extended mode is enabled (EXTMOD bit is set in the FMC_BCRx register), up to four extended modes (A, B, C and D) are available. It is possible to mix A, B, C and D modes for read and write operations. For example, read operation can be performed in mode A and write in mode B.
- If the Extended mode is disabled (EXTMOD bit is reset in the FMC_BCRx register), the FMC can operate in mode 1 or mode 2 as follows:
  - Mode 1 is the default mode when SRAM/PSRAM memory type is selected (MTYP = 0x0 or 0x01 in the FMC_BCRx register)
  - Mode 2 is the default mode when NOR memory type is selected (MTYP = 0x10 in the FMC_BCRx register).

Mode 1 - SRAM/FRAM/PSRAM (CRAM)

The next figures show the read and write transactions for the supported modes followed by the required configuration of FMC_BCRx, and FMC_BTRx/FMC_BWTRx registers.

Figure 152. Mode 1 read access waveforms

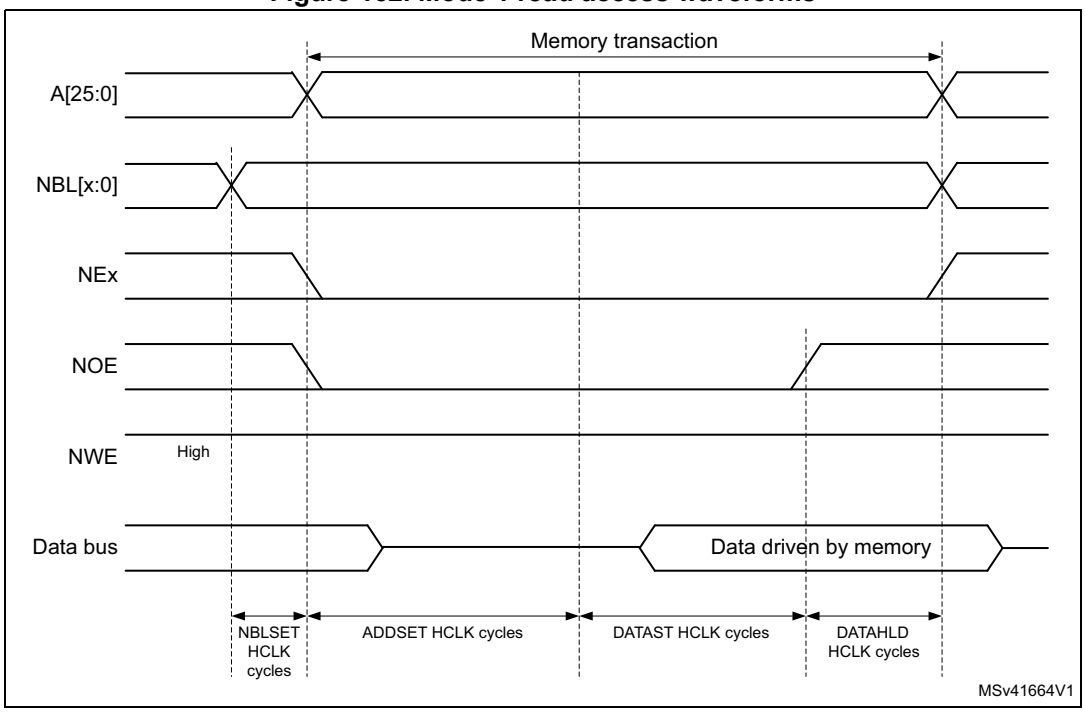
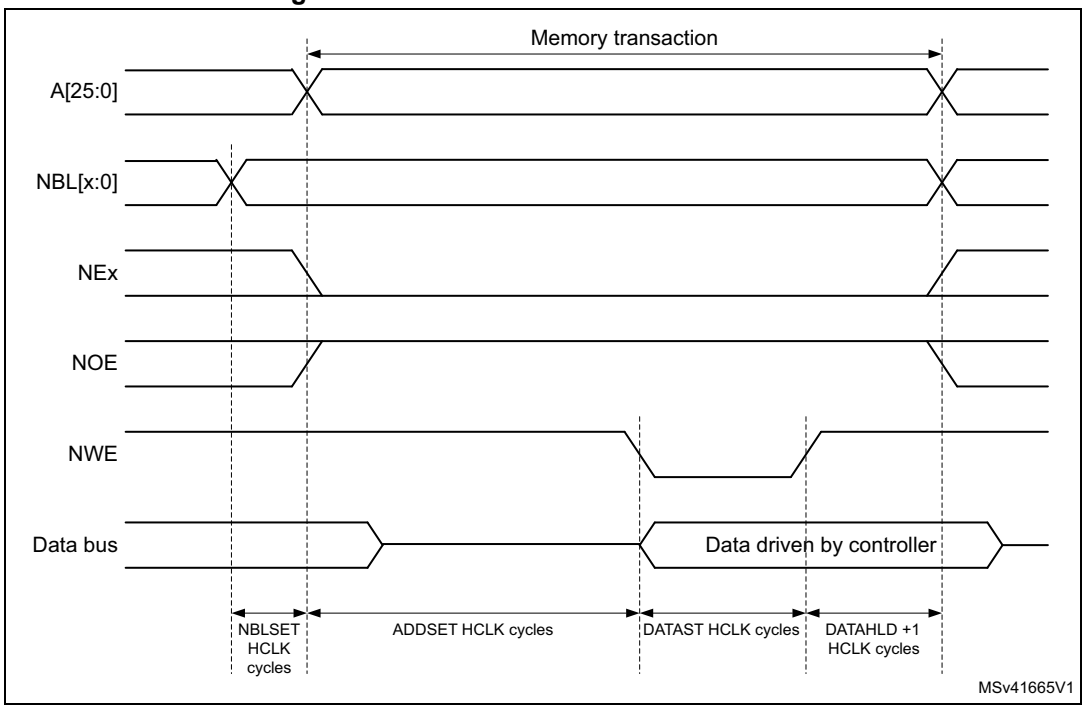


Figure 153. Mode 1 write access waveforms



The DATAHLD time at the end of the read and write transactions guarantee the address and data hold time after the NOE/NWE rising edge. The DATAST value must be greater than zero (DATAST > 0).

Table 218. FMC_BCRx bitfields (mode 1)

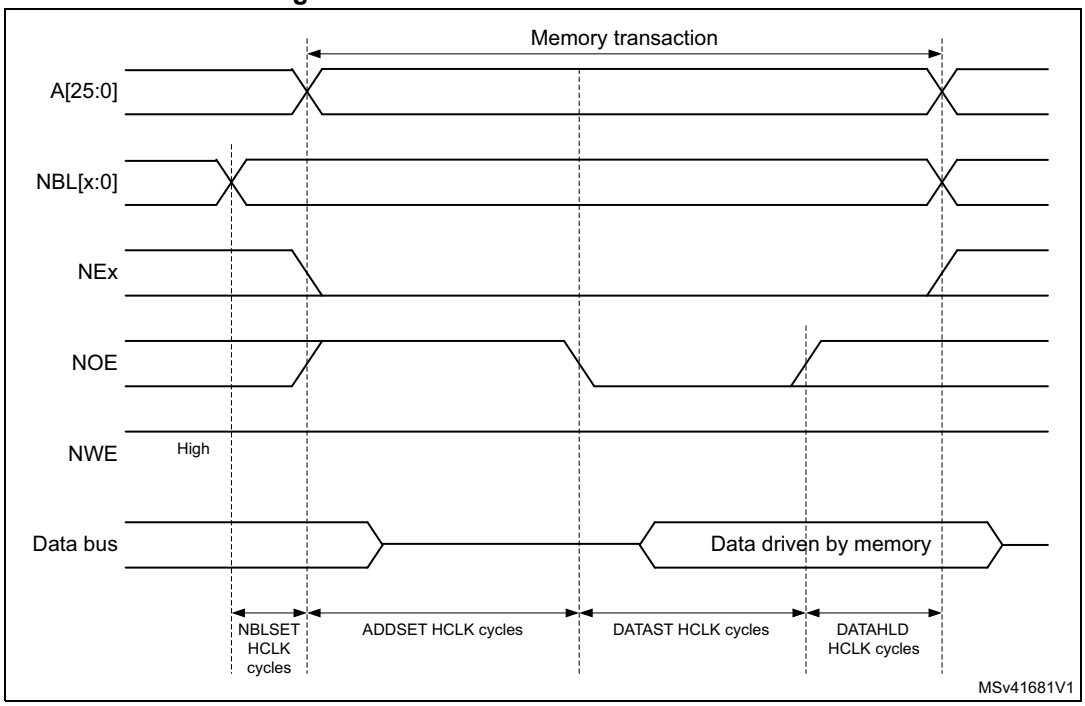
Bit number	Bit name	Value to set
31	FMCEN	0x1
30:24	Reserved	0x000
23:22	NBLSET[1:0]	As needed
20	CCLKEN	As needed
19	CBURSTRW	0x0 (no effect in Asynchronous mode)
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	Set to 1 if the memory supports this feature. Otherwise keep at 0.
14	EXTMOD	0x0
13	WAITEN	0x0 (no effect in Asynchronous mode)
12	WREN	As needed
10	Reserved	0x0
9	WAITPOL	Meaningful only if bit 15 is 1
8	BURSTEN	0x0
7	Reserved	0x1
6	FACCEN	Don’t care
5:4	MWID	As needed
3:2	MTYP	As needed, exclude 0x2 (NOR flash memory)
1	MUXE	0x0
0	MBKEN	0x1

Table 219. FMC_BTRx bitfields (mode 1)

Bit number	Bit name	Value to set
31:30	DATAHLD	Duration of the data hold phase (DATAHLD HCLK cycles for read accesses, DATAHLD+1 HCLK cycles for write accesses).
29:28	ACCMOD	Don’t care
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN HCLK).
15:8	DATAST	Duration of the second access phase (DATAST HCLK cycles).
7:4	ADDHLD	Don’t care
3:0	ADDSET	Duration of the first access phase (ADDSET HCLK cycles). Minimum value for ADDSET is 0.

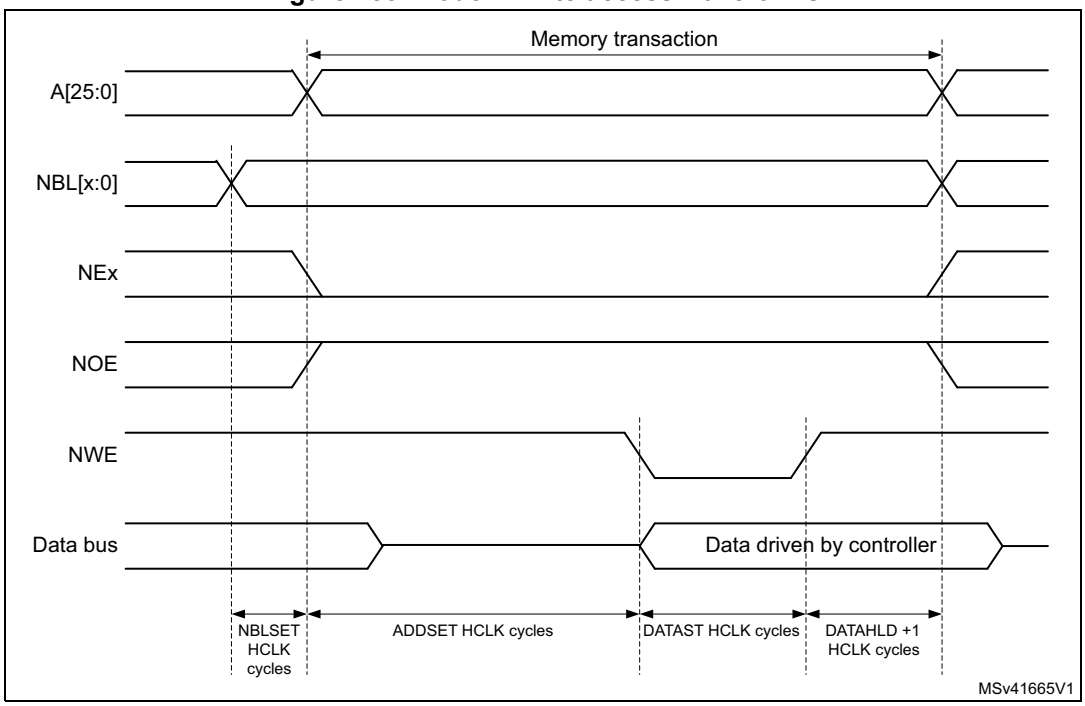
Mode A - SRAM/FRAM/PSRAM (CRAM) OE toggling

Figure 154. Mode A read access waveforms



1. NBL[3:0] are driven low during the read access

Figure 155. Mode A write access waveforms



The differences compared with Mode 1 are the toggling of NOE and the independent read and write timings.

Table 220. FMC_BCRx bitfields (mode A)

Bit number	Bit name	Value to set
31	FMCEN	0x1
30:24	Reserved	0x000
23:22	NBLSET[1:0]	As needed
20	CCLKEN	As needed
19	CBURSTRW	0x0 (no effect in Asynchronous mode)
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	Set to 1 if the memory supports this feature. Otherwise keep at 0.
14	EXTMOD	0x1
13	WAITEN	0x0 (no effect in Asynchronous mode)
12	WREN	As needed
11	WAITCFG	Don’t care
10	Reserved	0x0
9	WAITPOL	Meaningful only if bit 15 is 1
8	BURSTEN	0x0
7	Reserved	0x1
6	FACCEN	Don’t care
5:4	MWID	As needed
3:2	MTYP	As needed, exclude 0x2 (NOR flash memory)
1	MUXEN	0x0
0	MBKEN	0x1

Table 221. FMC_BTRx bitfields (mode A)

Bit number	Bit name	Value to set
31:30	DATAHLD	Duration of the data hold phase (DATAHLD HCLK cycles for read accesses).
29:28	ACCMOD	0x0
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN HCLK).
15:8	DATAST	Duration of the second access phase (DATAST HCLK cycles) for read accesses.
7:4	ADDHLD	Don’t care
3:0	ADDSET	Duration of the first access phase (ADDSET HCLK cycles) for read accesses. Minimum value for ADDSET is 0.

Table 222. FMC_BWTRx bitfields (mode A)

Bit number	Bit name	Value to set
31:30	DATAHLD	Duration of the data hold phase (DATAHLD+1 HCLK cycles for write accesses).
29:28	ACCMOD	0x0
27:24	DATLAT	Don't care
23:20	CLKDIV	Don't care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN HCLK).
15:8	DATAST	Duration of the second access phase (DATAST HCLK cycles) for write accesses.
7:4	ADDHLD	Don't care
3:0	ADDSET	Duration of the first access phase (ADDSET HCLK cycles) for write accesses. Minimum value for ADDSET is 0.

Mode 2/B - NOR flash

Figure 156. Mode 2 and mode B read access waveforms

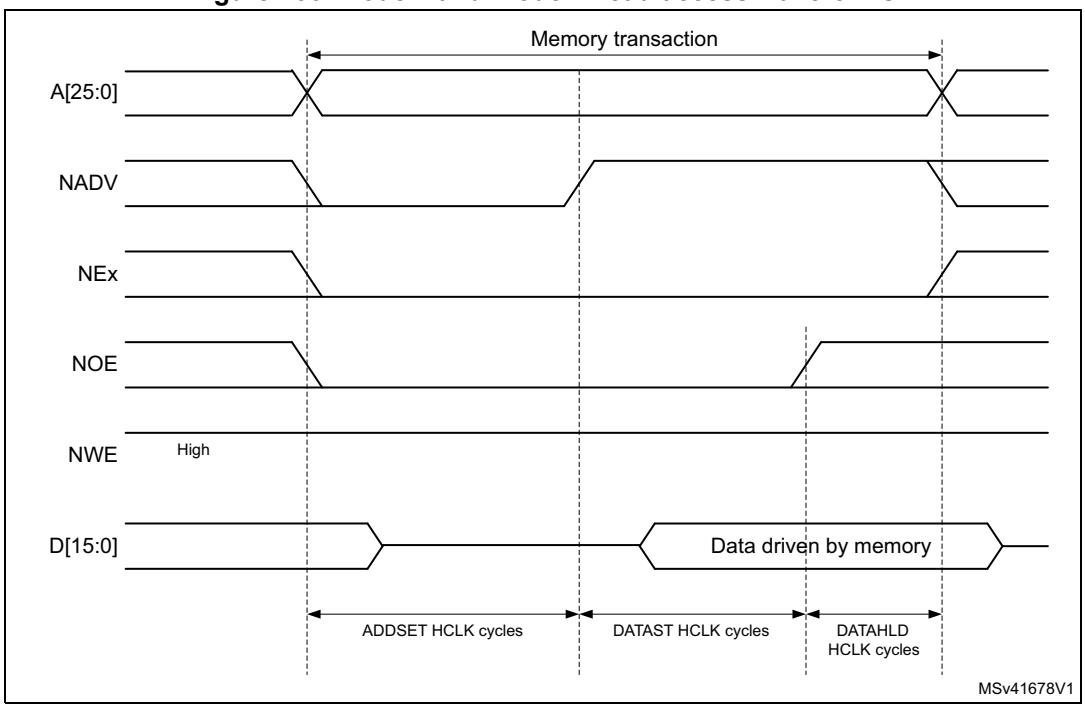


Figure 157. Mode 2 write access waveforms

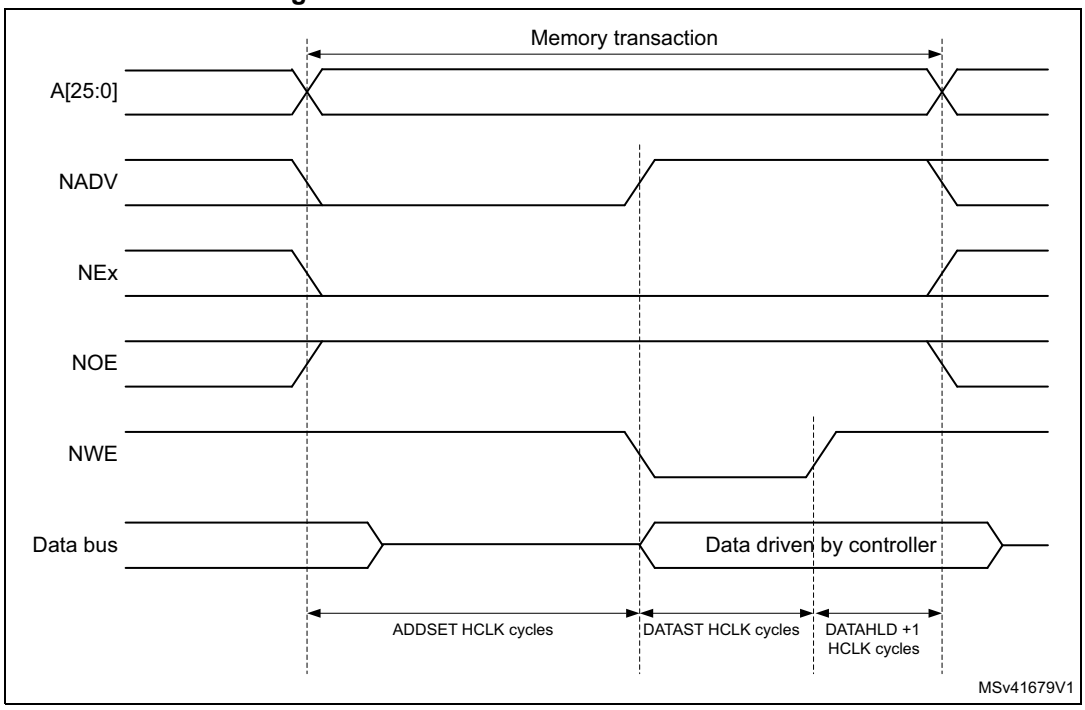
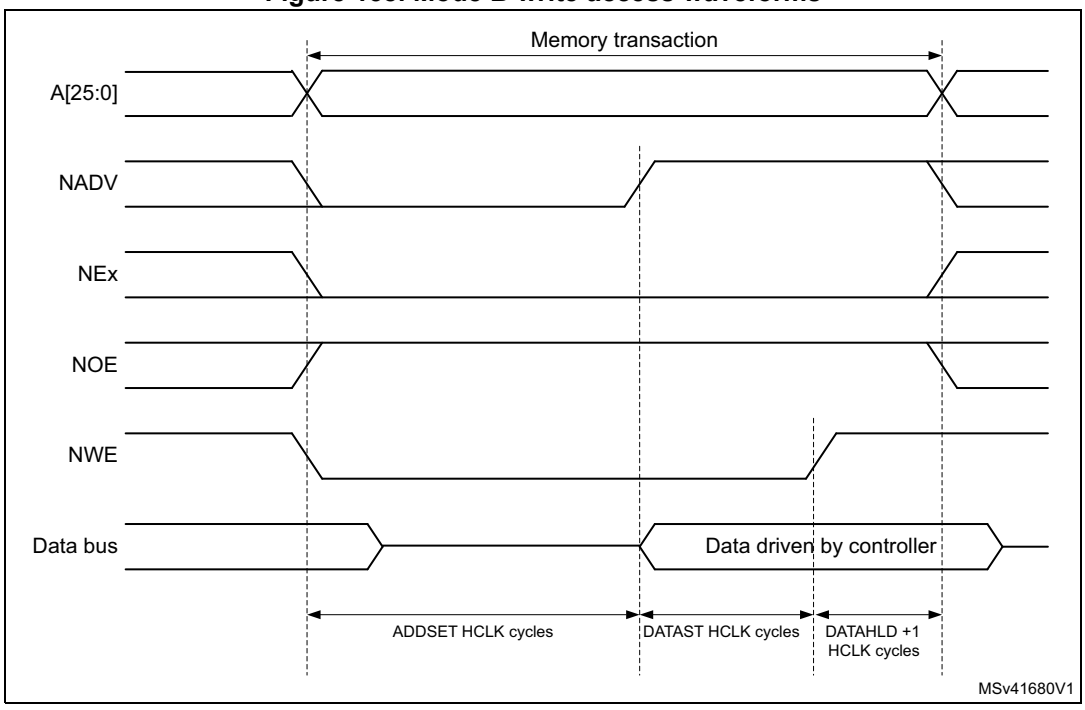


Figure 158. Mode B write access waveforms



The differences with mode 1 are the toggling of NWE and the independent read and write timings when extended mode is set (mode B).

Table 223. FMC_BCRx bitfields (mode 2/B)

Bit number	Bit name	Value to set
31	FMCEN	0x1
30:24	Reserved	0x000
23:22	NBLSET[1:0]	Don't care
20	CCLKEN	As needed
19	CBURSTRW	0x0 (no effect in Asynchronous mode)
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	Set to 1 if the memory supports this feature. Otherwise keep at 0.
14	EXTMOD	0x1 for mode B, 0x0 for mode 2
13	WAITEN	0x0 (no effect in Asynchronous mode)
12	WREN	As needed
11	WAITCFG	Don't care
10	Reserved	0x0
9	WAITPOL	Meaningful only if bit 15 is 1
8	BURSTEN	0x0
7	Reserved	0x1
6	FACCEN	0x1
5:4	MWID	As needed
3:2	MTYP	0x2 (NOR flash memory)
1	MUXEN	0x0
0	MBKEN	0x1

Table 224. FMC_BTRx bitfields (mode 2/B)

Bit number	Bit name	Value to set
31:30	DATAHLD	Duration of the data hold phase (DATAHLD HCLK cycles for read accesses and DATAHLD+1 HCLK cycles for write accesses when Extended mode is disabled).
29:28	ACCMOD	0x1 if Extended mode is set
27:24	DATLAT	Don't care
23:20	CLKDIV	Don't care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN HCLK).
15:8	DATAST	Duration of the access second phase (DATAST HCLK cycles) for read accesses.
7:4	ADDHLD	Don't care
3:0	ADDSET	Duration of the access first phase (ADDSET HCLK cycles) for read accesses. Minimum value for ADDSET is 0.

Table 225. FMC_BWTRx bitfields (mode 2/B)

Bit number	Bit name	Value to set
31:30	DATAHLD	Duration of the data hold phase (DATAHLD+1 HCLK cycles for write accesses).
29:28	ACCMOD	0x1 if Extended mode is set
27:24	DATLAT	Don't care
23:20	CLKDIV	Don't care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN HCLK).
15:8	DATAST	Duration of the access second phase (DATAST HCLK cycles) for write accesses.
7:4	ADDHLD	Don't care
3:0	ADDSET	Duration of the access first phase (ADDSET HCLK cycles) for write accesses. Minimum value for ADDSET is 0.

Note: The FMC_BWTRx register is valid only if the Extended mode is set (mode B), otherwise its content is don't care.

Mode C - NOR flash - OE toggling

Figure 159. Mode C read access waveforms

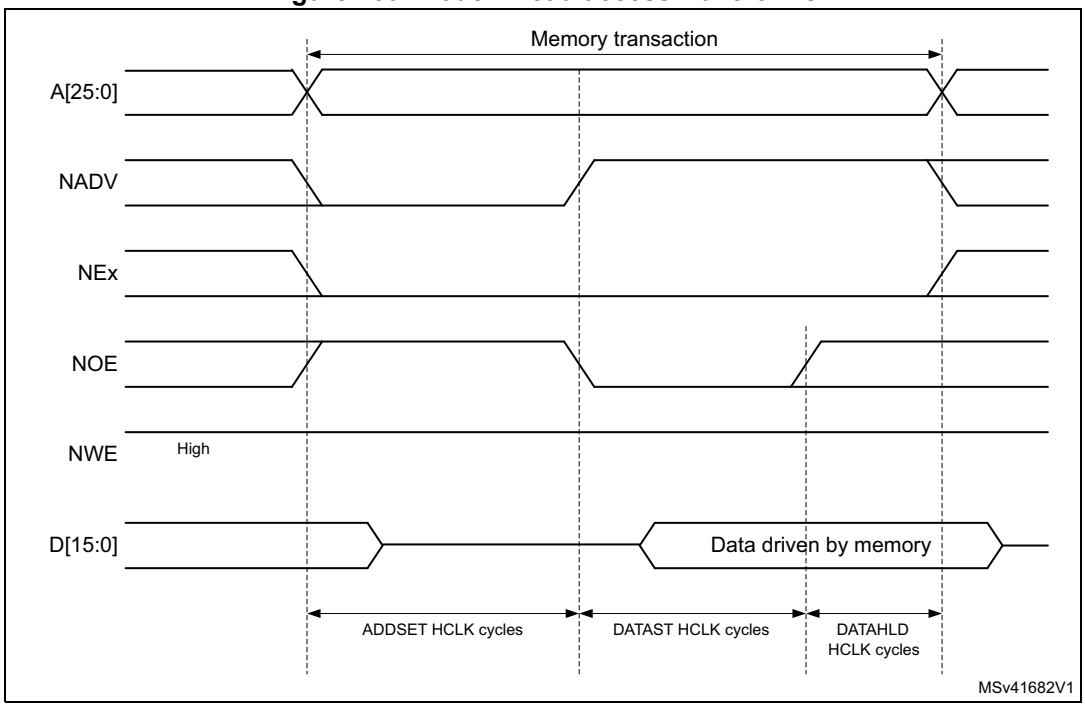
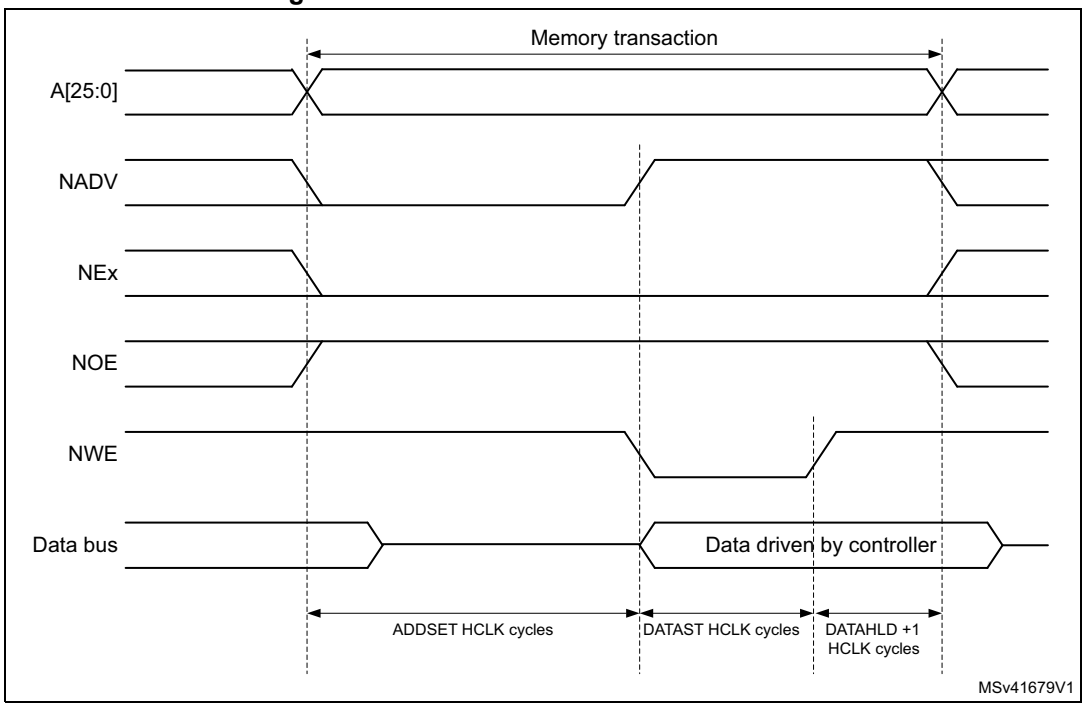


Figure 160. Mode C write access waveforms



The differences compared with mode 1 are the toggling of NOE and the independent read and write timings.

Table 226. FMC_BCRx bitfields (mode C)

Bit number	Bit name	Value to set
31	FMCEN	0x1
30:24	Reserved	0x000
23:22	NBLSET[1:0]	Don’t care
20	CCLKEN	As needed
19	CBURSTRW	0x0 (no effect in Asynchronous mode)
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	Set to 1 if the memory supports this feature. Otherwise keep at 0.
14	EXTMOD	0x1
13	WAITEN	0x0 (no effect in Asynchronous mode)
12	WREN	As needed
11	WAITCFG	Don’t care
10	Reserved	0x0
9	WAITPOL	Meaningful only if bit 15 is 1
8	BURSTEN	0x0
7	Reserved	0x1
6	FACCEN	0x1

Table 226. FMC_BCRx bitfields (mode C) (continued)

Bit number	Bit name	Value to set
5:4	MWID	As needed
3:2	MTYP	0x02 (NOR flash memory)
1	MUXEN	0x0
0	MBKEN	0x1

Table 227. FMC_BTRx bitfields (mode C)

Bit number	Bit name	Value to set
31:30	DATAHLD	Duration of the data hold phase (DATAHLD HCLK cycles for read accesses).
29:28	ACCMOD	0x2
27:24	DATLAT	0x0
23:20	CLKDIV	0x0
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN HCLK).
15:8	DATAST	Duration of the second access phase (DATAST HCLK cycles) for read accesses.
7:4	ADDHLD	Don’t care
3:0	ADDSET	Duration of the first access phase (ADDSET HCLK cycles) for read accesses. Minimum value for ADDSET is 0.

Table 228. FMC_BWTRx bitfields (mode C)

Bit number	Bit name	Value to set
31:30	DATAHLD	Duration of the data hold phase (DATAHLD+1 HCLK cycles for write accesses).
29:28	ACCMOD	0x2
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN HCLK).
15:8	DATAST	Duration of the second access phase (DATAST HCLK cycles) for write accesses.
7:4	ADDHLD	Don’t care
3:0	ADDSET	Duration of the first access phase (ADDSET HCLK cycles) for write accesses. Minimum value for ADDSET is 0.

Mode D - asynchronous access with extended address

Figure 161. Mode D read access waveforms

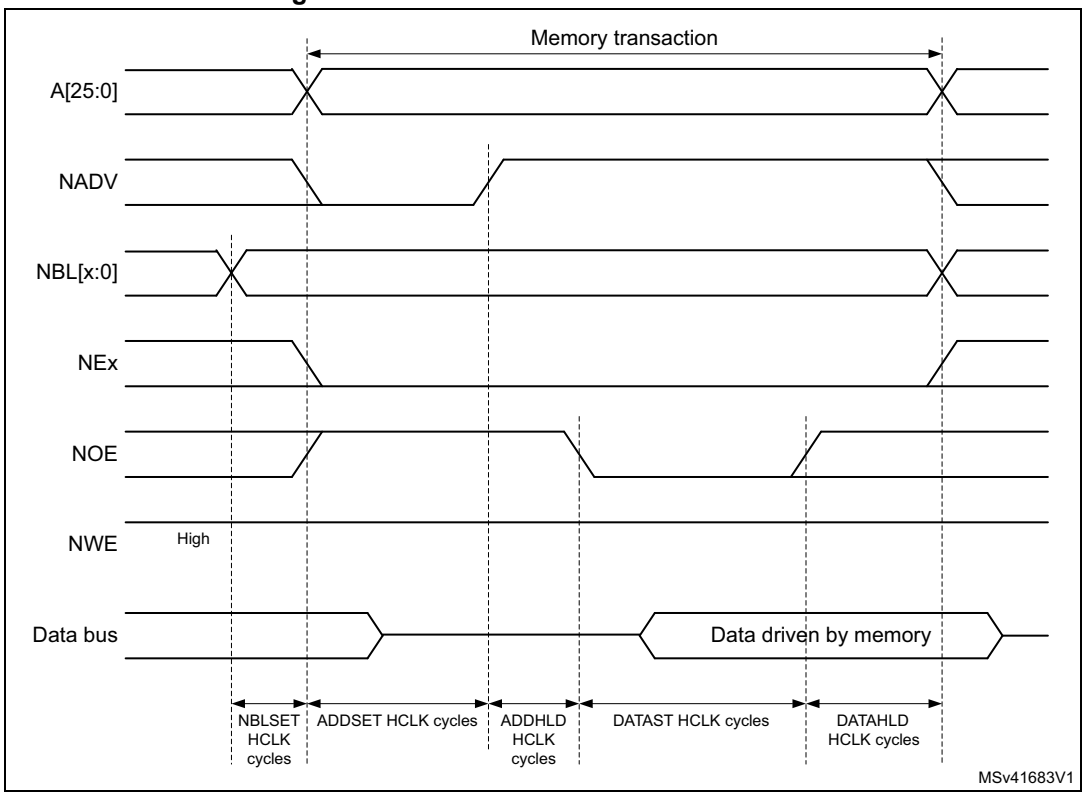
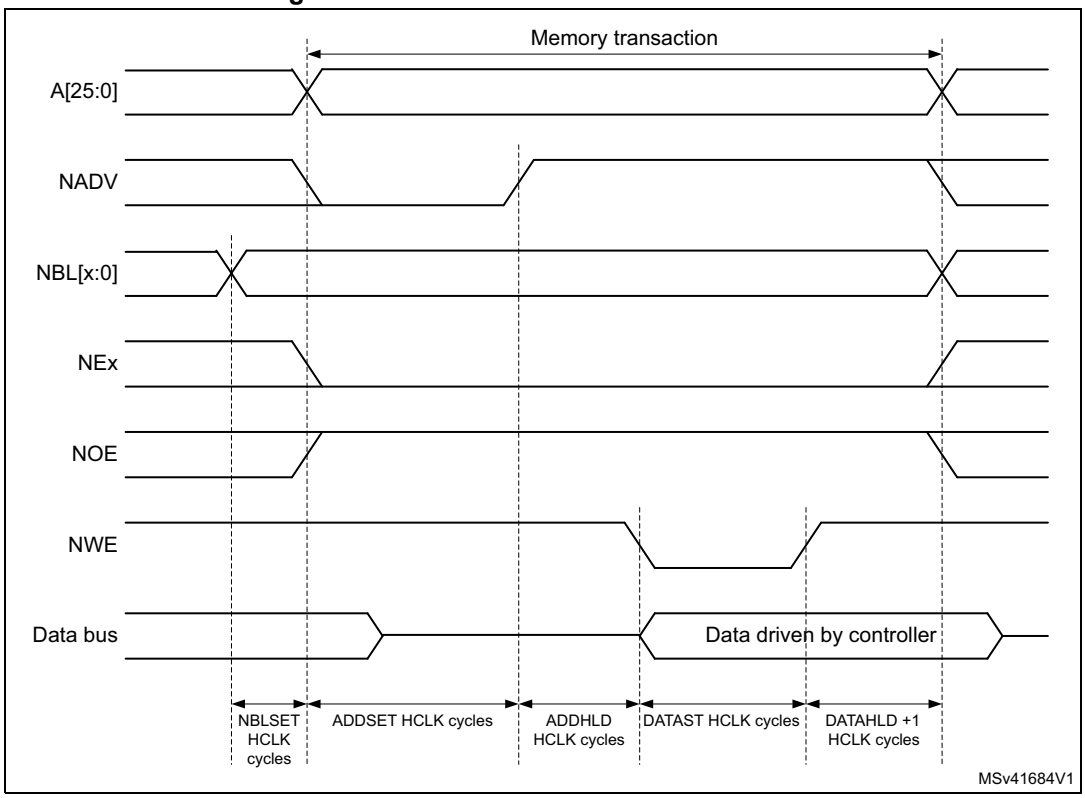


Figure 162. Mode D write access waveforms



The differences with mode 1 are the toggling of NOE that goes on toggling after NADV changes and the independent read and write timings.

Table 229. FMC_BCRx bitfields (mode D)

Bit number	Bit name	Value to set
31	FMCEN	0x1
30:24	Reserved	0x000
23:22	NBLSET[1:0]	As needed
20	CCLKEN	As needed
19	CBURSTRW	0x0 (no effect in Asynchronous mode)
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	Set to 1 if the memory supports this feature. Otherwise keep at 0.
14	EXTMOD	0x1
13	WAITEN	0x0 (no effect in Asynchronous mode)
12	WREN	As needed
11	WAITCFG	Don’t care
10	Reserved	0x0
9	WAITPOL	Meaningful only if bit 15 is 1
8	BURSTEN	0x0

Table 229. FMC_BCRx bitfields (mode D) (continued)

Bit number	Bit name	Value to set
7	Reserved	0x1
6	FACCEN	Set according to memory support
5:4	MWID	As needed
3:2	MTYP	As needed
1	MUXEN	0x0
0	MBKEN	0x1

Table 230. FMC_BTRx bitfields (mode D)

Bit number	Bit name	Value to set
31:30	DATAHLD	Duration of the data hold phase (DATAHLD HCLK cycles for read accesses).
29:28	ACCMOD	0x3
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN HCLK).
15:8	DATAST	Duration of the second access phase (DATAST HCLK cycles) for read accesses.
7:4	ADDHLD	Duration of the middle phase of the read access (ADDHLD HCLK cycles)
3:0	ADDSET	Duration of the first access phase (ADDSET HCLK cycles) for read accesses. Minimum value for ADDSET is 1.

Table 231. FMC_BWTRx bitfields (mode D)

Bit number	Bit name	Value to set
31:30	DATAHLD	Duration of the data hold phase (DATAHLD+1 HCLK cycles for write accesses).
29:28	ACCMOD	0x3
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN HCLK).
15:8	DATAST	Duration of the second access phase (DATAST HCLK cycles).
7:4	ADDHLD	Duration of the middle phase of the write access (ADDHLD HCLK cycles)
3:0	ADDSET	Duration of the first access phase (ADDSET HCLK cycles) for write accesses. Minimum value for ADDSET is 1.

Muxed mode - multiplexed asynchronous access to NOR flash memory

Figure 163. Muxed read access waveforms

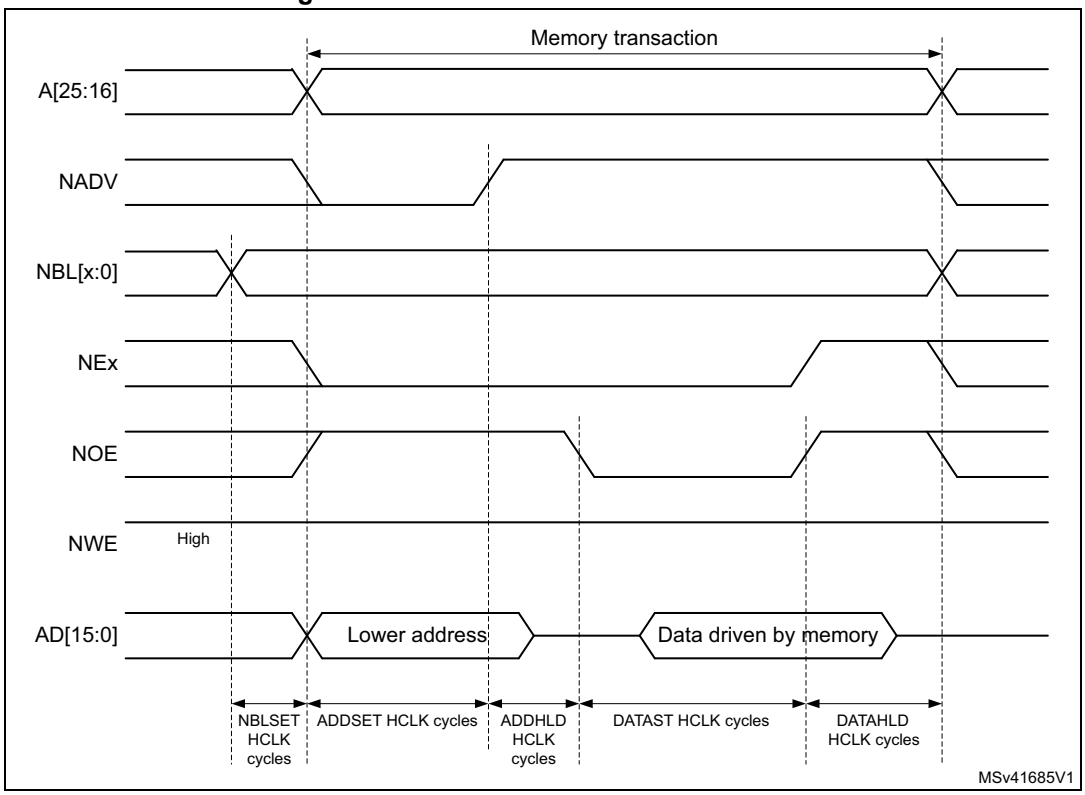
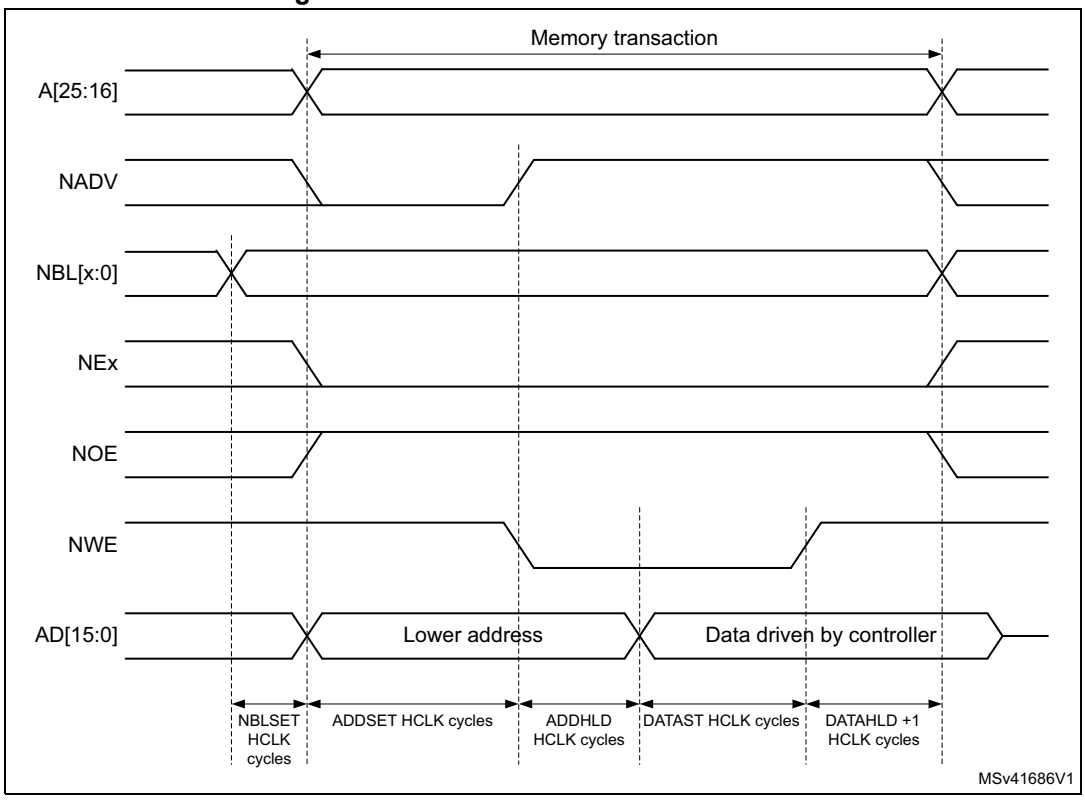


Figure 164. Muxed write access waveforms



The difference with mode D is the drive of the lower address byte(s) on the data bus.

Table 232. FMC_BCRx bitfields (Muxed mode)

Bit number	Bit name	Value to set
31	FMCEN	0x1
30:24	Reserved	0x000
23:22	NBLSET[1:0]	As needed
20	CCLKEN	As needed
19	CBURSTRW	0x0 (no effect in Asynchronous mode)
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	Set to 1 if the memory supports this feature. Otherwise keep at 0.
14	EXTMOD	0x0
13	WAITEN	0x0 (no effect in Asynchronous mode)
12	WREN	As needed
11	WAITCFG	Don’t care
10	Reserved	0x0
9	WAITPOL	Meaningful only if bit 15 is 1
8	BURSTEN	0x0
7	Reserved	0x1

Table 232. FMC_BCRx bitfields (Muxed mode) (continued)

Bit number	Bit name	Value to set
6	FACCEN	0x1
5:4	MWID	As needed
3:2	MTYP	0x2 (NOR flash memory) or 0x1(PSRAM)
1	MUXEN	0x1
0	MBKEN	0x1

Table 233. FMC_BTRx bitfields (Muxed mode)

Bit number	Bit name	Value to set
31:30	DATAHLD	Duration of the data hold phase (DATAHLD HCLK cycles for read accesses, DATAHLD+1 HCLK cycles for write accesses).
29:28	ACCMOD	0x0
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN HCLK).
15:8	DATAST	Duration of the second access phase (DATAST HCLK cycles).
7:4	ADDHLD	Duration of the middle phase of the access (ADDHLD HCLK cycles).
3:0	ADDSET	Duration of the first access phase (ADDSET HCLK cycles). Minimum value for ADDSET is 1.

WAIT management in asynchronous accesses

If the asynchronous memory asserts the WAIT signal to indicate that it is not yet ready to accept or to provide data, the ASYNCWAIT bit has to be set in FMC_BCRx register.

If the WAIT signal is active (high or low depending on the WAITPOL bit), the second access phase (Data setup phase), programmed by the DATAST bits, is extended until WAIT becomes inactive. Unlike the data setup phase, the first access phases (Address setup and Address hold phases), programmed by the ADDSET and ADDHLD bits, are not WAIT sensitive and so they are not prolonged.

The data setup phase must be programmed so that WAIT can be detected 4 HCLK cycles before the end of the memory transaction. The following cases must be considered:

1. The memory asserts the WAIT signal aligned to NOE/NWE which toggles:

$$DATAST \geq (4 \times HCLK) + max_wait_assertion_time$$

2. The memory asserts the WAIT signal aligned to NEx (or NOE/NWE not toggling):

   if

$$max_wait_assertion_time > address_phase + hold_phase$$

   then:

$$DATAST \geq (4 \times HCLK) + (max_wait_assertion_time - address_phase - hold_phase)$$

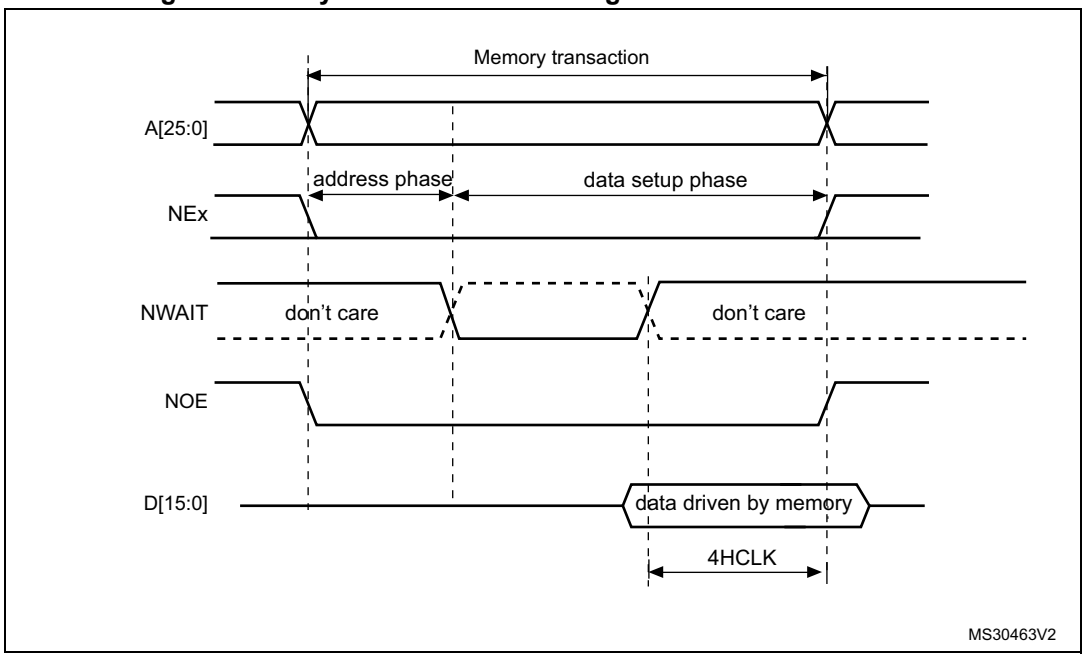
   otherwise

$$DATAST \geq 4 \times HCLK$$

   where max_wait_assertion_time is the maximum time taken by the memory to assert the WAIT signal once NEx/NOE/NWE is low.

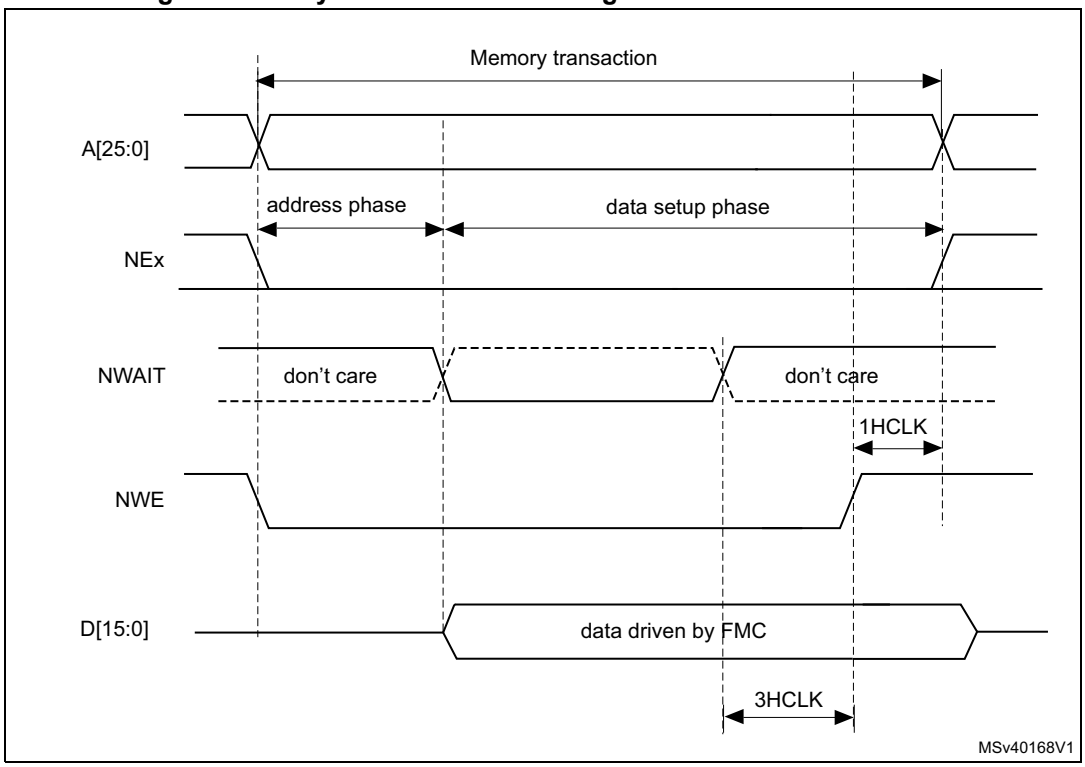
Figure 165 and *Figure 166* show the number of HCLK clock cycles that are added to the memory access phase after WAIT is released by the asynchronous memory (independently of the above cases).

Figure 165. Asynchronous wait during a read access waveforms



1. NWAIT polarity depends on WAITPOL bit setting in FMC_BCRx register.

Figure 166. Asynchronous wait during a write access waveforms



1. NWAIT polarity depends on WAITPOL bit setting in FMC_BCRx register.

CellularRAM™ (PSRAM) refresh management

The CellularRAM™ does not enable maintaining the chip select signal (NE) low for longer than the t_{CEM} timing specified for the memory device. This timing can be programmed in the FMC_PCSCNTR register. It defines the maximum duration of the NE low pulse in HCLK cycles for asynchronous accesses and FMC_CLK cycles for synchronous accesses

25.6.5 Synchronous transactions

The memory clock, FMC_CLK, is a submultiple of HCLK. It depends on the value of CLKDIV and the MWID/ AHB data size, following the formula given below:

If MWID is 16 or 8-bit, the FMC_CLK divider ratio is always defined by the programmed CLKDIV value.

If MWID is 32-bit, the FMC_CLK divider ratio depends also on AHB data size.

Example:

- If CLKDIV=1, MWID = 32 bits, AHB data size=8 bits, FMC_CLK=HCLK/4.
- If CLKDIV=1, MWID = 16 bits, AHB data size=8 bits, FMC_CLK=HCLK/2.

NOR flash memories specify a minimum time from NADV assertion to CLK high. To meet this constraint, the FMC does not issue the clock to the memory during the first internal clock cycle of the synchronous access (before NADV assertion). This guarantees that the rising edge of the memory clock occurs in the middle of the NADV low pulse.

Data latency versus NOR memory latency

The data latency is the number of cycles to wait before sampling the data. The DATLAT value must be consistent with the latency value specified in the NOR flash configuration register. The FMC does not include the clock cycle when NADV is low in the data latency count.

Caution: Some NOR flash memories include the NADV Low cycle in the data latency count, so that the exact relation between the NOR flash latency and the FMC DATLAT parameter can be either:

- NOR flash latency = (DATLAT + 2) CLK clock cycles
- or NOR flash latency = (DATLAT + 3) CLK clock cycles

Some recent memories assert NWAIT during the latency phase. In such cases DATLAT can be set to its minimum value. As a result, the FMC samples the data and waits long enough to evaluate if the data are valid. Thus the FMC detects when the memory exits latency and real data are processed.

Other memories do not assert NWAIT during latency. In this case the latency must be set correctly for both the FMC and the memory, otherwise invalid data are mistaken for good data, or valid data are lost in the initial phase of the memory access.

Single-burst transfer

When the selected bank is configured in Burst mode for synchronous accesses, if for example an AHB single-burst transaction is requested on 16-bit memories, the FMC performs a burst transaction of length 1 (if the AHB transfer is 16 bits), or length 2 (if the AHB transfer is 32 bits) and de-assert the chip select signal when the last data is strobed.

Such transfers are not the most efficient in terms of cycles compared to asynchronous read operations. Nevertheless, a random asynchronous access would first require to re-program the memory access mode, which would altogether last longer.

Cross boundary page for CellularRAM™ 1.5

CellularRAM™ 1.5 does not allow burst access to cross the page boundary. The FMC controller is used to split automatically the burst access when the memory page size is reached by configuring the CPSIZE bits in the FMC_BCR1 register following the memory page size.

Wait management

For synchronous NOR flash memories, NWAIT is evaluated after the programmed latency period, which corresponds to (DATLAT+2) CLK clock cycles.

If NWAIT is active (low level when WAITPOL = 0, high level when WAITPOL = 1), wait states are inserted until NWAIT is inactive (high level when WAITPOL = 0, low level when WAITPOL = 1).

When NWAIT is inactive, the data is considered valid either immediately (bit WAITCFG = 1) or on the next clock edge (bit WAITCFG = 0).

During wait-state insertion via the NWAIT signal, the controller continues to send clock pulses to the memory, keeping the chip select and output enable signals valid. It does not consider the data as valid.

In Burst mode, there are two timing configurations for the NOR flash NWAIT signal:

- The flash memory asserts the NWAIT signal one data cycle before the wait state (default after reset).
- The flash memory asserts the NWAIT signal during the wait state

The FMC supports both NOR flash wait state configurations, for each chip select, thanks to the WAITCFG bit in the FMC_BCRx registers (x = 0..3).

Figure 167. Wait configuration waveforms

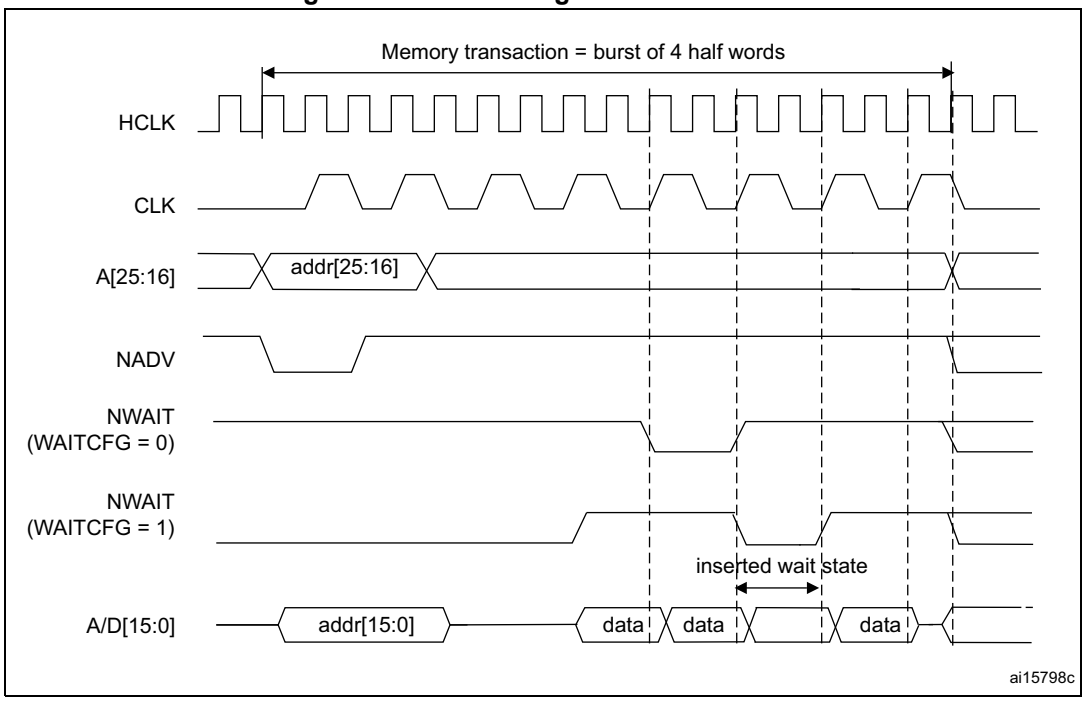
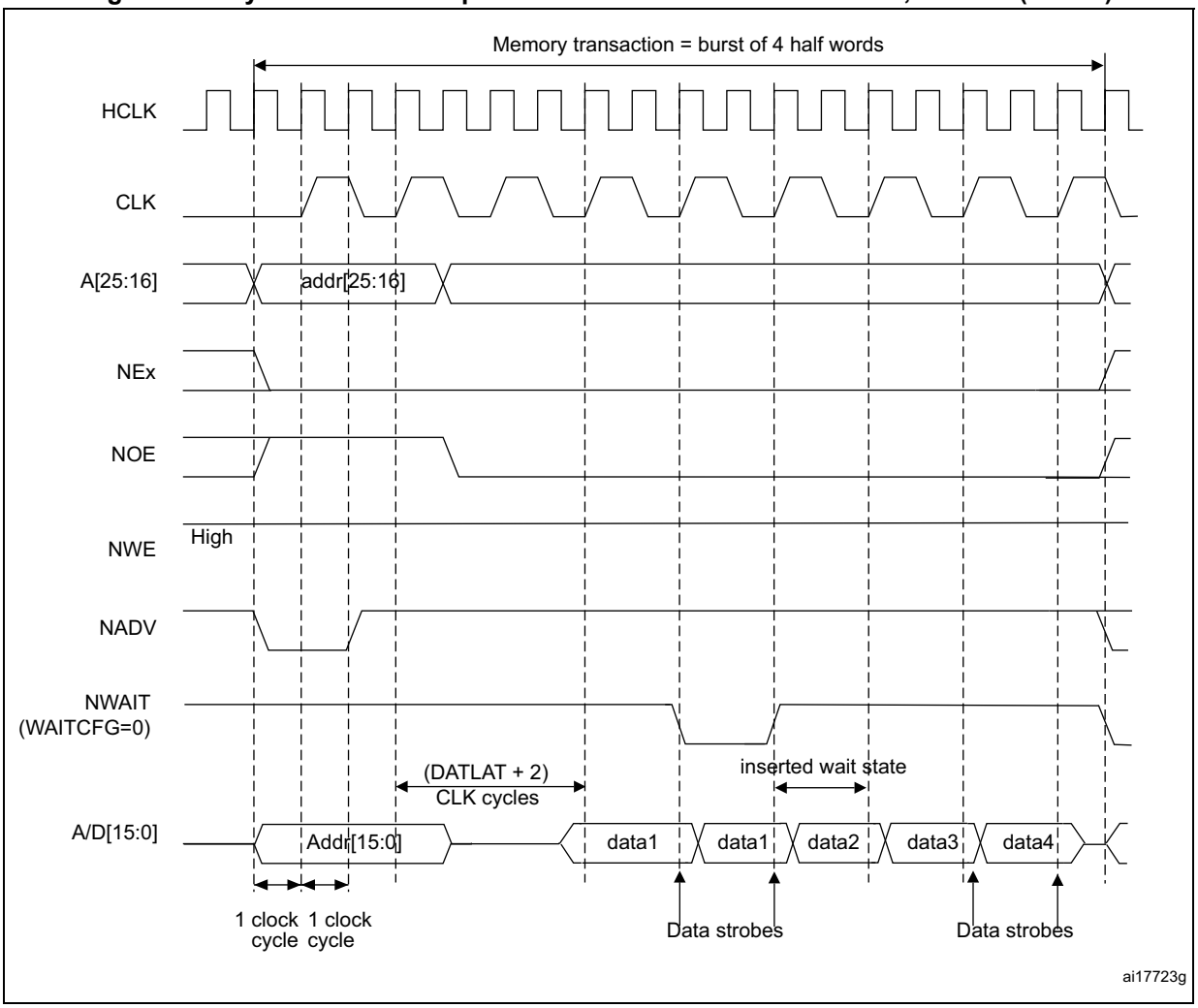


Figure 168. Synchronous multiplexed read mode waveforms - NOR, PSRAM (CRAM)



1. Byte lane outputs (NBL are not shown; for NOR access, they are held high, and, for PSRAM (CRAM) access, they are held low.

Table 234. FMC_BCRx bitfields (Synchronous multiplexed read mode)

Bit number	Bit name	Value to set
31	FMCEN	0x1
30:24	Reserved	0x000
23:22	NBLSET[1:0]	Don’t care
20	CCLKEN	As needed
19	CBURSTRW	No effect on synchronous read
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	0x0
14	EXTMOD	0x0
13	WAITEN	To be set to 1 if the memory supports this feature, to be kept at 0 otherwise

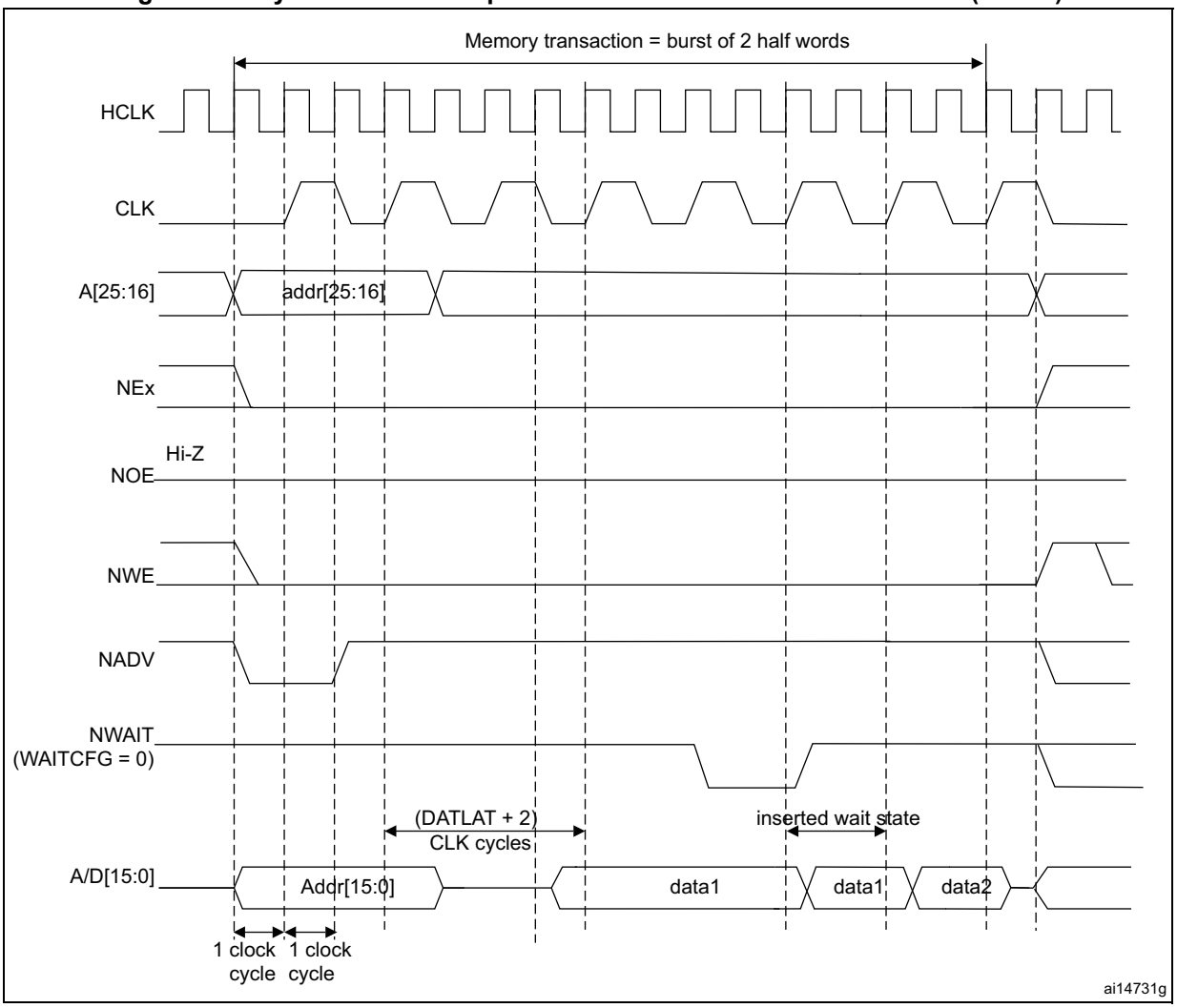
Table 234. FMC_BCRx bitfields (Synchronous multiplexed read mode) (continued)

Bit number	Bit name	Value to set
12	WREN	No effect on synchronous read
11	WAITCFG	To be set according to memory
10	Reserved	0x0
9	WAITPOL	To be set according to memory
8	BURSTEN	0x1
7	Reserved	0x1
6	FACCEN	Set according to memory support (NOR flash memory)
5-4	MWID	As needed
3-2	MTYP	0x1 or 0x2
1	MUXEN	As needed
0	MBKEN	0x1

Table 235. FMC_BTRx bitfields (Synchronous multiplexed read mode)

Bit number	Bit name	Value to set
31:30	DATAHLD	Don’t care
29:28	ACCMOD	0x0
27-24	DATLAT	Data latency
27-24	DATLAT	Data latency
23-20	CLKDIV	0x0 to get CLK = HCLK 0x1 to get CLK = 2 × HCLK ..
19-16	BUSTURN	Time between NEx high to NEx low (BUSTURN HCLK).
15-8	DATAST	Don’t care
7-4	ADDHLD	Don’t care
3-0	ADDSET	Don’t care

Figure 169. Synchronous multiplexed write mode waveforms - PSRAM (CRAM)



1. The memory must issue NWAIT signal one cycle in advance, accordingly WAITCFG must be programmed to 0.
2. Byte Lane (NBL) outputs are not shown, they are held low while NEx is active.

Table 236. FMC_BCRx bitfields (Synchronous multiplexed write mode)

Bit number	Bit name	Value to set
31	FMCEN	0x1
30:24	Reserved	0x000
23:22	NBLSET[1:0]	Don’t care
20	CCLKEN	As needed
19	CBURSTRW	0x1
18:16	CPSIZE	As needed (0x1 for CRAM 1.5)
15	ASYNCWAIT	0x0
14	EXTMOD	0x0

Table 236. FMC_BCRx bitfields (Synchronous multiplexed write mode) (continued)

Bit number	Bit name	Value to set
13	WAITEN	To be set to 1 if the memory supports this feature, to be kept at 0 otherwise.
12	WREN	0x1
11	WAITCFG	0x0
10	Reserved	0x0
9	WAITPOL	to be set according to memory
8	BURSTEN	no effect on synchronous write
7	Reserved	0x1
6	FACCEN	Set according to memory support
5-4	MWID	As needed
3-2	MTYP	0x1
1	MUXEN	As needed
0	MBKEN	0x1

Table 237. FMC_BTRx bitfields (Synchronous multiplexed write mode)

Bit number	Bit name	Value to set
31-30	DATAHLD	Don’t care
29:28	ACCMOD	0x0
27-24	DATLAT	Data latency
23-20	CLKDIV	0x0 to get CLK = HCLK 0x1 to get CLK = 2 × HCLK
19-16	BUSTURN	Time between NEx high to NEx low (BUSTURN HCLK).
15-8	DATAST	Don’t care
7-4	ADDHLD	Don’t care
3-0	ADDSET	Don’t care

25.6.6 NOR/PSRAM controller registers

SRAM/NOR-flash chip-select control register for bank x (FMC_BCRx)

Address offset: 0x00 + 0x8 * (x - 1), (x = 1 to 4)

Reset value: 0x0000 30DB, 0x0000 30D2, 0x0000 30D2, 0x0000 30D2

This register contains the control information of each memory bank, used for SRAMs, PSRAM, FRAM and NOR flash memories.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FMCEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NBLSET[1:0]		WFDIS	CCLK EN	CBURST RW	CPSIZE[2:0]		
rw								rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ASYNC WAIT	EXT MOD	WAIT EN	WREN	WAIT CFG	Res.	WAIT POL	BURST EN	Res.	FACC EN	MWID[1:0]		MTYP[1:0]		MUX EN	MBK EN
rw	rw	rw	rw	rw		rw	rw		rw	rw	rw	rw	rw	rw	rw

Bit 31 **FMCEN**: FMC controller enable

This bit enables or disables the FMC controller.

0: Disable the FMC controller

1: Enable the FMC controller

Note: The FMCEN bit of the FMC_BCR2..4 registers is don't care. It is only enabled through the FMC_BCR1 register.

Bits 30:24 Reserved, must be kept at reset value.

Bits 23:22 **NBLSET[1:0]:** Byte lane (NBL) setup

These bits configure the NBL setup timing from NBLx low to chip select NEx low.

00: NBL setup time is 0 AHB clock cycle

01: NBL setup time is 1 AHB clock cycle

10: NBL setup time is 2 AHB clock cycles

11: NBL setup time is 3 AHB clock cycles

Bit 21 **WFDIS:** Write FIFO disable

This bit disables the Write FIFO used by the FMC controller.

0: Write FIFO enabled (Default after reset)

1: Write FIFO disabled

Note: The WFDIS bit of the FMC_BCR2..4 registers is don't care. It is only enabled through the FMC_BCR1 register.

Bit 20 **CCLKEN:** Continuous clock enable

This bit enables the FMC_CLK clock output to external memory devices.

0: The FMC_CLK is only generated during the synchronous memory access (read/write transaction). The FMC_CLK clock ratio is specified by the programmed CLKDIV value in the FMC_BCRx register (default after reset).

1: The FMC_CLK is generated continuously during asynchronous and synchronous access. The FMC_CLK clock is activated when the CCLKEN is set.

Note: The CCLKEN bit of the FMC_BCR2..4 registers is don't care. It is only enabled through the FMC_BCR1 register. Bank 1 must be configured in Synchronous mode to generate the FMC_CLK continuous clock.

Note: If CCLKEN bit is set, the FMC_CLK clock ratio is specified by CLKDIV value in the FMC_BTR1 register. CLKDIV in FMC_BWTR1 is don't care.

Note: If the Synchronous mode is used and CCLKEN bit is set, the synchronous memories connected to other banks than Bank 1 are clocked by the same clock (the CLKDIV value in the FMC_BTR2..4 and FMC_BWTR2..4 registers for other banks has no effect.)

Bit 19 **CBURSTRW:** Write burst enable

For PSRAM (CRAM) operating in Burst mode, the bit enables synchronous accesses during write operations. The enable bit for synchronous read accesses is the BURSTEN bit in the FMC_BCRx register.

0: Write operations are always performed in Asynchronous mode.

1: Write operations are performed in Synchronous mode.

Bits 18:16 **CPSIZE[2:0]**: CRAM page size

These are used for CellularRAM™ 1.5 which does not allow burst access to cross the address boundaries between pages. When these bits are configured, the FMC controller splits automatically the burst access when the memory page size is reached (refer to memory datasheet for page size).

000: No burst split when crossing page boundary (default after reset)

001: 128 bytes

010: 256 bytes

011: 512 bytes

100: 1024 bytes

Others: Reserved, must not be used

Bit 15 **ASYNCWAIT**: Wait signal during asynchronous transfers

This bit enables/disables the FMC to use the wait signal even during an asynchronous protocol.

0: NWAIT signal is not taken in to account when running an asynchronous protocol (default after reset).

1: NWAIT signal is taken in to account when running an asynchronous protocol.

Bit 14 **EXTMOD:** Extended mode enable

This bit enables the FMC to program the write timings for non multiplexed asynchronous accesses inside the FMC_BWTR register, thus resulting in different timings for read and write operations.

0: values inside FMC_BWTR register are not taken into account (default after reset)

1: values inside FMC_BWTR register are taken into account

Note: When the Extended mode is disabled, the FMC can operate in mode 1 or mode 2 as follows:

- *Mode 1 is the default mode when the SRAM/PSRAM memory type is selected (MTYP = 0x0 or 0x01)*
- *Mode 2 is the default mode when the NOR memory type is selected (MTYP = 0x10).*

Bit 13 **WAITEN:** Wait enable bit

This bit enables/disables wait-state insertion via the NWAIT signal when accessing the memory in Synchronous mode.

0: NWAIT signal is disabled (its level not taken into account, no wait state inserted after the programmed flash latency period).

1: NWAIT signal is enabled (its level is taken into account after the programmed latency period to insert wait states if asserted) (default after reset).

Bit 12 **WREN:** Write enable bit

This bit indicates whether write operations are enabled/disabled in the bank by the FMC.

0: Write operations are disabled in the bank by the FMC, an AHB error is reported.

1: Write operations are enabled for the bank by the FMC (default after reset).

Bit 11 **WAITCFG:** Wait timing configuration

The NWAIT signal indicates whether the data from the memory are valid or if a wait state must be inserted when accessing the memory in Synchronous mode. This configuration bit determines if NWAIT is asserted by the memory one clock cycle before the wait state or during the wait state:

0: NWAIT signal is active one data cycle before wait state (default after reset).

1: NWAIT signal is active during wait state (not used for PSRAM).

Bit 10 Reserved, must be kept at reset value.

Bit 9 **WAITPOL:** Wait signal polarity bit

Defines the polarity of the wait signal from memory used for either in Synchronous or Asynchronous mode.

0: NWAIT active low (default after reset)

1: NWAIT active high

Bit 8 **BURSTEN:** Burst enable bit

This bit enables/disables synchronous accesses during read operations. It is valid only for synchronous memories operating in Burst mode.

0: Burst mode disabled (default after reset). Read accesses are performed in Asynchronous mode.

1: Burst mode enable. Read accesses are performed in Synchronous mode.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **FACCEN:** Flash access enable

Enables NOR flash memory access operations.

0: Corresponding NOR flash memory access is disabled.

1: Corresponding NOR flash memory access is enabled (default after reset).

Bits 5:4 **MWID[1:0]:** Memory data bus width

Defines the external memory device width, valid for all type of memories.

00: 8 bits

01: 16 bits (default after reset)

10: 32 bits

11: reserved

Bits 3:2 **MTYP[1:0]:** Memory type

Defines the type of external memory attached to the corresponding memory bank.

00: SRAM/FRAM (default after reset for Bank 2...4)

01: PSRAM (CRAM) / FRAM

10: NOR flash/OneNAND flash (default after reset for Bank 1)

11: reserved

Bit 1 **MUXEN:** Address/data multiplexing enable bit

When this bit is set, the address and data values are multiplexed on the data bus, valid only with NOR and PSRAM memories:

0: Address/data non multiplexed

1: Address/data multiplexed on databus (default after reset)

Bit 0 **MBKEN:** Memory bank enable bit

Enables the memory bank. After reset Bank1 is enabled, all others are disabled. Accessing a disabled bank causes an ERROR on AHB bus.

0: Corresponding memory bank is disabled.

1: Corresponding memory bank is enabled.

SRAM/NOR-flash chip-select timing register for bank x (FMC_BTRx)

Address offset: 0x04 + 0x8 * (x - 1), (x = 1 to 4)

Reset value: 0x0FFF FFFF

This register contains the control information of each memory bank, used for SRAMs, PSRAM and NOR flash memories.If the EXTMOD bit is set in the FMC_BCRx register, then this register is partitioned for write and read access, that is, 2 registers are available: one to configure read accesses (this register) and one to configure write accesses (FMC_BWTRx registers).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATAHLD[1:0]		ACCMOD[1:0]		DATLAT[3:0]				CLKDIV[3:0]				BUSTURN[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 **DATAHLD[1:0]:** Data hold phase duration

These bits are written by software to define the duration of the data hold phase in HCLK cycles (refer to *Figure 152* to *Figure 164*), used in asynchronous accesses:

For read accesses

00: DATAHLD phase duration = 0 × HCLK clock cycle (default)

01: DATAHLD phase duration = 1 × HCLK clock cycle

10: DATAHLD phase duration = 2 × HCLK clock cycle

11: DATAHLD phase duration = 3 × HCLK clock cycle

For write accesses

00: DATAHLD phase duration = 1 × HCLK clock cycle (default)

01: DATAHLD phase duration = 2 × HCLK clock cycle

10: DATAHLD phase duration = 3 × HCLK clock cycle

11: DATAHLD phase duration = 4 × HCLK clock cycle

Bits 29:28 **ACCMOD[1:0]:** Access mode

Specifies the asynchronous access modes as shown in the timing diagrams. These bits are taken into account only when the EXTMOD bit in the FMC_BCRx register is 1.

00: Access mode A

01: Access mode B

10: Access mode C

11: Access mode D

Bits 27:24 **DATLAT[3:0]:** (see note below bit descriptions): Data latency for synchronous memory

For synchronous access with read/write Burst mode enabled (BURSTEN / CBURSTRW bits set), defines the number of memory clock cycles (+2) to issue to the memory before reading/writing the first data:

This timing parameter is not expressed in HCLK periods, but in FMC_CLK periods.

For asynchronous access, this value is don't care.

0000: Data latency of 2 CLK clock cycles for first burst access

1111: Data latency of 17 CLK clock cycles for first burst access (default value after reset)

Bits 23:20 **CLKDIV[3:0]:** Clock divide ratio (for FMC_CLK signal)

Defines the period of FMC_CLK clock output signal, expressed in number of HCLK cycles:

0000: FMC_CLK period= 1x HCLK period

0001: FMC_CLK period = 2 × HCLK periods

0010: FMC_CLK period = 3 × HCLK periods

1111: FMC_CLK period = 16 × HCLK periods (default value after reset)

In asynchronous NOR flash, SRAM or PSRAM accesses, this value is don't care.

Note: Refer to Section 25.6.5: Synchronous transactions for FMC_CLK divider ratio formula)

Bits 19:16 **BUSTURN[3:0]:** Bus turnaround phase duration

These bits are written by software to add a delay at the end of current read or write transaction to next transaction on the same bank.

This delay is used to match the minimum time between consecutive transactions (t_{EHEL} from NEx high to NEx low) and the maximum time needed by the memory to free the data bus after a read access (t_{EHQZ}, chip enable high to output Hi-Z). This delay is recommended for mode D and muxed mode. For non-muxed memory, the bus turnaround delay can be set to minimum value.

(BUSTURN + 1)HCLK period ≥ max(t_{EHEL} min, t_{EHQZ} max)

For FRAM memories, the bus turnaround delay must be configured to match the minimum tPC (precharge time) timings. The bus turnaround delay is inserted between any consecutive transactions on the same bank (read/read, write/write, read/write and write/read) to match the tPC memory timing. The chip select is toggling between any consecutive accesses.

(BUSTURN + 1)HCLK period ≥ t_{PC} min

0000: BUSTURN phase duration = 1 HCLK clock cycle added

...

1111: BUSTURN phase duration = 16 x HCLK clock cycles added (default value after reset)

Bits 15:8 **DATAST[7:0]:** Data-phase duration

These bits are written by software to define the duration of the data phase (refer to *Figure 152* to *Figure 164*), used in asynchronous accesses:

0000 0000: Reserved

0000 0001: DATAST phase duration = 1 × HCLK clock cycles

0000 0010: DATAST phase duration = 2 × HCLK clock cycles

...

1111 1111: DATAST phase duration = 255 × HCLK clock cycles (default value after reset)

For each memory type and access mode data-phase duration, refer to the respective figure (*Figure 152* to *Figure 164*).

Example: Mode 1, write access, DATAST=1: Data-phase duration= DATAST+1 = 2 HCLK clock cycles.

Note: In synchronous accesses, this value is don't care.

Bits 7:4 **ADDHLD[3:0]:** Address-hold phase duration

These bits are written by software to define the duration of the *address hold* phase (refer to *Figure 152* to *Figure 164*), used in mode D or multiplexed accesses:
0000: Reserved
0001: ADDHLD phase duration =1 × HCLK clock cycle
0010: ADDHLD phase duration = 2 × HCLK clock cycle
...
1111: ADDHLD phase duration = 15 × HCLK clock cycles (default value after reset)
For each access mode address-hold phase duration, refer to the respective figure (*Figure 152* to *Figure 164*).

Note: In synchronous accesses, this value is not used, the address hold phase is always 1 memory clock period duration.

Bits 3:0 **ADDSET[3:0]:** Address setup phase duration

These bits are written by software to define the duration of the *address setup* phase (refer to *Figure 152* to *Figure 164*), used in SRAMs, ROMs, asynchronous NOR flash and PSRAM:
0000: ADDSET phase duration = 0 × HCLK clock cycle
...
1111: ADDSET phase duration = 15 × HCLK clock cycles (default value after reset)
For each access mode address setup phase duration, refer to the respective figure (*Figure 152* to *Figure 164*).

Note: In synchronous accesses, this value is don't care.
In Muxed mode or mode D, the minimum value for ADDSET is 1.
In mode 1 and PSRAM memory, the minimum value for ADDSET is 1.

Note: PSRAMs (CRAMs) have a variable latency due to internal refresh. Therefore these memories issue the NWAIT signal during the whole latency phase to prolong the latency as needed.
With PSRAMs (CRAMs) the filled DATLAT must be set to 0, so that the FMC exits its latency phase soon and starts sampling NWAIT from memory, then starts to read or write when the memory is ready.
This method can be used also with the latest generation of synchronous flash memories that issue the NWAIT signal, unlike older flash memories (check the datasheet of the specific flash memory being used).

SRAM/NOR-flash write timing registers x (FMC_BWTRx)

Address offset: 0x104 + 0x8 * (x - 1), (x = 1 to 4)

Reset value: 0x0FFF FFFF

This register contains the control information of each memory bank. It is used for SRAMs, PSRAMs and NOR flash memories. When the EXTMOD bit is set in the FMC_BCRx register, then this register is active for write access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATAHLD[1:0]		ACCMOD[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSTURN[3:0]			
rw	rw	rw	rw									rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 **DATAHLD[1:0]:** Data hold phase duration

These bits are written by software to define the duration of the data hold phase in HCLK cycles (refer to *Figure 152* to *Figure 164*), used in asynchronous write accesses:
00: DATAHLD phase duration = 1 × HCLK clock cycle (default)
01: DATAHLD phase duration = 2 × HCLK clock cycle
10: DATAHLD phase duration = 3 × HCLK clock cycle
11: DATAHLD phase duration = 4 × HCLK clock cycle

Bits 29:28 **ACCMOD[1:0]:** Access mode.

Specifies the asynchronous access modes as shown in the next timing diagrams.These bits are taken into account only when the EXTMOD bit in the FMC_BCRx register is 1.
00: Access mode A
01: Access mode B
10: Access mode C
11: Access mode D

Bits 27:20 Reserved, must be kept at reset value.

Bits 19:16 **BUSTURN[3:0]**: Bus turnaround phase duration

These bits are written by software to add a delay at the end of current write transaction to next transaction on the same bank.
For FRAM memories, the bus turnaround delay must be configured to match the minimum t_{PC} (precharge time) timings. The bus turnaround delay is inserted between any consecutive transactions on the same bank (read/read, write/write, read/write and write/read). The chip select is toggling between any consecutive accesses.
(BUSTURN + 1)HCLK period ≥ tPC min

0000: BUSTURN phase duration = 1 HCLK clock cycle added
...
1111: BUSTURN phase duration = 16 x HCLK clock cycles added (default value after reset)

Bits 15:8 **DATAST[7:0]:** Data-phase duration.

These bits are written by software to define the duration of the data phase (refer to *Figure 152* to *Figure 164*), used in asynchronous SRAM, PSRAM and NOR flash memory accesses:
0000 0000: Reserved
0000 0001: DATAST phase duration = 1 × HCLK clock cycles
0000 0010: DATAST phase duration = 2 × HCLK clock cycles
...
1111 1111: DATAST phase duration = 255 × HCLK clock cycles (default value after reset)

Bits 7:4 **ADDHLD[3:0]:** Address-hold phase duration.

These bits are written by software to define the duration of the *address hold* phase (refer to *Figure 161* to *Figure 164*), used in asynchronous multiplexed accesses:
0000: Reserved
0001: ADDHLD phase duration = 1 × HCLK clock cycle
0010: ADDHLD phase duration = 2 × HCLK clock cycle
...
1111: ADDHLD phase duration = 15 × HCLK clock cycles (default value after reset)

Note: In synchronous NOR flash accesses, this value is not used, the address hold phase is always 1 flash clock period duration.

Bits 3:0 **ADDSET[3:0]:** Address setup phase duration.

These bits are written by software to define the duration of the *address setup* phase in HCLK cycles (refer to *Figure 152* to *Figure 164*), used in asynchronous accesses:

0000: ADDSET phase duration = 0 × HCLK clock cycle

...

1111: ADDSET phase duration = 15 × HCLK clock cycles (default value after reset)

Note: In synchronous accesses, this value is not used, the address setup phase is always 1 flash clock period duration. In muxed mode, the minimum ADDSET value is 1.

PSRAM chip select counter register (FMC_PCSCNTR)

Address offset: 0x20

Reset value: 0x0000 0000

This register contains the PSRAM chip select counter value for Synchronous and Asynchronous modes. The chip select counter is common to all banks and can be enabled separately on each bank. During PSRAM read or write accesses, this value is loaded into a timer which is decremented while the NE signal is held low. When the timer reaches 0, the PSRAM controller splits the current access, toggles NE to allow PSRAM device refresh, and restarts a new access. The programmed counter value guarantees a maximum NE pulse width (t_{CEM}) as specified for PSRAM devices. The counter is reloaded and starts decrementing each time a new access is started by a transition of NE from high to low.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNTB4EN	CNTB3EN	CNTB2EN	CNTB1EN
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CSCOUNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **CNTB4EN:** Counter Bank 4 enable

This bit enables the chip select counter for PSRAM/NOR Bank 4.

0: Counter disabled for Bank 4

1: Counter enabled for Bank 4

Bit 18 **CNTB3EN:** Counter Bank 3 enable

This bit enables the chip select counter for PSRAM/NOR Bank 3.

0: Counter disabled for Bank 3.

1: Counter enabled for Bank 3

Bit 17 **CNTB2EN:** Counter Bank 2 enable

This bit enables the chip select counter for PSRAM/NOR Bank 2.

0: Counter disabled for Bank 2

1: Counter enabled for Bank 2

Bit 16 **CNTB1EN:** Counter Bank 1 enable

This bit enables the chip select counter for PSRAM/NOR Bank 1.

0: Counter disabled for Bank 1

1: Counter enabled for Bank 1

Bits 15:0 **CSCOUNT[15:0]:** Chip select counter.

This bitfield is used to define the maximum duration of the chip select low, which is obtained by the formula:

CSCOUNT[15:0] * T_{AHB}, where T_{AHB} is the AHB clock period.

For refresh considerations, the PSRAM chip select must not stay low for more than t_{CEM} = ~4 µs.

CSCOUNT[15:0] applies both to asynchronous and synchronous modes.

When CSCOUNT[15:0] = 0x0000, the feature is disabled.

25.7 NAND flash controller

The FMC generates the appropriate signal timings to drive the following types of device:

- 8- and 16-bit NAND flash memories

The NAND bank is configured through dedicated registers (*Section 25.7.7*). The programmable memory parameters include access timings (shown in *Table 238*) and ECC configuration.

Table 238. Programmable NAND flash access parameters

Parameter	Function	Access mode	Unit	Min.	Max.
Memory setup time	Number of clock cycles (HCLK) required to set up the address before the command assertion	Read/Write	AHB clock cycle (HCLK)	1	255
Memory wait	Minimum duration (in HCLK clock cycles) of the command assertion	Read/Write	AHB clock cycle (HCLK)	2	255
Memory hold	Number of clock cycles (HCLK) during which the address must be held (as well as the data if a write access is performed) after the command de-assertion	Read/Write	AHB clock cycle (HCLK)	1	254
Memory databus high-Z	Number of clock cycles (HCLK) during which the data bus is kept in high-Z state after a write access has started	Write	AHB clock cycle (HCLK)	1	255

25.7.1 External memory interface signals

The following tables list the signals that are typically used to interface NAND flash memory.

Note: The prefix “N” identifies the signals which are active low.

8-bit NAND flash memory

Table 239. 8-bit NAND flash

FMC signal name	I/O	Function
A[17]	O	NAND flash address latch enable (ALE) signal
A[16]	O	NAND flash command latch enable (CLE) signal
D[7:0]	I/O	8-bit multiplexed, bidirectional address/data bus

Table 239. 8-bit NAND flash (continued)

FMC signal name	I/O	Function
NCE	O	Chip select
NOE(= NRE)	O	Output enable (memory signal name: read enable, NRE)
NWE	O	Write enable
NWAIT/INT	I	NAND flash ready/busy input signal to the FMC

Theoretically, there is no capacity limitation as the FMC can manage as many address cycles as needed.

16-bit NAND flash memory

Table 240. 16-bit NAND flash

FMC signal name	I/O	Function
A[17]	O	NAND flash address latch enable (ALE) signal
A[16]	O	NAND flash command latch enable (CLE) signal
D[15:0]	I/O	16-bit multiplexed, bidirectional address/data bus
NCE	O	Chip select
NOE(= NRE)	O	Output enable (memory signal name: read enable, NRE)
NWE	O	Write enable
NWAIT/INT	I	NAND flash ready/busy input signal to the FMC

Theoretically, there is no capacity limitation as the FMC can manage as many address cycles as needed.

25.7.2 NAND flash supported memories and transactions

Table 241 shows the supported devices, access modes and transactions. Transactions not allowed (or not supported) by the NAND flash controller are shown in gray.

Table 241. Supported memories and transactions

Device	Mode	R/W	AHB data size	Memory data size	Allowed/ not allowed	Comments
NAND 8-bit	Asynchronous	R	8	8	Y	-
	Asynchronous	W	8	8	Y	-
	Asynchronous	R	16	8	Y	Split into 2 FMC accesses
	Asynchronous	W	16	8	Y	Split into 2 FMC accesses
	Asynchronous	R	32	8	Y	Split into 4 FMC accesses
	Asynchronous	W	32	8	Y	Split into 4 FMC accesses

Table 241. Supported memories and transactions (continued)

Device	Mode	R/W	AHB data size	Memory data size	Allowed/ not allowed	Comments
NAND 16-bit	Asynchronous	R	8	16	Y	-
	Asynchronous	W	8	16	N	-
	Asynchronous	R	16	16	Y	-
	Asynchronous	W	16	16	Y	-
	Asynchronous	R	32	16	Y	Split into 2 FMC accesses
	Asynchronous	W	32	16	Y	Split into 2 FMC accesses

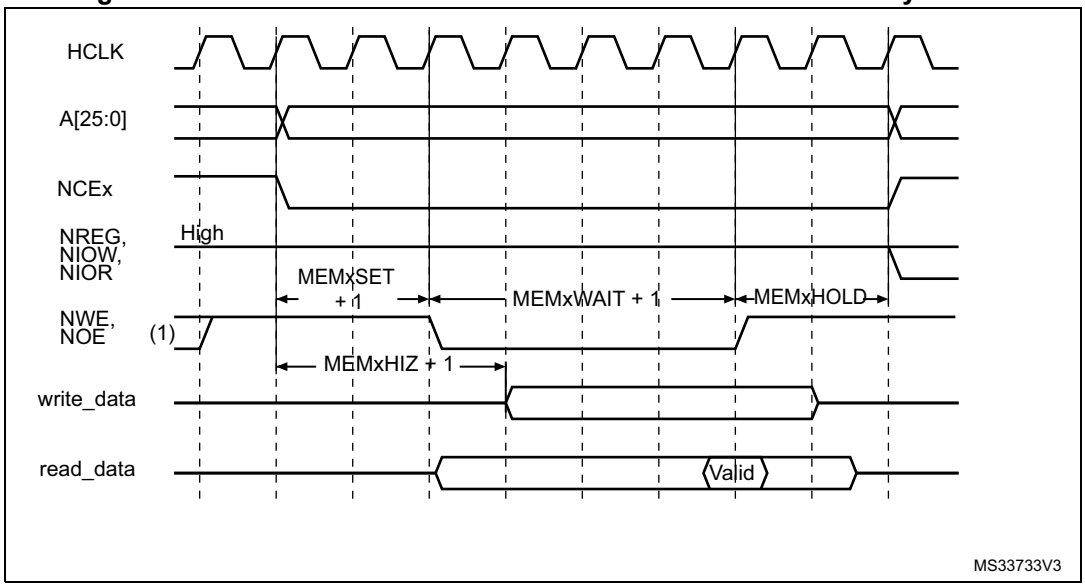
25.7.3 Timing diagrams for NAND flash memory

The NAND flash memory bank is managed through a set of registers:

- Control register: FMC_PCR
- Interrupt status register: FMC_SR
- ECC register: FMC_ECCR
- Timing register for Common memory space: FMC_PMEM
- Timing register for Attribute memory space: FMC_PATT

Each timing configuration register contains three parameters used to define number of HCLK cycles for the three phases of any NAND flash access, plus one parameter that defines the timing for starting driving the data bus when a write access is performed. *Figure 170* shows the timing parameter definitions for common memory accesses, knowing that Attribute memory space access timings are similar.

Figure 170. NAND flash controller waveforms for common memory access



1. NOE remains high (inactive) during write accesses. NWE remains high (inactive) during read accesses.
2. For write access, the hold phase delay is (MEMHOLD) HCLK cycles and for read access is (MEMHOLD + 2) HCLK cycles.

25.7.4 NAND flash operations

The command latch enable (CLE) and address latch enable (ALE) signals of the NAND flash memory device are driven by address signals from the FMC controller. This means that to send a command or an address to the NAND flash memory, the CPU has to perform a write to a specific address in its memory space.

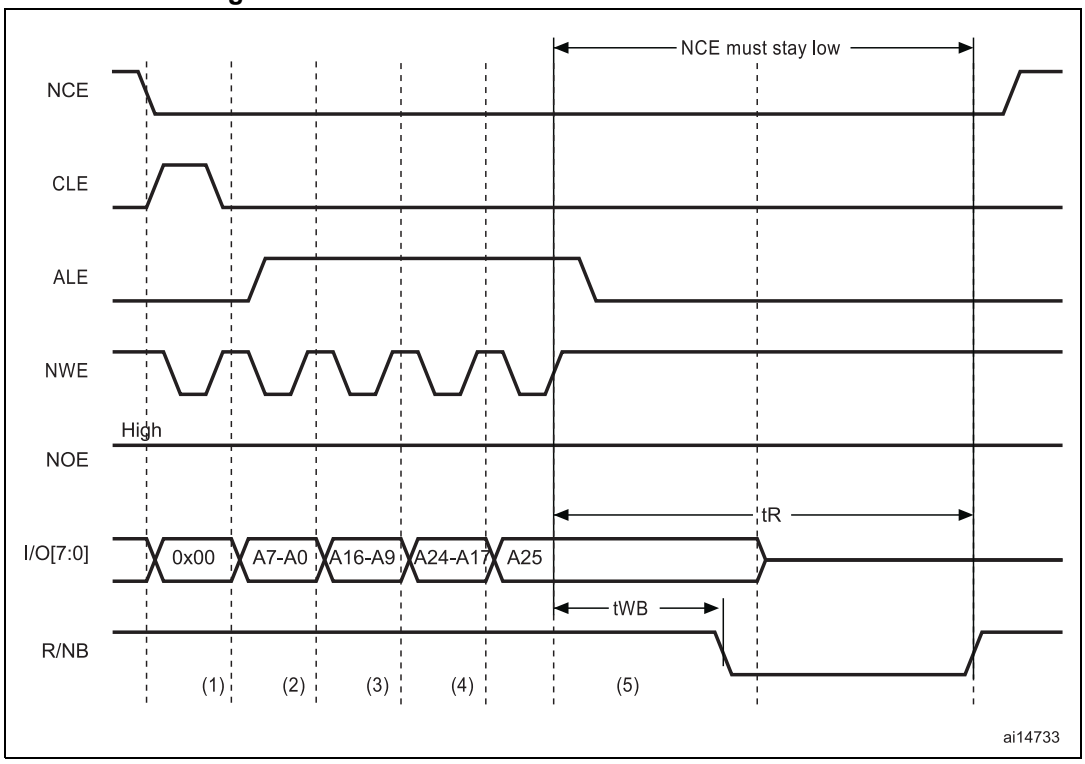
A typical page read operation from the NAND flash device requires the following steps:

1. Program and enable the corresponding memory bank by configuring the FMC_PCR and FMC_PMEM (and for some devices, FMC_PATT, see *Section 25.7.5: NAND flash prewait functionality*) registers according to the characteristics of the NAND flash memory (PWID bits for the data bus width of the NAND flash, PTYP = 1, PWAITEN = 0 or 1 as needed, see *Section 25.5.2: NAND flash memory address mapping* for timing configuration).
2. The CPU performs a byte write to the common memory space, with data byte equal to one flash command byte (for example 0x00 for Samsung NAND flash devices). The LE input of the NAND flash memory is active during the write strobe (low pulse on NWE), thus the written byte is interpreted as a command by the NAND flash memory. Once the command is latched by the memory device, it does not need to be written again for the following page read operations.
3. The CPU can send the start address (STARTAD) for a read operation by writing four bytes (or three for smaller capacity devices), STARTAD[7:0], STARTAD[16:9], STARTAD[24:17] and finally STARTAD[25] (for 64 Mb x 8 bit NAND flash memories) in the common memory or attribute space. The ALE input of the NAND flash device is active during the write strobe (low pulse on NWE), thus the written bytes are interpreted as the start address for read operations. Using the attribute memory space makes it possible to use a different timing configuration of the FMC, which can be used to implement the prewait functionality needed by some NAND flash memories (see details in *Section 25.7.5: NAND flash prewait functionality*).
4. The controller waits for the NAND flash memory to be ready (R/NB signal high), before starting a new access to the same or another memory bank. While waiting, the controller holds the NCE signal active (low).
5. The CPU can then perform byte read operations from the common memory space to read the NAND flash page (data field + Spare field) byte by byte.
6. The next NAND flash page can be read without any CPU command or address write operation. This can be done in three different ways:
   - by simply performing the operation described in step 5
   - a new random address can be accessed by restarting the operation at step 3
   - a new command can be sent to the NAND flash device by restarting at step 2

25.7.5 NAND flash prewait functionality

Some NAND flash devices require that, after writing the last part of the address, the controller waits for the R/NB signal to go low (see *Figure 171*).

Figure 171. Access to non 'CE don't care' NAND-flash



1. CPU wrote byte 0x00 at address 0x7001 0000.
2. CPU wrote byte A7~A0 at address 0x7002 0000.
3. CPU wrote byte A16~A9 at address 0x7002 0000.
4. CPU wrote byte A24~A17 at address 0x7002 0000.
5. CPU wrote byte A25 at address 0x7802 0000: FMC performs a write access using FMC_PATT timing definition, where ATTHOLD ≥ 7 (providing that (7+1) × HCLK = 112 ns > t_{WB} max). This guarantees that NCE remains low until R/NB goes low and high again (only requested for NAND flash memories where NCE is not don't care).

When this functionality is required, it can be ensured by programming the MEMHOLD value to meet the t_{WB} timing. However any CPU read access to the NAND flash memory has a hold delay of (MEMHOLD + 2) HCLK cycles and CPU write access has a hold delay of (MEMHOLD) HCLK cycles inserted between the rising edge of the NWE signal and the next access.

To cope with this timing constraint, the attribute memory space can be used by programming its timing register with an ATTHOLD value that meets the t_{WB} timing, and by keeping the MEMHOLD value at its minimum value. The CPU must then use the common memory space for all NAND flash read and write accesses, except when writing the last address byte to the NAND flash device, where the CPU must write to the attribute memory space.

25.7.6 Computation of the error correction code (ECC) in NAND flash memory

The FMC NAND Card controller includes two error correction code computation hardware blocks, one per memory bank. They reduce the host CPU workload when processing the ECC by software.

These two ECC blocks are identical and associated with Bank 2 and Bank 3. As a consequence, no hardware ECC computation is available for memories connected to Bank 4.

The ECC algorithm implemented in the FMC can perform 1-bit error correction and 2-bit error detection per 256, 512, 1 024, 2 048, 4 096 or 8 192 bytes read or written from/to the NAND flash memory. It is based on the Hamming coding algorithm and consists in calculating the row and column parity.

The ECC modules monitor the NAND flash data bus and read/write signals (NCE and NWE) each time the NAND flash memory bank is active.

The ECC operates as follows:

- When accessing NAND flash memory bank 2 or bank 3, the data present on the D[15:0] bus is latched and used for ECC computation.
- When accessing any other address in NAND flash memory, the ECC logic is idle, and does not perform any operation. As a result, write operations to define commands or addresses to the NAND flash memory are not taken into account for ECC computation.

Once the desired number of bytes has been read/written from/to the NAND flash memory by the host CPU, the FMC_ECCR registers must be read to retrieve the computed value. Once read, they must be cleared by resetting the ECCEN bit to ‘0’. To compute a new data block, the ECCEN bit must be set to one in the FMC_PCR registers.

To perform an ECC computation:

1. Enable the ECCEN bit in the FMC_PCR register.
2. Write data to the NAND flash memory page. While the NAND page is written, the ECC block computes the ECC value.
3. Read the ECC value available in the FMC_ECCR register and store it in a variable.
4. Clear the ECCEN bit and then enable it in the FMC_PCR register before reading back the written data from the NAND page. While the NAND page is read, the ECC block computes the ECC value.
5. Read the new ECC value available in the FMC_ECCR register.
6. If the two ECC values are the same, no correction is required, otherwise there is an ECC error and the software correction routine returns information on whether the error can be corrected or not.

25.7.7 NAND flash controller registers

NAND flash control registers (FMC_PCR)

Address offset: 0x80

Reset value: 0x0000 0018

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCPS[2:0]			TAR3
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TAR[2:0]			TCLR[3:0]				Res.	Res.	ECCEN	PWID[1:0]		PTYP	PBKEN	PWAITEN	Res.
rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw	

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:17 **ECCPS[2:0]:** ECC page size
Defines the page size for the extended ECC:
000: 256 bytes
001: 512 bytes
010: 1024 bytes
011: 2048 bytes
100: 4096 bytes
101: 8192 bytes

Bits 16:13 **TAR[3:0]:** ALE to RE delay
Sets time from ALE low to RE low in number of AHB clock cycles (HCLK).
Time is: t_ar = (TAR + SET + 2) × THCLK where THCLK is the HCLK clock period
0000: 1 HCLK cycle (default)
1111: 16 HCLK cycles
Note: SET is MEMSET or ATTSET according to the addressed space.

Bits 12:9 **TCLR[3:0]:** CLE to RE delay
Sets time from CLE low to RE low in number of AHB clock cycles (HCLK).
Time is t_clr = (TCLR + SET + 2) × THCLK where THCLK is the HCLK clock period
0000: 1 HCLK cycle (default)
1111: 16 HCLK cycles
Note: SET is MEMSET or ATTSET according to the addressed space.

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **ECCEN:** ECC computation logic enable bit
0: ECC logic is disabled and reset (default after reset),
1: ECC logic is enabled.

Bits 5:4 **PWID[1:0]:** Data bus width
Defines the external memory device width.
00: 8 bits
01: 16 bits (default after reset).
10: reserved.
11: reserved.

Bit 3 **PTYP:** Memory type
Defines the type of device attached to the corresponding memory bank:
0: Reserved, must be kept at reset value
1: NAND flash (default after reset)

Bit 2 **PBKEN:** NAND flash memory bank enable bit
Enables the memory bank. Accessing a disabled memory bank causes an ERROR on AHB bus
0: Corresponding memory bank is disabled (default after reset)
1: Corresponding memory bank is enabled

Bit 1 **PWAITEN:** Wait feature enable bit
Enables the Wait feature for the NAND flash memory bank:
0: disabled
1: enabled

Bit 0 Reserved, must be kept at reset value.

FIFO status and interrupt register (FMC_SR)

Address offset: 0x84

Reset value: 0x0000 0040

This register contains information about the FIFO status and interrupt. The FMC features a FIFO that is used when writing to memories to transfer up to 16 words of data from the AHB.

This is used to quickly write to the FIFO and free the AHB for transactions to peripherals other than the FMC, while the FMC is draining its FIFO into the memory. One of these register bits indicates the status of the FIFO, for ECC purposes.

The ECC is calculated while the data are written to the memory. To read the correct ECC, the software must consequently wait until the FIFO is empty.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FEMPT	IFEN	ILEN	IREN	IFS	ILS	IRS
									r	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **FEMPT:** FIFO empty

Read-only bit that provides the status of the FIFO

0: FIFO not empty

1: FIFO empty

Bit 5 **IFEN:** Interrupt falling edge detection enable bit

0: Interrupt falling edge detection request disabled

1: Interrupt falling edge detection request enabled

Bit 4 **ILEN:** Interrupt high-level detection enable bit

0: Interrupt high-level detection request disabled

1: Interrupt high-level detection request enabled

Bit 3 **IREN:** Interrupt rising edge detection enable bit

0: Interrupt rising edge detection request disabled

1: Interrupt rising edge detection request enabled

Bit 2 **IFS:** Interrupt falling edge status

The flag is set by hardware and reset by software.

0: No interrupt falling edge occurred

1: Interrupt falling edge occurred

Note: If this bit is written by software to 1 it is set.

Bit 1 **ILS:** Interrupt high-level status

The flag is set by hardware and reset by software.

0: No Interrupt high-level occurred

1: Interrupt high-level occurred

Bit 0 **IRS:** Interrupt rising edge status

The flag is set by hardware and reset by software.

0: No interrupt rising edge occurred

1: Interrupt rising edge occurred

Note: If this bit is written by software to 1 it is set.

Common memory space timing register (FMC_PMEM)

Address offset: 0x88

Reset value: 0xFCFC FCFC

The FMC_PMEM read/write register contains the timing information for NAND flash memory bank. This information is used to access either the common memory space of the NAND flash for command, address write access and data read/write access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MEMHIZ[7:0]								MEMHOLD[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MEMWAIT[7:0]								MEMSET[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **MEMHIZ[7:0]:** Common memory x data bus Hi-Z time

Defines the number of HCLK clock cycles during which the data bus is kept Hi-Z after the start of a NAND flash write access to common memory space on socket. This is only valid for write transactions:

0000 0000: 1 HCLK cycle

1111 1110: 255 HCLK cycles

1111 1111: reserved.

Bits 23:16 **MEMHOLD[7:0]:** Common memory hold time

Defines the number of HCLK clock cycles for write access and HCLK (+2) clock cycles for read access during which the address is held (and data for write accesses) after the command is deasserted (NWE, NOE), for NAND flash read or write access to common memory space on socket x:

0000 0000: reserved.

0000 0001: 1 HCLK cycle for write access / 3 HCLK cycles for read access

1111 1110: 254 HCLK cycles for write access / 256 HCLK cycles for read access

1111 1111: reserved.

Bits 15:8 **MEMWAIT[7:0]:** Common memory wait time

Defines the minimum number of HCLK (+1) clock cycles to assert the command (NWE, NOE), for NAND flash read or write access to common memory space on socket. The duration of command assertion is extended if the wait signal (NWAIT) is active (low) at the end of the programmed value of HCLK:

0000 0000: reserved

0000 0001: 2HCLK cycles (+ wait cycle introduced by deasserting NWAIT)

1111 1110: 255 HCLK cycles (+ wait cycle introduced by deasserting NWAIT)

1111 1111: reserved.

Bits 7:0 **MEMSET[7:0]:** Common memory x setup time

Defines the number of HCLK (+1) clock cycles to set up the address before the command assertion (NWE, NOE), for NAND flash read or write access to common memory space on socket x:
0000 0000: 1 HCLK cycle
1111 1110: 255 HCLK cycles
1111 1111: reserved

Attribute memory space timing register (FMC_PATT)

Address offset: 0x8C

Reset value: 0xFCFC FCFC

The FMC_PATT read/write register contains the timing information for NAND flash memory bank. It is used for 8-bit accesses to the attribute memory space of the NAND flash for the last address write access if the timing must differ from that of previous accesses (for Ready/Busy management, refer to *Section 25.7.5: NAND flash prewait functionality*).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ATTHIZ[7:0]								ATTHOLD[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ATTWAIT[7:0]								ATTSET[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **ATTHIZ[7:0]:** Attribute memory data bus Hi-Z time

Defines the number of HCLK clock cycles during which the data bus is kept in Hi-Z after the start of a NAND flash write access to attribute memory space on socket. Only valid for writ transaction:
0000 0000: 1 HCLK cycle
1111 1110: 255 HCLK cycles
1111 1111: reserved.

Bits 23:16 **ATTHOLD[7:0]:** Attribute memory hold time

Defines the number of HCLK clock cycles for write access and HCLK (+2) clock cycles for read access during which the address is held (and data for write access) after the command deassertion (NWE, NOE), for NAND flash read or write access to attribute memory space on socket:
0000 0000: reserved
0000 0001: 1 HCLK cycle for write access / 3 HCLK cycles for read access
1111 1110: 254 HCLK cycles for write access / 256 HCLK cycles for read access
1111 1111: reserved.

Bits 15:8 **ATTWAIT[7:0]:** Attribute memory wait time

Defines the minimum number of HCLK (+1) clock cycles to assert the command (NWE, NOE), for NAND flash read or write access to attribute memory space on socket x. The duration for command assertion is extended if the wait signal (NWAIT) is active (low) at the end of the programmed value of HCLK:
0000 0000: reserved
0000 0001: 2 HCLK cycles (+ wait cycle introduced by deassertion of NWAIT)
1111 1110: 255 HCLK cycles (+ wait cycle introduced by deasserting NWAIT)
1111 1111: reserved.

Bits 7:0 **ATTSET[7:0]:** Attribute memory setup time

Defines the number of HCLK (+1) clock cycles to set up address before the command assertion (NWE, NOE), for NAND flash read or write access to attribute memory space on socket:
0000 0000: 1 HCLK cycle
1111 1110: 255 HCLK cycles
1111 1111: reserved.

ECC result registers (FMC_ECCR)

Address offset: 0x94

Reset value: 0x0000 0000

This register contain the current error correction code value computed by the ECC computation modules of the FMC NAND controller. When the CPU reads the data from a NAND flash memory page at the correct address (refer to *Section 25.7.6: Computation of the error correction code (ECC) in NAND flash memory*), the data read/written from/to the NAND flash memory are processed automatically by the ECC computation module. When X bytes have been read (according to the ECCPS field in the FMC_PCR registers), the CPU must read the computed ECC value from the FMC_ECC registers. It then verifies if these computed parity data are the same as the parity value recorded in the spare area, to determine whether a page is valid, and, to correct it otherwise. The FMC_ECCR register must be cleared after being read by setting the ECCEN bit to 0. To compute a new data block, the ECCEN bit must be set to 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ECC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ECC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **ECC[31:0]:** ECC result

This field contains the value computed by the ECC computation logic. *Table 242* describes the contents of these bitfields.

Table 242. ECC result relevant bits

ECCPS[2:0]	Page size in bytes	ECC bits
000	256	ECC[21:0]
001	512	ECC[23:0]
010	1024	ECC[25:0]
011	2048	ECC[27:0]
100	4096	ECC[29:0]
101	8192	ECC[31:0]

25.8 SDRAM controller

25.8.1 SDRAM controller main features

The main features of the SDRAM controller are the following:

- Two SDRAM banks with independent configuration
- 8-bit, 16-bit, 32-bit data bus width
- 13-bits Address Row, 11-bits Address Column, 4 internal banks: 4x16Mx32bit (256 MB), 4x16Mx16bit (128 MB), 4x16Mx8bit (64 MB)
- Word, half-word, byte access
- Automatic row and bank boundary management
- Multibank ping-pong access
- Programmable timing parameters
- Automatic Refresh operation with programmable Refresh rate
- Self-refresh mode
- Power-down mode
- SDRAM power-up initialization by software
- CAS latency of 1,2,3
- Cacheable Read FIFO with depth of 6 lines x32-bit (6 x14-bit address tag)

25.8.2 SDRAM External memory interface signals

At startup, the SDRAM I/O pins used to interface the FMC SDRAM controller with the external SDRAM devices must configured by the user application. The SDRAM controller I/O pins which are not used by the application, can be used for other purposes.

Table 243. SDRAM signals

SDRAM signal	I/O type	Description	Alternate function
SDCLK	O	SDRAM clock	-
SDCKE[1:0]	O	SDCKE0: SDRAM Bank 1 Clock Enable SDCKE1: SDRAM Bank 2 Clock Enable	-
SDNE[1:0]	O	SDNE0: SDRAM Bank 1 Chip Enable SDNE1: SDRAM Bank 2 Chip Enable	-
A[12:0]	O	Address	FMC_A[12:0]
D[31:0]	I/O	Bidirectional data bus	FMC_D[31:0]
BA[1:0]	O	Bank Address	FMC_A[15:14]
NRAS	O	Row Address Strobe	-
NCAS	O	Column Address Strobe	-
SDNWE	O	Write Enable	-
NBL[3:0]	O	Output Byte Mask for write accesses (memory signal name: DQM[3:0]	FMC_NBL[3:0]

25.8.3 SDRAM controller functional description

All SDRAM controller outputs (signals, address and data) change on the falling edge of the memory clock (FMC_SDCLK).

SDRAM initialization

The initialization sequence is managed by software. If the two banks are used, the initialization sequence must be generated simultaneously to Bank 1and Bank 2 by setting the Target Bank bits CTB1 and CTB2 in the FMC_SDCMR register:

1. Program the memory device features into the FMC_SDCRx register. The SDRAM clock frequency, RBURST and RPIPE must be programmed in the FMC_SDCR1 register.
2. Program the memory device timing into the FMC_SDTRx register. The TRP and TRC timings must be programmed in the FMC_SDTR1 register.
3. Set MODE bits to ‘001’ and configure the Target Bank bits (CTB1 and/or CTB2) in the FMC_SDCMR register to start delivering the clock to the memory (SDCKE is driven high).
4. Wait during the prescribed delay period. Typical delay is around 100 µs (refer to the SDRAM datasheet for the required delay after power-up).
5. Set MODE bits to ‘010’ and configure the Target Bank bits (CTB1 and/or CTB2) in the FMC_SDCMR register to issue a “Precharge All” command.
6. Set MODE bits to ‘011’, and configure the Target Bank bits (CTB1 and/or CTB2) as well as the number of consecutive Auto-refresh commands (NRFS) in the FMC_SDCMR register. Refer to the SDRAM datasheet for the number of Auto-refresh commands that should be issued. Typical number is 8.
7. Configure the MRD field according to the SDRAM device, set the MODE bits to '100', and configure the Target Bank bits (CTB1 and/or CTB2) in the FMC_SDCMR register to issue a "Load Mode Register" command in order to program the SDRAM device. In particular:
   a) the CAS latency must be selected following configured value in FMC_SDCR1/2 registers
   b) the Burst Length (BL) of 1 must be selected by configuring the M[2:0] bits to 000 in the mode register. Refer to SDRAM device datasheet.

   If the Mode Register is not the same for both SDRAM banks, this step has to be repeated twice, once for each bank, and the Target Bank bits set accordingly.
8. Program the refresh rate in the FMC_SDRTR register

   The refresh rate corresponds to the delay between refresh cycles. Its value must be adapted to SDRAM devices.
9. For mobile SDRAM devices, to program the extended mode register it should be done once the SDRAM device is initialized: First, a dummy read access should be performed while BA1=1 and BA=0 (refer to SDRAM address mapping section for BA[1:0] address mapping) in order to select the extended mode register instead of the load mode register and then program the needed value.

At this stage the SDRAM device is ready to accept commands. If a system reset occurs during an ongoing SDRAM access, the data bus might still be driven by the SDRAM device. Therefor the SDRAM device must be first reinitialized after reset before issuing any new access by the NOR flash/PSRAM/SRAM or NAND flash controller.

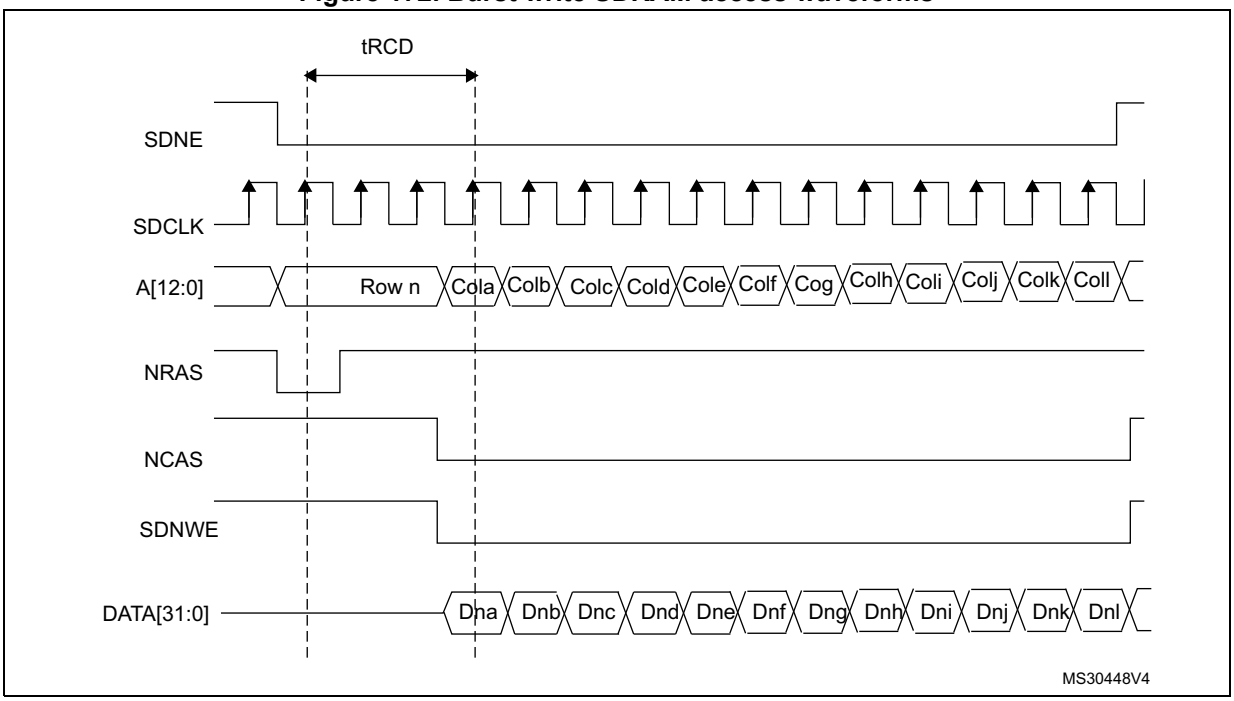
Note: If two SDRAM devices are connected to the FMC, all the accesses performed at the same time to both devices by the Command Mode register (Load Mode Register command) are issued using the timing parameters configured for SDRAM Bank 1 (TMRD andTRAS timings) in the FMC_SDTR1 register.

SDRAM controller write cycle

The SDRAM controller accepts single and burst write requests and translates them into single memory accesses. In both cases, the SDRAM controller keeps track of the active row for each bank to be able to perform consecutive write accesses to different banks (Multibank ping-pong access).

Before performing any write access, the SDRAM bank write protection must be disabled by clearing the WP bit in the FMC_SDCRx register.

Figure 172. Burst write SDRAM access waveforms



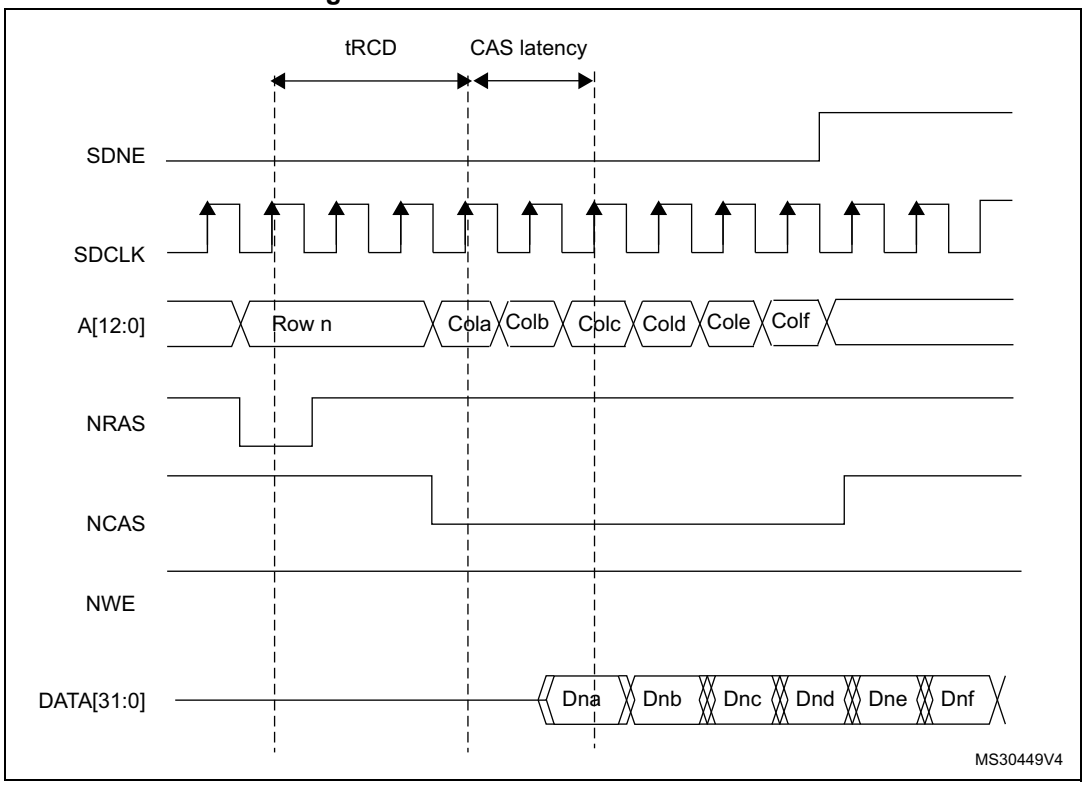
The SDRAM controller always checks the next access.

- If the next access is in the same row or in another active row, the write operation is carried out,
- if the next access targets another row (not active), the SDRAM controller generates a precharge command, activates the new row and initiates a write command.

SDRAM controller read cycle

The SDRAM controller accepts single and burst read requests and translates them into single memory accesses. In both cases, the SDRAM controller keeps track of the active row in each bank to be able to perform consecutive read accesses in different banks (Multibank ping-pong access).

Figure 173. Burst read SDRAM access



The FMC SDRAM controller features a Cacheable read FIFO (6 lines x 32 bits). It is used to store data read in advance during the CAS latency period and the RPIPE delay following the below formula. The RBURST bit must be set in the FMC_SDCR1 register to anticipate the next read access.

Number for anticipated data = CAS latency + 1 + (RPIPE delay)/2

Examples:

- CAS latency = 3, RPIPE delay = 0: Four data (not committed) are stored in the FIFO.
- CAS latency = 3, RPIPE delay = 2: Five data (not committed) are stored in the FIFO.

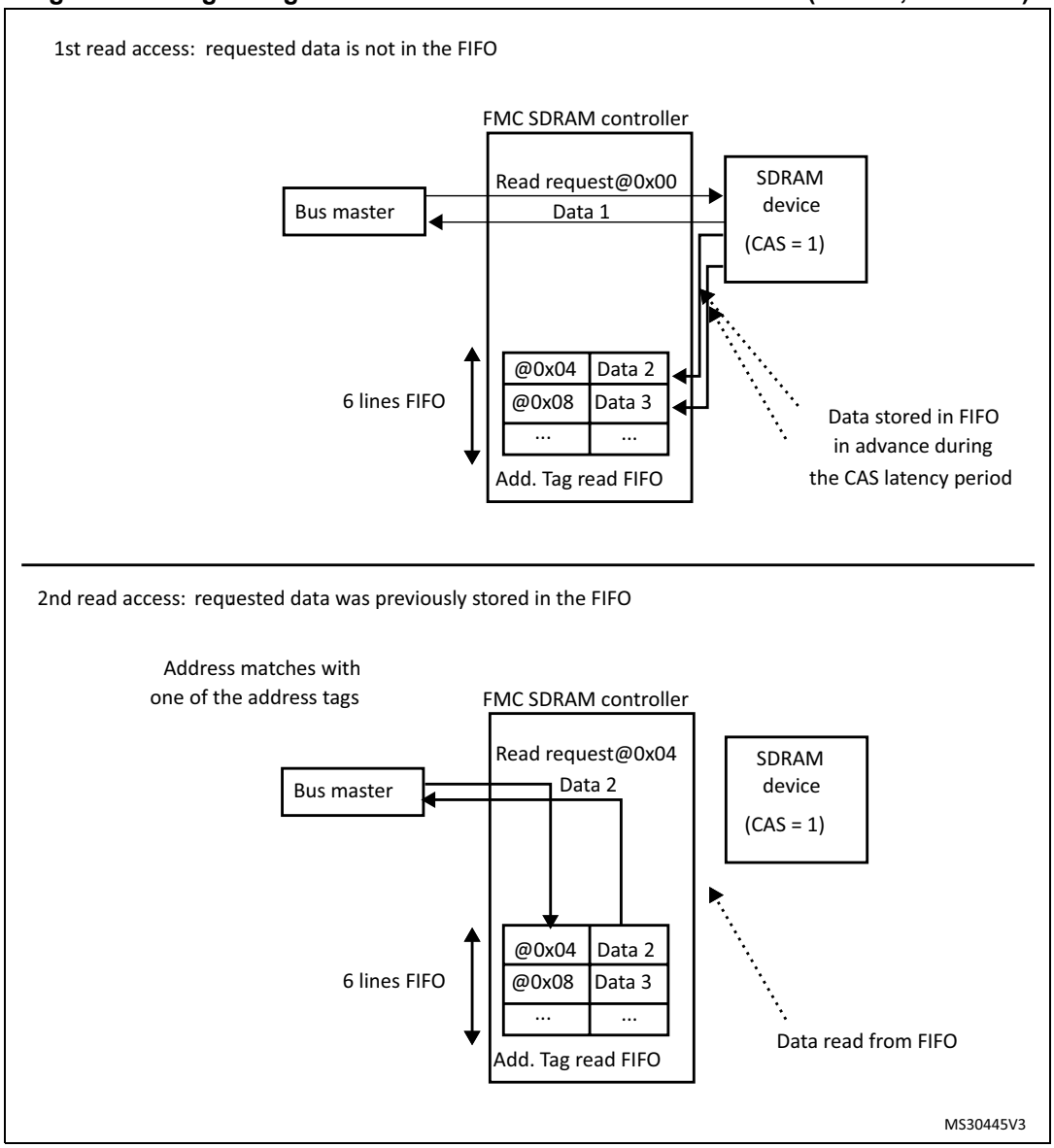
The read FIFO features a 14-bit address tag to each line to identify its content: 11 bits for the column address, 2 bits to select the internal bank and the active row, and 1 bit to select the SDRAM device

When the end of the row is reached in advance during an AHB burst read, the data read in advance (not committed) are not stored in the read FIFO. For single read access, data are correctly stored in the FIFO.

Each time a read request occurs, the SDRAM controller checks:

- If the address matches one of the address tags, data are directly read from the FIFO and the corresponding address tag/ line content is cleared and the remaining data in the FIFO are compacted to avoid empty lines.
- Otherwise, a new read command is issued to the memory and the FIFO is updated with new data. If the FIFO is full, the older data are lost.

Figure 174. Logic diagram of Read access with RBURST bit set (CAS=1, RPIPE=0)



During a write access or a Precharge command, the read FIFO is flushed and ready to be filled with new data.

After the first read request, if the current access was not performed to a row boundary, the SDRAM controller anticipates the next read access during the CAS latency period and the RPIPE delay (if configured). This is done by incrementing the memory address. The following condition must be met:

- RBURST control bit should be set to ‘1’ in the FMC_SDCR1 register.

The address management depends on the next AHB request:

- Next AHB request is sequential (AHB Burst)

  In this case, the SDRAM controller increments the address.
- Next AHB request is not sequential
  - If the new read request targets the same row or another active row, the new address is passed to the memory and the master is stalled for the CAS latency period, waiting for the new data from memory.
  - If the new read request does not target an active row, the SDRAM controller generates a Precharge command, activates the new row, and initiates a read command.

If the RURST is reset, the read FIFO is not used.

Row and bank boundary management

When a read or write access crosses a row boundary, if the next read or write access is sequential and the current access was performed to a row boundary, the SDRAM controller executes the following operations:

1. Precharge of the active row,
2. Activation of the new row
3. Start of a read/write command.

At a row boundary, the automatic activation of the next row is supported for all columns and data bus width configurations.

If necessary, the SDRAM controller inserts additional clock cycles between the following commands:

- Between Precharge and Activate commands to match TRP parameter (only if the next access is in a different row in the same bank),
- Between Activate and Read commands to match the TRCD parameter.

These parameters are defined into the FMC_SDTRx register.

Refer to *Figure 172* and *Figure 173* for read and burst write access crossing a row boundary.

Figure 175. Read access crossing row boundary

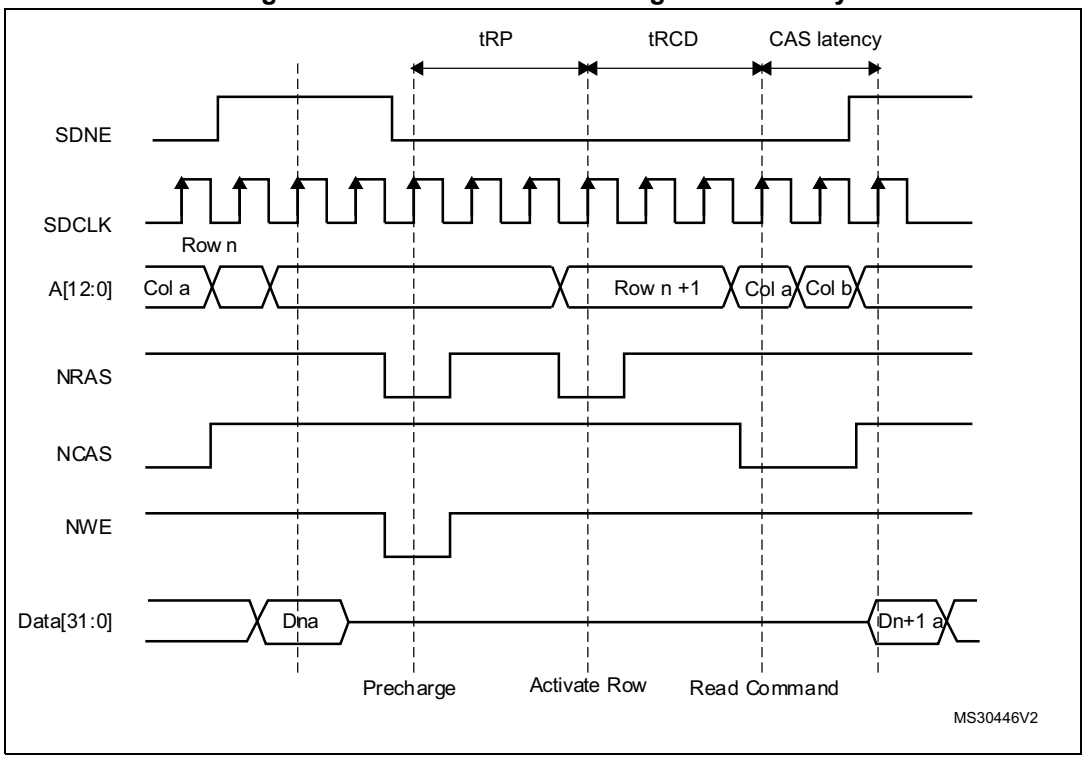
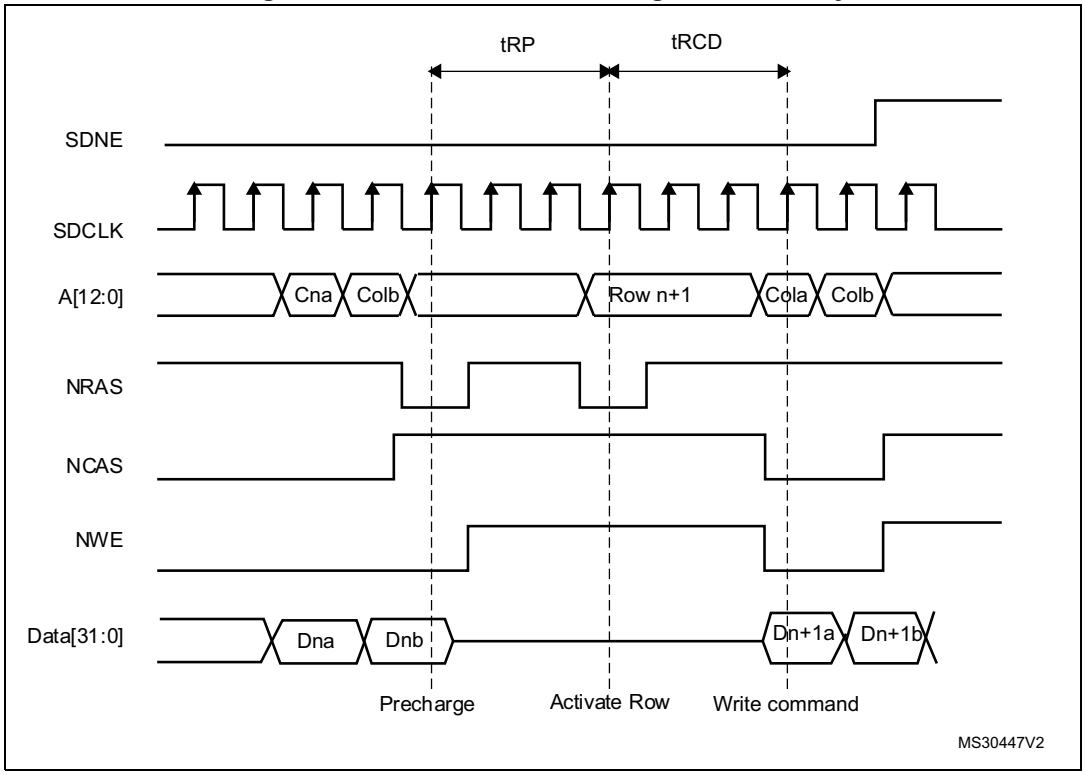


Figure 176. Write access crossing row boundary



If the next access is sequential and the current access crosses a bank boundary, the SDRAM controller activates the first row in the next bank and initiates a new read/write command. Two cases are possible:

- If the current bank is not the last one, the active row in the new bank must be precharged.At a bank boundary, the automatic activation of the next row is supported for all rows/columns and data bus width configuration.
- If the current bank is the last one, the automatic activation of the next row is supported only when addressing 13-bit rows, 11-bit columns, 4 internal banks and 32-bit data bus SDRAM devices. Otherwise, the SDRAM address range is violated and an AHB error is generated.
- In case of 13-bit row address, 11-bit column address, 4 internal banks and bus width 32-bit SDRAM memories, at boundary bank, the SDRAM controller continues to read/write from the second SDRAM device (assuming it has been initialized):
  a) The SDRAM controller activates the first row (after precharging the active row, if there is already an active row in the first internal bank, and initiates a new read/write command.
  b) If the first row is already activated, the SDRAM controller just initiates a read/write command.

SDRAM controller refresh cycle

The Auto-refresh command is used to refresh the SDRAM device content. The SDRAM controller periodically issues auto-refresh commands. An internal counter is loaded with the COUNT value in the register FMC_SDRTR. This value defines the number of memory clock cycles between the refresh cycles (refresh rate). When this counter reaches zero, an internal pulse is generated.

If a memory access is ongoing, the auto-refresh request is delayed. However, if the memory access and the auto-refresh requests are generated simultaneously, the auto-refresh request takes precedence.

If the memory access occurs during an auto-refresh operation, the request is buffered and processed when the auto-refresh is complete.

If a new auto-refresh request occurs while the previous one was not served, the RE (Refresh Error) bit is set in the Status register. An Interrupt is generated if it has been enabled (REIE = ‘1’).

If SDRAM lines are not in idle state (not all row are closed), the SDRAM controller generates a PALL (Precharge ALL) command before the auto-refresh.

If the Auto-refresh command is generated by the FMC_SDCMR Command Mode register (Mode bits = ‘011’), a PALL command (Mode bits =’ 010’) must be issued first.

25.8.4 Low-power modes

Two low-power modes are available:

- Self-refresh mode

  The auto-refresh cycles are performed by the SDRAM device itself to retain data without external clocking.
- Power-down mode

  The auto-refresh cycles are performed by the SDRAM controller.

Self-refresh mode

This mode is selected by setting the MODE bits to ‘101’ and by configuring the Target Bank bits (CTB1 and/or CTB2) in the FMC_SDCMR register.

The SDRAM clock stops running after a TRAS delay and the internal refresh timer stops counting only if one of the following conditions is met:

- A Self-refresh command is issued to both devices
- One of the devices is not activated (SDRAM bank is not initialized).

Before entering Self-Refresh mode, the SDRAM controller automatically issues a PALL command.

If the Write data FIFO is not empty, all data are sent to the memory before activating the Self-refresh mode and the BUSY status flag remains set.

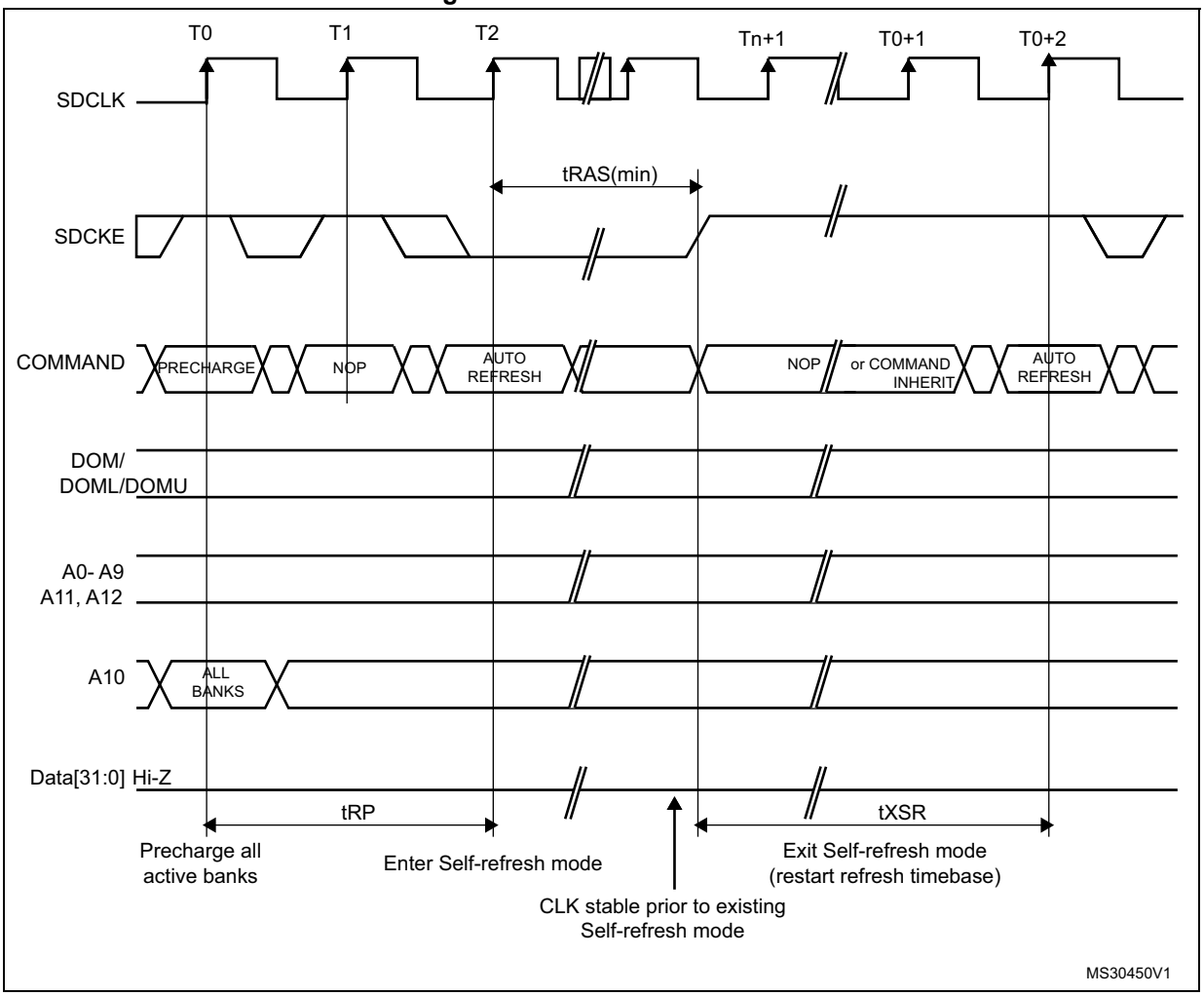
In Self-refresh mode, all SDRAM device inputs become don’t care except for SDCKE which remains low.

The SDRAM device must remain in Self-refresh mode for a minimum period of time of TRAS and can remain in Self-refresh mode for an indefinite period beyond that. To guarantee this minimum period, the BUSY status flag remains high after the Self-refresh activation during a TRAS delay.

As soon as an SDRAM device is selected, the SDRAM controller generates a sequence of commands to exit from Self-refresh mode. After the memory access, the selected device remains in Normal mode.

To exit from Self-refresh, the MODE bits must be set to ‘000’ (Normal mode) and the Target Bank bits (CTB1 and/or CTB2) must be configured in the FMC_SDCMR register.

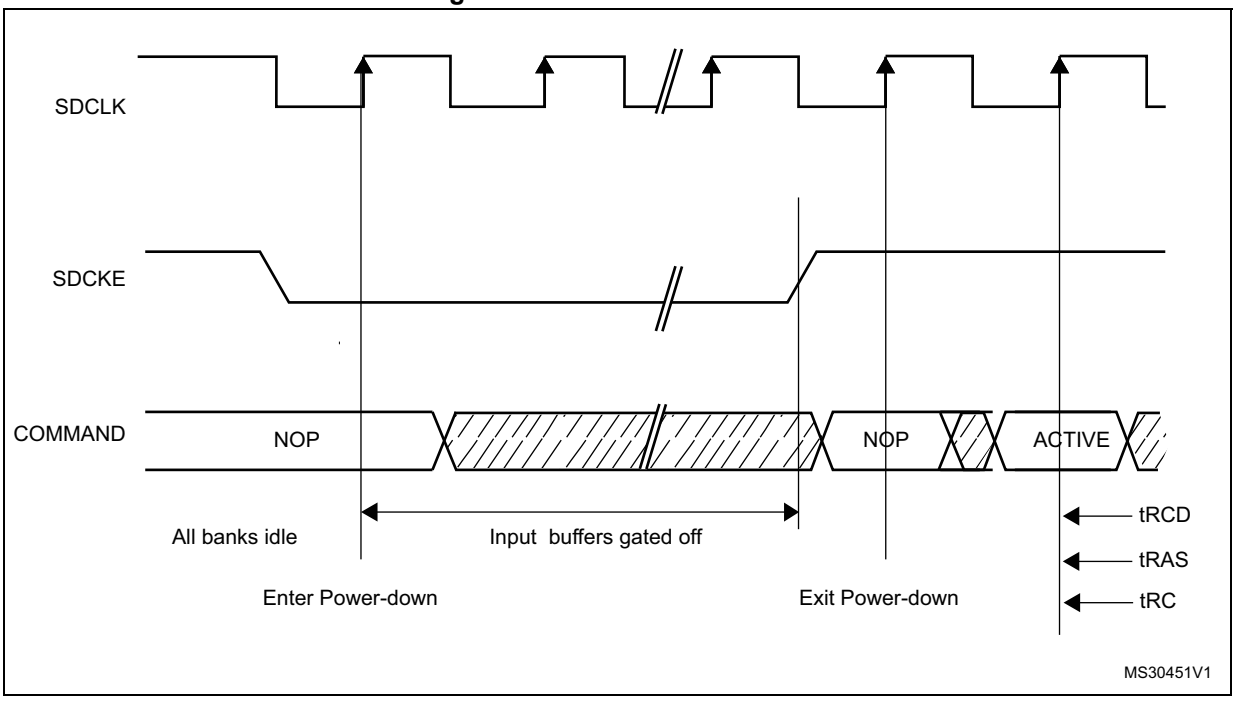
Figure 177. Self-refresh mode



Power-down mode

This mode is selected by setting the MODE bits to ‘110’ and by configuring the Target Bank bits (CTB1 and/or CTB2) in the FMC_SDCMR register.

Figure 178. Power-down mode



If the Write data FIFO is not empty, all data are sent to the memory before activating the Power-down mode.

As soon as an SDRAM device is selected, the SDRAM controller exits from the Power-down mode. After the memory access, the selected SDRAM device remains in Normal mode.

During Power-down mode, all SDRAM device input and output buffers are deactivated except for the SDCKE which remains low.

The SDRAM device cannot remain in Power-down mode longer than the refresh period and cannot perform the Auto-refresh cycles by itself. Therefore, the SDRAM controller carries out the refresh operation by executing the operations below:

1. Exit from Power-down mode and drive the SDCKE high
2. Generate the PALL command only if a row was active during Power-down mode
3. Generate the auto-refresh command
4. Drive SDCKE low again to return to Power-down mode.

To exit from Power-down mode, the MODE bits must be set to ‘000’ (Normal mode) and the Target Bank bits (CTB1 and/or CTB2) must be configured in the FMC_SDCMR register.

25.8.5 SDRAM controller registers

SDRAM control register x (FMC_SDCRx)

Address offset: 0x140+ 0x4* (x -1), (x = 1,2)

Reset value: 0x0000 02D0

This register contains the control parameters for each SDRAM memory bank

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RPIPE[1:0]		RBURST	SDCLK[1:0]		WP	CAS[1:0]		NB	MWID[1:0]		NR[1:0]		NC[1:0]	
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:15 Reserved, must be kept at reset value.

Bits 14:13 **RPIPE[1:0]:** Read pipe

These bits define the delay, in clock cycles, for reading data after CAS latency.
00: No clock cycle delay
01: One clock cycle delay
10: Two clock cycle delay
11: reserved.

Note: The corresponding bits in the FMC_SDCR2 register is read only.

Bit 12 **RBURST:** Burst read

This bit enables Burst read mode. The SDRAM controller anticipates the next read commands during the CAS latency and stores data in the Read FIFO.
0: single read requests are not managed as bursts
1: single read requests are always managed as bursts

Note: The corresponding bit in the FMC_SDCR2 register is don't care.

Bits 11:10 **SDCLK[1:0]:** SDRAM clock configuration

These bits define the SDRAM clock period for both SDRAM banks and allow disabling the clock before changing the frequency. In this case the SDRAM must be re-initialized.
00: SDCLK clock disabled
10: SDCLK period = 2 x HCLK periods
11: SDCLK period = 3 x HCLK periods
Others: Reserved, must not be used

Note: The corresponding bits in the FMC_SDCR2 register are don't care.

Bit 9 **WP:** Write protection

This bit enables write mode access to the SDRAM bank.
0: Write accesses allowed
1: Write accesses ignored

Bits 8:7 **CAS[1:0]:** CAS Latency

This bits sets the SDRAM CAS latency in number of memory clock cycles
00: reserved.
01: 1 cycle
10: 2 cycles
11: 3 cycles

Bit 6 **NB:** Number of internal banks
This bit sets the number of internal banks.
0: Two internal Banks
1: Four internal Banks

Bits 5:4 **MWID[1:0]:** Memory data bus width.
These bits define the memory device width.
00: 8 bits
01: 16 bits
10: 32 bits
11: reserved.

Bits 3:2 **NR[1:0]:** Number of row address bits
These bits define the number of bits of a row address.
00: 11 bit
01: 12 bits
10: 13 bits
11: reserved.

Bits 1:0 **NC[1:0]:** Number of column address bits
These bits define the number of bits of a column address.
00: 8 bits
01: 9 bits
10: 10 bits
11: 11 bits.

Note: Before modifying the RBURST or RPIPE settings or disabling the SDCLK clock, the user must first send a PALL command to make sure ongoing operations are complete.

SDRAM timing register x (FMC_SDTRx)

Address offset: 0x148 + 0x4 * (x - 1), (x = 1,2)

Reset value: 0x0FFF FFFF

This register contains the timing parameters of each SDRAM bank

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TRCD[3:0]				TRP[3:0]				TWR[3:0]			
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRC[3:0]				TRAS[3:0]				TXSR[3:0]				TMRD[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **TRCD[3:0]:** Row to column delay
These bits define the delay, tRCD, from the Activate command to a Read/Write command in number of memory clock cycles.
0000: 2 cycles
0001: 3 cycles
....
1111: 17 cycles
Note: tRCD delay is replaced by (TWR[3:0]+2) cycles when TWR[3:0] > TRCD[3:0].

Bits 23:20 **TRP[3:0]:** Row precharge delay

These bits define the delay, tRP, from a Precharge command to another command in number of memory clock cycles. The TRP timing is only configured in the FMC_SDTR1 register. If two SDRAM devices are used, the TRP must be programmed with the timing of the slowest device.

0000: 2 cycle

0001: 3 cycles

....

1111: 17 cycles

Note: The corresponding bits in the FMC_SDTR2 register are don't care.

Bits 19:16 **TWR[3:0]:** Recovery delay

These bits define the delay, tWR, from a Write to a Precharge command in number of memory clock cycles.

0000: 2 cycle

0001: 3 cycles

....

1111: 17 cycles

Note: TWR must be programmed to match the write recovery time (t_{WR}) defined in the SDRAM datasheet, and to guarantee that:

TWR ≥ TRAS - TRCD and TWR ≥TRC - TRCD - TRP

Example: TRAS= 4 cycles, TRCD= 2 cycles. So, TWR >= 2 cycles. TWR must be programmed to 0x0.

If two SDRAM devices are used, the FMC_SDTR1 and FMC_SDTR2 must be programmed with the same TWR timing corresponding to the slowest SDRAM device.

If only one SDRAM device is used, the TWR timing must be kept at reset value (0xF) for the not used bank.

Bits 15:12 **TRC[3:0]:** Row cycle delay

These bits define the delay, tRC, from the Refresh command to the Activate command, as well as the delay between two consecutive Refresh commands. It is expressed in number of memory clock cycles. The TRC timing is only configured in the FMC_SDTR1 register. If two SDRAM devices are used, the TRC must be programmed with the timings of the slowest device.

0000: 2 cycle

0001: 3 cycles

....

1111: 17 cycles

Note: TRC must match the TRC and TRFC (Auto Refresh period) timings defined in the SDRAM device datasheet.

Note: The corresponding bits in the FMC_SDTR2 register are don't care.

Bits 11:8 **TRAS[3:0]:** Self refresh time

These bits define the minimum Self-refresh period in number of memory clock cycles.

0000: 2 cycle

0001: 3 cycles

....

1111: 17 cycles

Bits 7:4 **TXSR[3:0]:** Exit Self-refresh delay

These bits define the delay from releasing the Self-refresh command to issuing the Activate command in number of memory clock cycles.
0000: 2 cycle
0001: 3 cycles
....
1111: 17 cycles

Note: The tXSR delay is replaced by (TWR[3:0]+2) cycles when TWR[3:0] > TXSR[3:0].

Note: If two SDRAM devices are used, the FMC_SDTR1 and FMC_SDTR2 must be programmed with the same TXSR timing corresponding to the slowest SDRAM device.

Bits 3:0 **TMRD[3:0]:** Load Mode Register to Active

These bits define the delay, tMRD, from a Load Mode Register command to an Active or Refresh command in number of memory clock cycles.
0000: 3 cycle
0001: 4 cycles
....
1111: 18 cycles

Note: If two SDRAM devices are connected, all the accesses performed simultaneously to both devices by the Command Mode register (Load Mode Register command) are issued using the timing parameters configured for Bank 1 (TMRD and TRAS timings) in the FMC_SDTR1 register.

The TRP and TRC timings are only configured in the FMC_SDTR1 register. If two SDRAM devices are used, the TRP and TRC timings must be programmed with the timings of the slowest device.

SDRAM Command Mode register (FMC_SDCMR)

Address offset: 0x150

Reset value: 0x0000 0000

This register contains the command issued when the SDRAM device is accessed. This register is used to initialize the SDRAM device, and to activate the Self-refresh and the Power-down modes. As soon as the MODE field is written, the command is issued only to one or to both SDRAM banks according to CTB1 and CTB2 command bits. This register is the same for both SDRAM banks.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MRD[12:7]					
										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MRD[6:0]							NRFS[3:0]				CTB1	CTB2	MODE[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	w	w	w	w

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:9 **MRD[12:0]:** Mode Register definition

This 13-bit field defines the SDRAM Mode Register content. The Mode Register is programmed using the Load Mode Register command.

Bits 8:5 **NRFS[3:0]:** Number of Auto-refresh
These bits define the number of consecutive Auto-refresh commands issued when MODE = '011'.
0000: 1 Auto-refresh cycle
0001: 2 Auto-refresh cycles
....
1110: 15 Auto-refresh cycles
1111: 16 Auto-refresh cycles

Bit 4 **CTB1:** Command Target Bank 1
This bit indicates whether the command is issued to SDRAM Bank 1 or not.
0: Command not issued to SDRAM Bank 1
1: Command issued to SDRAM Bank 1

Bit 3 **CTB2:** Command Target Bank 2
This bit indicates whether the command is issued to SDRAM Bank 2 or not.
0: Command not issued to SDRAM Bank 2
1: Command issued to SDRAM Bank 2

Bits 2:0 **MODE[2:0]:** Command mode
These bits define the command issued to the SDRAM device.
000: Normal Mode
001: Clock Configuration Enable
010: PALL ("All Bank Precharge") command
011: Auto-refresh command
100: Load Mode Register
101: Self-refresh command
110: Power-down command
111: Reserved

Note: When a command is issued, at least one Command Target Bank bit (CTB1 or CTB2) must be set otherwise the command is ignored.

Note: If two SDRAM banks are used, the Auto-refresh and PALL command must be issued simultaneously to the two devices with CTB1 and CTB2 bits set otherwise the command is ignored.

Note: If only one SDRAM bank is used and a command is issued with it's associated CTB bit set, the other CTB bit of the the unused bank must be kept to 0.

SDRAM refresh timer register (FMC_SDRTR)

Address offset:0x154

Reset value: 0x0000 0000

This register sets the refresh rate in number of SDCLK clock cycles between the refresh cycles by configuring the Refresh Timer Count value.

$$\text{Refresh rate} = (\text{COUNT} + 1) \times \text{SDRAM clock frequency}$$

$$\text{COUNT} = (\text{SDRAM refresh period} / \text{Number of rows}) - 20$$

Example

$$\text{Refresh rate} = 64\ \text{ms} / (8196\text{rows}) = 7.81\mu\text{s}$$

where 64 ms is the SDRAM refresh period.

$$7.81\mu s \times 60MHz = 468.6$$

The refresh rate must be increased by 20 SDRAM clock cycles (as in the above example) to obtain a safe margin if an internal refresh request occurs when a read request has been accepted. It corresponds to a COUNT value of '0000111000000' (448).

This 13-bit field is loaded into a timer which is decremented using the SDRAM clock. This timer generates a refresh pulse when zero is reached. The COUNT value must be set at least to 41 SDRAM clock cycles.

As soon as the FMC_SDRTR register is programmed, the timer starts counting. If the value programmed in the register is '0', no refresh is carried out. This register must not be reprogrammed after the initialization procedure to avoid modifying the refresh rate.

Each time a refresh pulse is generated, this 13-bit COUNT field is reloaded into the counter.

If a memory access is in progress, the Auto-refresh request is delayed. However, if the memory access and Auto-refresh requests are generated simultaneously, the Auto-refresh takes precedence. If the memory access occurs during a refresh operation, the request is buffered to be processed when the refresh is complete.

This register is common to SDRAM bank 1 and bank 2.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	REIE	COUNT[12:0]													CRE
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **REIE:** RES Interrupt Enable
0: Interrupt is disabled
1: An Interrupt is generated if RE = 1

Bits 13:1 **COUNT[12:0]:** Refresh Timer Count
This 13-bit field defines the refresh rate of the SDRAM device. It is expressed in number of memory clock cycles. It must be set at least to 41 SDRAM clock cycles (0x29).
Refresh rate = (COUNT + 1) x SDRAM frequency clock
COUNT = (SDRAM refresh period / Number of rows) - 20

Bit 0 **CRE:** Clear Refresh error flag
This bit is used to clear the Refresh Error Flag (RE) in the Status Register.
0: no effect
1: Refresh Error flag is cleared

Note: The programmed COUNT value must not be equal to the sum of the following timings: TWR+TRP+TRC+TRCD+4 memory clock cycles.

SDRAM status register (FMC_SDSR)

Address offset: 0x158

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSY	MODES2[1:0]		MODES1[1:0]		RE
										r	r	r	r	r	r

Bits 31:6 Reserved, must be kept at reset value.

Bit 5 **BUSY:** Busy status

This bit defines the status of the SDRAM controller after a Command Mode request

0: SDRAM Controller is ready to accept a new request

1; SDRAM Controller is not ready to accept a new request

Bits 4:3 **MODES2[1:0]:** Status Mode for Bank 2

This bit defines the Status Mode of SDRAM Bank 2.

00: Normal Mode

01: Self-refresh mode

10: Power-down mode

Bits 2:1 **MODES1[1:0]:** Status Mode for Bank 1

This bit defines the Status Mode of SDRAM Bank 1.

00: Normal Mode

01: Self-refresh mode

10: Power-down mode

Bit 0 **RE:** Refresh error flag

0: No refresh error has been detected

1: A refresh error has been detected

An interrupt is generated if REIE = 1 and RE = 1

25.8.6 FMC register map

Table 244. FMC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	FMC_BCR1	FMCEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NBL SET [1:0]		WFDIS	CCLKEN	CBURSTRW	CPSIZE [2:0]			ASYNCWAIT	EXTMOD	WAITEN	WREN	WAITCFG	Res.	WAITPOL	BURSTEN	Res.	FACCEN	MWID [1:0]		MTYP [1:0]		MUXEN	MBKEN
	Reset value	0								0	0	0	0	0	0	0	0	0	0	1	1	0		0	0		1	0	1	1	0	1	1
0x08	FMC_BCR2	FMCEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NBL SET [1:0]		Res.	Res.	CBURSTRW	CPSIZE [2:0]			ASYNCWAIT	EXTMOD	WAITEN	WREN	WAITCFG	Res.	WAITPOL	BURSTEN	Res.	FACCEN	MWID [1:0]		MTYP [1:0]		MUXEN	MBKEN
	Reset value	0								0	0			0	0	0	0	0	0	1	1	0		0	0		1	0	1	0	0	1	0

Table 244. FMC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x10	FMC_BCR3	FMCEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NBL SET [1:0]		Res.	Res.	CBURSTRW	CPSIZE [2:0]			ASYNCWAIT	EXTMOD	WAITEN	WREN	WAITCFG	Res.	WAITPOL	BURSTEN	Res.	FACCEN	MWID [1:0]		MTYP [1:0]		MUXEN	MBKEN
	Reset value	0								0	0			0	0	0	0	0	0	1	1	0		0	0		1	0	1	0	0	1	0
0x18	FMC_BCR4	FMCEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NBL SET [1:0]		Res.	Res.	CBURSTRW	CPSIZE [2:0]			ASYNCWAIT	EXTMOD	WAITEN	WREN	WAITCFG	Res.	WAITPOL	BURSTEN	Res.	FACCEN	MWID [1:0]		MTYP [1:0]		MUXEN	MBKEN
	Reset value	0								0	0			0	0	0	0	0	0	1	1	0		0	0		1	0	1	0	0	1	0
0x04	FMC_BTR1	DATAHLD[1:0]		ACCMOD[1:0]		DATLAT[3:0]				CLKDIV[3:0]				BUSTURN [3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0C	FMC_BTR2	DATAHLD[1:0]		ACCMOD[1:0]		DATLAT[3:0]				CLKDIV[3:0]				BUSTURN [3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x14	FMC_BTR3	DATAHLD[1:0]		ACCMOD[1:0]		DATLAT[3:0]				CLKDIV[3:0]				BUSTURN [3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x1C	FMC_BTR4	DATAHLD[1:0]		ACCMOD[1:0]		DATLAT[3:0]				CLKDIV[3:0]				BUSTURN [3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x20	FMC_ PCSCNTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNTB4EN	CNTB3EN	CNTB2EN	CNTB1EN	CSCOUNT[15:0]															
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x104	FMC_BWTR1	DATAHLD[1:0]		ACCMOD[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSTURN [3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value	0	0	0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x10C	FMC_BWTR2	DATAHLD[1:0]		ACCMOD[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSTURN [3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value	0	0	0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x114	FMC_BWTR3	DATAHLD[1:0]		ACCMOD[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSTURN [3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value	0	0	0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 244. FMC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x11C	FMC_BWTR4	DATAHLD[1:0]		ACCMOD[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSTURN [3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value	0	0	0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x80	FMC_PCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCPS [2:0]				TAR[3:0]				TCLR[3:0]				Res.	Res.	ECCEN	PWID [1:0]		PTYP	PBKEN	PWAITEN	Res.
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0			0	0	1	1	0	0	
0x84	FMC_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FEMPT	IFEN	ILEN	IREN	IFS	ILS	IRS
	Reset value																										1	0	0	0	0	0	0
0x88	FMC_PMEM	MEMHIZx[7:0]								MEMHOLDx[7:0]								MEMWAITx[7:0]								MEMSETx[7:0]							
	Reset value	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0
0x8C	FMC_PATT	ATTHIZ[7:0]								ATTHOLD[7:0]								ATTWAIT[7:0]								ATTSET[7:0]							
	Reset value	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0
0x94	FMC_ECCR	ECCx[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x140	FMC_SDCR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RPIPE [1:0]		RBURST	SDCLK [1:0]		WP	CAS [1:0]		NB	MWID [1:0]		NR [1:0]		NC	
	Reset value																		0	0	0	1	1	0	1	0	0	1	0	0	0	0	0
0x144	FMC_SDCR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RBURST	SDCLK [1:0]		WP	CAS [1:0]		NB	MWID [1:0]		NR [1:0]		NC	
	Reset value																				0	1	1	0	1	0	0	1	0	0	0	0	0
0x148	FMC_SDTR1	Res.	Res.	Res.	Res.	TRCD[3:0]				TRP[3:0]				TWR[3:0]				TRC[3:0]				TRAS[3:0]				TXSR[3:0]				TMRD[3:0]			
	Reset value					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x14C	FMC_SDTR2	Res.	Res.	Res.	Res.	TRCD[3:0]				TRP[3:0]				TWR[3:0]				TRC[3:0]				TRAS[3:0]				TXSR[3:0]				TMRD[3:0]			
	Reset value					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x150	FMC_SDCMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MRD[12:0]														NRFS[3:0]			CTB1	CTB2	MODE[2:0]		
	Reset value											0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x154	FMC_SDRTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REIE	COUNT[12:0]													CRE	
	Reset value																		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x158	FMC_SDSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSY	MODES2[1:0]		MODES1[1:0]		Res.	
	Reset value																											0	0	0	0	0	

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

26 Extended-SPI interface (OCTOSPI)

26.1 OCTOSPI introduction

The OCTOSPI supports most external serial memories such as serial PSRAMs, serial NAND and serial NOR flash memories, HyperRAM™ and HyperFlash™ memories, with the following functional modes:

- indirect mode: all the operations are performed using the OCTOSPI registers to preset commands, addresses, data, and transfer parameters.
- automatic status-polling mode: the external memory status register is periodically read and an interrupt can be generated in case of flag setting. This feature is only available in regular-command protocol.
- memory-mapped mode: the external memory is memory mapped and it is seen by the system as if it was an internal memory, supporting both read and write operations.

The OCTOSPI supports the following protocols with associated frame formats:

- the regular-command frame format with the command, address, alternate byte, dummy cycles, and data phase
- the HyperBus™ frame format

26.2 OCTOSPI main features

- Functional modes: indirect, automatic status-polling, and memory-mapped
- Read and write support in memory-mapped mode
- External (P)SRAM memory support
- Support for single, dual, quad, and octal communication
- Dual memory configuration, where eight bits can be sent/received simultaneously by accessing two quad memories in parallel
- SDR (single-data rate) and DTR (double-transfer rate) support
- Data strobe support
- Fully programmable opcode
- Fully programmable frame format
- Support wrapped-type access to memory in read direction
- HyperBus support
- Integrated FIFO for reception and transmission
- Asynchronous bus clock versus kernel clock support
- 8-, 16-, and 32-bit data accesses allowed
- DMA protocol support
- DMA channel for indirect mode operations
- Interrupt generation on FIFO threshold, timeout, operation complete, and access error
- AHB interface with transaction acceptance limited to one: the interface accepts the next transfer on AHB bus only once the previous is completed on memory side.
- Dual chip select support
- Extended external memory support: if two same size external memories (extmem1 and extmem2) are connected to the same I/O port, contiguously in the memory map and

driven by a single OCTOSPI, this OCTOSPI automatically switches CS to extmem1 or extmem2, according to the address on interconnect side.

- Possibility to disable the automatic prefetch

26.3 OCTOSPI implementation

Table 245. OCTOSPI implementation

OCTOSPI feature	OCTOSPI1/2
HyperBus standard compliant	X
Xccela standard compliant	X
XSPI (JESD251C) standard compliant	X
AMBA® AHB compliant data interface	X
Dual AHB interface	X
Asynchronous AHB clock versus kernel clock	X
Functional modes: indirect, automatic status-polling, and memory-mapped	X
Read and write support in memory-mapped mode	X
Dual-quad configuration	X
SDR (single-data rate) and DTR (double-transfer rate)	X
Data strobe (DS,DQS)	X
Fully programmable opcode	X
Fully programmable frame format	X
Integrated FIFO for reception and transmission	X
8-, 16-, and 32-bit data accesses	X
Interrupt on FIFO threshold, timeout, operation complete, and access error	X
Bus error bit	-
Address offset	-
Extended CSHT timeout	X
Memory-mapped write	X
Refresh counter	X
GPDMA interface	X
Dual chip select	X
Extended external memory	X
Prefetch disable	X
Prefetch hardware software	-

26.4 OCTOSPI functional description

26.4.1 OCTOSPI block diagram

Figure 179. OCTOSPI block diagram in octal configuration

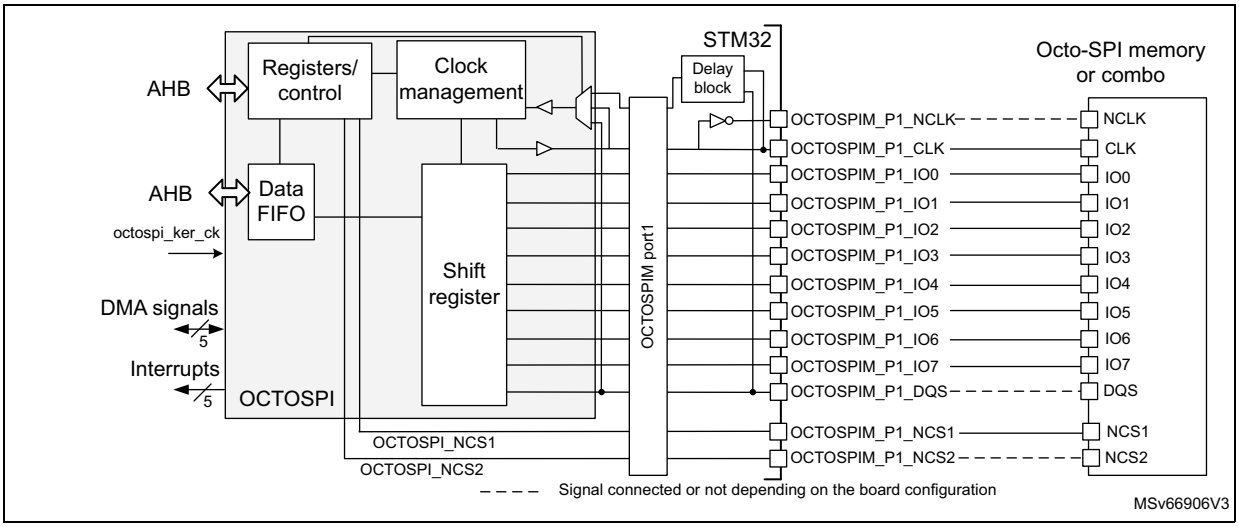


Figure 180. OCTOSPI block diagram in quad configuration

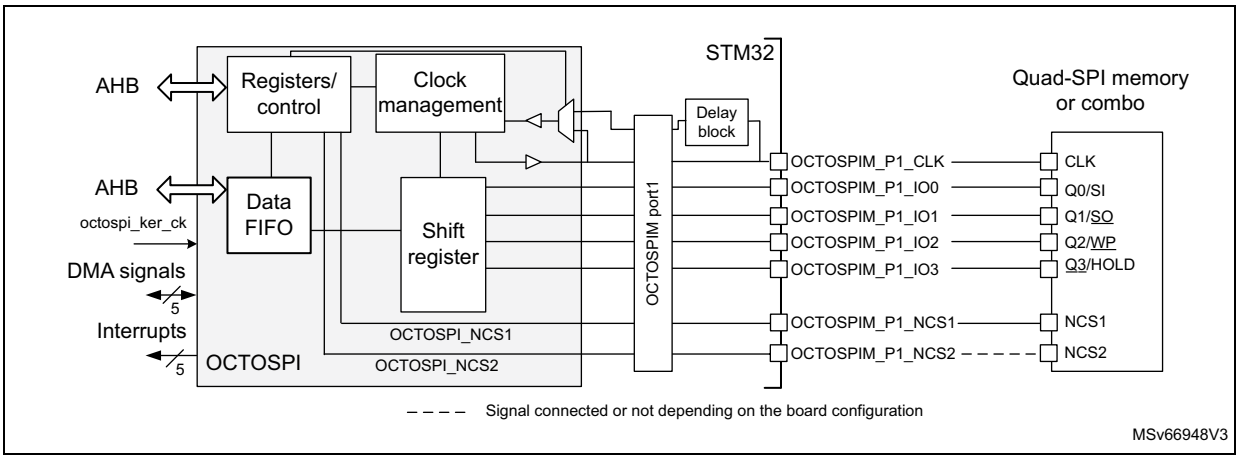
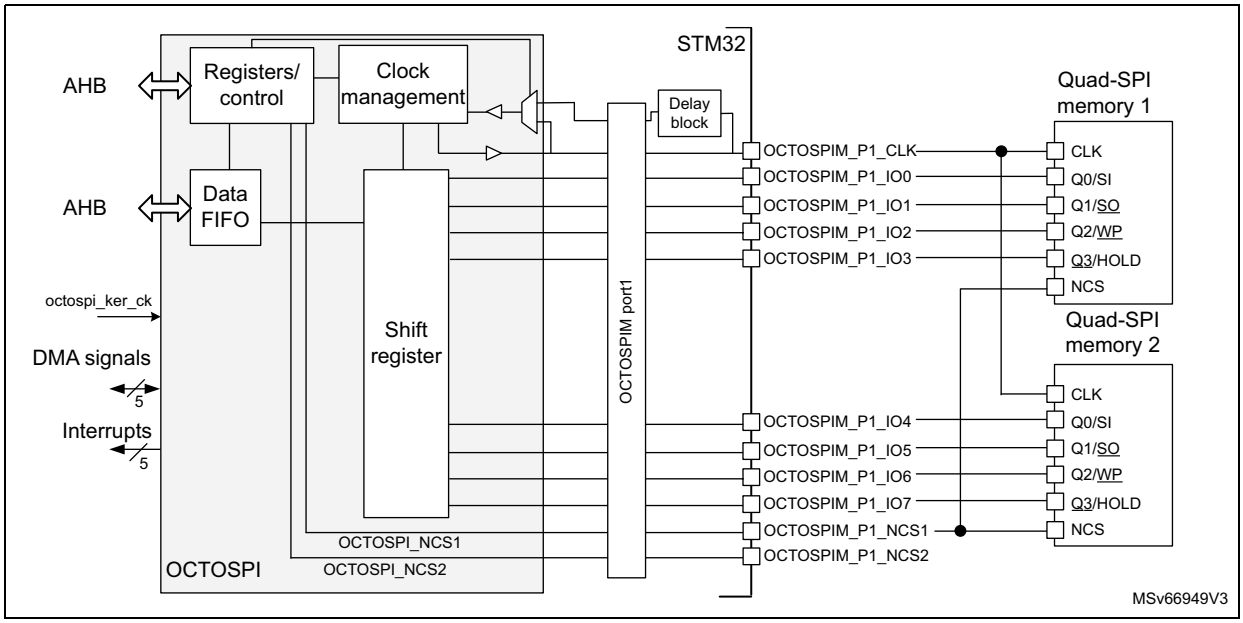


Figure 181. OCTOSPI block diagram in dual-quad configuration



26.4.2 OCTOSPI pins and internal signals

Table 246. OCTOSPI input/output pins(1)

Pin name	Type	Description
OCTOSPIM_Px_NCLK	Output	OCTOSPI inverted clock to support 1.8 V HyperBus protocol
OCTOSPIM_Px_CLK		OCTOSPI clock
OCTOSPIM_Px_IOn (n = 0 to 7)	Input/output	OCTOSPI data pins
OCTOSPIM_Px_NCS1,2	Output	Chip select for the memory
OCTOSPIM_Px_DQS	Input/output	Data strobe/write mask signal from/to the memory

1. x = 1 to 2.

Caution: Use the same configuration (output speed, HSLV(a)) for all OCTOSPI input/output pins to avoid any data corruption.

Table 247. OCTOSPI internal signals

Signal name	Type	Description
octospi_hclk	Input	OCTOSPI AHB clock
octospi_ker_ck	Input	OCTOSPI kernel clock
octospi_dma	N/A	DMA request signal
octospi_it	Output	Global interrupt line (see *Table 251* for the multiple sources of interrupt)

a. When applicable.

26.4.3 OCTOSPI interface to memory modes

The OCTOSPI supports the following protocols:

- regular-command protocol
- HyperBus protocol

The OCTOSPI uses from 6 to 12 signals to interface with a memory, depending on the functional mode:

- NCS: chip-select (in the following sections, unless otherwise specified, NCS applies for NCS1 or NCS2. Only one of these two signals is active at a given moment in time)
- CLK: communication clock
- NCLK: inverted clock used only in the 1.8 V HyperBus protocol
- DQS: data strobe used only in regular-command protocol as input only
- IO[3:0]: data bus LSB
- IO[7:4]:
  - data bus MSB used in dual-quad and octal configurations
  - data bus can be used as possible remap for quad-SPI mode

26.4.4 OCTOSPI regular-command protocol

When in regular-command protocol, the OCTOSPI communicates with the external device using commands. Each command can include the following phases:

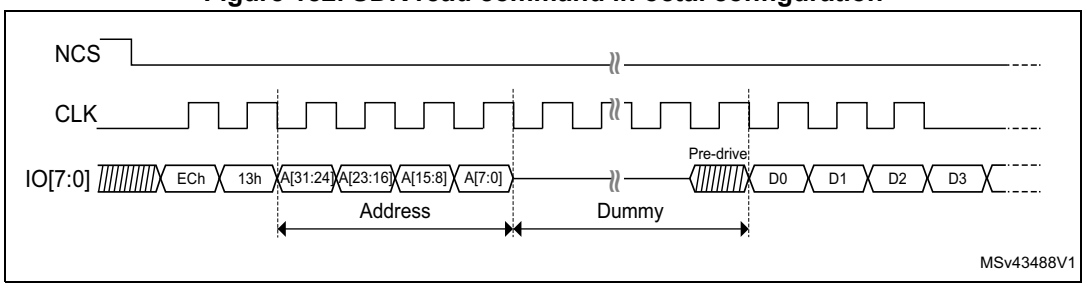
- Instruction phase
- Address phase
- Alternate-byte phase
- Dummy-cycle phase
- Data phase

Any of these phases can be configured to be skipped but, in case of single-phase command, the only use case supported is instruction-phase-only.

The NCS falls before the start of each command and rises again after each command finishes.

In memory-mapped mode, both read and write operations are supported: as a consequence, some of the configuration registers are duplicated to specify write operations (read operations are configured using regular registers).

Figure 182. SDR read command in octal configuration



The specific regular-command protocol features are configured through the registers in the 0x0100-0x01FC offset range.

Instruction phase

During this phase, a 1- to 4-byte instruction is sent to the external device specifying the type of operation to be performed. The size of the instruction to be sent is configured by ISIZE[1:0] in OCTOSPI_CCR and the instruction is programmed in INSTRUCTION[31:0] of OCTOSPI_IR.

The instruction phase can optionally send:

- 1 bit at a time (over IO0, SO single in single-SPI mode)
- 2 bits at a time (over IO0/IO1 in dual-SPI mode)
- 4 bits at a time (over IO0 to IO3 in quad-SPI mode)
- 8 bits at a time (over IO0 to IO7 in octal-SPI mode)

This can be configured using IMODE[2:0] of OCTOSPI_CCR.

The instruction can be sent in DTR mode on each rising and falling edge of the clock, by setting IDTR in OCTOSPI_CCR.

When IMODE[2:0] = 000 in OCTOSPI_CCR, the instruction phase is skipped, and the command sequence starts with the address phase, if present.

In memory-mapped mode, the instruction used for the write operation is specified in OCTOSPI_WIR, and the instruction format is specified in OCTOSPI_WCCR. The instruction used for the read operation and the instruction format are specified in OCTOSPI_IR and OCTOSPI_CCR.

Address phase

In the address phase, 1 to 4 bytes are sent to the external device, to indicate the address of the operation. The number of address bytes to be sent is configured by ADSIZE[1:0] in OCTOSPI_CCR.

In indirect and automatic status-polling modes, the address bytes to be sent are specified by ADDRESS[31:0] in OCTOSPI_AR. In memory-mapped mode, the address is given directly via the AHB (from any master in the system).

The address phase can send:

- 1 bit at a time (over IO0, SO single in single-SPI mode)
- 2 bits at a time (over IO0/IO1 in dual-SPI mode)
- 4 bits at a time (over IO0 to IO3 in quad-SPI mode)
- 8 bits at a time (over IO0 to IO7 in octal-SPI mode)

This can be configured using ADMODE[2:0] in OCTOSPI_CCR.

The address can be sent in DTR mode (on each rising and falling edge of the clock) setting ADDTR in OCTOSPI_CCR.

When ADMODE[2:0] = 000, the address phase is skipped and the command sequence proceeds directly to the next phase, if any.

In memory-mapped mode, the address format for the write operation is specified in OCTOSPI_WCCR. The address format for the read operation is specified in OCTOSPI_CCR.

Alternate-byte phase

In the alternate-byte phase, 1 to 4 bytes are sent to the external device, generally to control the mode of operation. The number of alternate bytes to be sent is configured by ABSIZE[1:0] in OCTOSPI_CCR. The bytes to be sent are specified in OCTOSPI_ABR.

The alternate-byte phase can send:

- 1 bit at a time (over IO0, SO single in single-SPI mode)
- 2 bits at a time (over IO0/IO1 in dual-SPI mode)
- 4 bits at a time (over IO0 to IO3 in quad-SPI mode)
- 8 bits at a time (over IO0 to IO7 in octal-SPI mode)

This can be configured using ABMODE[2:0] in OCTOSPI_CCR.

The alternate bytes can be sent in DTR mode (on each rising and falling edge of the clock) setting ABDTR in OCTOSPI_CCR.

When ABMODE[2:0] = 000, the alternate-byte phase is skipped and the command sequence proceeds directly to the next phase, if any.

There may be times when only a single nibble needs to be sent during the alternate-byte phase rather than a full byte, such as when the dual-SPI mode is used and only two cycles are used for the alternate bytes.

In this case, the firmware can use the quad-SPI mode (ABMODE[2:0] = 011) and send a byte with bits 7 and 3 of ALTERNATE[31:0] set to 1 (keeping the IO3 line high), and bits 6 and 2 set to 0 (keeping the IO2 line low), in OCTOSPI_IR.

The upper two bits of the nibble to be sent are then placed in bits 5:4 of ALTERNATE[31:0] while the lower two bits are placed in bits 1:0. For example, if the nibble 2 (0010) is to be sent over IO0/IO1, then ALTERNATE[31:0] must be set to 0x8A (1000_1010).

In memory-mapped mode, the alternate bytes used for the write operation are specified in OCTOSPI_WABR, and the alternate byte format is specified in OCTOSPI_WCCR. The alternate bytes used for read operation and the alternate byte format are specified in OCTOSPI_ABR and OCTOSPI_CCR.

Dummy-cycle phase (memory latency)

In the dummy-cycle phase, 1 to 31 cycles are given without any data being sent or received, in order to give the external device, the time to prepare for the data phase when higher clock frequencies are used. The number of cycles given during this phase is specified by DCYC[4:0] in OCTOSPI_TCR. In both SDR and DTR modes, the duration is specified as a number of full CLK cycles.

When DCYC[4:0] = 00000, the dummy-cycle phase is skipped, and the command sequence proceeds directly to the data phase, if present.

In order to assure enough “turn-around” time for changing the data signals from the output mode to the input mode, there must be at least one dummy cycle when using the dual-SPI, the quad-SPI, or the octal-SPI mode, to receive data from the external device.

In memory-mapped mode, the dummy cycles for the write operations are specified in OCTOSPI_WTCR. The dummy cycles for the read operation are specified in OCTOSPI_TCR.

Data phase

During the data phase, any number of bytes can be sent to or received from the external device.

In indirect mode, the number of bytes to be sent/received is specified in OCTOSPI_DLR. In this mode, the data to be sent to the external device must be written to OCTOSPI_DR, while in indirect-read mode the data received from the external device is obtained by reading OCTOSPI_DR.

In automatic status-polling mode, the number of bytes to be received is specified in OCTOSPI_DLR, and the data received from the external device can be obtained by reading OCTOSPI_DR.

In memory-mapped mode, the data read or written, is sent or received directly over the AHB to the Cortex core or to a DMA.

The data phase can send/receive:

- 1 bit at a time (over IO0/IO1 (SO/SI respectively) in single-SPI mode)
- 2 bits at a time (over IO0/IO1 in dual-SPI mode)
- 4 bits at a time (over IO0 to IO3 in quad-SPI mode)
- 8 bits at a time (over IO0 to IO7 in octal-SPI mode)

This can be configured using DMODE[2:0] in OCTOSPI_CCR.

The data can be sent or received in DTR mode (on each rising and falling edge of the clock) setting DDTR in OCTOSPI_CCR.

When DMODE[2:0] = 000, the data phase is skipped, and the command sequence finishes immediately by raising the NCS. This configuration must be used only in indirect-write mode.

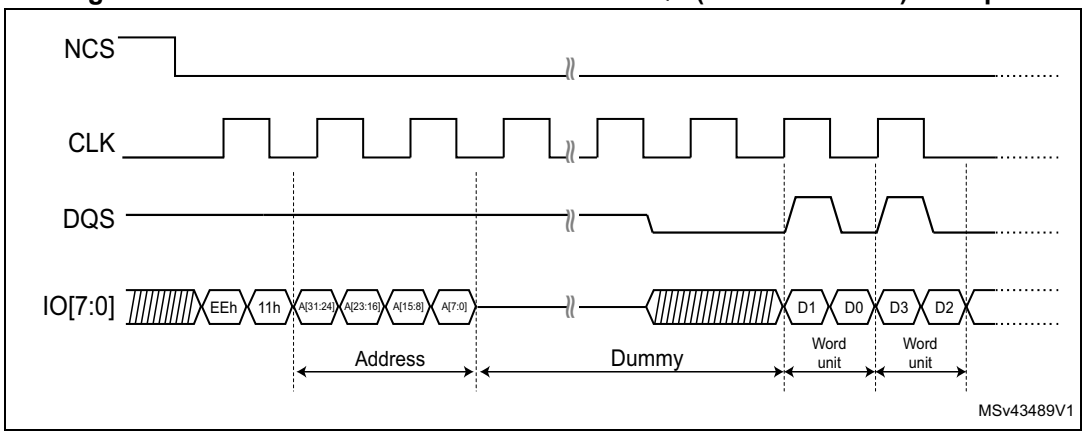
In memory-mapped mode, the data format for the write operation is specified in OCTOSPI_WCCR. The data format for the read operation is specified in OCTOSPI_CCR.

DQS use

The DQS signal can be used for data strobing during the read transactions when the device toggles the DQS aligned with the data.

The DQS management can be enabled by setting DQSE in OCTOSPI_CCR.

Figure 183. DTR read in octal-SPI mode with DQS (Macronix mode) example



26.4.5 OCTOSPI regular-command protocol signal interface

Single-SPI mode

The legacy SPI mode allows just a single bit to be sent/received serially. In this mode, the data is sent to the external device over the SO signal (Single-SPI Output) (whose I/Os are shared with IO0). The data received from the external device arrives via SI (Single-SPI Input) (whose I/Os are shared with IO1).

Compared to the SPI legacy mode, I0/SO and I1/SI are respectively equivalent to MOSI and MISO, having the OCTOSPI generating the clock.

The different phases can each be configured separately to use this single-SPI mode by setting to 001 the IMODE, ADMODE, ABMODE, and DMODE fields in OCTOSPI_CCR and OCTOSPI_WCCR.

In each phase configured in single-SPI mode:

- IO0 (SO) is in output mode.
- IO1 (SI) is in input mode (high impedance).
- IO2 is in output mode and forced to 0.
- IO3 is in output mode and forced to 1 (to deactivate the “hold” function).
- IO4 to IO7 are in output mode and forced to 0.

This is the case even for the dummy phase if DMODE[2:0] = 001.

Dual-SPI mode

In dual-SPI mode, two bits are sent/received simultaneously over the IO0/IO1 signals.

The different phases can each be configured separately to use dual-SPI mode by setting to 010 the IMODE, ADMODE, ABMODE, and DMODE fields in OCTOSPI_CCR and OCTOSPI_WCCR.

In each phase configured in dual-SPI mode:

- IO0/IO1 are at high-impedance (input) during the data phase for the read operations, and outputs in all other cases.
- IO2 is in output mode and forced to 0.
- IO3 is in output mode and forced to 1.
- IO4 to IO7 are in output mode and forced to 0.

In the dummy phase, when DMODE[2:0] = 010, IO0 and IO1 are in a high-impedance state during read transactions, and are forced to either high or low levels during write transactions.

Quad-SPI mode

In quad-SPI mode, four bits are sent/received simultaneously over the IO0/IO1/IO2/IO3 signals.

The different phases can each be configured separately to use the quad-SPI mode by setting to 011 the IMODE, ADMODE, ABMODE, and DMODE fields in OCTOSPI_CCR and OCTOSPI_WCCR.

In each phase configured in quad-SPI mode:

- IO0 to IO3 are all at high-impedance (inputs) during the data phase for the read operations, and outputs in all other cases.
- IO4 to IO7 are in output mode and forced to 0.

In the dummy phase, when DMODE[2:0] = 011, IO0 to IO3 are in a high-impedance state during read transactions, and are forced to either high or low levels during write transactions.

Octal-SPI mode

In regular octal-SPI mode, the eight bits are sent/received simultaneously over the IO[0:7] signals.

The different phases can each be configured separately to use the octal-SPI mode by setting to 100 the IMODE, ADMODE, ABMODE, and DMODE fields in OCTOSPI_CCR and OCTOSPI_WCCR.

In each phase that is configured in octal-SPI mode, IO[0:7] are all at high-impedance (input) during the data phase for read operations, and outputs in all other cases.

In the dummy phase, when DMODE[2:0] = 100, IO[0:7] are in a high-impedance state during read transactions, and are forced to either high or low levels during write transactions.

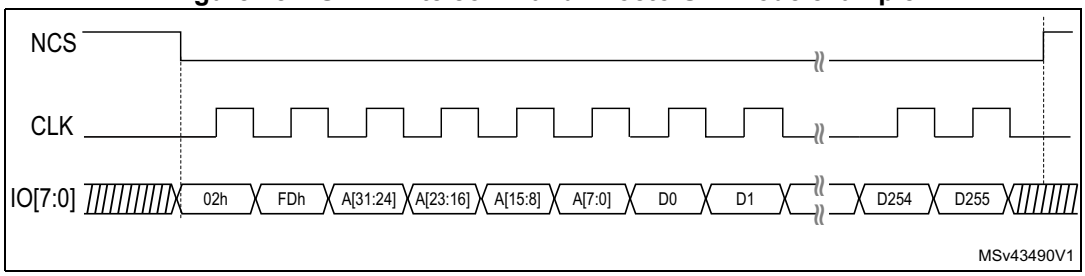
Single-data rate (SDR) mode

By default, all the phases operate in SDR mode.

In this mode, when the OCTOSPI drives the IO0/SO, IO1 to IO7 signals, these signals transition only with the falling edge of CLK.

When receiving data in SDR mode, the OCTOSPI assumes that the external devices also send the data using CLK falling edge. By default (when SSHIFT = 0 in OCTOSPI_TCR), the signals are sampled using the following (rising) edge of CLK.

Figure 184. SDR write command in octo-SPI mode example



Note: Due to internal synchronization, up to six extra dummy clock cycles may be generated by the Octo-SPI interface after the last data is read.

Double-transfer rate (DTR) mode

Each of the instruction, address, alternate-byte, and data phases can be configured to operate in DTR mode setting IDTR, ADDTR, ABDTR, and DDTR in OCTOSPI_CCR.

In memory-mapped mode, the DTR mode for each phase of the write operations is specified in OCTOSPI_WCCR. The DTR mode for each phase of the read operations is specified in OCTOSPI_CCR.

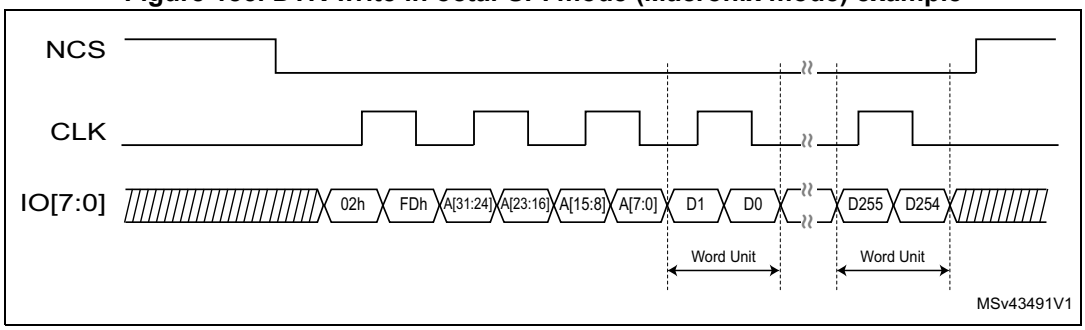
In DTR mode, when the OCTOSPI drives the IO0/SO and IO1 to IO7 signals in the instruction, address, and alternate-byte phases, a bit is sent or received on each of the falling and rising edges of CLK.

When receiving data in DTR mode, the OCTOSPI assumes that the external devices also send the data using both CLK rising and falling edges. When DDTR = 1 in OCTOSPI_CCR, the software must clear SSHIFT in OCTOSPI_TCR. Thus, the signals are sampled one half of a CLK cycle later (on the following, opposite edge).

In DTR mode, it is recommended to set DHQC of OCTOSPI_TCR, to shift the outputs by a quarter of cycle and avoid holding issues on the memory side.

Note: DHQC must not be set when the prescaler value is 0, as this action leads to unpredictable behavior.

Figure 185. DTR write in octal-SPI mode (Macronix mode) example



Note: Due to internal synchronization, up to six extra dummy clock cycles may be generated by the Octo-SPI interface after the last data is read.

Dual-quad configuration

When DMM = 1 in OCTOSPI_CR, the OCTOSPI is in dual-memory configuration: if DMODE = 011, two external Quad-SPI devices (device A and device B) are used in order to send/receive eight bits (or 16 bits in DTR mode) every cycle, effectively doubling the throughput.

Each device (A or B) uses the same CLK and NCS signals, but each has separate IO0 to IO3 signals.

The dual-quad configuration can be used in conjunction with the single-SPI, dual-SPI, and quad-SPI modes, as well as with either the SDR or DTR mode.

The device size, as specified by DEVSIZE[4:0] in OCTOSPI_DCR1, must reflect the total external device capacity that is the double of the size of one individual component.

If address X is even, then the byte that the OCTOSPI gives for address X is the byte at the address X/2 of device A, and the byte that the OCTOSPI gives for address X + 1 is the byte at the address X/2 of device B. In other words, the bytes at even addresses are all stored in device A and the bytes at odd addresses are all stored in device B.

When reading the status registers of the devices in dual-quad configuration, twice as many bytes must be read compared to the same read in regular-command protocol: if each device gives eight valid bits after the instruction for fetching the status register, then the OCTOSPI must be configured with a data length of 2 bytes (16 bits), and the OCTOSPI receives one byte from each device.

If each device gives a status of 16 bits, then the OCTOSPI must be configured to read 4 bytes to get all the status bits of both devices in dual-quad configuration. The least-significant byte of the result (in the data register) is the least-significant byte of device A status register. The next byte is the least-significant byte of device B status register. Then, the third byte of the data register is the device A second byte. The fourth byte is the device B second byte (if devices have 16-bit status registers).

An even number of bytes must always be accessed in dual-quad configuration. For this reason, bit 0 of DL[31:0] in OCTOSPI_DLR is stuck at 1 when DMM = 1.

In dual-quad configuration, the behavior of device A interface signals is basically the same as in normal mode. Device B interface signals have exactly the same waveforms as device A ones during the instruction, address, alternate-byte, and dummy-cycle phases. In other words, each device always receives the same instruction and the same address.

Then, during the data phase, the AIOx and the BIOx buses both transfer data in parallel, but the data that is sent to (or received from) device A is distinct than the one from device B.

26.4.6 HyperBus protocol

The OCTOSPI can communicate with the external device using the HyperBus protocol.

The HyperBus uses 11 to 12 pins depending on the operating voltage:

- IO[7:0] as bidirectional data bus
- DQS for read and write data strobe and latency insertion
- NCS
- CLK
- NCLK for 1.8 V operations (to support this mode, the device must be powered with 1.8 V)

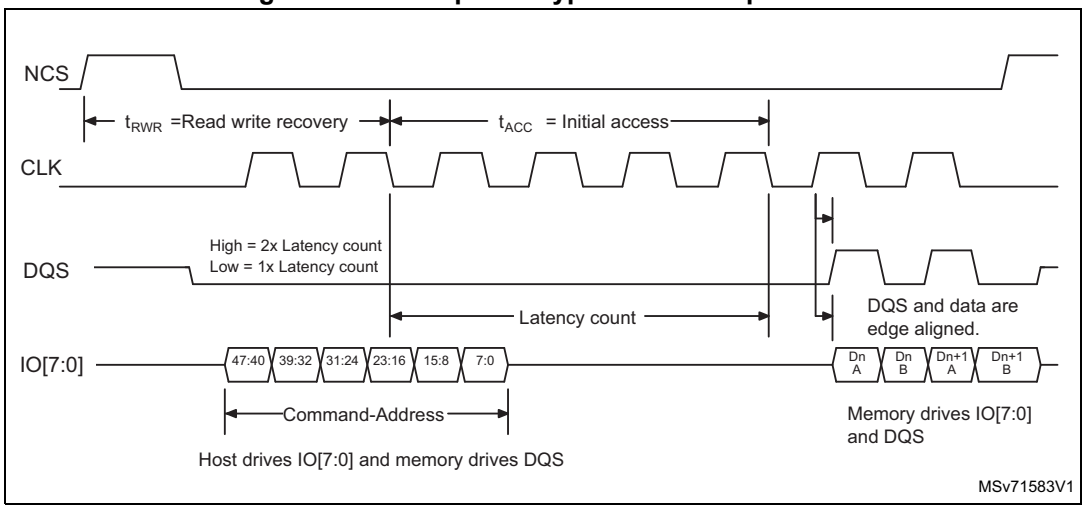
The HyperBus does not require any command specification nor any alternate bytes. As a consequence, a separate register set is used to define the timing of the transaction.

The HyperBus frame is composed of the following phases:

- Command/address phase
- Data phase

The NCS falls before the start of a transaction and rises again after each transaction finishes.

Figure 186. Example of HyperBus read operation



Note: Due to internal synchronization, up to six extra dummy clock cycles may be generated by the Octo-SPI interface after the last data is read.

The specific HyperBus features are configured through the registers in the 0x0200-0x02FC offset range.

Command/address phase

During this initial phase, the OCTOSPI sends 48 bits over IO[7:0] to specify the operations to be performed with the external device.

Table 248. Command/address phase description

CA bit	Bit name	Description
47	R/W#	Identifies the transaction as a read or a write.
46	Address space	Indicates if the transaction accesses the memory or the register space.
45	Burst type	Indicates if the burst is linear or wrapped.
44-16	Row and upper column address	Selects the row and the upper column addresses.
15-3	Reserved	-
2-0	Lower column address	Selects the starting 16-bit word within the half page.

The address space is configured through the memory type MTYP[2:0] in OCTOSPI_DCR1.

The total size of the device must be configured through DEVSIZE[4:0] of OCTOSPI_DCR1. In case of multi-chip product (MCP), the device size is the sum of all the sizes of all the MCP dies.

Read/write operation with initial latency

The HyperBus read and write operations need to respect two timings:

- t_{RWR}: minimal read/write recovery time for the device (defined by TRWR[7:0] in OCTOSPI_HLCR)
- t_{ACC}: access time for the device (defined by TACC[7:0] in OCTOSPI_HLCR) according to the memory latency

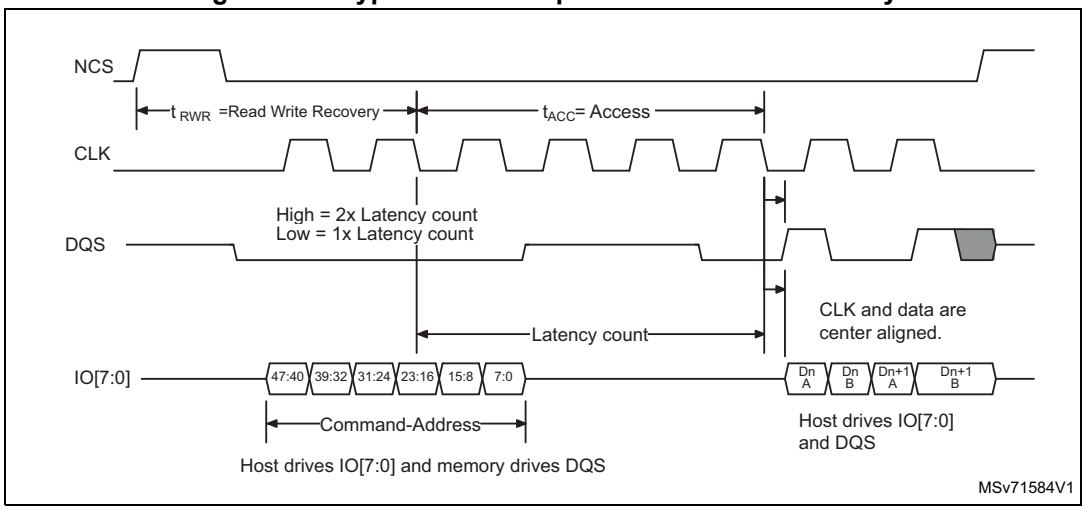
During the read operation, the DQS is used by the device, in two ways (see *Figure 186*):

- during the command/address phase, to request an additional latency
- during the data phase, for data strobing

During the write operation, the DQS is used:

- by the device, during the command/address phase, to request an additional latency.
- by the OCTOSPI, during the data phase, for write data masking.

Figure 187. HyperBus write operation with initial latency



Read/write operation with additional latency

If the device needs an additional latency (during refresh period of an SDRAM for example), DQS must be tied to one during one of the DQS signals, during the command/address phase.

An additional t_{ACC} duration is added by the OCTOSPI to meet the device request.

Figure 188. HyperBus read operation with additional latency

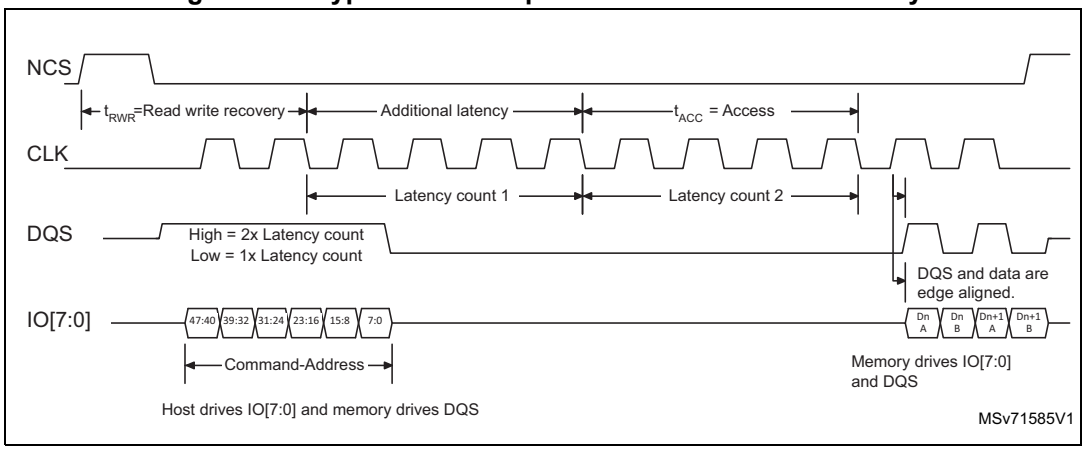
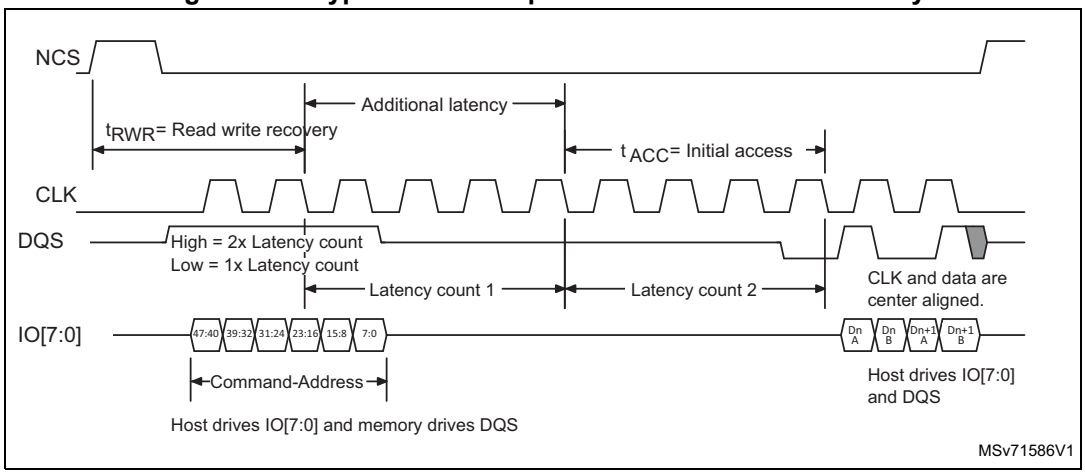


Figure 189. HyperBus write operation with additional latency



Fixed-latency mode

Some devices or some applications may not want to operate with a variable latency time as described above.

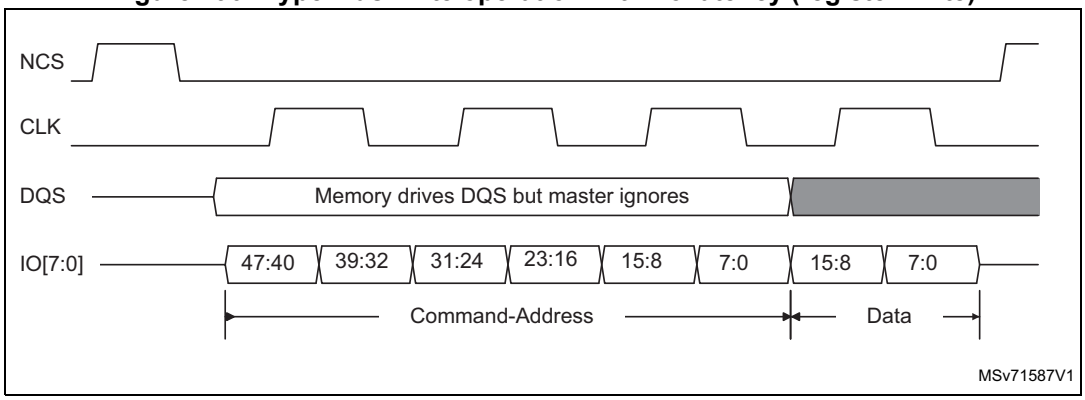
The latency can be forced to 2 x t_{ACC} by setting LM in OCTOSPI_HLCR.

In this OCTOSPI latency mode, the state of the DQS signal is not taken into account by the OCTOSPI, and an additional latency is always added, leading to a fixed 2 x t_{ACC} latency time.

Write operation with no latency

Some devices can also require a zero latency for the write operations. This write-zero latency can be forced by setting WZL in OCTOSPI_HLCR.

Figure 190. HyperBus write operation with no latency (register write)

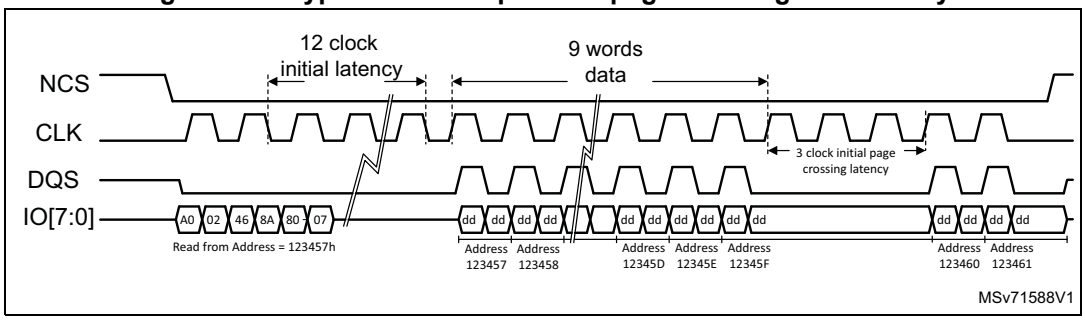


Latency on page-crossing during the read operations

An additional latency can be needed by some devices for the read operation when crossing pages.

The initial latency must be respected for any page access, as a consequence, when the first access is close to the page boundary, a latency is automatically added at the page crossing to respect the t_{ACC} time.

Figure 191. HyperBus read operation page crossing with latency



26.4.7 Specific features

The OCTOSPI supports some specific features, such as:

- Wrap support
- NCS boundary and refresh
- Communication regulation

Wrap support

The OCTOSPI supports a hybrid wrap as defined by the HyperBus protocol. A hybrid wrap is also supported in the regular-command protocol.

In hybrid wrap, the transaction can continue after the initial wrap with an incremental access.

The wrap size supported by the target memory is configured by WRAPSIZE in OCTOSPI_DCR2.

Wrap is supported only in memory-read direction and only for data size = 4 bytes. Wrapped reads are supported for both HyperBus and regular-command protocols. To enable wrapped-read accesses, the dedicated OCTOSPI_WPxxx registers must be programmed according to the wrapped-read access characteristics. These registers apply for both HyperBus and regular-command protocols.

If the target memory is not supporting the hybrid wrap, WRAPSIZE must be set to 0.

Note: Hybrid wrap requires that the nonwrapped registers (OCTOSPI_CCR, OCTOSPI_TCR, OCTOSPI_IR) are set according to the memory configuration to satisfy its correct data prefetch (initiated after the wrap command).

The wrap operation cannot be interrupted by a refresh. The refresh event is only considered after the wrap completion.

NCS boundary and refresh

Two processes can be activated to regulate the OCTOSPI transactions:

- NCS boundary
- Refresh

The NCS boundary feature limits a transaction to a boundary of aligned addresses. The size of the address to be aligned with, is configured by CSBOUND[4:0] in OCTOSPI_DCR3: it is equal to $2^{CSBOUND}$.

As an example, if CSBOUND(4:0] = 0x4, the boundary is set to 2^4 = 16 bytes. The NCS is then released each time the LSB address is equal to 0xF, and each time a new transaction is issued to address the next data.

If CSBOUND[4:0] = 0, the feature is disabled. A minimum value of three is recommended.

The NCS boundary feature cannot be used for flash memory devices in write mode since a command is necessary to program another page of the flash memory.

The refresh feature limits the duration of the transactions to the value programmed by REFRESH[31:0] in OCTOSPI_DCR4. The duration is expressed in number of cycles. This allows an external RAM to perform its internal refresh operation regularly.

The refresh value must be greater than the minimal transaction size in terms of number of cycles including the command/address/alternate/dummy phases.

If NCS boundary and refresh are enabled at the same time, the NCS is released on the first condition met.

Communication regulation

The communication regulation feature limits the maximum length of a transaction to the value programmed by MAXTRAN[7:0] in OCTOSPI_DCR3.

If the number of clock cycles reaches the MAXTRAN + 1 value, and if the second OCTOSPI requests access, the NCS is released and a new transaction is issued to address the next data. If the second OCTOSPI does not request an access, the transaction is not stopped and the NCS is not released.

If MAXTRAN[7:0] = 0, no limitation occurs.

The MAXTRAN[7:0] value must be greater than the minimal transaction size in terms of number of cycles including the command, address, alternate, and dummy phases.

Note: The communication regulation feature cannot be used in write mode for the flash memory devices that require extra command to reenable the write operation after the NCS is active again.

If NCS boundary, refresh, and communication regulation are enabled at the same time, the NCS is released on the first condition met.

Restarting after an interrupted transfer

When a read or write operation is interrupted by a timeout or communication regulation feature, the Octo-SPI interface, as soon as possible after getting back the port ownership, reissues the initial command sequence together with the address following the last address actually accessed before interruption. The transfer initially set goes on and ends seamlessly.

26.4.8 OCTOSPI operating mode introduction

The OCTOSPI has the following operating modes regardless of the low-level protocol used (either regular-command or HyperBus):

- indirect mode (read or write)
- automatic status-polling mode (only in regular-command protocol)
- memory-mapped mode

26.4.9 OCTOSPI indirect mode

In indirect mode, the commands are started by writing to the OCTOSPI registers, and data are transferred by writing or reading the data register, in a similar way to other communication peripherals.

When FMODE[1:0] = 00 in OCTOSPI_CR, the OCTOSPI is in indirect-write mode: bytes are sent to the external device during the data phase. Data are provided by writing to OCTOSPI_DR.

When FMODE[1:0] = 01, the OCTOSPI is in indirect-read mode: bytes are received from the external device during the data phase. Data are recovered by reading OCTOSPI_DR.

In indirect mode, when the OCTOSPI is configured in DTR mode over eight lanes with DQS disabled, the given starting address and the data length must be even.

Note: The OCTOSPI_AR register must be updated even if the start address is the same as the start address of the previous indirect access.

The number of bytes to be read/written is specified in OCTOSPI_DLR:

- If DL[31:0] = 0xFFFF FFFF, the data length is considered undefined and the OCTOSPI simply continues to transfer data until it reaches the end of the external device (as defined by DEVSIZE). If no bytes are to be transferred, DMODE[2:0] must be set to 0 in OCTOSPI_CCR.
- If DL[31:0] = 0xFFFF FFFFF and DEVSIZE[4:0] = 0x1F (its maximum value indicating at 4-Gbyte device), the transfers continue indefinitely, stopping only after an abort request or after the OCTOSPI is disabled. After the last memory address is read (at address 0xFFFF FFFF), reading continues with address = 0x0000 0000.

When the programmed number of bytes to be transmitted or received is reached, the TCF bit is set in OCTOSPI_SR, and an interrupt is generated if TCIE = 1 in OCTOSPI_CR. In the case of an undefined number of data, TCF is set when the limit of the external SPI memory is reached, according to the device size defined in OCTOSPI_DCR1.

Triggering the start of a transfer in regular-command protocol

Depending on the OCTOSPI configuration, there are three different ways to trigger the start of a transfer in indirect mode when using the regular-command protocol. In general, the start of transfer is triggered as soon as the software gives the last information that is necessary for the command. More specifically in indirect mode, a transfer starts when one of the following sequence of events occurs:

- if no address is necessary (ADMODE[2:0] = 000) and if no data need to be provided by the software (FMODE[1:0] = 01 or DMODE[2:0] = 000), and at the moment when a write is performed to INSTRUCTION[31:0] in OCTOSPI_IR
- if an address is necessary (when ADMODE[2:0] ≠ 000) and if no data need to be provided by the software (when FMODE[1:0] = 01 or DMODE[2:0] = 000), and at the moment when a write is performed to ADDRESS[31:0] in OCTOSPI_AR
- if data need to be provided by the software (when FMODE[1:0] = 00 and DMODE[2:0] ≠ 000), and at the moment when a write is performed to DATA[31:0] in OCTOSPI_DR

A write to OCTOSPI_ABR never triggers the communication start. If alternate bytes are required, they must have been programmed before.

As soon as a command is started, the BUSY bit is automatically set in OCTOSPI_SR.

Triggering the start of a transfer in HyperBus protocol

Depending on the OCTOSPI configuration, there are different ways to trigger the start of a command in indirect mode. In general, it is triggered as soon as the firmware gives the last information that is necessary for the transfer to start, and more specifically, a communication in indirect mode is triggered by one of the following register settings, when it is the last one to be executed:

- when a write is performed to ADDRESS[31:0] (OCTOSPI_AR) with ADMODE[2:0] ≠ 000 in indirect read mode (FMODE[1:0] = 01).
- when a write is performed to DATA[31:0] (OCTOSPI_DR) in indirect-write mode (when FMODE = 00).
- when a (dummy) write is performed to INSTRUCTION[31:0] (OCTOSPI_IR) for indirect read mode (with ADMODE[2:0] = 000 and FMODE = 01).

As soon as a transfer is started, the BUSY bit (OCTOSPI_SR[5]) is automatically set.

FIFO and data management

Data in indirect mode passes through a 32-byte FIFO that is internal to the OCTOSPI. FLEVEL in OCTOSPI_SR indicates how many bytes are currently being held in the FIFO.

AHB burst transactions are supported. Data of the burst are successively written in OCTOSPI_DR, and immediately transferred in the internal FIFO.

In indirect-write mode (FMODE[1:0] = 00), the software adds data to the FIFO when it writes in OCTOSPI_DR. A word write adds 4 bytes to the FIFO, a half-word write adds 2 bytes, and a byte write adds only 1 byte. If the software adds too many bytes to the FIFO (more than indicated in DL[31:0]), the extra bytes are flushed from the FIFO at the end of the write operation (when TCF is set).

The byte/half-word accesses to OCTOSPI_DR must be done only to the least significant byte/halfword of the 32-bit register.

FTHRES is used to define a FIFO threshold after which point the FIFO threshold flag, FTF, gets set. In indirect-read mode, FTF is set when the number of valid bytes to be read from the FIFO is above the threshold. FTF is also set if there is any data left in the FIFO after the last byte is read from the external device, regardless of FTHRES setting. In indirect-write mode, the FTF is set when the number of empty bytes in the FIFO is above the threshold.

If FTIE = 1, there is an interrupt when the FTF is set. If DMAEN = 1, a DMA transfer is initiated when the FTF is set. The FTF is cleared by hardware as soon as the threshold condition is no longer true (after enough data has been transferred by the CPU or DMA).

The last data read in RX FIFO remains valid as long as there is no request for the next line. This means that, when the application reads several times in a row at the same location, the data is provided from the RX FIFO and not read again from the distant memory.

26.4.10 OCTOSPI automatic status-polling mode

In automatic status-polling mode, the OCTOSPI periodically starts a command to read a defined number of status bytes (up to four). The received bytes can be masked to isolate some status bits and an interrupt can be generated when the selected bits have a defined value. The automatic status-polling mode must be used only in regular-command protocol. For HyperBus protocol, it is not exploitable since the read status register into the HyperFlash memory must be performed in two steps (a write operation followed by a read operation).

The access to the device begins in the same manner as in indirect-read mode. BUSY in OCTOSPI_SR goes high at this point and stays high even between the periodic accesses.

The content of MASK[31:0] in OCTOSPI_PSMAR is used to mask the data from the external device in automatic status-polling mode:

- If the MASK[n] = 0, then bit n of the result is masked and not considered.
- If MASK[n] = 1, and the content of bit[n] is the same as MATCH[n] in OCTOSPI_PSMAR, then there is a match for bit n.

If PMM = 0 in OCTOSPI_CR, the AND-match mode is activated: SMF is set in OCTOSPI_SR only when there is a match on all of the unmasked bits.

If PMM = 1 in OCTOSPI_CR, the OR-match mode is activated: SMF gets set if there is a match on any of the unmasked bits.

An interrupt is called when SMF = 1 if SMIE = 1.

If APMS is set in OCTOSPI_CR, the operation stops and BUSY goes to 0 as soon as a match is detected. Otherwise, BUSY stays at 1 and the periodic accesses continue until there is an abort or until the OCTOSPI is disabled (EN = 0).

OCTOSPI_DR contains the latest received status bytes (FIFO deactivated). The content of this register is not affected by the masking used in the matching logic. FTF in OCTOSPI_SR is set as soon as a new reading of the status is complete. FTF is cleared as soon as the data is read.

In automatic status-polling mode, variable latency is not supported. The memory must then be configured in fixed latency.

26.4.11 OCTOSPI memory-mapped mode

When configured in memory-mapped mode, the external SPI device is seen as an internal memory.

Note: No more than 256 Mbytes can be addressed even if the external device capacity is larger.

If an access is made to an address outside of the range defined by DEVSIZE[4:0] but still within the 256 Mbytes range, then an AHB error is given. The effect of this error depends on the AHB master that attempted the access:

- If it is the Cortex CPU, a hard-fault interrupt is generated.
- If it is a DMA, a DMA transfer error is generated, and the corresponding DMA channel is automatically disabled.

Byte, half-word, and word access types are all supported.

A support for execute in place (XIP) operation is implemented, where the OCTOSPI continues to load the bytes to the addresses following the most recent access. If subsequent accesses are continuous to the bytes that follow, then these operations end up quickly since their results were prefetched.

By default, the OCTOSPI never stops its prefetch operation. It either keeps the previous read operation active with the NCS maintained low or it relaunches a new transfer, even if no access to the external device occurs for a long time.

Since external devices tend to consume more power when the NCS is held low, the application may want to activate the timeout counter (TCEN = 1 in OCTOSPI_CR): the NCS is released after a period defined by TIMEOUT[15:0] in OCTOSPI_LPTR, when x cycles have elapsed without access since the clock is inactive.

BUSY goes high as soon as the first memory-mapped access occurs. Because of the prefetch operations, BUSY does not fall until there is an abort, or the peripheral is disabled.

It is not recommended to program the flash memory using the memory-mapped writes. The indirect-write mode fulfills this operation.

However, if the application requires the use of the MCE for encryption (check MCE product availability), the memory-mapped write mode may be used to program encrypted data to external flash memory under the following conditions:

- Prefetch must be enabled.
- In block cipher mode, the CPU must write a complete 128-bit data block to prevent the MCE from initiating read-modify-write operations when only a few bytes need to be programmed. This precaution avoids incorrect programming operations. There are no specific constraints to respect if the MCE is used in stream cipher mode.
- Apply the abort sequence to exit memory-mapped mode when the data linked to the page has been written in the external memory buffers. The abort sequence triggers the start of the page programming.
- Switch to the automatic status-polling mode to monitor the completion of the page programing phase.
- Relaunch the write enable command in indirect mode, then switch back to the memory-mapped mode configuration to continue to program additional pages if any.

It is recommended to add a synchronization barrier between the end of the controller registers configuration and the first memory-mapped access to the external memory when the controller is configured in memory-mapped mode.

The controller can apply an automatic address offset to simplify memory area code switching, such as during a firmware update (if the address offset feature is available in the product implementation table). To enable this feature, set the ADOFFEN bit in the XSPI_CR register and configure the offset value in the ADOFF[4:0] bitfield of the XSPI_DCR1 register. The offset is modulo 256 bytes.

26.4.12 OCTOSPI configuration introduction

The OCTOSPI configuration is done in three steps:

1. OCTOSPI system configuration
2. OCTOSPI device configuration
3. OCTOSPI mode configuration

26.4.13 OCTOSPI system configuration

The OCTOSPI is configured using OCTOSPI_CR. The user must program:

- the functional mode with FMODE[1:0]
- the automatic status-polling mode behavior if needed with PMM and APMS
- the FIFO level with FTHRES
- the DMA use with DMAEN
- the timeout counter use with TCEN
- the dual-memory configuration, if needed, with DMM

In case of an interrupt use, the respective enable bit can also be set during this phase.

If the timeout counter is used, the timeout value is programmed in OCTOSPI_LPTR.

The DMA channel must not be enabled during the OCTOSPI configuration: it must be enabled only when the operation is fully configured, to avoid any unexpected request generation.

The DMA and OCTOSPI must be configured in a coherent manner regarding data length: FTHRES value must reflect the DMA burst size.

26.4.14 OCTOSPI device configuration

The parameters related to the external device targeted are configured through OCTOSPI_DCR1 and OCTOSPI_DCR2.The user must program:

- the device size with DEVSIZE[4:0]
- the chip-select minimum high time with CSHT[5:0]
- the clock mode with FRCK and CKMODE
- the device frequency with PRESCALER[7:0]

DEVSIZE[4:0] defines the size of external memory using the following formula:

$$\text{Number of bytes in the device} = 2^{DEVSIZE+1}$$

where DEVSIZE+1 is the number of address bits required to address the external device. The external device capacity can go up to 4 Gbytes (addressed using 32 bits) in indirect mode, but the addressable space in memory-mapped mode is limited to 256 Mbytes.

If DMM = 1, DEVSIZE[4:0] must reflect the total capacity of the two devices together considering the above formula (DEVSIZE[4:0] value is so equal to one of the two memory capacities).

When the OCTOSPI executes two commands, one immediately after the other, it raises the chip-select signal (NCS) high between the two commands for only one CLK cycle by default.

If the external device requires more time between commands, the chip-select high time CSHT[5:0] can be used to specify the minimum number of CLK cycles for which the NCS must remain high.

CKMODE indicates the level that the CLK takes between commands (when NCS = 1).

In HyperBus protocol, the device timing (t_{ACC} and t_{RWR}) and the latency mode must be configured in OCTOSPI_HLCR.

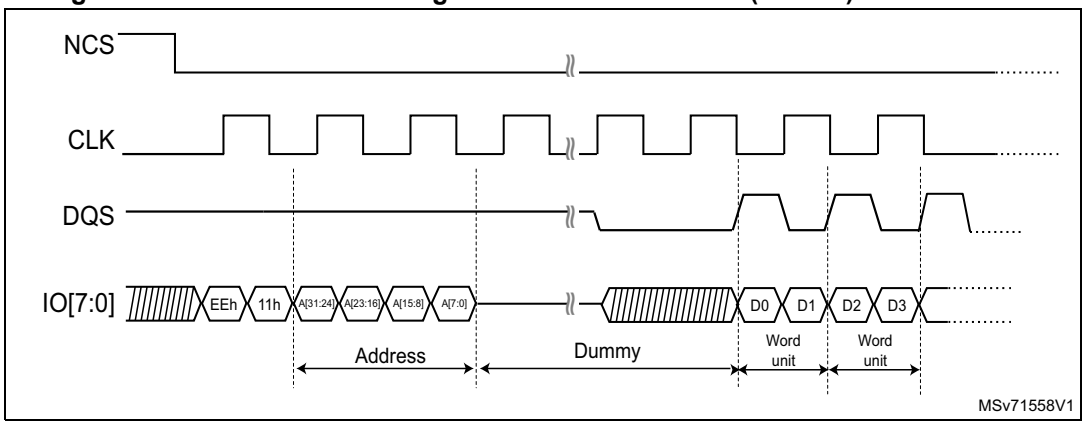
Memory types

External memory providers may present some architecture and slight data formatting differences between them. The bitfield MTYP[2:0] into the OCTOSPI_CR register allows targeting the right controller configuration depending on the associated memory type selected in the application. This is the responsibility of the software developer to align the controller configuration to fit with the targeted memory type.

The memory types are grouped in a such way:

- D0/D1 data ordering in octal-SPI data mode (DMODE[2:0] = 100) in DTR mode by configuring MTYP[2:0] = 000. For instance, Micron is using such data ordering. In this configuration, the DQS is sent with a polarity inverted respect to the clock polarity.

Figure 192. D0/D1 data ordering in octal-SPI DTR mode (Micron) - Read access



- D1/D0 data ordering in octal-SPI data mode (DMODE[2:0] = 100) in DTR mode by configuring MTYP[2:0] = 001. For instance, Macronix is using this reverse data ordering in its Octaflash portfolio (this configuration is not adapted to its OctaRAM™ memories). DQS is keeping the same polarity as the clock when reading data from the memory. Refer to *Figure 183: DTR read in octal-SPI mode with DQS (Macronix mode) example*.
- D1/D0 data ordering in octal-SPI data mode (DMODE[2:0] = 100) in DTR mode by configuring MTYP[2:0] = 011 with specific address phase built with row and column to fit with Macronix OctaRAM™ memories requirement (refer to *Table 249: OctaRAM command address bit assignment (based on 64-Mbyte OctaRAM)*. This is the controller which translates internally the targeted address provided by the software in row/column address formatting to sent to the memory. DQS is keeping the same polarity as the clock one when reading data from the memory.

Figure 193. OctaRAM read operation with reverse data ordering D1/D0

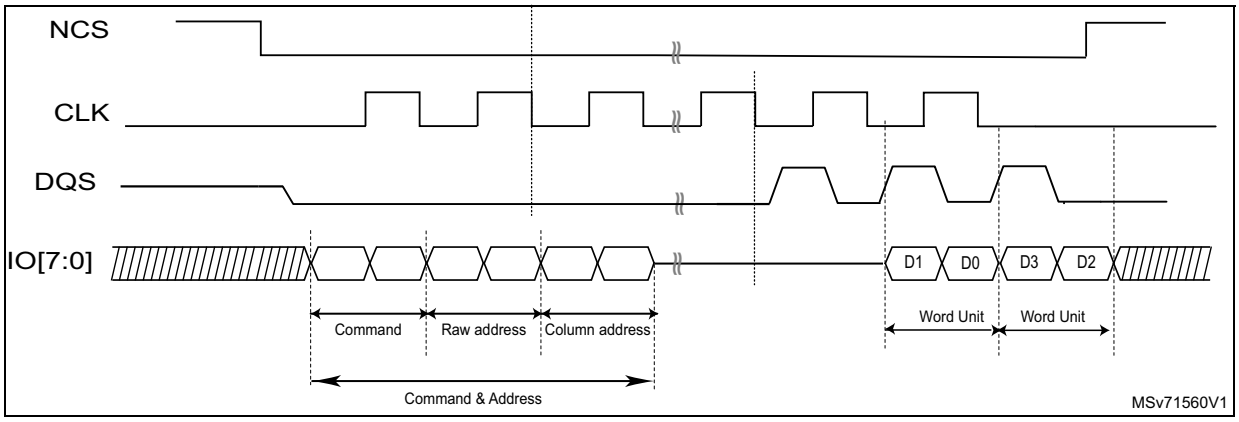


Table 249. OctaRAM command address bit assignment (based on 64-Mbyte(1) OctaRAM)

Clock	1st clock	2nd clock		3rd clock	
Function	Command	Row address		Column address	
SIO[7]	Command	Reserved	RA7	CA9	Reserved
SIO[6]		Reserved	RA6	CA8	Reserved
SIO[5]		Reserved	RA5	CA7	Reserved
SIO[4]		RA12	RA4	CA6	Reserved
SIO[3]		RA11	RA3	CA5	CA3
SIO[2]		RA10	RA2	CA4	CA2
SIO[1]		RA9	RA1	Reserved	CA1
SIO[0]		RA8	RA0	Reserved	CA0(2)

1. Example of 64-Mbyte OctaRAM address assignment:
Row Address [RA12:RA0]: 8K. Column address [CA9:CA0]: 1K. 64-Mbyte density = 8K x 1K x 8 bits
2. Column address A0 must be always 0.

- HyperBus memories need to be selected when targeted by the application. The configuration to set depends on the access type:
  - HyperBus memory mode: The protocol follows the HyperBus specification. MTYP[2:0] = 100 is the configuration to use to access the memory space.
  - HyperBus register mode (addressing register space): the memory-mapped accesses in this mode must be noncacheable, or the indirect read/write modes must be used. The configuration to be set for this particular register space access is MTYP[2:0] = 101.
- Standard mode. It is the mode to use whenever the targeted memory is not corresponding to any others configurations described in this section. MTYP[2:0] = 010 for this standard mode.

26.4.15 OCTOSPI regular-command mode configuration

Indirect mode configuration

When FMODE[1:0] = 00, the indirect-write mode is selected and data can be sent to the external device. When FMODE[1:0] = 01, the indirect-read mode is selected, and data can be read from the external device.

When the OCTOSPI is used in indirect mode, the frames are constructed in the following way:

1. Specify a number of data bytes to read or write in OCTOSPI_DLR.
2. Specify the frame timing in OCTOSPI_TCR.
3. Specify the frame format in OCTOSPI_CCR.
4. Specify the instruction in OCTOSPI_IR.
5. Specify the optional alternate byte to be sent right after the address phase in OCTOSPI_ABR.
6. Specify the targeted address in OCTOSPI_AR.

7. Enable the DMA channel if needed.
8. Read/write the data from/to the FIFO through OCTOSPI_DR (if no DMA usage).

If neither the address register (OCTOSPI_AR) nor the data register (OCTOSPI_DR) need to be updated for a particular command, then the command sequence starts as soon as OCTOSPI_IR is written. This is the case when both ADMODE[2:0] and DMODE[2:0] equal 000, or if just ADMODE[2:0] = 000 when in indirect-read mode (FMODE[1:0] = 01).

When an address is required (ADMODE[2:0] ≠ 000) and the data register does not need to be written (FMODE[1:0] = 01 or DMODE[2:0] = 000), the command sequence starts as soon as the address is updated with a write to OCTOSPI_AR.

In case of data transmission (FMODE[1:0] = 00 and DMODE[2:0] ≠ 000), the communication start is triggered by a write in the FIFO through OCTOSPI_DR.

Automatic status-polling mode configuration

The automatic status-polling mode is enabled by setting FMODE[1:0] = 10. In this mode, the programmed frame is sent and data are retrieved periodically.

The maximum amount of data read in each frame is 4 bytes. If more data is requested in OCTOSPI_DLR, it is ignored, and only 4 bytes are read. The periodicity is specified in OCTOSPI_PIR.

Once the status data has been retrieved, the following can be processed:

- Set SMF (an interrupt is generated if enabled).
- Stop automatically the periodic retrieving of the status bytes.

The received value can be masked with the value stored in OCTOSPI_PSMKR, and can be ORed or ANDed with the value stored in OCTOSPI_PSMAR.

In case of a match, SMF is set and an interrupt is generated if enabled. The OCTOSPI can be automatically stopped if AMPS is set. In any case, the latest retrieved value is available in OCTOSPI_DR.

When the OCTOSPI is used in automatic status-polling mode, the frames are constructed in the following way:

1. Specify the input mask in OCTOSPI_PSMKR.
2. Specify the comparison value in OCTOSPI_PSMAR.
3. Specify the read period in OCTOSPI_PIR.
4. Specify a number of data bytes to read in OCTOSPI_DLR.
5. Specify the frame timing in OCTOSPI_TCR.
6. Specify the frame format in OCTOSPI_CCR.
7. Specify the instruction in OCTOSPI_IR.
8. Specify the optional alternate byte to be sent right after the address phase in OCTOSPI_ABR.
9. Specify the optional targeted address in OCTOSPI_AR.

If the address register (OCTOSPI_AR) does not need to be updated for a particular command, then the command sequence starts as soon as OCTOSPI_CCR is written. This is the case when ADMODE[2:0] = 000.

When an address is required (ADMODE[2:0] ≠ 000), the command sequence starts as soon as the address is updated with a write to OCTOSPI_AR.

Memory-mapped mode configuration

In memory-mapped mode, the external device is seen as an internal memory but with some latency during accesses. Read and write operations are allowed to the external device in this mode.

It is not recommended to program the flash memory using memory-mapped writes, as the internal flags for erase or programming status have to be polled. The indirect-write mode fulfills this operation, possibly in conjunction with the automatic status-polling mode.

The memory-mapped mode is entered by setting FMODE[1:0] = 11 in OCTOSPI_CR.

The programmed instruction and frame are sent when an AHB master accesses the memory-mapped space.

The FIFO is used as a prefetch buffer to anticipate any linear reads. Any access to OCTOSPI_DR in this mode returns zero.

The data length register (OCTOSPI_DLR) has no meaning in memory-mapped mode.

When the OCTOSPI is used in memory-mapped mode, the frames are constructed in the following way:

1. Specify the frame timing in OCTOSPI_TCR for read operation.
2. Specify the frame format in OCTOSPI_CCR for read operation.
3. Specify the instruction in OCTOSPI_IR.
4. Specify the optional alternate byte to be sent right after the address phase in OCTOSPI_ABR for read operation.
5. Specify the frame timing in OCTOSPI_WTCR for write operation.
6. Specify the frame format in OCTOSPI_WCCR for write operation.
7. Specify the instruction in OCTOSPI_WIR.
8. Specify the optional alternate byte to be sent right after the address phase in OCTOSPI_WABR for write operation.

All configuration operations must be completed (ensured by checking BUSY = 0) before the first access to the memory area: any register write operation when BUSY = 1 has no effect and is not signaled with an error response. On the first access, the OCTOSPI becomes busy, and no further configuration is allowed. Then, the only way to get BUSY low is to clear the ENABLE bit or to abort by setting the ABORT bit.

OCTOSPI delayed data sampling when no DQS is used

By default, when no DQS is used, the OCTOSPI samples the data driven by the external device one half of a CLK cycle after the external device drives the signal.

In case of any external signal delays, it may be useful to sample the data later. Using SSHIFT in OCTOSPI_TCR, the sampling of the data can be shifted by half of a CLK cycle.

The firmware must clear SSHIFT when the data phase is configured in DTR mode (DDTR = 1).

OCTOSPI delayed data sampling when DQS is used

When external DQS is used as a sampling clock, it can be shifted in time to compensate the data propagation delay.

This shift is performed by a delay hardware element located outside of the controller into the RCC (RCC_DLYCFGR) or implemented on an external dedicated block delay peripheral

depending on the product (refer to the product reference manual for information about how to manage and configure the delay).

In configurations where delay does not need to be compensated, the external delay block can be bypassed by setting DLYBYP in OCTOSPI_DCR1.

26.4.16 OCTOSPI HyperBus protocol configuration

Indirect mode configuration (HyperBus)

When FMODE[1:0] = 00, the indirect-write mode is selected and data can be sent to the external device. When FMODE[1:0] = 01, the indirect-read mode is selected where data can be read from the external device. ADMODE must be configured with a value different from 000 (for instance ADMODE = 100).

When the OCTOSPI is used in indirect mode, the frames are constructed in the following way:

1. Specify a number of data bytes to read or write in OCTOSPI_DLR.
2. Specify the targeted address in OCTOSPI_AR.
3. Enable the DMA channel if needed.
4. Read/write the data from/to the FIFO through OCTOSPI_DR (if no DMA usage).

In indirect-read mode, the command sequence starts as soon as the address is updated with a write to OCTOSPI_AR.

In indirect-write mode, the communication start is triggered by a write in the FIFO through OCTOSPI_DR.

Memory-mapped mode configuration (HyperBus)

In memory-mapped mode, the external device is seen as an internal memory but with some latency during the accesses. Read and write operations are allowed to the external device in this mode.

It is not recommended to program the flash memory using the memory-mapped writes: the indirect-write mode fulfills this operation.

The memory-mapped mode is entered by setting FMODE[1:0] = 11. The programmed instruction and frame is sent when an AHB master accesses the memory-mapped space.

The FIFO is used as a prefetch buffer to anticipate any linear reads. Any access to OCTOSPI_DR in this mode returns zero.

The data length register (OCTOSPI_DLR) has no meaning in memory-mapped mode.

All the configuration operation must be completed before the first access to the memory area. On the first access, the OCTOSPI becomes busy, and no configuration is allowed. Then, the only way to get BUSY low is to clear the ENABLE bit, or to abort by setting the ABORT bit.

26.4.17 OCTOSPI error management

The following errors set the TEF flag in OCTOSPI_SR and generates an interrupt if enabled (TEIE = 1 in OCTOSPI_CR):

- in indirect or automatic status-polling mode, when a wrong address has been programmed in OCTOSPI_AR (according to the device size defined by DEVSIZE[4:0]).

- in indirect mode, if the address plus the data length exceed the device size: TEF is set as soon as the access is triggered.

In memory-mapped mode, the OCTOSPI generates an AHB slave error in the following situations, setting the BERRF flag in XSPI_SR and generating an interrupt if enabled (BERRIE = 1 in XSPI_CR) (if the Bus error bit feature is available in the product implementation table, otherwise the Slave bus error response is generated at system level as transaction response with no dedicated bit into the controller status register):

- The memory-mapped mode is disabled and an AHB read or write request occurs.
- A read or write address (including the address offset if ADOFFEN bit is set) exceeds the size of the external memory.
- An abort is received while a read or write burst is ongoing.
- The OCTOSPI is disabled while a read or write burst is requested.
- A write wrap burst is received.
- A write request is received while DQSE = 0 in OCTOSPI_WCCR in octal DTR mode, in dual-memory configuration, in HyperBus mode.
- A read or write request is received while DMODE[2:0] = 000 (no data phase), except when MTYP[2:0] is HyperBus.
- Illegal access size when wrap read burst. This means that the AHB bus transfer size (HSIZE) is different from 4 bytes (only for memory-mapped mode).
- Bit DMM is set in OCTOSPI_CR (dual-memory configuration) and octal mode is set.

26.4.18 OCTOSPI BUSY and ABORT

Once the OCTOSPI starts an operation with the external device, BUSY is automatically set in OCTOSPI_SR.

In indirect mode, BUSY is reset once the OCTOSPI has completed the requested command sequence and the FIFO is empty.

In automatic status-polling mode, BUSY goes low only after the last periodic access is complete, due to a match when APMS = 1 or due to an abort.

After the first access in memory-mapped mode, BUSY goes low only on an abort.

Any operation can be aborted by setting ABORT in OCTOSPI_CR. Once the abort is completed, BUSY and ABORT are automatically reset, and the FIFO is flushed.

Before setting ABORT, the software must ensure that all the current transactions are finished using the synchronization barriers. When DMA is enabled to handle the data read or write operations in OCTOSPI_DR, it is recommended to disable the DMA channel before aborting the OCTOSPI.

Note: Some devices may misbehave if a write operation to a status register is aborted.

26.4.19 OCTOSPI reconfiguration or deactivation

Before any OCTOSPI reconfiguration, the software must ensure that all the transactions are completed:

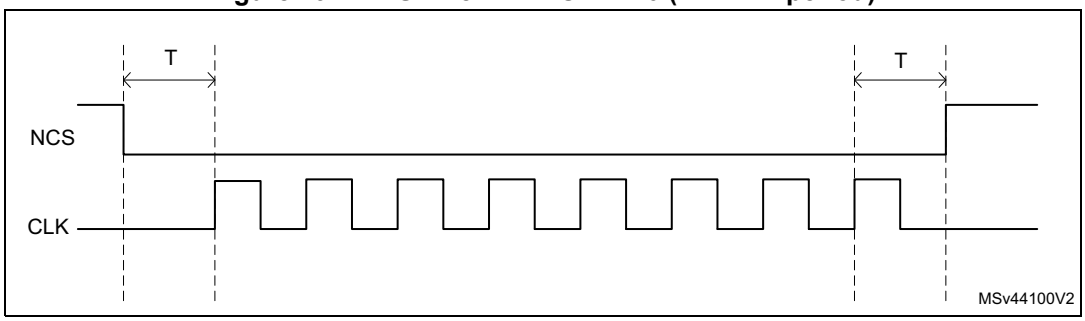
- After a memory-mapped write, the software must perform a dummy read followed by a synchronization barrier, then an abort.
- After a memory-mapped read, the software must perform a synchronization barrier than an abort.

26.4.20 NCS behavior

By default, NCS is high, deselecting the external device. NCS falls before an operation begins and rises as soon as it finishes.

When CKMODE = 0 (clock mode 0: CLK stays low when no operation is in progress), NCS falls one CLK cycle before an operation first rising CLK edge, and NCS rises one CLK cycle after the operation final rising CLK edge (see the figure below).

Figure 194. NCS when CKMODE = 0 (T = CLK period)



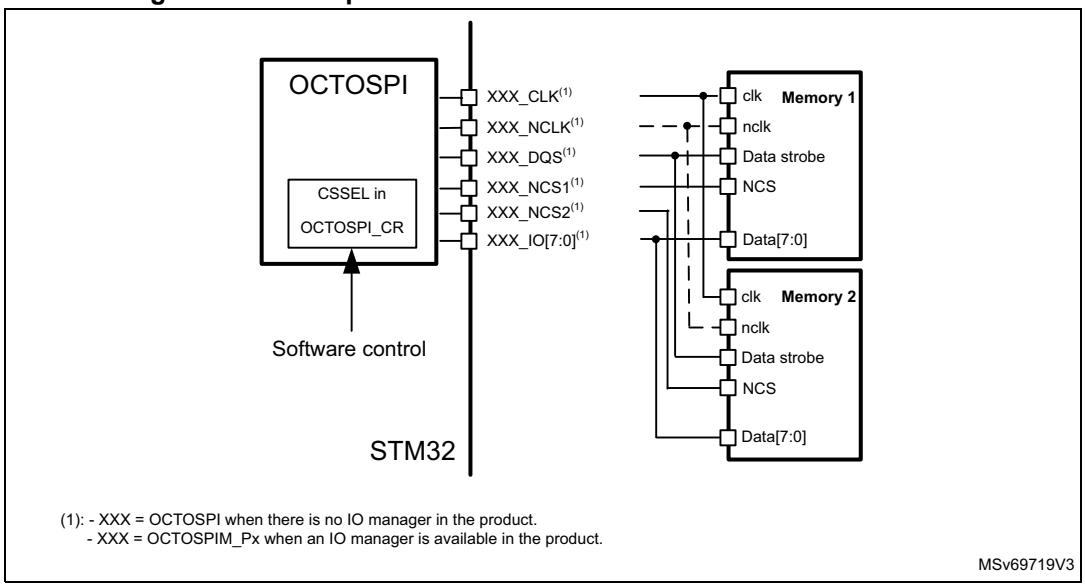
Note: Clock mode 3 is not supported.

In dual memory configuration, the NCS2 behaves exactly the same as the NCS1.
The quad-SPI/octal-SPI memory 2 can then use the NCS1, and the NCS2 pin can be used for other functions.

26.4.21 Software control of two external memories

One OCTOSPI instance is able to control the generation of the two chip-select signals (NCS1 and NCS2). This allows two external memories to be connected to the same I/O port driven by the OCTOSPI. The OCTOSPI generates one NCS signal and the user defines how the NCS is directed to NCS1 or NCS2, by setting the CSSEL bit in OCTOSPI_CR. Intended operation is semistatic commutation, such as starting an application reading an external flash memory and then, for the rest of the application, use an external SRAM connected to the same I/O bus. From a memory-map point of view, these two memories are located in the same address.

Figure 195. Example of software control of two external memories



26.4.22 Hardware-controlled extended memory support

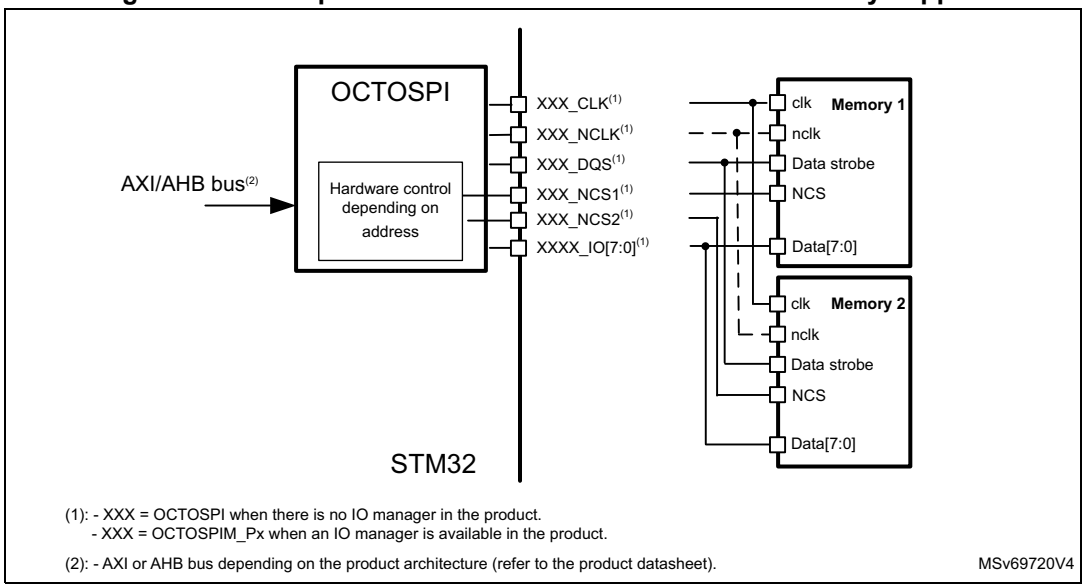
One OCTOSPI instance is able to control autonomously the generation of the two chip-select signals (NCS1 and NCS2). This feature is activated by setting EXTENDMEM in OCTOSPI_DCR1 and allows two external memories to be connected to the same I/O port driven by the OCTOSPI. The aim is to extend by a factor two, the available external memory size. Both memories must be contiguous in the memory map. Both external memories must be of the same type and size. The size of one external memory must be set in DEVSIZE of OCTOSPI_CR.

- When the address presented on the interconnect bus in memory-mapped mode or in OCTOSPI_AR in indirect mode is in the range [OCTOSPI_base_address: OCTOSPI_base_address + $2^{DEVSIZE}$ - 1], NCS1 is generated.
- When the address presented on the interconnect bus in memory-mapped mode or in OCTOSPI_AR in indirect mode is in the range [OCTOSPI_base_address + $2^{DEVSIZE}$: OCTOSPI_base_address + 2 × $2^{DEVSIZE}$ - 1], NCS2 is generated.

Note: If the access crosses the middle boundary of the external memory, CS changes automatically (no write into OCTOSPI_AR in indirect mode, or new memory access in memory-mapped mode is needed).

EXTENDMEM feature (set in bit21 of OCTOSPI_DCR1) and dual-memory mode (set in bit6 of OCTOSPI_CR) are exclusive: EXTENDMEM = 1 and DMM = 1 is not supported.

Figure 196. Example of hardware-controller extended memory support



Note: It is recommended to set EXTENDMEM = 0 for write transfers targeting flash memories (HyperFlash, NOR Flash, etc.).

These memories require preliminary commands that do not include an address phase used by the controller to select the targeted memory.

This recommendation does not apply to RAM memories, as those extra commands are not needed for RAM access.

26.5 Address alignment and data number

The table below summarizes the effect of the address alignment and programmed data number depending on the use case.

Table 250. Address alignment cases

Memory type	Transaction type	Constraint on address(1)	Impact if constraint on address not respected	Constraint on number of bytes(1)	Impact if constraint on bytes not respected
Single, dual, quad flash or SRAM (DMM = 0)	IND(2) read	None	None	None	None
	MM(3) read				
	IND write				
	MM write				
Single, dual, quad flash or SRAM (DMM = 1)	IND read	Even	ADDR[0] is set to 0.(4)	Even	DLR[0] is set to 1.(5)
	MM read	None	None	None	None
	IND write	Even	ADDR[0] is set to 0.(4)	Even	DLR[0] is set to 1.(5)
	MM write	Even	Slave error	Even	Last byte is lost.

Table 250. Address alignment cases (continued)

Memory type	Transaction type	Constraint on address(1)	Impact if constraint on address not respected	Constraint on number of bytes(1)	Impact if constraint on bytes not respected
Octal flash in SDR mode	IND read	None	None	None	None
	MM read				
	IND write				
	MM write				
Octal memory in DTR mode without WDM(6) or 8-bit HyperFLASH	IND read	Even	ADDR[0] is set to 0.(4)	Even	DLR[0] is set to 1.(5)
	MM read	None	None	None	None
	IND write	Even	ADDR[0] is set to 0.(4)	Even	DLR[0] is set to 1.(5)
	MM write	Even	Slave error	Even	Last byte is lost.
Octal flash or RAM in DTR mode with WDM	IND read	Even	ADDR[0] is set to 0.(4)	Even	DLR[0] is set to 1.(5)
	MM read	None	None	None	None
	IND write(7)				
	MM write				
8-bit HyperRAM	IND read	Even	ADDR[0] is set to 0.(4)	Even	DLR[0] is set to 1.(5)
	MM read	None	None	None	None
	IND write(7)				
	MM write				

1. To be respected by the software.
2. IND = indirect mode.
3. MM = memory-mapped mode
4. Extra data at transfer start.
5. Extra data at transfer end.
6. WDM = write data mask.
7. If the FTHRES bitfield is set to the maximum value with DLR value greater than the data burst length, and if the DMA is enabled or the interrupt based on FIFO THRESHOLD Flag is enabled (FTF), the address must be modulo 2 aligned in DTR mode when the initiator (DMA, CPU, ...) is writing the data with a burst length equal to the FIFO size.

26.6 OCTOSPI interrupts

An interrupt can be produced on the following events:

- Timeout
- Status match
- FIFO threshold
- Transfer complete
- Transfer error

Separate interrupt enable bits are available to provide more flexibility.

Table 251. OCTOSPI interrupt requests

Interrupt event	Event flag	Enable control bit
Timeout	TOF	TOIE
Status match	SMF	SMIE
FIFO threshold	FTF	FTIE
Transfer complete	TCF	TCIE
Transfer error	TEF	TEIE

26.7 OCTOSPI registers

26.7.1 OCTOSPI control register (OCTOSPI_CR)

Address offset: 0x0000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	MSEL	FMODE[1:0]		Res.	Res.	NOPREF	CSSEL	PMM	APMS	BERRIE	TOIE	SMIE	FTIE	TCIE	TEIE
	rw	rw	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	FTHRES[4:0]					Res.	DMM	Res.	ADOFFEN	TCEN	DMAEN	ABORT	EN
			rw	rw	rw	rw	rw		rw		rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **MSEL**: External memory select

This bit selects the external memory to be addressed in single-, dual-, quad-SPI mode in single-memory configuration (when DMM = 0).

0: External memory 1 selected (data exchanged over IO[3:0])

1: External memory 2 selected (data exchanged over IO[7:4])

This bit is ignored when DMM = 1 or when octal-SPI mode is selected.

Note: This bit is mirrored in bit 7. This bit can be modified only when BUSY = 0.

Bits 29:28 **FMODE[1:0]**: Functional mode

This bitfield defines the OCTOSPI functional mode of operation.

00: Indirect-write mode

01: Indirect-read mode

10: Automatic status-polling mode (relevant in regular-command protocol only)

11: Memory-mapped mode

If DMAEN = 1 already, then the DMA controller for the corresponding channel must be disabled before changing the FMODE[1:0] value.

Note: This bitfield can be modified only when BUSY = 0.

Bits 27:26 Reserved, must be kept at reset value.

Bit 25 **NOPREF**: No prefetch data

This bit disables the automatic prefetch in the external memory.

0: Automatic prefetch enabled

1: Automatic prefetch disabled

Bit 24 **CSSEL**: Chip-select selection

This bit indicates to OCTOSPI I/O manager if it must copy NCS to NCS1 or NCS2.

0: NCS I/O manager input is copied to NCS1 I/O manager output.

1: NCS I/O manager input is copied to NCS2 I/O manager output.

Note: This bit can be modified only when BUSY = 0.

Bit 23 **PMM**: Polling match mode

This bit indicates which method must be used to determine a match during the automatic status-polling mode.

0: AND-match mode, SMF is set if all the unmasked bits received from the device match the corresponding bits in the match register.

1: OR-match mode, SMF is set if any of the unmasked bits received from the device matches its corresponding bit in the match register.

Note: This bit can be modified only when BUSY = 0.

Bit 22 **APMS**: Automatic status-polling mode stop

This bit determines if the automatic status-polling mode is stopped after a match.

0: Automatic status-polling mode is stopped only by abort or by disabling the OCTOSPI.

1: Automatic status-polling mode stops as soon as there is a match.

Note: This bit can be modified only when BUSY = 0.

Bit 21 **BERRIE**: Bus error interrupt enable

This bit enables the bus error interrupt (if Bus error bit feature is available in the product implementation table).

0: Interrupt disabled

1: Interrupt enabled

Bit 20 **TOIE**: Timeout interrupt enable

This bit enables the timeout interrupt.

0: Interrupt disabled

1: Interrupt enabled

Bit 19 **SMIE**: Status-match interrupt enable

This bit enables the status-match interrupt.

0: Interrupt disabled

1: Interrupt enabled

Bit 18 **FTIE**: FIFO threshold interrupt enable

This bit enables the FIFO threshold interrupt.

0: Interrupt disabled

1: Interrupt enabled

Bit 17 **TCIE**: Transfer complete interrupt enable

This bit enables the transfer complete interrupt.

0: Interrupt disabled

1: Interrupt enabled

Bit 16 **TEIE**: Transfer error interrupt enable

This bit enables the transfer error interrupt.

0: Interrupt disabled

1: Interrupt enabled

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **FTHRES[4:0]**: FIFO threshold level

This bitfield defines, in indirect mode, the threshold number of bytes in the FIFO that causes the FIFO threshold flag FTF in OCTOSPI_SR, to be set.

00000: FTF is set if there are one or more free bytes available to be written to in the FIFO in indirect-write mode, or if there are one or more valid bytes can be read from the FIFO in indirect-read mode.

00001: FTF is set if there are two or more free bytes available to be written to in the FIFO in indirect-write mode, or if there are two or more valid bytes can be read from the FIFO in indirect-read mode.

...

11111: FTF is set if there are 32 free bytes available to be written to in the FIFO in indirect-write mode, or if there are 32 valid bytes can be read from the FIFO in indirect-read mode.

Note: If DMAEN = 1, the DMA controller for the corresponding channel must be disabled before changing the FTHRES[4:0] value.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **DMM**: Dual-memory configuration

This bit activates the dual-memory configuration, where two external devices are used simultaneously to double the throughput and the capacity

0: Dual-memory configuration disabled

1: Dual-memory configuration enabled

Note: This bit can be modified only when BUSY = 0.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **ADOFFEN**: Address offset enable

An offset may be applied on the memory address. The offset value is set into ADOFF[4:0].

0: Address offset disabled

1: Address offset enabled

Note: This bit can be modified only when BUSY = 0. This bit is present only if the address offset feature is available in the product implementation table.

Bit 3 **TCEN**: Timeout counter enable

This bit is valid only when the memory-mapped mode (FMODE[1:0] = 11) is selected. This bit enables the timeout counter.

0: The timeout counter is disabled, and thus the chip-select (NCS) remains active indefinitely after an access in memory-mapped mode.

1: The timeout counter is enabled, and thus the chip-select is released in the memory-mapped mode after TIMEOUT[15:0] cycles of external device inactivity.

Note: This bit can be modified only when BUSY = 0.

Bit 2 **DMAEN**: DMA enable

In indirect mode, the DMA can be used to input or output data via OCTOSPI_DR. DMA transfers are initiated when FTF is set.

0: DMA disabled for indirect mode

1: DMA enabled for indirect mode

Note: Resetting the DMAEN bit while a DMA transfer is ongoing, breaks the handshake with the DMA. Do not write this bit during DMA operation.

Bit 1 **ABORT**: Abort request

This bit aborts the ongoing command sequence. It is automatically reset once the abort is completed. This bit stops the current transfer.

0: No abort requested

1: Abort requested

Note: This bit is always read as 0.

Bit 0 **EN**: Enable

This bit enables the OCTOSPI.

0: OCTOSPI disabled

1: OCTOSPI enabled

Note: The DMA request can be aborted without having received the ACK in case this EN bit is cleared during the operation.
In case this bit is set to 0 during a DMA transfer, the REQ signal to DMA returns to inactive state without waiting for the ACK signal from DMA to be active.

26.7.2 OCTOSPI device configuration register 1 (OCTOSPI_DCR1)

Address offset: 0x0008

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADOFF[4:0]					MTYP[2:0]			Res.	Res.	EXTEN DMEM	DEVSIZE[4:0]				
rw	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CSHT[5:0]						Res.	Res.	Res.	Res.	DLY BYP	Res.	FRCK	CKMO DE
		rw	rw	rw	rw	rw	rw					rw		rw	rw

Bits 31:27 **ADOFF[4:0]**: Address offset

This bitfield defines the memory address offset value added to the current address requested to be sent by the controller to hit the external memory using the following formula:
Offset value = $2^{[ADOFF+8]}$. (modulo 256 bytes)
Maximum allowed value is 19 since the memory-mapped mode is limited to 256 Mbytes address space. For greater value, the address offset will not be applied to the address sent by the controller.
This bitfield is relevant only if ADOFFEN is set and if FMODE[1:0] = 11 (memory-mapped mode) and if the address offset feature is available in the product implementation table.

Bits 26:24 **MTYP[2:0]**: Memory type

This bitfield indicates the type of memory to be supported.

000: Micron mode, D0/D1 ordering in DTR 8-data-bit mode. regular-command protocol in single-, dual-, quad- and octal-SPI modes.

Note: In this mode, DQS signal polarity is inverted with respect to the memory clock signal. This is the default value and care must be taken to change MTYP[2:0] for memories different from Micron.

001: Macronix mode, D1/D0 ordering in DTR 8-data-bit mode. Regular-command protocol in single-, dual-, quad-, and octal-SPI modes.

010: Standard mode

011: Macronix RAM mode, D1/D0 ordering in DTR 8-data-bit mode. Regular-command protocol in single-, dual-, quad-, and octal-SPI modes with dedicated address mapping (address is built with row and column to fit with Macronix requirements).

100: HyperBus memory mode, the protocol follows the HyperBus specification.

101: HyperBus register mode, addressing register space. The memory-mapped accesses in this mode must be noncacheable, or indirect-read/write modes must be used.

Others: Reserved

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **EXTENDMEM**: Extended memory support

This bit is only relevant when one OCTOSPI drives two same size external memories located in contiguous places in the memory map. In this case, DEVSIZE[4:0] represents the size of each external memory. When this bit is set, the OCTOSPI automatically controls which of NCS1 or NCS2 is active.

0: NCS1 and NCS2 values depend from CSSEL bit in OCTOSPI_CR (software controlled).

1: NCS1 and NCS2 values depend from the address of transfer (hardware controlled).

Note: It is recommended to keep EXTENDMEM = 0 for write operations targeting flash memories (such as NOR Flash and HyperFlash).

Bits 20:16 **DEVSIZE[4:0]**: Device size

This bitfield defines the size of the external device using the following formula:
Number of bytes in device = $2^{[DEVSIZE+1]}$.

DEVSIZE + 1 is effectively the number of address bits required to address the external device. The device capacity can be up to 4 Gbytes (addressed using 32-bits) in indirect mode, but the addressable space in memory-mapped mode is limited to 256 Mbytes.

In regular-command protocol, if DMM = 1 or EXTENDMEM = 1, DEVSIZE[4:0] must reflect the total capacity of the two devices together considering the above formula (DEVSIZE[4:0] value is so equal to one of the two memory capacities).

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:8 **CSHT[5:0]**: Chip-select high time

CSHT + 1 defines the minimum number of CLK cycles where the chip-select (NCS) must remain high between commands issued to the external device.

0x0: NCS stays high for at least 1 cycle between external device commands.

0x1: NCS stays high for at least 2 cycles between external device commands.

...

0x3F: NCS stays high for at least 64 cycles between external device commands.

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **DLYBYP**: Delay block bypass

0: The internal sampling clock (called feedback clock) or the DQS data strobe external signal is delayed by the delay block (for more details on this block, refer to the dedicated section of the reference manual as it is not part of the OCTOSPI peripheral).

1: The delay block is bypassed, so the internal sampling clock or the DQS data strobe external signal is not affected by the delay block. The delay is shorter than when the delay block is not bypassed, even with the delay value set to minimum value in delay block.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **FRCK**: Free running clock

This bit configures the free running clock.

0: CLK is not free running.

1: CLK is free running (always provided).

Note: Free running clock mode is intended for delay calibration only. No memory or other device access is possible when FRCK is set. Once the bit has been set to 1, the BSY bit is set, the NCS signal remains set to 1 and the clock is sent. The only way to stop the clock is to perform an abort (which clears the BSY bit). Then, the FRCK bit must be cleared by software to allow controller transactions to take place with the external memory.

Bit 0 **CKMODE**: Clock mode 0/mode 3

This bit indicates the level taken by the CLK between commands (when NCS = 1).

0: CLK must stay low while NCS is high (chip-select released). This is referred to as clock mode 0.

1: CLK must stay high while NCS is high (chip-select released). This is referred to as clock mode 3.

26.7.3 OCTOSPI device configuration register 2 (OCTOSPI_DCR2)

Address offset: 0x000C

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRAPSIZE[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **WRAPSIZE[2:0]**: Wrap size

This bitfield indicates the wrap size to which the memory is configured. For memories which have a separate command for wrapped instructions, this bitfield indicates the wrap-size associated with the command held in the OCTOSPI1_WPIR register.

000: Wrapped reads are not supported by the memory.

010: External memory supports wrap size of 16 bytes.

011: External memory supports wrap size of 32 bytes.

100: External memory supports wrap size of 64 bytes.

101: External memory supports wrap size of 128 bytes.

Others: Reserved

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **PRESCALER[7:0]**: Clock prescaler

This bitfield defines the scaler factor for generating the CLK based on the kernel clock (value + 1).

0: $F_{CLK} = F_{KERNEL}$, kernel clock used directly as OCTOSPI CLK (prescaler bypassed). In this case, if the DTR mode is used, it is mandatory to provide to the OCTOSPI a kernel clock that has 50% duty-cycle.

1: $F_{CLK} = F_{KERNEL}/2$

2: $F_{CLK} = F_{KERNEL}/3$

...

255: $F_{CLK} = F_{KERNEL}/256$

For odd clock division factors, the CLK duty cycle is not 50 %. The clock signal remains low one cycle longer than it stays high.

26.7.4 OCTOSPI device configuration register 3 (OCTOSPI_DCR3)

Address offset: 0x0010

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSBOUND[4:0]				
											rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MAXTRAN[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:16 **CSBOUND[4:0]**: NCS boundary

This bitfield enables the transaction boundary feature. When active, a minimum value of 3 is recommended. The NCS is released on each boundary of $2^{CSBOUND}$ bytes.

0: NCS boundary disabled

Others: NCS boundary set to $2^{CSBOUND}$ bytes

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **MAXTRAN[7:0]**: Maximum transfer

This bitfield enables the communication regulation feature. The NCS is released every MAXTRAN+1 clock cycles when the other OCTOSPI request the access to the bus.

0: Maximum communication disabled

Others: Maximum communication is set to MAXTRAN + 1 bytes.

26.7.5 OCTOSPI device configuration register 4 (OCTOSPI_DCR4)

Address offset: 0x0014

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REFRESH[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REFRESH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **REFRESH[31:0]**: Refresh rate

This bitfield enables the refresh rate feature. The NCS is released every REFRESH + 1 clock cycles for writes, and REFRESH + 4 clock cycles for reads. These two values can be extended with few clock cycles when refresh occurs during a byte transmission in single-, dual- or quad-SPI mode, because the byte transmission must be completed.

0: Refresh disabled

Others: Maximum communication length is set to REFRESH + 1 clock cycles.

Note: REFRESH count is based on the divided clock period: if OCTOSPI_DCR2 PRESCALER bitfield is changed, the REFRESH field must be updated accordingly.

26.7.6 OCTOSPI status register (OCTOSPI_SR)

Address offset: 0x0020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	FLEVEL[5:0]						Res.	BERRF	BUSY	TOF	SMF	FTF	TCF	TEF
		r	r	r	r	r	r		r	r	r	r	r	r	r

Bits 31:14 Reserved, must be kept at reset value.

Bits 13:8 **FLEVEL[5:0]**: FIFO level

This bitfield gives the number of valid bytes that are being held in the FIFO. FLEVEL = 0 when the FIFO is empty, and 32 when it is full.

In automatic status-polling mode, FLEVEL is zero.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **BERRF**: Bus error flag

This bit is set when a bus error occurs. It is cleared by writing 1 to CBERRF. This bit has a meaning if Bus error bit feature is available in the product implementation table.

Bit 5 **BUSY**: Busy

This bit is set when an operation is ongoing. It is cleared automatically when the operation with the external device is finished and the FIFO is empty.

Bit 4 **TOF**: Timeout flag

This bit is set when timeout occurs. It is cleared by writing 1 to CTOF.

Bit 3 **SMF**: Status match flag

This bit is set in automatic status-polling mode when the unmasked received data matches the corresponding bits in the match register (OCTOSPI_PSMAR).
It is cleared by writing 1 to CSMF.

Bit 2 **FTF**: FIFO threshold flag

In indirect mode, this bit is set when the FIFO threshold has been reached, or if there is any data left in the FIFO after the reads from the external device are complete.
It is cleared automatically as soon as the threshold condition is no longer true.
In automatic status-polling mode, this bit is set every time the status register is read, and the bit is cleared when the data register is read.

Bit 1 **TCF**: Transfer complete flag

This bit is set in indirect mode when the programmed number of data has been transferred or in any mode when the transfer has been aborted.It is cleared by writing 1 to CTCF.

Bit 0 **TEF**: Transfer error flag

This bit is set in indirect mode when an invalid address is being accessed in indirect mode.
It is cleared by writing 1 to CTEF.

26.7.7 OCTOSPI flag clear register (OCTOSPI_FCR)

Address offset: 0x0024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CBERRF	Res.	CTOF	CSMF	Res.	CTCF	CTEF
									w		w	w		w	w

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **CBERRF**: Clear bus error flag

Writing 1 clears the BERRF flag in the XSPI_SR register (if Bus error bit feature is available in the product implementation table).

Bit 5 Reserved, must be kept at reset value.

Bit 4 **CTOF**: Clear timeout flag

Writing 1 clears the TOF flag in the OCTOSPI_SR register.

Bit 3 **CSMF**: Clear status match flag
Writing 1 clears the SMF flag in the OCTOSPI_SR register.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CTCF**: Clear transfer complete flag
Writing 1 clears the TCF flag in the OCTOSPI_SR register.

Bit 0 **CTEF**: Clear transfer error flag
Writing 1 clears the TEF flag in the OCTOSPI_SR register.

26.7.8 OCTOSPI data length register (OCTOSPI_DLR)

Address offset: 0x0040

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DL[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DL[31:0]**: Data length
Number of data to be retrieved (value+1) in indirect and automatic status-polling modes. A value not greater than three (indicating 4 bytes) must be used for automatic status-polling mode.
All 1's in indirect mode means undefined length, where OCTOSPI continues until the end of the memory, as defined by DEVSIZE.
0x0000_0000: 1 byte is to be transferred.
0x0000_0001: 2 bytes are to be transferred.
0x0000_0002: 3 bytes are to be transferred.
0x0000_0003: 4 bytes are to be transferred.
...
0xFFFF_FFFD: 4,294,967,294 (4G-2) bytes are to be transferred.
0xFFFF_FFFE: 4,294,967,295 (4G-1) bytes are to be transferred.
0xFFFF_FFFF: undefined length; all bytes, until the end of the external device, (as defined by DEVSIZE) are to be transferred. Continue reading indefinitely if DEVSIZE = 0x1F.
DL[0] is stuck at 1 in dual-memory configuration (DMM = 1) even when 0 is written to this bit, thus assuring that each access transfers an even number of bytes.
This bitfield has no effect in memory-mapped mode.

26.7.9 OCTOSPI address register (OCTOSPI_AR)

Address offset: 0x0048

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0 and FMODE ≠ 11.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADDRESS[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDRESS[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ADDRESS[31:0]**: Address

Address to be sent to the external device. In HyperBus protocol, this field must be even as this protocol is 16-bit word oriented. In dual-memory configuration, AR[0] is forced to 0.

26.7.10 OCTOSPI data register (OCTOSPI_DR)

Address offset: 0x0050

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DATA[31:0]**: Data

Data to be sent/received to/from the external SPI device

In indirect-write mode, data written to this register is stored on the FIFO before it is sent to the external device during the data phase. If the FIFO is too full, a write operation is stalled until the FIFO has enough space to accept the amount of data being written.

In indirect-read mode, reading this register gives (via the FIFO) the data that was received from the external device. If the FIFO does not have as many bytes as requested by the read operation and if BUSY = 1, the read operation is stalled until enough data is present or until the transfer is complete, whichever happens first.

In automatic status-polling mode, this register contains the last data read from the external device (without masking).

Word, half-word, and byte accesses to this register are supported. In indirect-write mode, a byte write adds 1 byte to the FIFO, a half-word write 2 bytes, and a word write 4 bytes.

Similarly, in indirect-read mode, a byte read removes 1 byte from the FIFO, a halfword read 2 bytes, and a word read 4 bytes. Accesses in indirect mode must be aligned to the bottom of this register: A byte read must read DATA[7:0] and a half-word read must read DATA[15:0].

26.7.11 OCTOSPI polling status mask register (OCTOSPI_PSMKR)

Address offset: 0x0080

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MASK[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MASK[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MASK[31:0]**: Status mask

Mask to be applied to the status bytes received in automatic status-polling mode

For bit n:

0: Bit n of the data received in automatic status-polling mode is masked and its value is not considered in the matching logic.

1: Bit n of the data received in automatic status-polling mode is unmasked and its value is considered in the matching logic.

26.7.12 OCTOSPI polling status match register (OCTOSPI_PSMAR)

Address offset: 0x0088

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MATCH[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MATCH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MATCH[31:0]**: Status match

Value to be compared with the masked status register to get a match

26.7.13 OCTOSPI polling interval register (OCTOSPI_PIR)

Address offset: 0x0090

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INTERVAL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **INTERVAL[15:0]**: Polling interval

Number of CLK cycles between a read during the automatic status-polling phases

26.7.14 OCTOSPI communication configuration register (OCTOSPI_CCR)

Address offset: 0x0100

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	DQSE	Res.	DDTR	DMODE[2:0]			Res.	Res.	ABSIZE[1:0]		ABDTR	ABMODE[2:0]		
		rw		rw	rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	ADSIZE[1:0]		AD DTR	ADMODE[2:0]			Res.	Res.	ISIZE[1:0]		IDTR	IMODE[2:0]		
		rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **DQSE**: DQS enable

This bit enables the data strobe management.

0: DQS disabled

1: DQS enabled

Bit 28 Reserved, must be kept at reset value.

Bit 27 **DDTR**: Data double transfer rate

This bit sets the DTR mode for the data phase.

0: DTR mode disabled for data phase

1: DTR mode enabled for data phase

Bits 26:24 **DMODE[2:0]**: Data mode
This bitfield defines the data phase mode of operation.
000: No data
001: Data on a single line
010: Data on two lines
011: Data on four lines
100: Data on eight lines
Others: Reserved

Bits 23:22 Reserved, must be kept at reset value.

Bits 21:20 **ABSIZE[1:0]**: Alternate-byte size
This bitfield defines the alternate-byte size.
00: 8-bit alternate bytes
01: 16-bit alternate bytes
10: 24-bit alternate bytes
11: 32-bit alternate bytes

Bit 19 **ABDTR**: Alternate- byte double transfer rate
This bit sets the DTR mode for the alternate-byte phase.
0: DTR mode disabled for the alternate-byte phase
1: DTR mode enabled for the alternate-byte phase

Bits 18:16 **ABMODE[2:0]**: Alternate-byte mode
This bitfield defines the alternate-byte phase mode of operation.
000: No alternate bytes
001: Alternate bytes on a single line
010: Alternate bytes on two lines
011: Alternate bytes on four lines
100: Alternate bytes on eight lines
Others: Reserved

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:12 **ADSIZE[1:0]**: Address size
This bitfield defines the address size.
00: 8-bit address
01: 16-bit address
10: 24-bit address
11: 32-bit address

Bit 11 **ADDTR**: Address double transfer rate
This bit sets the DTR mode for the address phase.
0: DTR mode disabled for the address phase
1: DTR mode enabled for the address phase

Bits 10:8 **ADMODE[2:0]**: Address mode
This bitfield defines the address phase mode of operation.
000: No address
001: Address on a single line
010: Address on two lines
011: Address on four lines
100: Address on eight lines
Others: Reserved

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **ISIZE[1:0]**: Instruction size
This bitfield defines instruction size.
00: 8-bit instruction
01: 16-bit instruction
10: 24-bit instruction
11: 32-bit instruction

Bit 3 **IDTR**: Instruction double transfer rate
This bit sets the DTR mode for the instruction phase.
0: DTR mode disabled for the instruction phase
1: DTR mode enabled for the instruction phase

Bits 2:0 **IMODE[2:0]**: Instruction mode
This bitfield defines the instruction phase mode of operation.
000: No instruction
001: Instruction on a single line
010: Instruction on two lines
011: Instruction on four lines
100: Instruction on eight lines
Others: Reserved

26.7.15 OCTOSPI timing configuration register (OCTOSPI_TCR)

Address offset: 0x0108

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	SSHIFT	Res.	DHQC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw		rw												
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCYC[4:0]				
											rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **SSHIFT**: Sample shift
By default, the OCTOSPI samples data 1/2 of a CLK cycle after the data is driven by the external device.
This bit allows the data to be sampled later in order to consider the external signal delays.
0: No shift
1: 1/2 cycle shift
The software must ensure that SSHIFT = 0 when the data phase is configured in DTR mode (when DDTR = 1.)

Bit 29 Reserved, must be kept at reset value.

Bit 28 **DHQC**: Delay hold quarter cycle
0: No delay hold
1: 1/4 cycle hold

Bits 27:5 Reserved, must be kept at reset value.

Bits 4:0 **DCYC[4:0]**: Number of dummy cycles
This bitfield defines the duration of the dummy phase according to the memory latency. In both SDR and DTR modes, it specifies a number of CLK cycles (0-31).

26.7.16 OCTOSPI instruction register (OCTOSPI_IR)

Address offset: 0x0110

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
INSTRUCTION[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INSTRUCTION[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **INSTRUCTION[31:0]**: Instruction
Instruction to be sent to the external SPI device

26.7.17 OCTOSPI alternate bytes register (OCTOSPI_ABR)

Address offset: 0x0120

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALTERNATE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ALTERNATE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ALTERNATE[31:0]**: Alternate bytes
Optional data to be sent to the external SPI device right after the address.

26.7.18 OCTOSPI low-power timeout register (OCTOSPI_LPTR)

Address offset: 0x00130

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TIMEOUT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **TIMEOUT[15:0]**: Timeout period

After each access in memory-mapped mode, the OCTOSPI prefetches the subsequent bytes and hold them in the FIFO.

This bitfield indicates how many CLK cycles the OCTOSPI waits after the clock becomes inactive and until it raises the NCS, putting the external device in a lower-consumption state.

26.7.19 OCTOSPI wrap communication configuration register (OCTOSPI_WPCCR)

Address offset: 0x0140

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	DQSE	Res.	DDTR	DMODE[2:0]			Res.	Res.	ABSIZE[1:0]		ABDTR	ABMODE[2:0]		
		rw		rw	rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	ADSIZE[1:0]		AD DTR	ADMODE[2:0]			Res.	Res.	ISIZE[1:0]		IDTR	IMODE[2:0]		
		rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **DQSE**: DQS enable

This bit enables the data strobe management.

0: DQS disabled

1: DQS enabled

Bit 28 Reserved, must be kept at reset value.

Bit 27 **DDTR**: Data double transfer rate

This bit sets the DTR mode for the data phase.

0: DTR mode disabled for the data phase

1: DTR mode enabled for the data phase

Bits 26:24 **DMODE[2:0]**: Data mode
This bitfield defines the data phase mode of operation.
000: No data
001: Data on a single line
010: Data on two lines
011: Data on four lines
100: Data on eight lines
Others: Reserved

Bits 23:22 Reserved, must be kept at reset value.

Bits 21:20 **ABSIZE[1:0]**: Alternate-byte size
This bitfield defines the alternate-byte size.
00: 8-bit alternate bytes
01: 16-bit alternate bytes
10: 24-bit alternate bytes
11: 32-bit alternate bytes

Bit 19 **ABDTR**: Alternate-byte double transfer rate
This bit sets the DTR mode for the alternate-byte phase.
0: DTR mode disabled for the alternate-byte phase
1: DTR mode enabled for the alternate-byte phase

Bits 18:16 **ABMODE[2:0]**: Alternate-byte mode
This bitfield defines the alternate-byte phase mode of operation.
000: no alternate bytes
001: alternate bytes on a single line
010: alternate bytes on two lines
011: alternate bytes on four lines
100: alternate bytes on eight lines
Others: reserved

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:12 **ADSIZE[1:0]**: Address size
This bitfield defines the address size.
00: 8-bit address
01: 16-bit address
10: 24-bit address
11: 32-bit address

Bit 11 **ADDTR**: Address double transfer rate
This bit sets the DTR mode for the address phase.
0: DTR mode disabled for address phase
1: DTR mode enabled for address phase

Bits 10:8 **ADMODE[2:0]**: Address mode
This bitfield defines the address phase mode of operation.
000: No address
001: Address on a single line
010: Address on two lines
011: Address on four lines
100: Address on eight lines
Others: Reserved

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **ISIZE[1:0]**: Instruction size
This bitfield defines the instruction size.
00: 8-bit instruction
01: 16-bit instruction
10: 24-bit instruction
11: 32-bit instruction

Bit 3 **IDTR**: Instruction double transfer rate
This bit sets the DTR mode for the instruction phase.
0: DTR mode disabled for the instruction phase
1: DTR mode enabled for the instruction phase

Bits 2:0 **IMODE[2:0]**: Instruction mode
This bitfield defines the instruction phase mode of operation.
000: No instruction
001: Instruction on a single line
010: Instruction on two lines
011: Instruction on four lines
100: Instruction on eight lines
Others: Reserved

26.7.20 OCTOSPI wrap timing configuration register (OCTOSPI_WPTCR)

Address offset: 0x0148

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	SSHIFT	Res.	DHQC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw		rw												

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCYC[4:0]				
											rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **SSHIFT**: Sample shift
By default, the OCTOSPI samples data 1/2 of a CLK cycle after the data is driven by the external device.
This bit allows the data to be sampled later in order to consider the external signal delays.
0: No shift
1: 1/2 cycle shift
The firmware must assure that SSHIFT=0 when the data phase is configured in DTR mode (when DDTR = 1).

Bit 29 Reserved, must be kept at reset value.

Bit 28 **DHQC**: Delay hold quarter cycle
Add a quarter cycle delay on the outputs in DTR communication to match hold requirement.
0: No quarter cycle delay
1: 1/4 cycle delay inserted

Bits 27:5 Reserved, must be kept at reset value.

Bits 4:0 **DCYC[4:0]**: Number of dummy cycles
This bitfield defines the duration of the dummy phase according to the memory latency. In both SDR and DTR modes, it specifies a number of CLK cycles (0-31).

26.7.21 OCTOSPI wrap instruction register (OCTOSPI_WPIR)

Address offset: 0x0150

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
INSTRUCTION[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INSTRUCTION[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **INSTRUCTION[31:0]**: Instruction
Instruction to be sent to the external SPI device

26.7.22 OCTOSPI wrap alternate bytes register (OCTOSPI_WPABR)

Address offset: 0x0160

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALTERNATE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ALTERNATE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ALTERNATE[31:0]**: Alternate bytes
Optional data to be sent to the external SPI device right after the address

26.7.23 OCTOSPI write communication configuration register (OCTOSPI_WCCR)

Address offset: 0x0180

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0. Its content has a meaning only when requesting write operations in memory-mapped mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	DQSE	Res.	DDTR	DMODE[2:0]			Res.	Res.	ABSIZE[1:0]		ABDTR	ABMODE[2:0]		
		rw		rw	rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	ADSIZE[1:0]		ADDTR	ADMODE[2:0]			Res.	Res.	ISIZE[1:0]		IDTR	IMODE[2:0]		
		rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **DQSE**: DQS enable
This bit enables the data strobe management.
0: DQS disabled
1: DQS enabled

Bit 28 Reserved, must be kept at reset value.

Bit 27 **DDTR**: data double transfer rate
This bit sets the DTR mode for the data phase.
0: DTR mode disabled for the data phase
1: DTR mode enabled for the data phase

Bits 26:24 **DMODE[2:0]**: Data mode
This bitfield defines the data phase mode of operation.
000: No data
001: Data on a single line
010: Data on two lines
011: Data on four lines
100: Data on eight lines
Others: Reserved

Bits 23:22 Reserved, must be kept at reset value.

Bits 21:20 **ABSIZE[1:0]**: Alternate-byte size
This bitfield defines the alternate-byte size.
00: 8-bit alternate bytes
01: 16-bit alternate bytes
10: 24-bit alternate bytes
11: 32-bit alternate bytes

Bit 19 **ABDTR**: Alternate bytes double transfer rate
This bit sets the DTR mode for the alternate-bytes phase.
0: DTR mode disabled for alternate-bytes phase
1: DTR mode enabled for alternate-bytes phase

Bits 18:16 **ABMODE[2:0]**: Alternate-byte mode
This bitfield defines the alternate-byte phase mode of operation.
000: No alternate bytes
001: Alternate bytes on a single line
010: Alternate bytes on two lines
011: Alternate bytes on four lines
100: Alternate bytes on eight lines
Others: Reserved

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:12 **ADSIZE[1:0]**: Address size
This bitfield defines the address size.
00: 8-bit address
01: 16-bit address
10: 24-bit address
11: 32-bit address

Bit 11 **ADDTR**: Address double transfer rate
This bit sets the DTR mode for the address phase.
0: DTR mode disabled for the address phase
1: DTR mode enabled for the address phase

Bits 10:8 **ADMODE[2:0]**: Address mode
This bitfield defines the address phase mode of operation.
000: No address
001: Address on a single line
010: Address on two lines
011: Address on four lines
100: Address on eight lines
Others: Reserved

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **ISIZE[1:0]**: Instruction size
This bitfield defines the instruction size.
00: 8-bit instruction
01: 16-bit instruction
10: 24-bit instruction
11: 32-bit instruction

Bit 3 **IDTR**: Instruction double transfer rate
This bit sets the DTR mode for the instruction phase.
0: DTR mode disabled for instruction phase
1: DTR mode enabled for instruction phase

Bits 2:0 **IMODE[2:0]**: Instruction mode
This bitfield defines the instruction phase mode of operation.
000: No instruction
001: Instruction on a single line
010: Instruction on two lines
011: Instruction on four lines
100: Instruction on eight lines
Others: Reserved

26.7.24 OCTOSPI write timing configuration register (OCTOSPI_WTCR)

Address offset: 0x0188

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0. Its content has a meaning only when requesting write operations in memory-mapped mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCYC[4:0]				
											rw	rw	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bits 4:0 **DCYC[4:0]**: Number of dummy cycles

This bitfield defines the duration of the dummy phase according to the memory latency. In both SDR and DTR modes, it specifies a number of CLK cycles (0-31).

26.7.25 OCTOSPI write instruction register (OCTOSPI_WIR)

Address offset: 0x0190

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0. Its content has a meaning only when requesting write operations in memory-mapped mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
INSTRUCTION[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INSTRUCTION[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **INSTRUCTION[31:0]**: Instruction

Instruction to be sent to the external SPI device

26.7.26 OCTOSPI write alternate bytes register (OCTOSPI_WABR)

Address offset: 0x01A0

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0. Its content has a meaning only when requesting write operations in memory-mapped mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALTERNATE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ALTERNATE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ALTERNATE[31:0]**: Alternate bytes

Optional data to be sent to the external SPI device right after the address

26.7.27 OCTOSPI HyperBus latency configuration register (OCTOSPI_HLCR)

Address offset: 0x0200

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRWR[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TACC[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	WZL	LM
rw	rw	rw	rw	rw	rw	rw	rw							rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **TRWR[7:0]:** Read-write minimum recovery time

Device read-to-write/write-to-read minimum recovery time expressed in number of communication clock cycles

Bits 15:8 **TACC[7:0]**: Access time

Device access time according to the memory latency, expressed in number of communication clock cycles

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **WZL:** Write zero latency

This bit enables zero latency on write operations.

0: Latency on write accesses

1: No latency on write accesses

Bit 0 **LM:** Latency mode
This bit selects the latency mode.
0: Variable initial latency
1: Fixed latency
Note: This bit must be kept cleared for HyperFLASH memory.

26.7.28 OCTOSPI register map

Table 252. OCTOSPI register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0000	OCTOSPI_CR	Res.	MSEL	FMDOE[1:0]		Res.	Res.	NOPREFI	CSSEL	PMM	APMS	BERRIE	TOIE	SMIE	FTIE	TCIE	TEIE	Res.	Res.	FTHRES[5:0]						Res.	DMM	Res.	ADOFFEN	TCEN	DMAEN	ABORT	EN
	Reset value		0	0	0			0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0		0		0	0	0	0	0
0x0004	Reserved	Reserved																															
0x0008	OCTOSPI_DCR1	ADOFF[4:0]					MTYP [2:0]			Res.	Res.	EXTENDMEM	DEVSIZE[4:0]					Res.	Res.	CSHT[5:0]						Res.	Res.	Res.	Res.	DLYBYP	Res.	FRCK	CKMODE
	Reset value	0	0	0	0	0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0					0		0	0
0x000C	OCTOSPI_DCR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRAPSIZE [2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[7:0]							
	Reset value														0	0	0									0	0	0	0	0	0	0	0
0x0010	OCTOSPI_DCR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSBOUND[4:0]					Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MAXTRAN[7:0]							
	Reset value												0	0	0	0	0									0	0	0	0	0	0	0	0
0x0014	OCTOSPI_DCR4	REFRESH[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0018-0x001C	Reserved	Reserved																															
0x0020	OCTOSPI_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLEVEL[5:0]						Res.	BERRF	BUSY	TOF	SMF	FTF	TCF	TEF
	Reset value																			0	0	0	0	0	0		0	0	0	0	0	0	0
0x0024	OCTOSPI_FCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CBERRF	Res.	CTOF	CSMF	Res.	CTCF	CTEF
	Reset value																										0		0	0		0	0
0x0028-0x003C	Reserved	Reserved																															
0x0040	OCTOSPI_DLR	DL[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0044	Reserved	Reserved																															

Table 252. OCTOSPI register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0048	OCTOSPI_AR	ADDRESS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x004C	Reserved	Reserved																															
0x0050	OCTOSPI_DR	DATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0054-0x007C	Reserved	Reserved																															
0x0080	OCTOSPI_ PSMKR	MASK[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0084	Reserved	Reserved																															
0x0088	OCTOSPI_ PSMAR	MATCH[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x008C	Reserved	Reserved																															
0x0090	OCTOSPI_PIR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INTERVAL[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0094-0x00FC	Reserved	Reserved																															
0x0100	OCTOSPI_CCR	Res.	Res.	DQSE	Res.	DDTR	DMODE [2:0]			Res.	Res.	ABSIZE [1:0]		ABDTR	ABMODE [2:0]			Res.	Res.	ADSIZE [1:0]		ADDTR	ADMODE [2:0]			Res.	Res.	ISIZE[1:0]		IDTR	IMODE [2:0]		
	Reset value			0		0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0
0x0104	Reserved	Reserved																															
0x0108	OCTOSPI_TCR	Res.	SSHIFT	Res.	DHQC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCYC[4:0]				
	Reset value		0		0																								0	0	0	0	0
0x010C	Reserved	Reserved																															
0x0110	OCTOSPI_IR	INSTRUCTION[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0114-0x011C	Reserved	Reserved																															
0x0120	OCTOSPI_ABR	ALTERNATE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0124-0x012C	Reserved	Reserved																															
0x0130	OCTOSPI_LPTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIMEOUT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0134-0x013C	Reserved	Reserved																															

Table 252. OCTOSPI register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0140	OCTOSPI_ WPCCR	Res.	Res.	DQSE	Res.	DDTR	DMODE [2:0]			Res.	Res.	ABSIZE [1:0]		ABDTR	ABMODE [2:0]			Res.	Res.	ADSIZE [1:0]		ADDTR	ADMODE [2:0]			Res.	Res.	ISIZE [1:0]		IDTR	IMODE [2:0]		
	Reset value	0		0		0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0
0x0144	Reserved	Reserved																															
0x0148	OCTOSPI_ WPTCR	Res.	SSHIFT	Res.	DHQC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCYC[4:0]				
	Reset value		0		0																								0	0	0	0	0
0x014C	Reserved	Reserved																															
0x0150	OCTOSPI_WPIR	INSTRUCTION[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0154- 0x015C	Reserved	Reserved																															
0x0160	OCTOSPI_ WPABR	ALTERNATE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0164- 0x017C	Reserved	Reserved																															
0x0180	OCTOSPI_WCCR	Res.	Res.	DQSE	Res.	DDTR	DMODE [2:0]			Res.	Res.	ABSIZE [1:0]		ABDTR	ABMODE [2:0]			Res.	Res.	ADSIZE [1:0]		ADDTR	ADMODE [2:0]			Res.	Res.	ISIZE [1:0]		IDTR	IMODE [2:0]		
	Reset value	0		0		0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0
0x0184	Reserved	Reserved																															
0x0188	OCTOSPI_WTCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCYC[4:0]				
	Reset value																												0	0	0	0	0
0x018C	Reserved	Reserved																															
0x0190	OCTOSPI_WIR	INSTRUCTION[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0194- 0x019C	Reserved	Reserved																															
0x01A0	OCTOSPI_WABR	ALTERNATE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x01A4- 0x01FC	Reserved	Reserved																															
0x0200	OCTOSPI_HLCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRWR[7:0]								TACC[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	WZL	LM
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0							0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

27 Extended-SPI I/O manager (OCTOSPIM)

27.1 Introduction

The Extended-SPI I/O manager is a low-level interface that enables an efficient OCTOSPI pin assignment with a full I/O matrix (before alternate function map), and multiplex of single/dual/quad/octal SPI interfaces over the same bus.

27.2 OCTOSPIM main features

- Supports up to two single/dual/quad/octal SPI interfaces
- Supports up to two ports for pin assignment

27.3 OCTOSPIM implementation

The following table describes the OCTOSPIM implementation.

Table 253. OCTOSPIM implementation

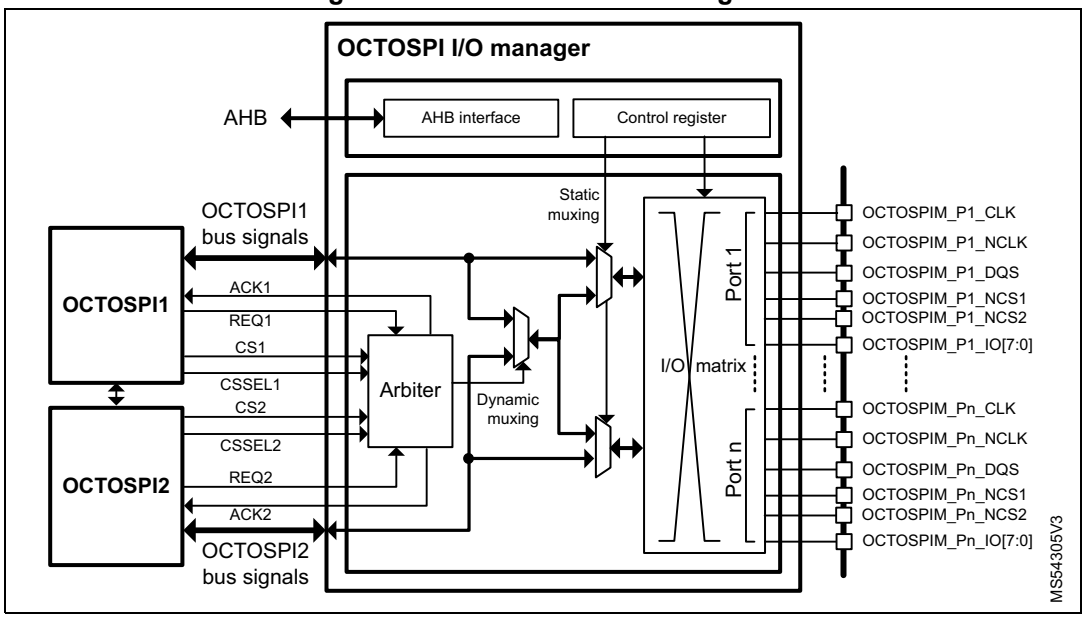
OCTOSPI feature	Available on the devices
Supports up to two single/dual/quad interfaces	X
Fully I/O multiplexing capability	X
Supports time-multiplexed mode	X
Supports high-speed interface	-
Chip select selection if OCTOSPI provides dual chip select	X
Supports 16-bit data interface and dual-octal mode	-

27.4 OCTOSPIM functional description

27.4.1 OCTOSPIM block diagram

The block diagram of the OCTOSPI I/O manager is shown in *Figure 197*.

Figure 197. OCTOSPIM block diagram



1. The number of ports (n) is 2.

27.4.2 OCTOSPIM input/output pins

Table 254. OCTOSPIM input/output pins

Pin name(1)	Signal type	Description
OCTOSPIM_Px_NCLK	Output	OCTOSPI inverted clock to support 1.8 V HyperBus protocol
OCTOSPIM_Px_CLK		OCTOSPI clock
OCTOSPIM_Px_IOn (n = 0 to 7)	Input/output	OCTOSPI data pins
OCTOSPIM_Px_NCS1,2	Output	Chip select for the memories
OCTOSPIM_Px_DQS	Input/output	Data strobe/write mask signal from/to the memory

1. x = 1 to 2.

27.4.3 OCTOSPIM matrix

The OCTOSPI I/O manager matrix allows the user to set a premapping of functions:

- OCTOSPI1 mapped to Port 1, with OCTOSPI2 mapped to Port 2 (direct mode)
- OCTOSPI1 mapped to Port 2, with OCTOSPI2 mapped to Port 1 (swapped mode)
- OCTOSPI1 and OCTOSPI2 both mapped to Port 1, with arbitration (multiplexed mode)
- OCTOSPI1 and OCTOSPI2 both mapped to Port 2, with arbitration (multiplexed mode)

Note: There is no possibility to use mixed combinations of signals (like NCS of OCTOSPI1 with data of OCTOSPI2).

When several I/O pins have the same configuration and are enabled at the same time, the result can be unpredictable.

In the default out-of-reset configuration, the OCTOSPI1 and OCTOSPI2 signals are mapped, respectively, on Port 1 and on Port 2.

The OCTOSPIM configuration can be changed only when all OCTOSPIs are disabled.

27.4.4 OCTOSPIM multiplexed mode

When this mode is set, the OCTOSPIs are time-multiplexed over the same bus. They get the ownership of the bus (in turn) through a request/acknowledge protocol with REQ/ACK signals.

The time-multiplexing is enabled by setting the MUXEN bit of the configuration register OCTOSPIM_CR.

The fairness counter (MAXTRAN) of each OCTOSPI can be used to manage accurately the maximum duration for which a given OCTOSPI takes the bus: this feature ensures a maximum bus access latency for the other OCTOSPI(s). When the bus is released by one OCTOSPI, an arbitration phase occurs, which is round-robin: when another OCTOSPI requests the bus, it gets it.

When the multiplexed mode is enabled, either the fairness counter or the refresh timeout counter of both OCTOSPI interfaces must be activated.

Each OCTOSPI delivers one NCS signal together with a CSSEL control signal. The CSSEL signal selects which of the two outputs (NCS1, NCS2) is active. In multiplexed modes, the active CCSEL signal is the one of the OCTOSPI owning the bus. The default value of OCTOSPI_CR.CSSEL is 0 for OCTOSPI1 and 1 for OCTOSPI2. Only OCTOSPIn_IOs, OCTOSPIn_DQS and OCTOSPIn_CLK / OCTOSPIn_NCLK are multiplexed.

When the multiplexed mode is used, only clock mode 0 is supported on the OCTOSPIs.

Due to arbitration and bus sharing, the auto polling interval time of the OCTOSPI, when used, may increase.

Minimum switching duration

The minimum number of cycles needed to switch from an OCTOSPI to another can be configured.

This internal timer guarantees a latency between the falling edge of the REQ signal of the active OCTOSPI (the active one releases the bus), and the rising edge of the ACK signal to the requesting OCTOSPI (the bus is granted to the requesting one).

The REQ2ACK_TIME field of the configuration register OCTOSPIM_CR defines the duration.

27.5 Use cases description

Table 255 summarizes the use cases corresponding to IO manager modes.

Table 255. Use cases

IO manager mode	MUXEN	Mode	Reference
Direct	0	0	*Section 27.5.1*
Swapped	0	1	*Section 27.5.2*

Table 255. Use cases (continued)

IO manager mode	MUXEN	Mode	Reference
Multiplexed to Port1	1	0	*Section 27.5.3*
Multiplexed to Port2	1	1	*Section 27.5.4*
Two OCTOSPIs drive one external memory	1	0 or 1, depending upon the port connected to the memory	*Section 27.5.5*
One OCTOSPI drives two external memories	0	0 with CS selection command from OCTOSPI1 or 2.	*Section 27.5.6*

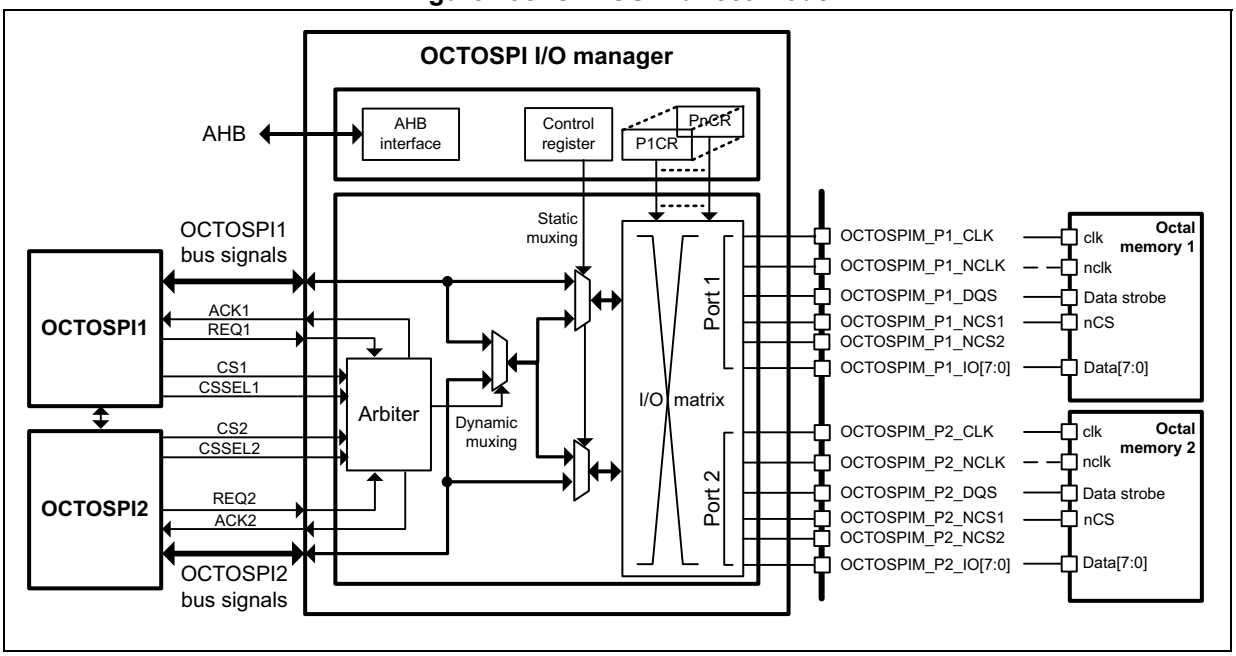
27.5.1 Two OCTOSPIs direct mode

This is the baseline mode: each OCTOSPI drives independently the corresponding port. There is no multiplexing.

Alternate function signals can be routed on NCS2 pins (these signals are not used for the OCTOSPI bus), nclk clocks are requested in case of 1.8 V HyperBus memory type.

This mode is selected by default through bits OCTOSPIM_CR[1:0].

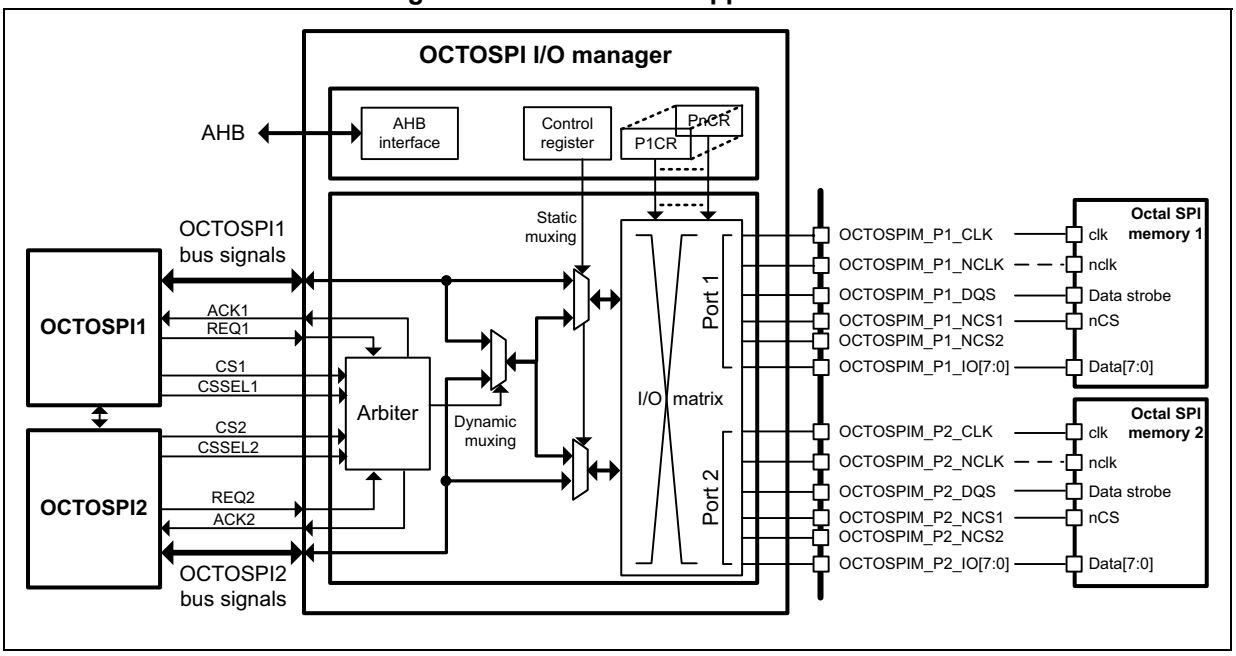
Figure 198. OCTOSPI direct mode



27.5.2 OCTOSPI swapped mode

This mode is similar to OCTOSPI direct mode but the ports are swapped, for example to help I/O mapping. The mode is selected by bits OCTOSPIM_CR[1:0].

Figure 199. OCTOSPI swapped mode



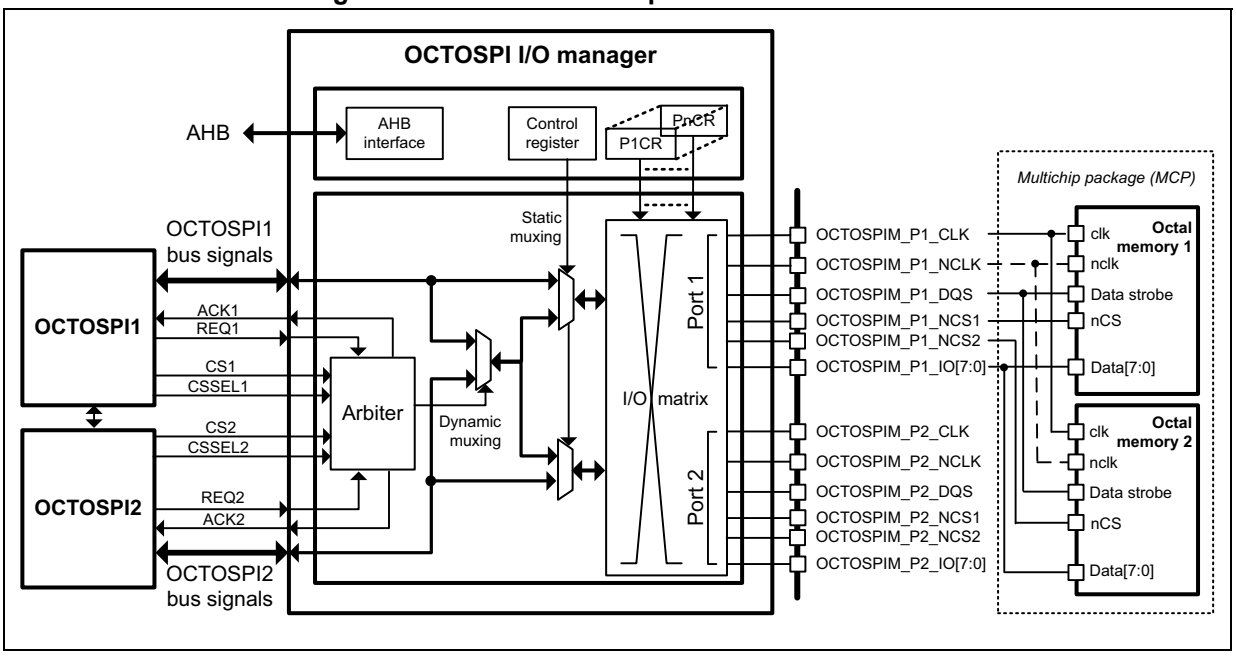
27.5.3 Two OCTOSPIs multiplexed mode to Port 1 accessing two external memories

If only one output port is used to access two memories, alternate function signals can be routed to pins corresponding to the other port. This mode is selected by bits OCTOSPIM_CR[1:0].

The arbiter in IO manager selects OCTOSPI1 or OCTOSPI2 to own the Octal-SPI bus according to existing transfer requests and status of the two MAXTRAN fairness counters.

The external memories can be two separate chips or embedded in a single multichip package. In this case each memory requests a dedicated Chip select, selected according to the CSSEL control of the OCTOSPI currently owning the bus.

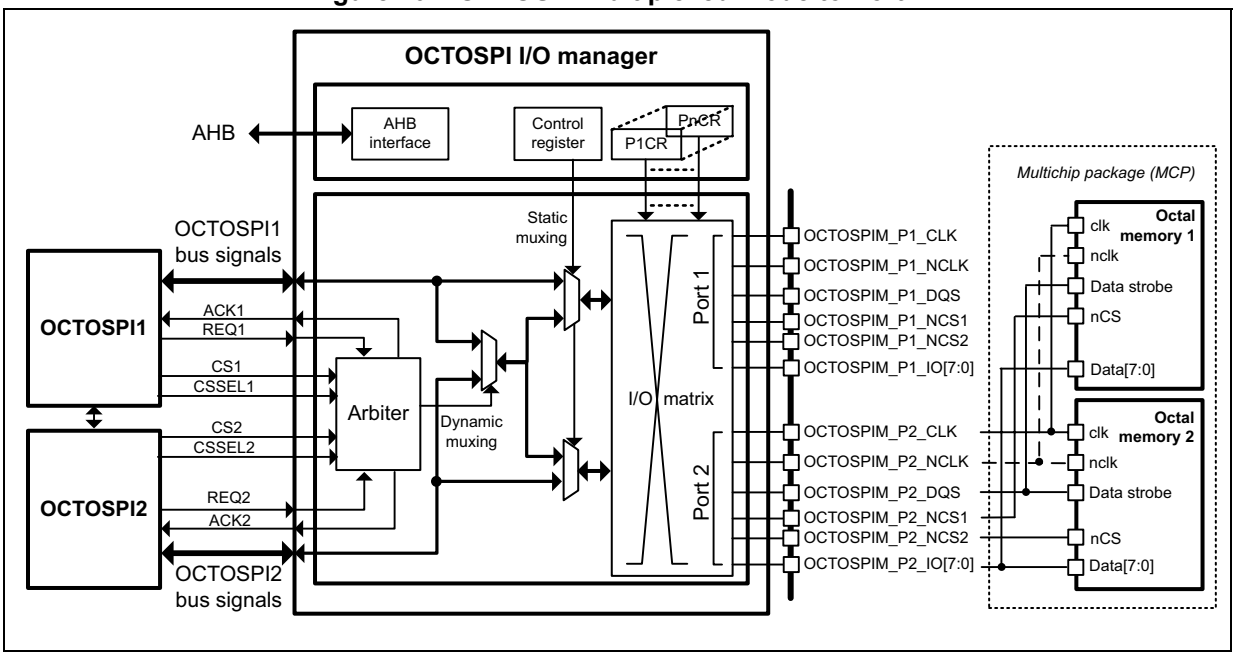
Figure 200. OCTOSPI multiplexed mode to Port 1



27.5.4 Two OCTOSPIs multiplexed mode to Port 2 accessing two external memories

This is similar to OCTOSPI multiplexed mode to Port 1, but target is Port 2. This mode is selected by bits OCTOSPIM_CR[2:1].

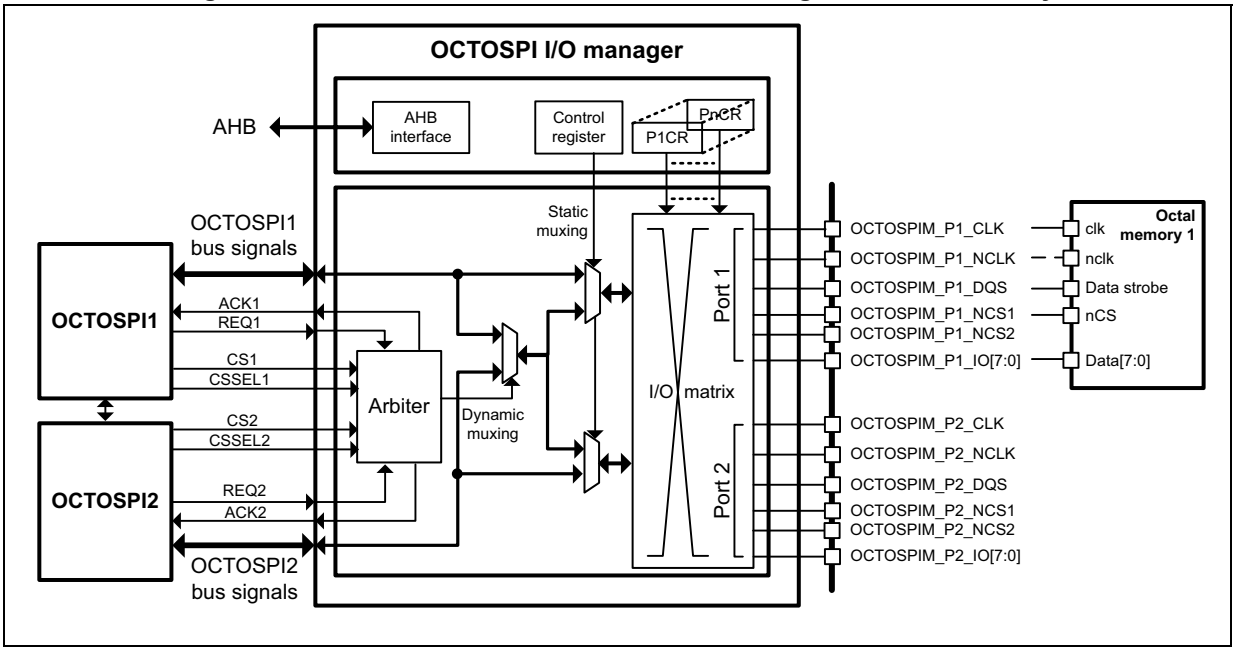
Figure 201. OCTOSPI multiplexed mode to Port 2



27.5.5 OCTOSPI1 and OCTOSPI2 drive a single external memory

This is similar to OCTOSPIs multiplexed mode to Port 1, but in this case only one external memory is present. Both CSSEL controls must target the same NCS (NCS1 in *Figure 202*).

Figure 202. OCTOSPI1 and OCTOSPI2 drive a single external memory



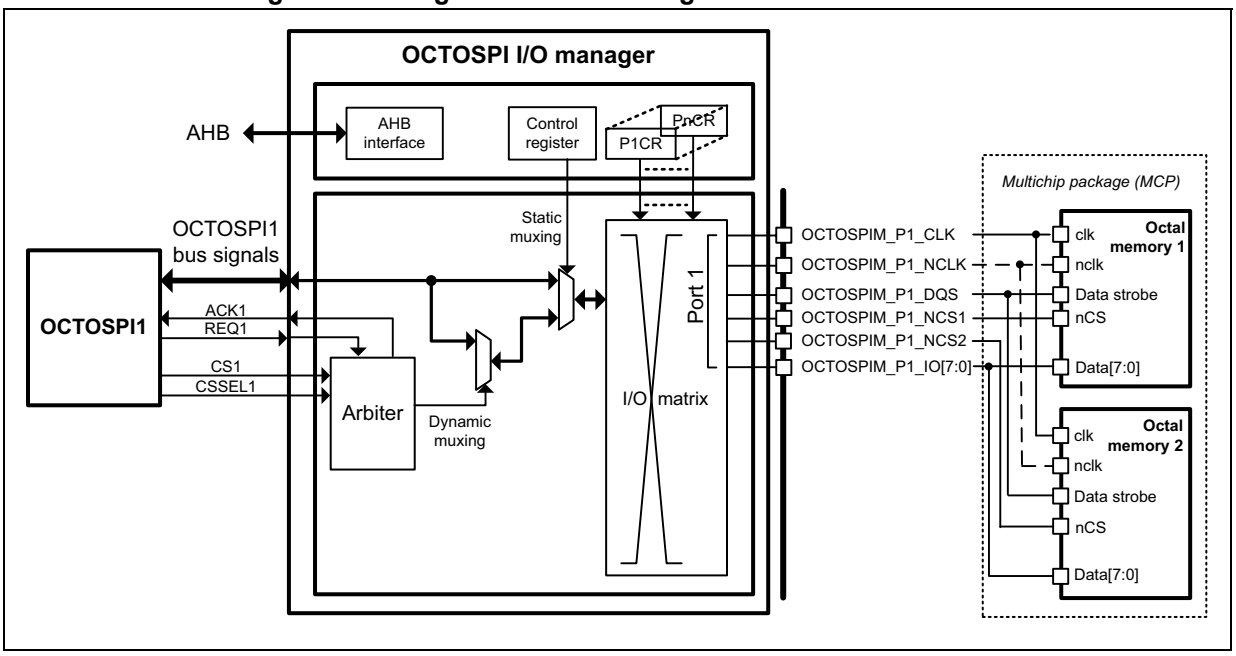
This use case is valid even when Port 2 is used instead of Port 1.

27.5.6 A single OCTOSPI drives two external memories

This is a subset of direct mode and corresponds to semi-dynamic switching. There are two target memories but the arbiter is not used. The software has to set the OCTOSPI1 chip select selector (bit 24 of OCTOSPI_CR register) each time the target memory changes.

Baseline use case boots on flash (memory1) and then switches to SRAM (memory2) for the rest of the application.

Figure 203. Single OCTOSPI driving two external memories



This use case is valid even when OCTOSPI2 is used instead of OCTOSPI1.

27.6 OCTOSPIM registers

27.6.1 OCTOSPIM control register (OCTOSPIM_CR)

Address offset: 0x0000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REQ2ACK_TIME[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSSEL_OVR_O2	CSSEL_OVR_O1	CSSEL_OVR_EN	Res.	Res.	MODE	MUXEN
									rw	rw	rw			rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **REQ2ACK_TIME[7:0]**: REQ to ACK time

In multiplexed mode (MUXEN = 1), this field defines the time between two transactions. The value is the number of OCTOSPI clock cycles - 1

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **CSSEL_OVR_O2**: Chip select selector override setting for OCTOSPI2

0: the chip select signal from OCTOSPI2 is sent to NCS1

1: the chip select signal from OCTOSPI2 is sent to NCS2

Bit 5 **CSSEL_OVR_O1**: Chip select selector override setting for OCTOSPI1

0: the chip select signal from OCTOSPI1 is sent to NCS1

1: the chip select signal from OCTOSPI1 is sent to NCS2

Bit 4 **CSSEL_OVR_EN**: Chip select selector override enable

0: override not enabled

1: CSSEL_OVR_O1 and CSSEL_OVR_O2 bit values overwrite the CSSEL signal values coming from OCTOSPI1 and OCTOSPI2

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **MODE**: OCTOSPIM multiplexing mode

0: if MUXEN = 0 direct mode, if MUXEN = 1 arbitration mode to output Port 1

1: if MUXEN = 0 swapped mode, if MUXEN = 1 arbitration mode to output Port 2

Bit 0 **MUXEN**: Multiplexed mode enable

This bit enables the multiplexing of the two OCTOSPIs.

0: No multiplexing, hence no arbitration

1: OCTOSPI1 and OCTOSPI2 are multiplexed over the same bus.

27.6.2 OCTOSPIM register map

Table 256. OCTOSPIM register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0000	OCTOSPIM _CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REQ2ACK_TIME[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSSEL_OVR_O2	CSSEL_OVR_O1	CSSEL_OVR_EN	Res.	Res.	MODE	MUXEN
	Reset value									0	0	0	0	0	0	0	0										0	0	0			0	0

Refer to *Section 2.3 on page 140* for the register boundary addresses.

28 Secure digital input/output MultiMediaCard interface (SDMMC)

28.1 SDMMC main features

The SD/SDIO, embedded MultiMediaCard (*e*•MMC) host interface (SDMMC) provides an interface between the AHB bus and SD memory cards, SDIO cards and *e*•MMC devices.

The MultiMediaCard system specifications are available through the MultiMediaCard Association website at www.jedec.org, published by the MMCA technical committee.

SD memory card and SD I/O card system specifications are available through the SD card Association website at www.sdcard.org.

The SDMMC features include the following:

- Compliance with *Embedded MultiMediaCard System Specification Version 5.1*. Card support for three different databus modes: 1-bit (default), 4-bit and 8-bit. (HS200 SDMMC_CK speed limited to maximum allowed I/O speed)(HS400 is not supported).
- Full compatibility with previous versions of MultiMediaCards (backward compatibility).
- Full compliance with *SD memory card specifications version 6.0*. (SDR104 SDMMC_CK speed limited to maximum allowed I/O speed, SPI mode and UHS-II mode not supported).
- Full compliance with *SDIO card specification version 4.0.* Card support for two different databus modes: 1-bit (default) and 4-bit. (SDR104 SDMMC_CK speed limited to maximum allowed I/O speed, SPI mode and UHS-II mode not supported).
- Data transfer up to 208 Mbyte/s for the 8-bit mode. (depending maximum allowed I/O speed).
- Data and command output enable signals to control external bidirectional drivers.
- IDMA linked list support

The MultiMediaCard/SD bus connects cards to the host.

The current version of the SDMMC supports only one SD/SDIO/*e*•MMC card at any one time and a stack of *e*•MMC.

28.2 SDMMC implementation

Table 257. SDMMC features

SDMMC modes/features(1)	SDMMC1	SDMMC2
Variable delay (SRD104, HS200)	X	X
SDMMC_CKIN	X	X
SDMMC_CDIR, SDMMC_D0DIR	X	-
SDMMC_D123DIR	X	-

1. X = supported.

28.3 SDMMC bus topology

Communication over the bus is based on command/response and data transfers.

The basic transaction on the SD/SDIO/*e*•MMC bus is the command/response transaction. These types of bus transaction transfer their information directly within the command or response structure. In addition, some operations have a data token.

Data transfers are done in the following ways:

- Block mode: data block(s) with block size 2^N bytes with N in the range 0-14
- SDIO multibyte mode: single data block with block size range 1-512 bytes
- *e*•MMC Stream mode: continuous data stream

Data transfers to/from *e*•MMC cards are done in data blocks or streams.

Figure 204. SDMMC "no response" and "no data" operations

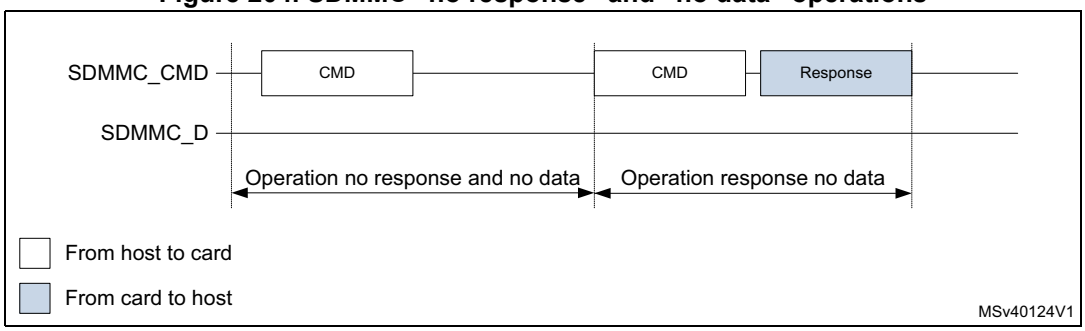
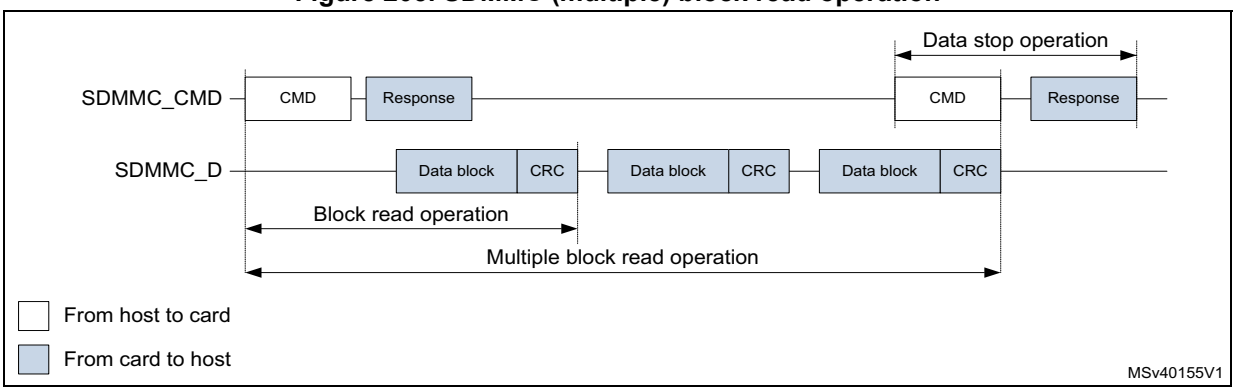
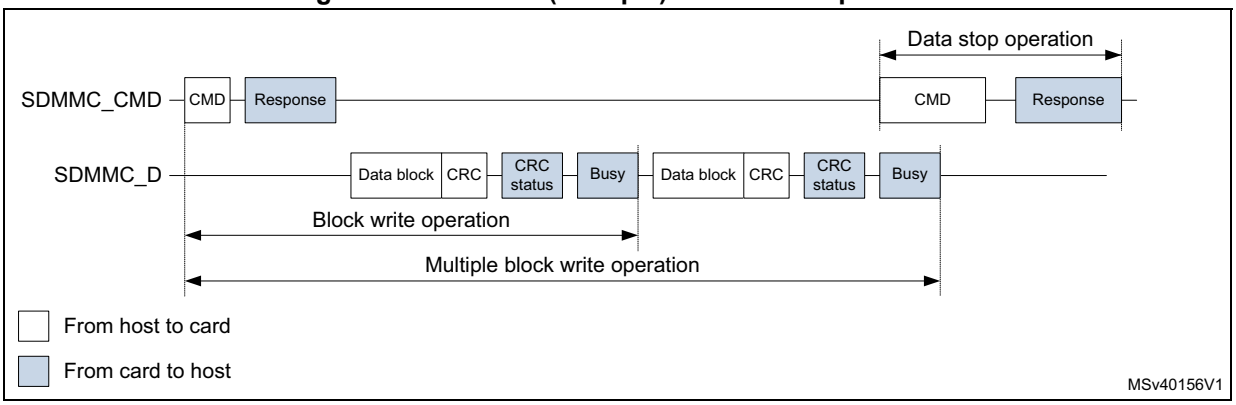


Figure 205. SDMMC (multiple) block read operation



Note: The Stop Transmission command is not required at the end of a e•MMC multiple block read with predefined block count.

Figure 206. SDMMC (multiple) block write operation



Note: The Stop Transmission command is not required at the end of an e•MMC multiple block write with predefined block count.

The SDMMC does not send any data as long as the Busy signal is asserted (SDMMC_D0 pulled low).

Figure 207. SDMMC (sequential) stream read operation

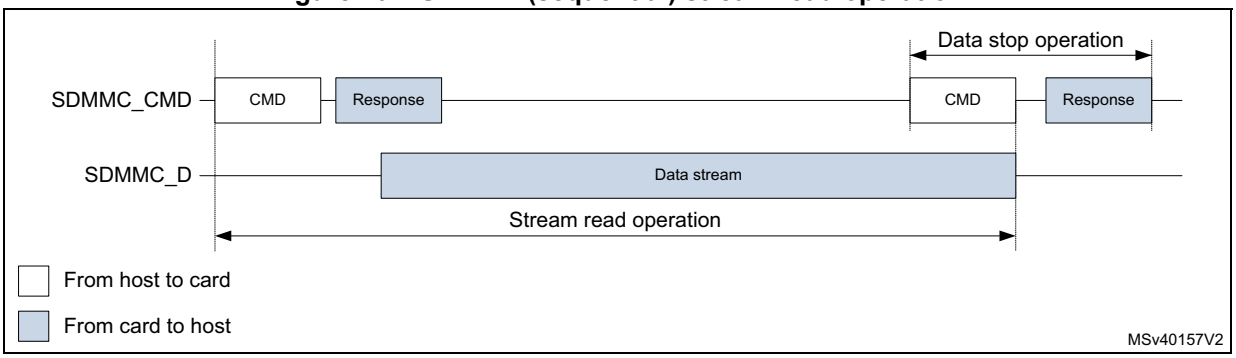
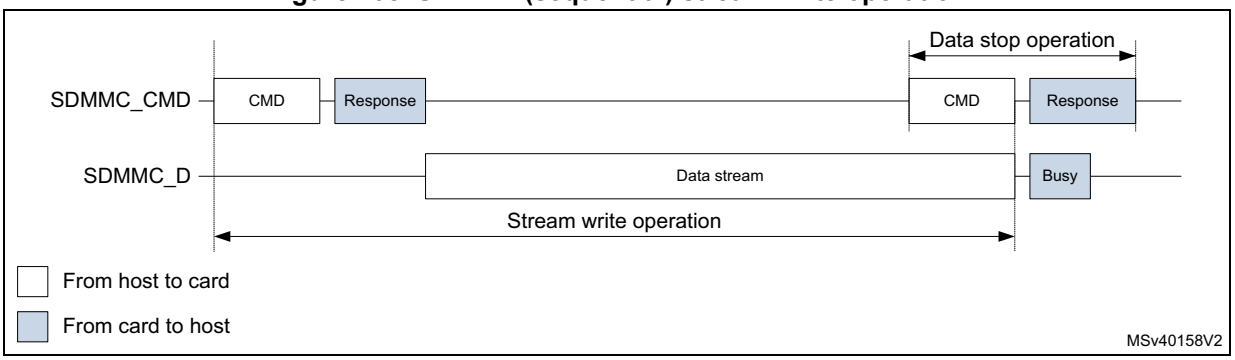


Figure 208. SDMMC (sequential) stream write operation



Stream data transfer operates only in a 1-bit wide bit bus configuration on SDMMC_D0 in single data rate modes (DS, HS, and SDR).

28.4 SDMMC operation modes

Table 258. SDMMC operation modes SD and SDIO

SDIO bus speed modes(1)(2)	Max bus speed (3) [Mbyte/s]	Max clock frequency [MHz](4)	Signal voltage [V]
DS (default speed)	12.5	25	3.3
HS (high speed)	25	50	3.3
SDR12	12.5	25	1.8
SDR25	25	50	1.8
DDR50	50	50	1.8
SDR50	50	100	1.8
SDR104	104	208	1.8

1. SDR single data rate signaling.
2. DDR double data rate signaling (data is sampled on both SDMMC_CK clock edges).
3. SDIO bus speed with 4-bit bus width.
4. Maximum frequency depending on maximum allowed I/O speed.

SDR104 mode requires variable delay support using sampling point tuning. The use of variable delay is optional for SDR50 mode.

Table 259. SDMMC operation modes *e*•MMC

e•MMC bus speed modes (1)(2)	Max bus speed (3) [Mbyte/s]	Max clock frequency [MHz](4)	Signal voltage [V](5)
Legacy compatible	26	26	3/1.8/1.2V
High speed SDR	52	52	3/1.8/1.2V
High speed DDR	104	52	3/1.8/1.2V
High speed HS200	200	200	1.8/1.2V

1. SDR single data rate signaling.
2. DDR double data rate signaling. (data is sampled on both SDMMC_CK clock edges).
3. *e*•MMC bus speed with 8-bit bus width.
4. Maximum frequency depending on maximum allowed I/O speed.
5. Supported signal voltage level depends on I/O port characteristics, refer to device datasheet.

HS200 mode requires variable delay support using sampling point tuning.

28.5 SDMMC functional description

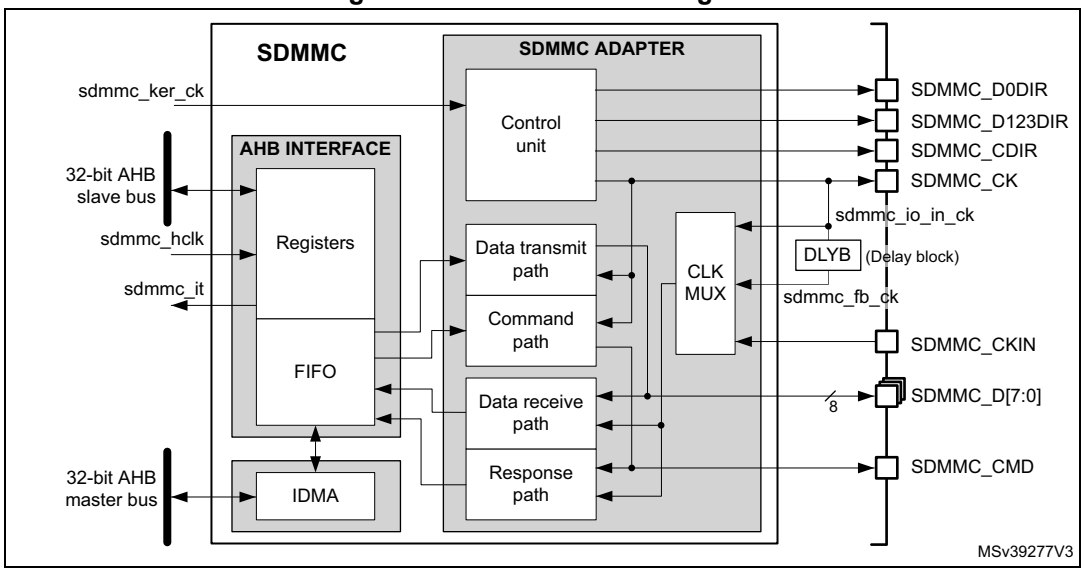
The SDMMC consists of four parts:

- The AHB slave interface accesses the SDMMC adapter registers, and generates interrupt signals and IDMA control signals.
- The SDMMC adapter block provides all functions specific to the *e*•MMC/SD/SD I/O card such as the clock generation unit, command and data transfer.
- The internal DMA (IDMA) block with its AHB master interface.
- A delay block (DLYB) taking care of the receive data sample clock alignment. The delay block is NOT part of the SDMMC. A delay block is mandatory when supporting SDR104 or HS200.

28.5.1 SDMMC block diagram

Figure 209 shows the SDMMC block diagram.

Figure 209. SDMMC block diagram



28.5.2 SDMMC pins and internal signals

Table 260 lists the SDMMC internal input/output signals, *Table 261* the SDMMC pins (alternate functions).

Table 260. SDMMC internal input/output signals

Signal name	Signal type	Description
sdmmc_ker_ck	Digital input	SDMMC kernel clock
sdmmc_hclk	Digital input	AHB clock
sdmmc_it	Digital output	SDMMC global interrupt

Table 260. SDMMC internal input/output signals (continued)

Signal name	Signal type	Description
sdmmc_io_in_ck	Digital input	SD/SDIO/*e*•MMC card feedback clock. This signal is internally connected to the SDMMC_CK pin (for DS and HS modes).
sdmmc_fb_ck	Digital input	SD/SDIO/*e*•MMC card tuned feedback clock after DLYB delay block (for SDR50, DDR50, SDR104, HS200)

Table 261. SDMMC pins

Pin name	Pin type	Description
SDMMC_CK	Digital output	Clock to SD/SDIO/*e*•MMC card
SDMMC_CKIN	Digital input	Clock feedback from an external driver for SD/SDIO/*e*•MMC card. (for SDR12, SDR25, SDR50, DDR50)
SDMMC_CMD	Digital input/output	SD/SDIO/*e*•MMC card bidirectional command/response signal.
SDMMC_CDIR	Digital output	SD/SDIO/*e*•MMC card I/O direction indication for the SDMMC_CMD signal.
SDMMC_D[7:0]	Digital input/output	SD/SDIO/*e*•MMC card bidirectional data lines.
SDMMC_D0DIR	Digital output	SD/SDIO/*e*•MMC card I/O direction indication for the SDMMC_D0 data line.
SDMMC_D123DIR	Digital output	SD/SDIO/*e*•MMC card I/O direction indication for the data lines SDMMC_D[3:1].

28.5.3 General description

The **SDMMC_D[7:0]** lines have different operating modes:

- By default, SDMMC_D0 line is used for data transfer. After initialization, the host can change the databus width.
- For an *e*•MMC, 1-bit (SDMMC_D0), 4-bit (SDMMC_D[3:0]) or 8-bit (SDMMC_D[7:0]) data bus widths can be used.
- For an SD or an SDIO card, 1-bit (SDMMC_D0) or 4-bit (SDMMC_D[3:0]) can be used. All data lines operate in push-pull mode.

To allow the connection of an external driver (a voltage switch transceiver), the direction of data flow on the data lines is indicated with I/O direction signals. The **SDMMC_D0DIR** signal indicates the I/O direction for the SDMMC_D0 data line, the **SDMMC_D123DIR** for the SDMMC_D[3:1] data lines.

SDMMC_CMD only operates in push-pull mode:

To allow the connection of an external driver (a voltage switch transceiver), the direction of data flow on the SDMMC_CMD line is indicated with the I/O direction signal **SDMMC_CDIR**.

SDMMC_CK clock to the card originates from **sdmmc_ker_ck**:

- When the sdmmc_ker_ck clock has 50 % duty cycle, it can be used even in bypass mode (CLKDIV = 0).
- When the sdmmc_ker_ck duty cycle is not 50 %, the CLKDIV must be used to divide it by 2 or more (CLKDIV > 0).
- The phase relation between the SDMMC_CMD / SDMMC_D[7:0] outputs and the SDMMC_CK can be selected through the NEGEDGE bit. The phase relation depends on the CLKDIV, NEGEDGE, and DDR settings. See *Figure 210*.

Figure 210. SDMMC Command and data phase relation

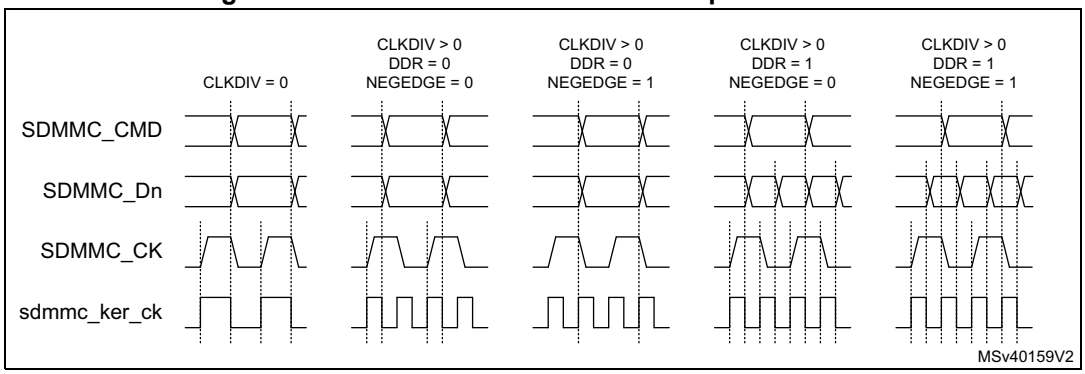


Table 262. SDMMC Command and data phase selection

CLKDIV	DDR	NEGEDGE	SDMMC_CK	Command out	Data out
0	x	x	= sdmmc_ker_ck	Generated on sdmmc_ker_ck falling edge	
>0	0	0	Generated on sdmmc_ker_ck rising edge	Generated on sdmmc_ker_ck falling edge succeeding the SDMMC_CK rising edge.	
		1		Generated on the same sdmmc_ker_ck rising edge that generates the SDMMC_CK falling edge.	
	1	0		Generated on sdmmc_ker_ck falling edge succeeding the SDMMC_CK rising edge.	Generated on sdmmc_ker_ck falling edge succeeding a SDMMC_CK edge.
		1		Generated on the same sdmmc_ker_ck rising edge that generates the SDMMC_CK falling edge.	

By default, the **sdmmc_io_in_ck** feedback clock input is selected for sampling incoming data in the SDMMC receive path. It is derived from the SDMMC_CK pin.

For tuning the phase of the sampling clock to accommodate the receive data timing, the DLYB delay block available on the device can be connected between **sdmmc_io_in_ck** signal (DLYB input dlyb_in_ck) and **sdmmc_fb_ck** clock input of SDMMC (DLYB output dlyb_out_ck). Selecting the **sdmmc_fb_ck** clock input in the receive path then enables using the phase-tuned sampling clock for the incoming data. This is required for SDMMC to support the SDR104 and HS200 operating mode and optional for SDR50 and DDR50 modes.

When using an external driver (a voltage switch transceiver), the SDMMC_CKIN feedback clock input can be selected to sample the receive data.

For an SD/SDIO/*e*•MMC card, the clock frequency can vary between 0 and 208 MHz (limited by maximum I/O speed).

Depending on the selected bus mode (SDR or DDR), one bit or two bits are transferred on SDMMC_D[7:0] lines with each clock cycle. The SDMMC_CMD line transfers only one bit per clock cycle.

28.5.4 SDMMC adapter

The SDMMC adapter (see *Figure 209: SDMMC block diagram*) is a multimedia/secure digital memory card bus master that provides an interface to a MultiMediaCard stack or to a secure digital memory card. It consists of the following subunits:

- Control unit
- Data transmit path
- Command path
- Data receive path
- Response path
- Receive data path clock multiplexer
- Delay block (DLYB), external to the SDMMC
- Adapter register block
- Data FIFO
- Internal DMA (IDMA)

Note: The adapter registers and FIFO use the AHB clock domain (sdmmc_hclk). The control unit, command path and data transmit path use the SDMMC adapter clock domain (sdmmc_ker_ck). The response path and data receive path use the SDMMC adapter feedback clock domain from the sdmmc_io_in_ck, or SDMMC_CKIN, or from the sdmmc_fb_ck generated by DLYB.

The DLYB delay block on the device can be used in conjunction with the SDMMC adapter, to tune the phase of the sampling clock for incoming data in SDMMC receive mode. It is required for the SDMMC to support the SDR104 and HS200 operating mode and optional for SDR50 and DDR50 modes.

Adapter register block

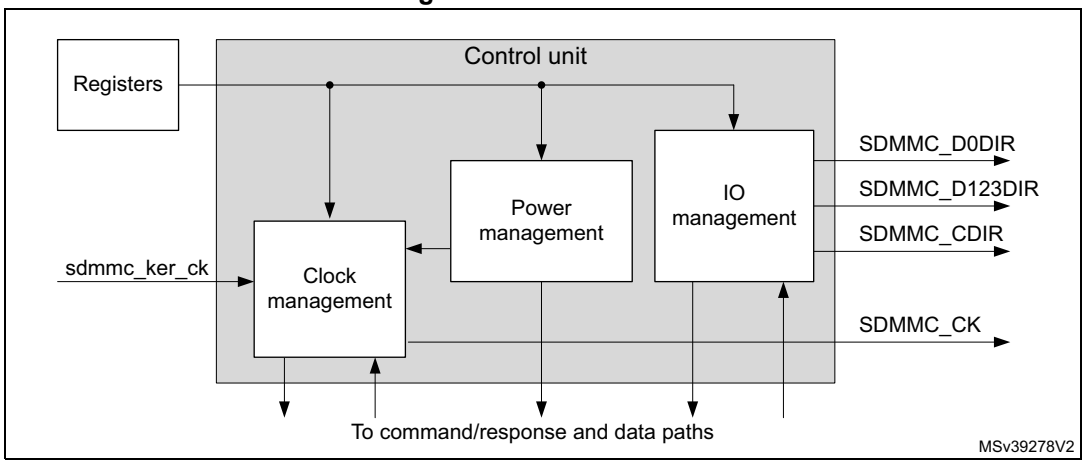
The adapter register block contains all system control registers, the SDMMC command and response registers and the data FIFO.

This block also generates the signals from the corresponding bit location in the SDMMC Clear register that clear the static flags in the SDMMC adapter.

Control unit

The control unit illustrated in *Figure 211*, contains the power management functions, the SDMMC_CK clock management with divider, and the I/O direction management.

Figure 211. Control unit



The power management subunit disables the card bus output signals during the power-off and power-up phases.

There are three power phases:

- power-off
- power-up
- power-on

The clock management subunit uses the sdmmc_ker_ck to generate the SDMMC_CK and provides the division control. It also takes care of stopping the SDMMC_CK for flow control, for example.

The clock outputs are inactive:

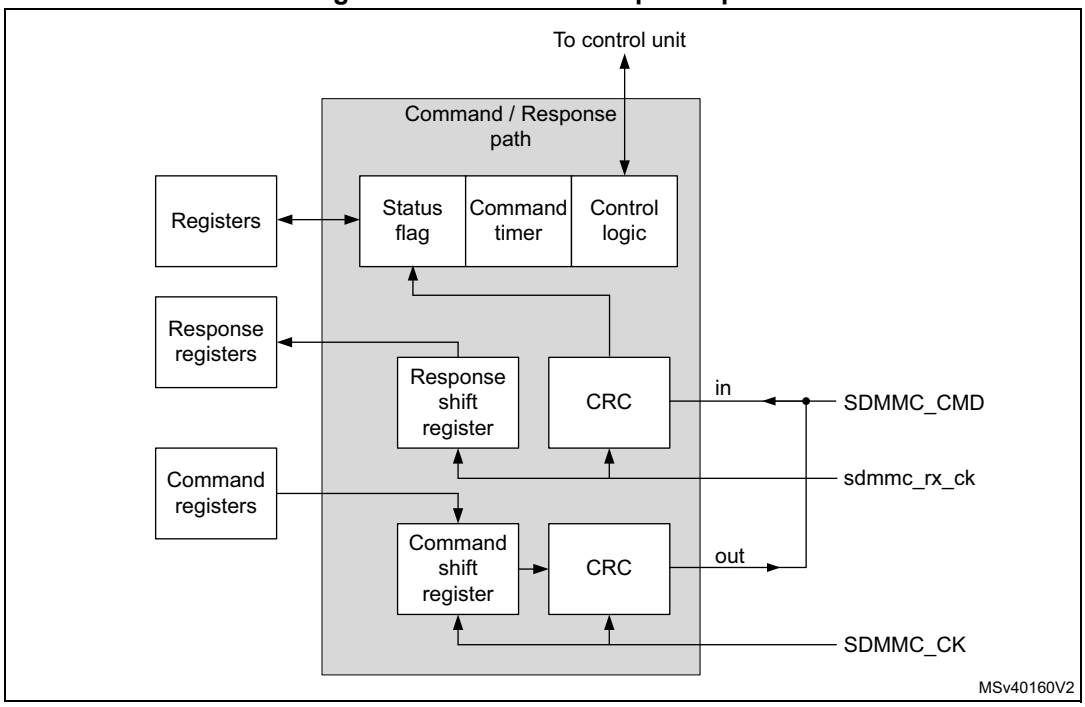
- after reset
- during the power-off or power-up phases
- if the power saving mode (register bit PWRSAV) is enabled and the card bus is in the Idle state for eight clock periods. The clock is stopped eight cycles after both the command/response CPSM and data path DPSM subunits have enter the Idle phase. The clock is restarted when the command/response CPSM or data path DPSM is activated (enabled).

The I/O management subunit takes care of the SDMMC_Dn and SDMMC_CMD I/O direction signals, which controls the external voltage transceiver.

Command/response path

The command/response path subunit transfers commands and responses on the SDMMC_CMD line. The command path is clocked on the SDMMC_CK and sends commands to the card,. The response path is clocked on the sdmmc_rx_ck and receives responses from the card.

Figure 212. Command/response path

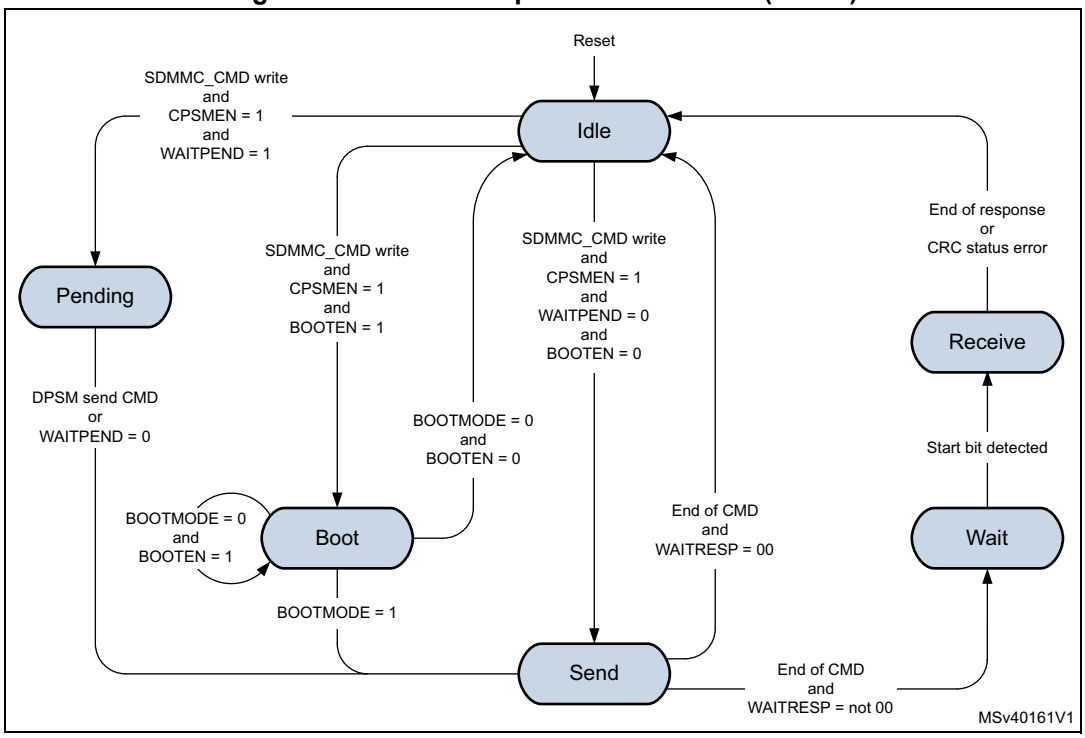


Command/response path state machine (CPSM):

- When the command register is written to and the enable bit is set, command transfer starts. When the command has been sent the CRC is appended and the command path state machine (CPSM) sets the status flags and:
  - if a response is not required enters the Idle state.
  - If a response is required, it waits for the response.
- When the response is received,
  - for a response with CRC, the received CRC code and the internally generated code are compared, and the appropriate status flag is set according the result.
  - for a response without CRC, no CRC is checked, and the appropriate status flag is not set.

When ever the CPSM is active (not in the Idle state), the CPSMACT bit is set.

Figure 213. Command path state machine (CPSM)



- **Idle**: The command path is inactive. When the command control register is written and the enable bit (CPSMEN) is set, the CPSM activates the SDMMC_CK clock (when stopped due to power save PWRSAV bit) and moves
  - to the Send state when WAITPEND = 0 and BOOTEN = 0.
  - to the Pending state when WAITPEND = 1.
  - to the Boot state when BOOTEN = 1.
- **Send**: The command is sent and the CRC is appended.
  - When CMDTRANS bit is set or when BOOTEN bit is set and BOOTMODE is alternative boot, and the DTDIR = receive, the CPSM DataEnable signal is issued to the DPSM at the end of the command.
  - When the CMDTRANS bit is set and the CMDSUSPEND bit is 0 the interrupt period is terminated at the end of the command.
  - When CMDSTOP bit is set the CPSM Abort signal is issued to the DPSM at the end of the command.
  - If no response is expected (WAITRESP = 00) the CPSM moves to the Idle state and the CMDSENT flag is set. When BOOTMODE = 1 and BOOTEN = 0 the CMDSENT flag is delayed 56 cycles after the command end bit, otherwise the

CMDSENT flag is generated immediately after the command end bit.
The RESPCMDR and RESPxR registers are not modified.

– If a command response is expected (WAITRESP = not 00) the CPSM moves to the Wait state and start the response timeout.

- **Wait**: The command path waits for a response.
  – When WAITINT bit is 0 the command timer starts running and the CPSM waits for a start bit.
  a) If a start bit is detected before the timeout the CPSM moves to the Receive state.
  b) If the timeout is reached before the CPSM detect a response start bit, the timeout flag (CTIMEOUT) is set and the CPSM moves to the Idle state.
  The RESPCMDR and RESPxR registers are not modified.
  – When WAITINT bit is 1, the timer is disabled and the CPSM waits for an interrupt request (response start bit) from one of the cards.
  a) When a start bit is detected the CPSM moves to the Receive state.
  b) When writing WAITINT to 0 (interrupt mode abort), the host sends a response by its self and on detecting the start bit the CPSM move to the Receive state.
- **Receive**: The command response is received. Depending the response mode bits WAITRESP in the command control register, the response can be either short or long, with CRC or without CRC. The received CRC code when present is verified against the internally generated CRC code.
  – When the CMDSUSPEND bit is set and the SDIO Response bit BS = 0 (response bit [39]), the interrupt period is started after the response.
  When the CMDSUSPEND bit is cleared, or the CMDSUSPEND bit is 1 and the SDIO Response bit BS = 1 (response bit [39]), there is no interrupt period started.
  – When the CMDTRANS bit is set and the CMDSUSPEND bit is set and the SDIO Response bit DF= 1 (response bit [32]) the interrupt period is terminated after the response.
  – When the CRC status passes or no CRC is present the CMDREND flag is set, the CPSM moves to the Idle state.
  The RESPCMDR and RESPxR registers are updated with received response.
  - When BOOTMODE = 1 and BOOTEN = 0 the CMDREND flag is delayed 56 cycles after the response end bit, otherwise the CMDREND flag is generated immediately after the response end bit.
  - When CMDTRANS bit is set and the DTDIR = transmit, the CPSM DataEnable signal is issued to the DPSM at the end of the command response.
  – When the CRC status fails the CCRCFAIL flag is set and the CPSM moves to the Idle state.
  The RESPCMDR and RESPxR registers are updated with received response.
- **Pending**: According the pending WAITPEND bit in the command register, the CPSM enters the pending state.
  – When DATALENGTH ≤ 5 bytes the CPSM moves to the Sent state and generates the DataEnable signal to start the data transfer aligned with the CMD12 Stop Transmission command.
  – When DATALENGTH > 5 bytes, the CPSM DataEnable signal is issued to the DPSM to start the data transfer. The CPSM waits for a send CMD signal from the

DPSM before moving to the Send state. This enables, for example, the CMD12 Stop Transmission command to be sent aligned with the data.

– When writing WAITPEND to 0, the CPSM moves to the Send state.

- **Boot**: If the BOOTEN bit is set in the command register, the CPSM enters the Boot state, and when:
  – BOOTMODE = 0 the SDMMC_CMD line is driven low and when CMDTRANS bit is set and the DTDIR = receive, the CPSM DataEnable signal is issued to the DPSM. This enables normal boot operation. This state is left at the end of the boot procedure by clearing the register bit BOOTEN, which cause the SDMMC_CMD line to be driven high and the CPSM Abort signal is issued to the DPSM, before moving to the Idle state. The CMDSENT flag is generated 56 cycles after SDMMC_CMD line is high.
  – BOOTMODE = 1, move to the Send state. This enables sending of the CMD0 (boot). Clearing BOOTEN has no effect.

Note: The CPSM remains in the Idle state for at least eight SDMMC_CK periods to meet the N_{CC} and N_{RC} timing constraints. N_{CC} is the minimum delay between two host commands, and N_{RC} is the minimum delay between the host command and the card response.

The response timeout has a fixed value of 64 SDMMC_CK clock periods.

A command is a token that starts an operation. Commands are sent from the host to either a single card (addressed command) or all connected cards (broadcast command are available for *e*•MMC V3.31 or previous). Commands are transferred serially on the SDMMC_CMD line. All commands have a fixed length of 48 bits. The general format for a command token for SD-Memory cards, SDIO cards, and *e*•MMC cards is shown in *Table 263.*

The command token data is taken from two registers, one containing a 32-bit argument and the other containing the 6-bit command index (six bits sent to a card).

Table 263. Command token format

Bit position	Width	Value	Description
47	1	0	Start bit
46	1	1	Transmission bit
[45:40]	6	x	Command index
[39:8]	32	x	Argument
[7:1]	7	x	CRC7
0	1	1	End bit

Next to the command data there are command type (WAITRESP) bits controlling the command path state machine (CPSM). These bits also determine whether the command requires a response, and whether the response is short (48 bit) or long (136 bits) long, and if a CRC is present or not.

A response is a token that is sent from an addressed card or synchronously from all connected cards to the host as an answer to a previous received command. All responses are sent via the command line SDMMC_CMD. The response transmission always starts with the left bit of the bit string corresponding to the response code word. The code length depends on the response type. Response tokens R1, R2, R3, R4, R5, and R6 have various

coding schemes, depending on their content. The general formats for the response tokens for SD-Memory cards, SDIO cards, and *e*•MMC cards are shown in *Table 264*, *Table 265* and *Table 266*.

A response always starts with a start bit (always 0), followed by the bit indicating the direction of transmission (card = 0). A value denoted by x in the tables below indicates a variable entry. Most responses, except some, are protected by a CRC. Every command code word is terminated by the end bit (always 1).

The response token data is stored in five registers, four containing the 32-bits card status, OCR register, argument or 127-bits CID or CSD register including internal CRC, and one register containing the 6-bits command index.

Table 264. Short response with CRC token format

Bit position	Width	Value	Description
47	1	0	Start bit
46	1	0	Transmission bit
[45:40]	6	x	Command index (or reserved 111111)
[39:8]	32	x	Argument
[7:1]	7	x	CRC7
0	1	1	End bit

Table 265. Short response without CRC token format

Bit position	Width	Value	Description
47	1	0	Start bit
46	1	0	Transmission bit
[45:40]	6	x	Command index (or reserved 111111)
[39:8]	32	x	Argument
[7:1]	7	1111111	(reserved 1111111)
0	1	1	End bit

Table 266. Long response with CRC token format

Bit position	Width	Value	Description
135	1	0	Start bit
134	1	0	Transmission bit
[133:128]	6	111111	Reserved
[127:1]	127:8	x	CID or CSD slices
	7:1	x	CRC7 (included in CID or CSD)
0	1	1	End bit

The command/response path operates in a half-duplex mode, so that either commands can be sent or responses can be received. If the CPSM is not in the Send state, the

SDMMC_CMD output is in the Hi-Z state. Data sent on SDMMC_CMD are synchronous with the SDMMC_CK according the NEGEDGE register bit see *Figure 210*.

The command and short response with CRC, the CRC generator calculates the CRC checksum for all 40 bits before the CRC code. This includes the start bit, transmission bit, command index, and command argument (or card status).

For the long response the CRC checksum is calculated only over the 120 bits of R2 CID or CSD. Note that the start bit, transmission bit and the six reserved bits are not used in the CRC calculation.

The CRC checksum is a 7-bit value:

CRC[6:0] = remainder $[(M(x) * x^7) / G(x)]$

$G(x) = x^7 + x^3 + 1$

$M(x) = (\text{first bit}) * x^n + (\text{second bit}) * x^{n-1} + \ldots + (\text{last bit before CRC}) * x^0$

Where n = 39 or 119.

The CPSM can send a number of specific commands to handle various operating modes when CPSMEN is set, see *Table 267*.

Table 267. Specific Commands overview

VSWITCH	BOOTEN	BOOTMOD	CMDTRAN	WAITPEND	CMDSTOP	WAITINT	Description
1	x	x	x	x	x	x	Start voltage switch sequence
0	1	x	x	x	x	x	Start normal boot
0	1	1	x	x	x	x	Start alternative boot
0	0	1	x	x	x	x	Stop alternative boot.
0	0	0	1	x	x	x	Send command with associated data transfer.
0	0	0	0	1	1	x	*e*•MMC stream data transfer, command (STOP_TRANSMISSION) pending until end of data transfer.
0	0	0	0	1	0	x	*e*•MMC stream data transfer, command different from (STOP_TRANSMISSION) pending until end of data transfer.
0	0	0	0	0	1	x	Send command (STOP_TRANSMISSION), stopping any ongoing data transmission.
0	0	0	0	0	0	1	Enter *e*•MMC wait interrupt (Wait-IRQ) mode.
0	0	0	0	0	0	0	Any other none specific command

The command/response path implements the status flags and associated clear bits shown in *Table 268*:

Table 268. Command path status flags

Flag	Description
CMDSENT	Set at the end of the command without response (CPSM moves from Send to Idle).
CMDREND	Set at the end of the command response when the CRC is OK (CPSM moves from Receive to Idle).
CCRCFAIL	Set at the end of the command response when the CRC is FAIL (CPSM moves from Receive to Idle).
CTIMEOUT	Set after the command when no response start bit received before the timeout (CPSM moves from Wait to Idle).
CKSTOP	Set after the voltage switch (VSWITCHEN = 1) command response when the CRC is OK and the SDMMC_CK is stopped (no impact on CPSM).
VSWEND	Set after the voltage switch (VSWITCH = 1) timeout of 5 ms + 1 ms (no impact on CPSM).
CPSMACT	Command transfer in progress (CPSM not in Idle state).

The command path error handling is shown in *Table 269*:

Table 269. Command path error handling

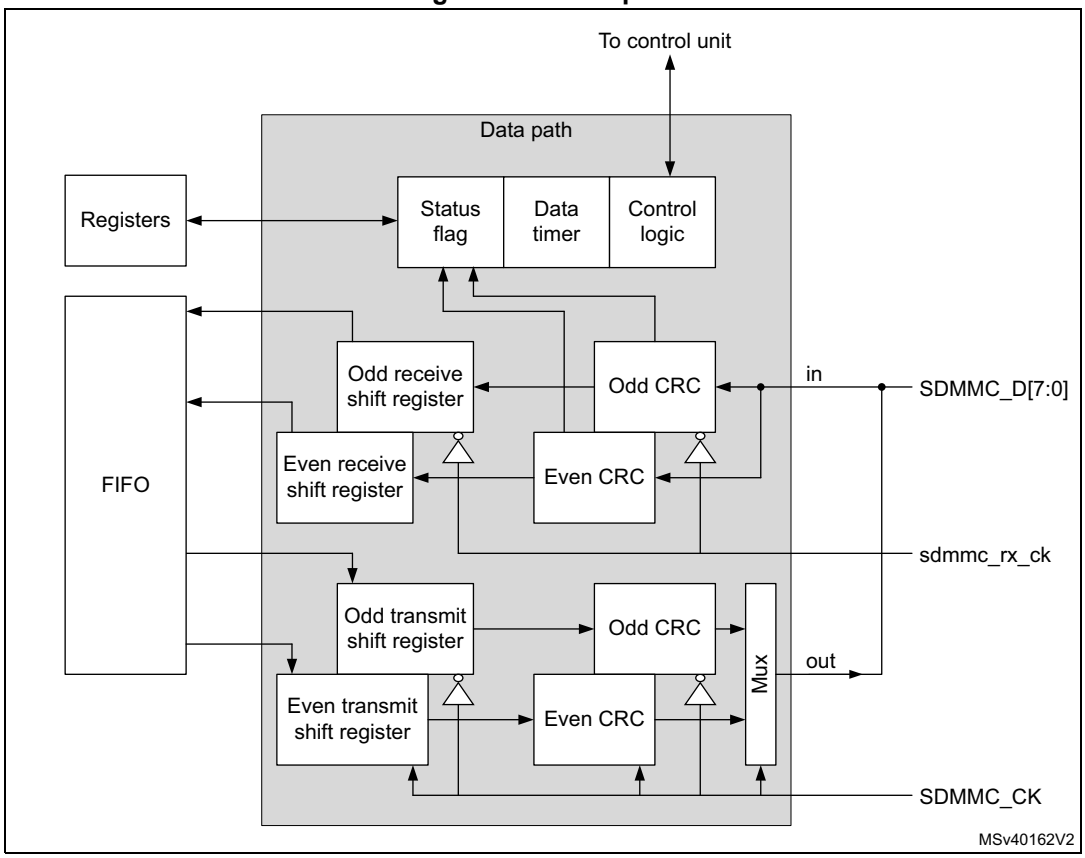
Error	CPSM state	Cause	Card action	Host action	CPSM action
Timeout	Wait	No start bit in time	Unknown	Reset or cycle power card(1)	Move to Idle
CRC status	Receive	Negative status	Command ignored	Resend command(1)	Move to Idle
		Transmission error	Command accepted	Resend command(1)	

1. When CMDTRANS is set, also a stop_transmission command must be send to move the DPSM to Idle.

Data path

The data path subunit transfers data on the SDMMC_D[7:0] lines to and from cards. The data transmit path is clocked on the SDMMC_CK and sends data to the card. The data receive path is clocked on the sdmmc_rx_ck and receives data from the card. *Figure 214* shows the data path block diagram.

Figure 214. Data path



The card data bus width can be programmed in the clock control register bits WIDBUS. The supported data bus width modes are:

- If the wide bus mode is not enabled, only one bit is transferred over SDMMC_D0.
- If the 4-bit wide bus mode is enabled, data is transferred at four bits over SDMMC_D[3:0].
- If the 8-bit wide bus mode is enabled, data is transferred at eight bits over SDMMC_D[7:0].

Next to the data bus width the data sampling mode can be programmed in the clock control register bit DDR. The supported data sampling modes are:

- Single data rate signaling (SDR), data is clocked on the rising edge of the clock.
- Double data rate signaling (DDR), data is clocked on the both edges of the clock. DDR mode is only supported in wide bus mode (4-bit wide and 8-bit wide).

Note: The data sampling mode only applies to the SDMMC_D[7:0] lines. (not applicable to the SDMMC_CMD line.)

In DDR mode, data is sampled on both edges of the SDMMC_CK according the following rules, see also *Figure 215* and *Figure 216*:

- On the rising edge of the clock odd bytes are sampled.
- On the falling edge of the clock even bytes are sampled.
- Data payload size is always a multiple of 2 bytes.
- Two CRC16 are computed per data line
  - Odd bits CRC16 clocked on the falling edge of the clock.
  - Even bits CRC16 clocked on the rising edge of the clock.
- Start, end bits and idle conditions are full cycle.
- CRC status / boot acknowledgment and busy signaling are full cycle and are only sampled on the rising edge of the clock.

In DDR mode, the SDMMC_CK clock division must be ≥ 2.

Figure 215. DDR mode data packet clocking

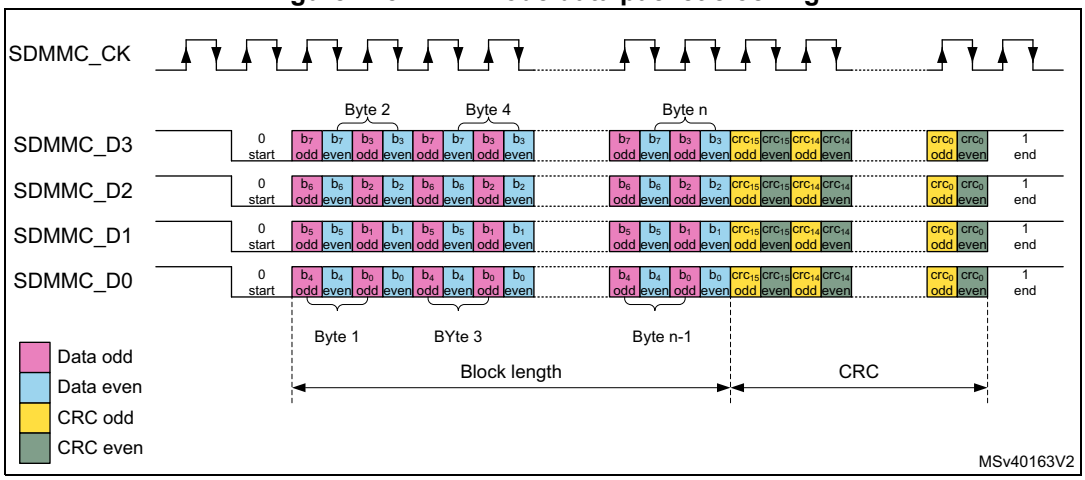
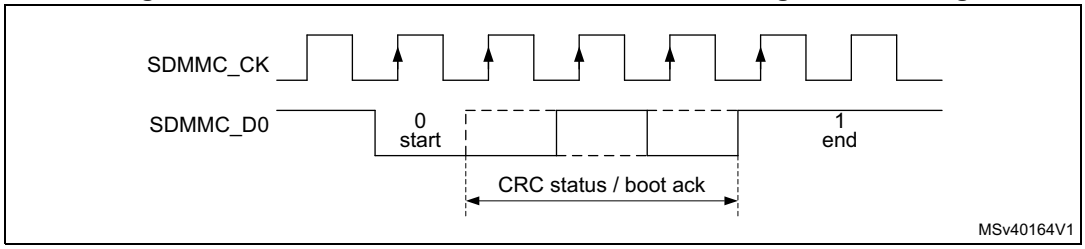


Figure 216. DDR mode CRC status / boot acknowledgment clocking



Data path state machine (DPSM)

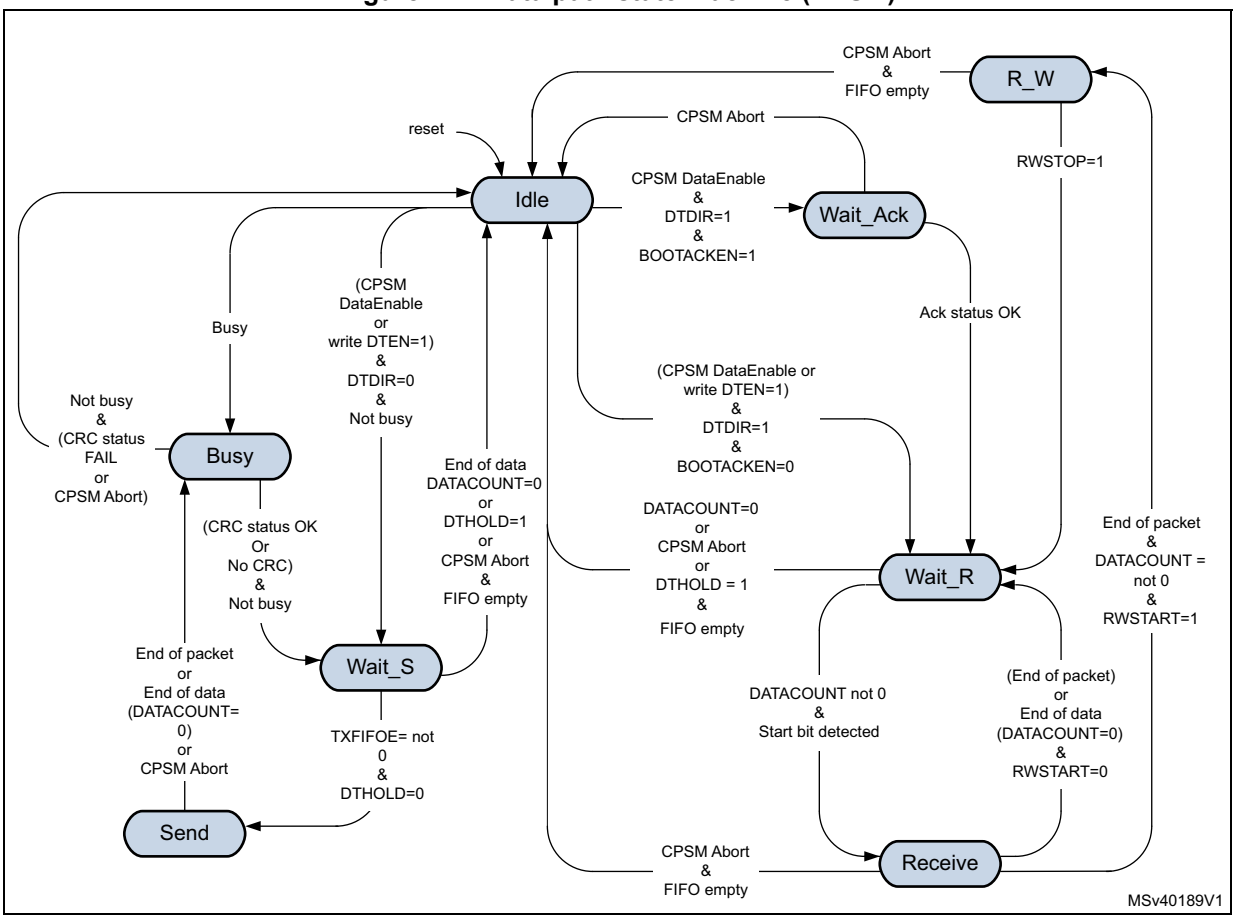
Depending on the transfer direction (send or receive), the data path state machine (DPSM) moves to the Wait_S or Wait_R state when it is enabled:

- Send: the DPSM moves to the Wait_S state. If there is data in the transmit FIFO, the DPSM moves to the Send state, and the data path subunit starts sending data to a card.
- Receive: the DPSM moves to the Wait_R state and waits for a start bit. When it receives a start bit, the DPSM moves to the Receive state, and the data path subunit starts receiving data from a card.

For boot operation with acknowledgment the DPSM moves to the Wait_Ack state and waits for the boot acknowledgment before moving to the Wait_R state.

The DPSM operates at SDMMC_CK. The DPSM has the following states, as shown in *Figure 217*. When ever the DPSM is active (not in the Idle state), the DPSMACT bit is set.

Figure 217. Data path state machine (DPSM)



- **Idle** state: the data path is inactive, and the SDMMC_D[7:0] outputs are according the PWRCTRL setting. The DPSM is activated either by sending a command with CMDTRANS bit set or by setting the DTEN bit, or by detecting Busy on SDMMC_D0 (that is, after a command with R1b response).

  When not busy, the DPSM activates the SDMMC_CK clock (when stopped due to power save PWRSAV bit), loads the data counter with a new (DATALENGTH) value and:

  – When the data direction bit (DTDIR) indicates send, moves to the Wait_S.

  – When the data direction bit (DTDIR) indicates receive, moves to the
  - Wait_R when BOOTACKEN register bit is clear.
  - Wait_Ack when BOOTACKEN register bit is set and start the acknowledgment timeout.

  When busy the DPSM keeps the SDMMC_CK clock active and move to the Busy state.

Note: DTEN must not be used to start data transfer with SD, SDIO and e•MMC cards.

- **Wait_Ack** state: the data path waits for the boot acknowledgment token.
  - The DPSM moves to the Wait_R state if it receives an error free acknowledgment before a timeout.
  - When a pattern different from the acknowledgment is received an acknowledgment status error is generated, and the ack fail status flag (ACKFAIL) is set. The DPSM stays in Wait_Ack.
  - If it reaches a timeout (ACKTIME) before it detects a start bit, it sets the timeout status flag (ACKTIMEOUT). The DPSM stays in Wait_Ack.
  - When the CPSM Abort signal is set it moves to the Idle state and sets the DABORT flag.
- **Wait_R** state: the data path, if the data counter is not zero and data is not hold, waits for a start bit on SDMMC_D[n:0]. If the data counter is zero or data is hold, wait for the FIFO to be empty.
  - In block mode, if a start bit is received before a timeout the DPSM moves to the Receive state and loads the data block counter with DBLOCKSIZE.
  - In SDIO multibyte mode, if a start bit is received before a timeout the DPSM moves to the Receive state and loads the data block counter with DATALENGTH.
  - In stream mode, if a start bit is received before a timeout the DPSM moves to the Receive state and loads the data counter with DATALENGTH.
  - if the data counter (DATACOUNT) equals zero (end of data) the DPSM moves to the Idle state when the receive FIFO is empty and the DATAEND flag is set.
  - If it reaches a timeout (DATATIME) before it detects a start bit, it sets the timeout status flag (DTIMEOUT) and the DPSM stays in the Wait_R state.
  - If the CPSM Abort signal is set:
    If DATACOUNT > 0, the DPSM moves to the Idle state when the FIFO is empty and when IDMAEN = 0 reset with FIFORST, and sets the DABORT flag.
    If DATACOUNT is zero normal operation is continued, there is no DABORT flag since the transfer has completed normally.
  - if the DTHOLD bit is set:
    - When DATACOUNT > 0, the DPSM moves to the Idle state when the receive FIFO is empty and when IDMAEN = 0 reset with FIFORST, and issues the DHOLD flag. When holding the timeout is disabled. When an CPSM Abort signal is received during holding, the transfer is aborted.
    - When DATACOUNT = 0, the transfer is completed normally and there is no DHOLD flag.
  - When DPSM has been started with DTEN, after an error (DTIMEOUT) the DPSM moves to the Idle state when the FIFO is empty and when IDMAEN = 0 reset with FIFORST.

- **R_W** state: the data path Read Wait the bus.
  - The DPSM moves to the Wait_R state when the Read Wait stop bit (RWSTOP) is set, and start the receive timeout.
  - If the CPSM Abort signal is set, wait for the FIFO to be empty and when IDMAEN = 0 reset with FIFORST, then moves to the Idle state and sets the DABORT flag.
- **Receive** state: the data path receives serial data from a card. Pack the data in bytes and written it to the data FIFO. Depending on the transfer mode selected in the data control register (DTMODE), the data transfer mode can be either block or stream:
  - In block mode, when the data block size (DBLOCKSIZE) number of data bytes are received, the DPSM waits until it receives the CRC code.
  - In SDIO multibyte mode, when the data block size (DATALENGTH) number of data bytes are received, the DPSM waits until it receives the CRC code.

  a) If the received CRC code matches the internally generated CRC code, the DPSM moves to the
  - R_W state when RWSTART = 1 and DATACOUNT > zero, the DBCKEND flag is set.
  - Wait_R state otherwise.

  b) If the received CRC code fails the internally generated CRC code any further data reception is prevented.
  - When not all data has been received (DATACOUNT > 0), the CRC fail status flag (DCRCFAIL) is set and the DPSM stays in the Receive state.
  - When all data has been received (DATACOUNT = 0), wait for the FIFO to be empty after which the CRC fail status flag (DCRCFAIL) is set and the DPSM moves to the Idle state.

  - In stream mode, the DPSM receives data while the data counter DATACOUNT > 0. When the counter is zero, the remaining data in the shift register is written to the data FIFO, and the DPSM moves to the Wait_R state.
  - When a FIFO overrun error occurs, the DPSM sets the FIFO overrun error flag (RXOVERR) and any further data reception is prevented. The DPSM stays in the Receive state.
  - When an CPSM Abort signal is received:
  - If the CPSM Abort signal is received before the 2 last bits of the data with DATACOUNT = 0, the transfer is aborted. The remaining data in the shift register is written to the data FIFO, wait for the FIFO to be empty and when IDMAEN = 0 reset with FIFORST, then the DPSM moves to the Idle state and the DABORT flag is set.
  - If the CPSM Abort signal is received during or after the 2 last bits of the transfer with DATACOUNT = 0, the transfer is completed normally. The DPSM stays in the Receive state no DABORT flag is generated.
  - When DPSM has been started with DTEN, after an error (DCRCFAIL when DATACOUNT > 0, or RXOVERR) the DPSM moves to the Idle state when the FIFO is empty and when IDMAEN = 0 reset with FIFORST.

- **Wait_S** state: the data path waits for data to be available from the FIFO.
  - If the data counter DATACOUNT > 0, waits until the data FIFO empty flag (TXFIFOE) is de-asserted and DTHOLD is not set, and moves to the Send state.
  - If the data counter (DATACOUNT) = 0 the DPSM moves to the Idle state.
    - When DTHOLD is disabled, the DATAEND flag is set.
    - When DTHOLD is enabled, the DHOLD flag is set.
  - When DTHOLD is set and the DATACOUNT > 0
    - When IDMA is enabled, the DBCKEND flag is set and subsequently the FIFO is flushed, furthermore the DPSM moves to the Idle state and the DHOLD flag is set.
    - When IDMA is disabled the DBCKEND flag is set. Wait for the FIFO to be reset by software with FIFORST, then DPSM moves to the Idle state and issues the DHOLD flag.
  - When DTHOLD is set and DATACOUNT = 0 the transfer is completed normally.
  - When receiving the CPSM Abort signal
    - If the CPSM Abort signal is received before the 2 last bits of the data with DATACOUNT = 0, the transfer is aborted, wait for the FIFO to be empty and when IDMAEN = 0 reset with FIFORST, then the DPSM moves to the Idle state and sets the DABORT flag.
    - If the CPSM Abort signal is received during or after the 2 last bits of the transfer with DATACOUNT = 0, normal operation is continued, there is no DABORT flag since the transfer has completed normally.

Note: The DPSM remains in the Wait_S state for at least two clock periods to meet the N_{WR} timing requirements, where N_{WR} is the number of clock cycles between the reception of the card response and the start of the data transfer from the host.

- **Send** state: the DPSM starts sending data to a card. Depending on the transfer mode bit in the data control register, the data transfer mode can be either block, SDIO multibyte or stream:
  - In block mode, when the data block size (DBLOCKSIZE) number of data bytes are send, the DPSM sends an internally generated CRC code and end bit, and moves to the Busy state and start the transmit timeout.
  - In SDIO multibyte mode, when the data block size (DATALENGTH) number of data bytes are send, the DPSM sends an internally generated CRC code and end bit, and moves to the Busy state and start the transmit timeout.
  - In stream mode, the DPSM sends data to a card while the data counter DATACOUNT > 0. When the data counter reaches zero moves to the Busy state and start the transmit timeout.
    Before sending the last stream byte according to DATACOUNT, the DPSM issues a trigger on the send CMD signal. This signal is used by the CPSM to sent any pending command (CMD12 Stop Transmission command).
  - If a FIFO underrun error occurs, the DPSM sets the FIFO underrun error flag (TXUNDERR). The DPSM stays in the Send state.
  - When receiving the CPSM Abort signal
    - If the CPSM Abort signal is received before the 2 last bits of the transfer with DATACOUNT = 0, the transfer is aborted. The DPSM sends a last data bit followed by an end bit. The FIFO is disabled/flushed, and the DPSM moves to the Busy state to wait for not busy before setting the DABORT flag.
    - If the CPSM Abort signal is received during or after the 2 last bits of the transfer

with DATACOUNT = 0, the transfer is completed normally, there is no DABORT flag.

- **Busy** state: the DPSM waits for the CRC status token when expected, and wait for a not busy signal:
  - If a CRC status token is expected and indicate “non-erroneous transmission” or when there is no CRC expected:
    - it moves to the Wait_S state when SDMMC_D0 is not low (the card is not busy).
    - When the card is busy SDMMC_D0 is low it remains in the Busy state.
  - If a CRC status token is expected and indicates “erroneous transmission”.
    - When not all data has been send (DATACOUNT > 0). The DPSM waits for not busy after which the CRC fail status flag (DCRCFAIL) is set. The FIFO is disabled/flushed and the DPSM stays in the Busy state.
    - When all data has been send (DATACOUNT = 0). The DPSM waits for not busy after which the CRC fail status flag (DCRCFAIL) is set and the DPSM moves to the Idle state.
  - If a CRC status (Ncrc) timeout occurs while the DPSM is in the Busy state, it sets the data timeout flag (DTIMEOUT) and stays in the Busy state.
  - If a busy timeout occurs while the DPSM is in the Busy state, it sets the data timeout flag (DTIMEOUT) and stays in the Busy state.
  - When receiving the CPSM Abort signal in the Busy state:
    - If the CPSM Abort signal is received before the 2 last bits of the CRC response with DATACOUNT > 0, the data transfer is aborted. The DPSM waits for not busy and the FIFO to be disabled/flushed before moving to the Idle state and the DABORT flag is set.
    - If the CPSM Abort signal is received during or after the 2 last bits of the CRC response when DATACOUNT = 0 or when no CRC is expected and DATACOUNT = 0 and there has been no DTIMEOUT error, the DPSM stays in the Busy state no DABORT flag is generated, since the transfer may completed normally.
    - If the CPSM Abort signal is received when a DTIMEOUT error has occurred the DPSM waits for not busy and the FIFO to be disabled/flushed before moving to the Idle state and the DABORT flag is set.
  - When entering the Busy state due to an abort in the Send state, the DPSM waits for not busy before moving to the Idle state and the DABORT flag is set.
  - When DPSM has been started with DTEN, after an error (DCRCFAIL when DATACOUNT > 0, or DTIMEOUT) the DPSM moves to the Idle state when the FIFO is reset.
  - When the DPSM has been started due to Busy on SDMMC_D0, waits for not busy after which the Busy end status flag (BUSYD0END) is set and the DPSM moves to the Idle state.

The data timer (DATATIME) is enabled when the DPSM is in the Wait_R or Busy state 2 cycles after the data block end bit, or data read command end bit, or R1b response, and generates the data timeout error (DTIMEOUT):

- When transmitting data, the timeout occurs
  - when a CRC status is expected and no start bit is received withing 8 SDMMC_CK cycles, the DTIMEOUT flag is set.
  - when the Busy state takes longer than the programmed timeout period., the DTIMEOUT flag is set.
- When receiving data, the timeout occurs
  - when there is still data to be received DATACOUNT > 0 and no start bit is received before the programmed timeout period, the DTIMEOUT flag is set.
- After a R1b response, the timeout occurs
  - when the Busy state takes longer than the programmed timeout period., the DTIMEOUT flag is set.

When DATATIME = 0:

- In receive the start bit must be present 2 cycles after the data block end bit or data read command end bit.
- In transmit busy is timed out 2 cycles after the CRC token end bit or stream data end bit.
- After a R1b response busy is timed out 2 cycles after the response end bit.

Data can be transferred from the card to the host (transmit, send) or vice versa (receive). Data are transferred via the SDMMC_Dn data lines, they are stored in a FIFO.

Table 270. Data token format

Description	Start bit	Data(1)	CRC16	End bit	DTMODE
Block data	0	(DBLOCKSIZE, DATALENGTH)	Yes	1	00
SDIO multibyte	0	(DATALENGTH)	Yes	1	01
e•MMC stream	0	(DATALENGTH)	No	1	10

1. The total amount of data to transfer is given by DATALENGTH. Where for Block data the amount of data in each block is given by DBLOCKSIZE.

The data token format is selected with register bits DTMODE according.

The data path implements the status flags and associated clear bits shown in *Table 271*:

Table 271. Data path status flags and clear bits

Flag		Description
DATAEND	TX	Set at the end of the complete data transfer when the CRC is OK and busy has finished and both DTHOLD = 0 and DATACOUNT = 0. (DPSM moves from Wait_S to Idle)
	RX	Set at the end of the complete data transfer when the CRC is OK and all data has been read, (DATACOUNT = 0 and FIFO is empty). (DPSM moves from Wait_R to Idle)
	Boot	

Table 271. Data path status flags and clear bits (continued)

Flag		Description
DCRCFAIL	TX	Set at the end of the CRC when FAIL and busy has finished. (DPSM stay in Busy when there is still data to send and wait for CPSM Abort) (DPSM moves from Busy to Idle when all data has been sent) or DPSM has been started with DTEN
	RX	Set at the end of the CRC when FAIL and FIFO is empty. (DPSM stays in Receive when there is still data to be received and wait for CPSM Abort) (DPSM moves from Receive to Idle when all data has been received or DPSM has been started with DTEN)
	Boot	
ACKFAIL	Boot	Set at the end of the boot acknowledgment when fail. (DPSM stays in Wait_Ack and wait for CPSM Abort)
DTIMEOUT	CMD R1b	Set after the command response no end of busy received before the timeout. (DPSM stays in Busy and wait for CPSM Abort)
	TX	Set when no CRC token start bit received within Ncrc, or no end of busy received before the timeout. (DPSM stays in Busy and wait for CPSM Abort) (When DPSM has been started with DTEN move to Idle) Note: The DCRCFAIL flag may also be set when CRC failed before the busy timeout.
	RX	Set when no start bit received before the timeout. (DPSM stays in Wait_R and wait for CPSM Abort) (When DPSM has been started with DTEN move to Idle)
	Boot	
ACKTIMEOUT	Boot	Set when no start bit received before the timeout. (DPSM stays in Wait_Ack and wait for CPSM Abort)
DBCKEND	TX	When DTHOLD = 1 and IDMAEN = 0: Set at the end of data block transfer when the CRC is OK and busy has finished, when data transfer is not complete (DATACOUNT >0). (DPSM moves from Busy to Wait_S)
	RX	When RWSTART = 1: Set at the end of data block transfer when the CRC is OK, when data transfer is not complete (DATACOUNT > 0). (DPSM moves from Receive to R_W)
	Boot	
DHOLD	TX	When DTHOLD = 1: Set at the end of data block transfer when the CRC is OK and busy has finished. (DPSM moves from Wait_S to Idle)
	RX	When DTHOLD = 1: Set at the end of data block transfer when the CRC is OK and all data has been read (FIFO is empty), when data transfer is not complete (DATACOUNT >0). (DPSM moves from Wait_R to Idle)
DABORT	CMD R1b	When CPSM Abort event has been sent by the CPSM and busy has finished. (DPSM moves from Busy to Idle)
	TX	When CPSM Abort event has been sent by the CPSM before the 2 last bits of the transfer. (DPSM moves from any state to Idle)
	RX	
	Boot	
BUSYD0END	CMD R1b	Set after the command response when end of busy before the timeout. (DPSM moves from Busy to Idle)
DPSMACT		Data transfer in progress. (DPSM not in Idle state)

The data path error handling is shown in *Table 272*:

Table 272. Data path error handling

Error	DPSM state	Cause	Card action	Host action	DPSM action
Timeout	Wait_Ack	No Ack in time	unknown	Card cycle power	Stay in Wait_Ack (reset the SDMMC with the RCC.SDMMCxRST register bit)
	Wait_R	No start bit in time	unknown	Stop data reception Send stop transmission command	On CPSM Abort move to Idle
			unknown	Stop boot procedure	
	Busy	Busy too long (due to data transfer)	unknown	Stop data reception Send stop transmission command	
		Busy too long (due to R1b)	unknown	Send reset command	
CRC	Receive	transmission error	Send further data	Stop data reception Send stop transmission command	On CPSM Abort move to Idle
CRC status	Busy	Negative status	Ignore further data	Stop data transmission Send stop transmission command	On CPSM Abort move to Idle
		transmission error	wait for further data		
Ack status	Wait_Ack	transmission error	Send boot data	Stop boot procedure	On CPSM Abort move to Idle
Overrun	Receive	FIFO full	Send further data	Stop data reception Send stop transmission command	On CPSM Abort move to Idle
Underrun	Send	FIFO empty	Receive further data	Stop data transmission Send stop transmission command	On CPSM Abort move to Idle

Data FIFO

The data FIFO (first-in-first-out) subunit contains the transmit and receive data buffer. A single FIFO is used for either transmit or receive as selected by the DTDIR bit. The FIFO contain a 32-bit wide, 16-word deep data buffer and control logic. Because the data FIFO operates in the AHB clock domain (sdmmc_hclk), all signals from the subunits in the SDMMC clock domain (SDMMC_CK/sdmmc_rx_ck) are resynchronized.

The FIFO can be in one of the following states:

- The transmit FIFO refers to the transmit logic and data buffer when sending data out to the card. (DTDIR = 0)
- The receive FIFO refers to the receive logic and data buffer when receiving data in from the card. (DTDIR = 1)

The end of a correctly completed SDMMC data transfer from the FIFO is indicated by the DATAEND flags driven by the data path subunit. Any incorrect (aborted) SDMMC data transfer from the FIFO is indicated by one of the error flags (DCRCFAIL, DTIMEOUT, DABORT) driven by the data path subunit, or one of the FIFO error flags (TXUNDERR, RXOVERR) driven by the FIFO control.

The data FIFO can be accessed in the following ways, see *Table 273*.

Table 273. Data FIFO access

Data FIFO access	IDMAEN
From firmware via AHB slave interface	0
From IDMA via AHB master interface	1

Transmit FIFO:

Data can be written to the transmit FIFO when the DPSM has been activated (DPSMACT = 1).

When IDMAEN = 1 the FIFO is fully handled by the IDMA.

When IDMAEN = 0 the FIFO is controlled by firmware via the AHB slave interface. The transmit FIFO is accessible via sequential addresses. The transmit FIFO contains a data output register that holds the data word pointed to by the read pointer. When the data path subunit has loaded its shift register, it increments the read pointer and drives new data out. The transmit FIFO is handled in the following way:

1. Write the data length into DATALENGTH and the block length in DBLOCKSIZE.
   – For block data transfer (DTMODE = 0), DATALENGTH must be an integer multiple of DBLOCKSIZE.
2. Set the SDMMC in transmit mode (DTDIR = 0).
   – Configures the FIFO in transmit mode.
3. Enable the data transfer
   – either by sending a command from the CPSM with the CMDTRANS bit set
   – or by setting DTEN bit
4. When (DPSMACT = 1) write data to the FIFO.
   – The DPSM stays in the Wait_S state until FIFO is full (TXFIFOF = 1), or the number indicated by DATALENGTH.

- The SDMMC keeps sending data as long as FIFO is not empty, hardware flow control during data transfer is used to prevent FIFO underrun.

5. Write data to the FIFO.
   – When the FIFO is handled by software, wait until the FIFO is half empty (TXFIFOHE flag), write data to the FIFO until FIFO is full (TXFIFOF = 1), or last data has been written.
   – When the FIFO is handled by the IDMA, the IDMA transfers the FIFO date.
6. When last data has been written wait for end of data (DATAEND flag)
   – SDMMC has completely sent all data and the DPSM is disabled (DPSMACT = 0).

In case of a data transfer error or transfer hold when IDMAEN = 0, firmware must stop writing to the FIFO and flush and reset the FIFO with the FIFORST register bit.

The transmit FIFO status flags are listed in *Table 274*.

Table 274. Transmit FIFO status flags

Flag	Description
TXFIFOF	Set to high when all transmit FIFO words contain valid data.
TXFIFOE	Set to high when the transmit FIFO does not contain valid data.
TXFIFOHE	Set to high when half or more transmit FIFO words are empty.
TXUNDERR	Set to high when an underrun error occurs. This flag is cleared by writing to the SDMMC Clear register.

Receive FIFO:

Data can be read from the receive FIFO when the DPSM is activated (DPSMACT = 1).

When IDMAEN = 1 the FIFO is fully handled by the IDMA.

When IDMAEN = 0 the FIFO is controlled by firmware via the AHB slave interface.When the data path subunit receives a word of data, it drives the data on the write databus. The write pointer is incremented after the write operation completes. On the read side, the contents of the FIFO word pointed to by the current value of the read pointer is driven onto the read databus. The receive FIFO is accessible via sequential addresses.

The receive FIFO is handled in the following way:

1. Write the data length into DATALENGTH and the block length in DBLOCKSIZE.
   – For block data transfer (DTMODE = 0), DATALENGTH must be an integer multiple of DBLOCKSIZE.
2. Set the SDMMC in receive mode (DTDIR = 1).
   – Configures the FIFO in receive mode.
3. Enable the DPSM transfer
   – either by sending a command from the CPSM with the CMDTRANS bit set
   – or by setting DTEN bit.
4. When (DPSMACT = 1) the FIFO is ready to receive data.
   – The DPSM writes the received data to the FIFO.
   - The SDMMC keeps receiving data as long as FIFO is not full, hardware flow control during the data transfer is used to prevent FIFO overrun.
5. Read data from the FIFO.
   – When the FIFO is handled by software, wait until the FIFO is half full (RXFIFOHF flag), read data from the FIFO until FIFO is empty (RXFIFOE = 1).
   - When last data has been received, read data from the FIFO until FIFO is empty (DATAEND = 1).
   – When the FIFO is handled by the IDMA, the IDMA transfers the FIFO date.
6. SDMMC has completely received all data and the DPSM is disabled (DPSMACT = 0).

In case of a data transfer hold when IDMAEN = 0, the firmware must read the remaining data until the FIFO is empty and reset the FIFO with the FIFORST register bit. This causes the DPSM to go to the Idle state (DPSMACT = 0).

In case of a data transfer error when IDMAEN = 0, the firmware must stop reading the FIFO and flush and reset the FIFO with the FIFORST register bit. This causes the DPSM to go to the Idle state (DPSMACT = 0).

The receive FIFO status flags are listed in *Table 275*.

Table 275. Receive FIFO status flags

Flag	Description
RXFIFOF	Set to high when all receive FIFO words contain valid data
RXFIFOE	Set to high when the receive FIFO does not contain valid data.
RXFIFOHF	Set to high when half or more receive FIFO words contain valid data.
RXOVERR	Set to high when an overrun error occurs. This flag is cleared by writing to the SDMMC Clear register.

CLKMUX unit

The CLKMUX selects the source for clock sdmmc_rx_ck to be used with the received data and command response. The receive data clock source can be selected by the clock control register bit SELCLKRX, between:

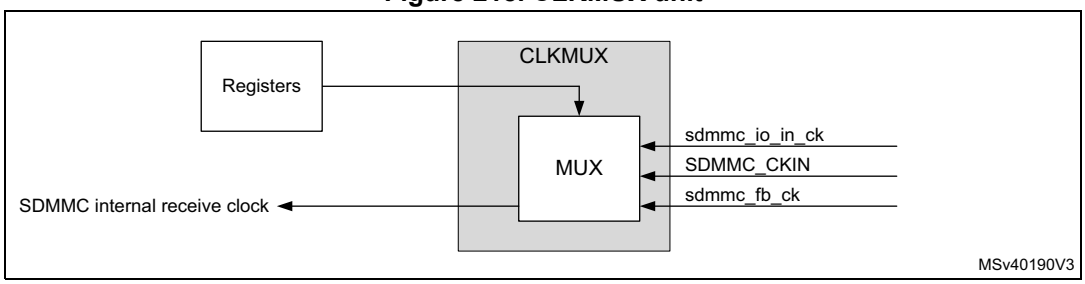
- sdmmc_io_in_ck bus master main feedback clock.
- SDMMC_CKIN external bus feedback clock.
- sdmmc_fb_ck bus tuned feedback clock.

The sdmmc_io_in_ck is selected when there is no external driver, with DS and HS.

The SDMMC_CKIN is selected when there is an external driver with SDR12, SDR25, SDR50 and DDR50.

The sdmmc_fb_ck clock input must be selected when the DLYB block on the device is used with SDR104, HS200 and optionally with SDR50 and DDR50 modes.

Figure 218. CLKMUX unit



The sdmmc_rx_ck source must be changed when the CPSM and DPSM are in the Idle state.

28.5.5 SDMMC AHB slave interface

The AHB slave interface generates the interrupt requests, and accesses the SDMMC adapter registers and the data FIFO. It consists of a data path, register decoder, and interrupt logic.

SDMMC FIFO

The FIFO access is restricted to word access only:

- In transmit FIFO mode
  - Data are written to the FIFO in words (32-bits) until all data according DATALENGTH has been transfered. When the DATALENGTH is not an integer multiple of 4, the last remaining data (1, 2 or 3 bytes) are written with a word transfer.
- In receive FIFO mode
  - Data are read from the FIFO in words (32-bits) until all data according DATALENGTH has been transfered. When the DATALENGTH is not an integer multiple of 4, the last remaining data (1, 2 or 3 bytes) are read with a word transfer padded with 0 value bytes.

When accessing the FIFO with half word or byte accesses an AHB bus fault is generated.

SDMMC interrupts

The interrupt logic generates an interrupt request signal that is asserted when at least one of the unmasked status flags is active. A mask register is provided to allow selection of the conditions that generate an interrupt. A status flag generates the interrupt request if a corresponding mask flag is set. Some status flags require an implicit clear in the clear register.

28.5.6 SDMMC AHB master interface

The AHB master interface is used to transfer the data between a memory and the FIFO using the SDMMC IDMA.

SDMMC IDMA

Direct memory access (DMA) is used to provide high-speed transfer between the SDMMC FIFO and the memory. The AHB master optimizes the bandwidth of the system bus. The SDMMC internal DMA (IDMA) provides one channel to be used either for transmit or receive.

The IDMA is enabled by the IDMAEN bit and supports burst transfers of 8 beats.

- In transmit burst transfer mode:
  - Data are fetched in burst from memory whenever the FIFO is empty for the number of burst transfers, until all data according DATALENGTH has been transfered. When the DATALENGTH is not an integer multiple of the burst size the remaining, smaller then burst size data is transfered using single transfer mode. When the DATALENGTH is not an integer multiple of 4, the last remaining data (1, 2 or 3 bytes) are fetched with a word transfer.
- In receive burst transfer mode:
  - Data are stored in burst in to memory whenever the FIFO contains the number of burst transfers, until all data according DATALENGTH has been transfered. When the DATALENGTH is not an integer multiple of the burst transfer the remaining, smaller then burst size data, is transfered using single transfer mode. When the DATALENGTH is not an integer multiple of 4, the last remaining data (1, 2 or 3 bytes) are stored with halfword and or byte transfers.

In addition the IDMA provides the following channel configurations selected by bit IDMABMODE:

- single buffered channel
- linked list channel

Single buffered channel

In single buffer configuration the data at the memory side is accessed in a linear matter starting from the base address IDMABASE. When the IDMA has finished transferring all data the and the DPSM has completed the transfer the DATAEND flag is set.

Linked list channel

In linked list configuration, IDMAMODE = 1, the data at the memory side is subsequently accessed from linked buffers, located at base address IDMABASE. The size of the memory buffers is defined by IDMABSIZE. The buffer size must be an integer multiple of the burst size. The bit ULA is used to indicate if a new linked list buffer configuration has to be loaded from the linked list table. A new linked list configuration is loaded when the ULA bit for the current linked list item is set.

The first linked list item configuration is programmed by firmware directly in the SDMMC registers.

When the IDMA has finished transferring all the data of one linked list buffer, according IDMABSIZE, and when the linked list item ULA bit is set, the IDMA loads the new linked list item from the linked list table, and continues transferring data from the next linked list buffer.

When the IDMA has finished transferring all data, according IDMABSIZE and ULA, and the DPSM has completed the transfer, according DATALENGTH, the DATAEND flag is set.

In the following cases, the linked list provides more buffer space than the data to transfer which means the current linked list buffer data has not completely be transfered:

- the ULA bit is set, and all SDMMC data according DATALENGTH has been transfered (DATAEND flag)
- a transfer error (DCRCFAIL when DATACOUNT > 0, RXOVERR, TXUNDERR) occurs
- a transfer is hold (DTHOLD)

In all above cases, the IDMA linked list is stopped and the FIFO is flushed/reset. Before starting or restarting a new SDMMC transfer, the software must initialize a new linked list with correct IDMABASE and IDMABSIZE.

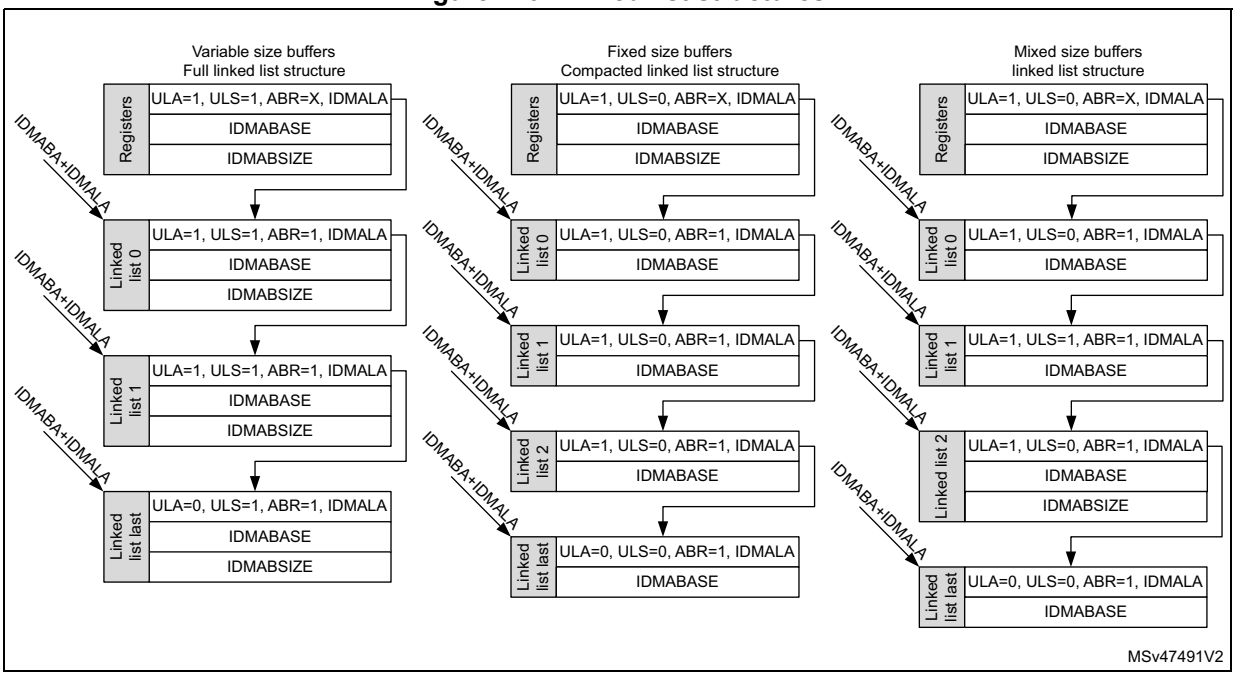
When a IDMA transfer error occurs (see *Section : IDMA transfer error management*) or when the linked list does not provide sufficient buffer space:

- the linked list ends with ULA = 0 and all last linked list buffer data has been transfered, and not all SDMMC data according DATALENGTH has been transfered. The SDMMC transfer is stopped and an IDMA transfer error is generated (see *Section : IDMA transfer error management*).

For a given linked list item, the base address is given by the linked list base IDMABA register value plus the linked list offset IDMALA register value.

The content of each linked list item can be specified by the ULS bit, which makes possible to optionally load the IDMABSIZE, resulting in a 3-word linked list structure. When the IDMABSIZE is not to be loaded (fixed size buffers) a compacted reduced 2-word linked list structure can be used containing only the IDMABASER and the IDMALAR values.

Figure 219. Linked list structures



There is no restriction on mixing both linked list item structures in a single list, this enables the IDMABSIZE to be updated only when needed.

Whenever a linked list buffer has been transfered and the current buffer ULA = 1, an end-of-linked-list-buffer-transfer-complete interrupt (IDMABTC) may be generated (if interrupt is enabled).

Linked list acknowledgment

In the case where software dynamically updates the linked list, during the SDMMC transfer, the availability of a new linked list buffer can be acknowledged by the acknowledge buffer ready (ABR) bit.

When ABR acknowledges that the new linked list buffer is ready, the IDMA continues transferring data from the new linked list buffer.

When ABR indicates that the new linked list buffer is not ready, an IDMA transfer error is generated (see *Section : IDMA transfer error management*). Depending when the IDMA transfer error occurs, it normally causes the generation of an TXUNDERR or RXOVERR error. When a linked list buffer is not acknowledged in time the SDMMC transfer is stopped.

The ABR information is “don't care” when starting the linked list from software programmed register information. The first linked list buffer must be ready to be used before starting the SDMMC transfer.

IDMA transfer error management

An IDMA transfer error can occur:

- When reading or writing a reserved address space (for data or linked list information).
- When there is no more linked list buffer space to store received SDMMC data.
- When all linked list buffer data has been transfered and still more SDMMC data needs to be sent.
- When the availability of a linked list buffer is not acknowledged.

On an IDMA transfer error subsequent IDMA transfers are disabled and an IDMATE flag is set and hardware flow control is disabled. Depending when the IDMA transfer error occurs, it normally causes the generation of a TXUNDERR or RXOVERR error.

The behavior of the IDMATE flag depend on when the IDMA transfer error occurs during the SDMMC transfer:

- An IDMA transfer error is detected before any SDMMC transfer error (TXUNDERR, RXOVERR, DCRCFAIL, or DTIMEOUT):
  - The IDMATE flag is set at the same time as the SDMMC transfer error flag.
  - The TXUNDERR, RXOVERR, DCRCFAIL, or DTIMEOUT interrupt is generated.
- An IDMA transfer error is detected during a STOP_TRANSNMISSION command:
  - The IDMATE flag is set at the same time as the DABORT flag.
  - The DABORT interrupt is generated.
- An IDMA transfer error is detected at the end of the SDMMC transfer (DHOLD, or DATAEND).
  - The IDMATE flag is set at the end of the SDMMC transfer.
  - A SDMMC transfer end interrupt is generated and a DHOLD or DATAEND flag is set.

The IDMATE is generated on an other SDMMC transfer interrupt (TXUNDERR. RXOVERR, DCRCFAIL, DTIMEOUT, DABORT, DHOLD, or DATAEND).

28.5.7 AHB and SDMMC_CK clock relation

The AHB must at least have 3x more bandwidth than the SDMMC bus bandwidth: for example, for SDR50 4-bit mode (50 Mbyte/s), the minimum sdmmc_hclk frequency is 37.5 MHz (150 Mbyte/s).

Table 276. AHB and SDMMC_CK clock frequency relation

SDMMC bus mode	SDMMC bus width	Maximum SDMMC_CK [MHz]	Minimum AHB clock [MHz]
e•MMC DS	8	26	19.5
e•MMC HS	8	52	39
e•MMC DDR52	8	52	78
e•MMC HS200	8	200	150
SD DS / SDR12	4	25	9.4
SD HS / SDR25	4	50	18.8
SD DDR50	4	50	37.5
SD SDR50	4	100	37.5
SD SDR104	4	208	78

28.6 Card functional description

28.6.1 SD I/O mode

The following features are SDMMC specific operations:

- SDIO interrupts
- SDIO suspend/resume operation (write and read suspend)
- SDIO Read Wait operation by stopping the clock
- SDIO Read Wait operation by SDMMC_D2 signaling

Table 277. SDIO special operation control

Operation mode	SDIOEN	RWMOD	RWSTOP	RWSTART	DTDIR
Interrupt detection	1	X	X	X	X
Suspend/Resume operation	X	X	X	X	X
Read Wait SDMMC_CK clock stop (START)	X	1	0	1	1
Read Wait SDMMC_CK clock stop (STOP)	X	1	1	1	1
Read Wait SDMMC_D2 signaling (START)	X	0	0	1	1
Read Wait SDMMC_D2 signaling (STOP)	X	0	1	1	1

SD I/O interrupts

To allow the SD I/O card to interrupt the host, an interrupt function is available on pin 8 (shared with SDMMC_D1 in 4-bit mode) on the SD interface. The use of the interrupt is optional for each card or function within a card. The SD I/O interrupt is level-sensitive, which means that the interrupt line must be held active (low) until it is either recognized and acted upon by the host or deasserted due to the end of the interrupt period. After the host has serviced the interrupt, the interrupt status bit is cleared via an I/O write to the appropriate bit in the SD I/O card internal registers. The interrupt output of all SD I/O cards is active low and the application must provide external pull-up resistors on all data lines (SDMMC_D[3:0]).

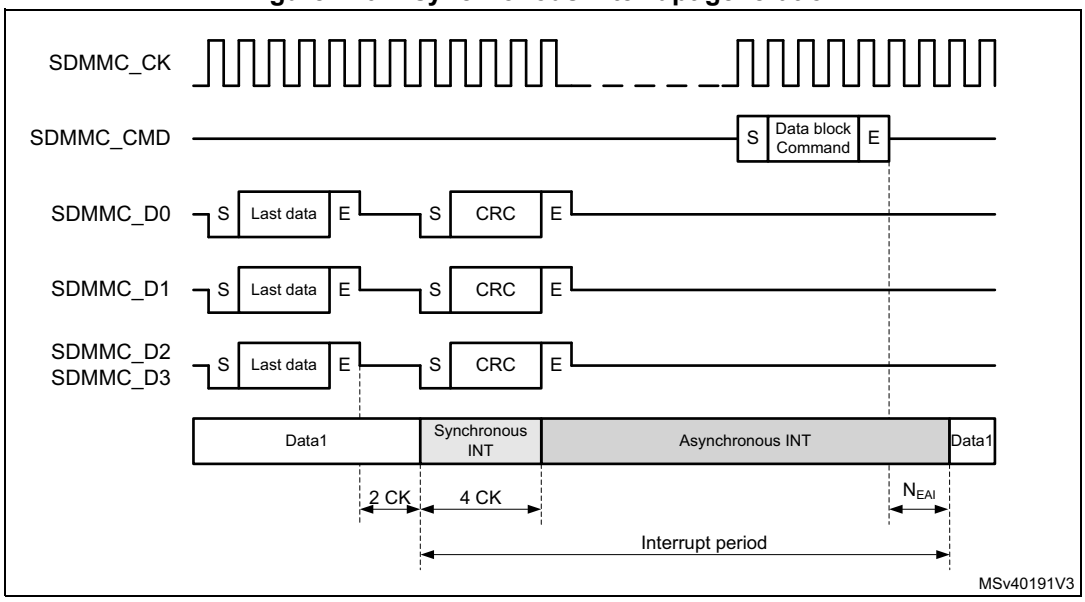
In SD 1-bit mode pin 8 is dedicated to the interrupt function (IRQ), and there are no timing constraints on interrupts.

In SD 4-bit mode the host samples the level of pin 8 (SDMMC_D1/IRQ) into the interrupt detector only during the interrupt period. At all other times, the host interrupt ignores this value. The interrupt period begins when interrupts are enabled at the card and SDIOEN bit is set see register settings in *Table 277*.

In 4-bit mode the card can generate a synchronous or asynchronous interrupt as indicated by the card CCCR register SAI and EAI bits.

- Synchronous interrupt, require the SDMMC_CK to be active.
- Asynchronous interrupt, can be generated when the SDMMC_CK is stopped, 4 cycles after the start of the card interrupt period following the last data block.

Figure 220. Asynchronous interrupt generation



The timing of the interrupt period is depending on the bus speed mode.

In DS, HS, SDR12, and SDR25 mode, selected by register bit BUSSPEED, the interrupt period is synchronous to the SD clock.

- The interrupt period ends at the next clock from the end bit of a command that transfers data block(s) (Command sent with the CMDTRANS bit is set), or when the DTEN bit is set.
- The interrupt period resumes 2 SDMMC_CK after the completion of the data block.
- At the data block gap the interrupt period is limited to 2 SDMMC_CK cycles.

Note: DTEN must not be used to start data transfer with SD and e•MMC cards.

Figure 221. Synchronous interrupt period data read

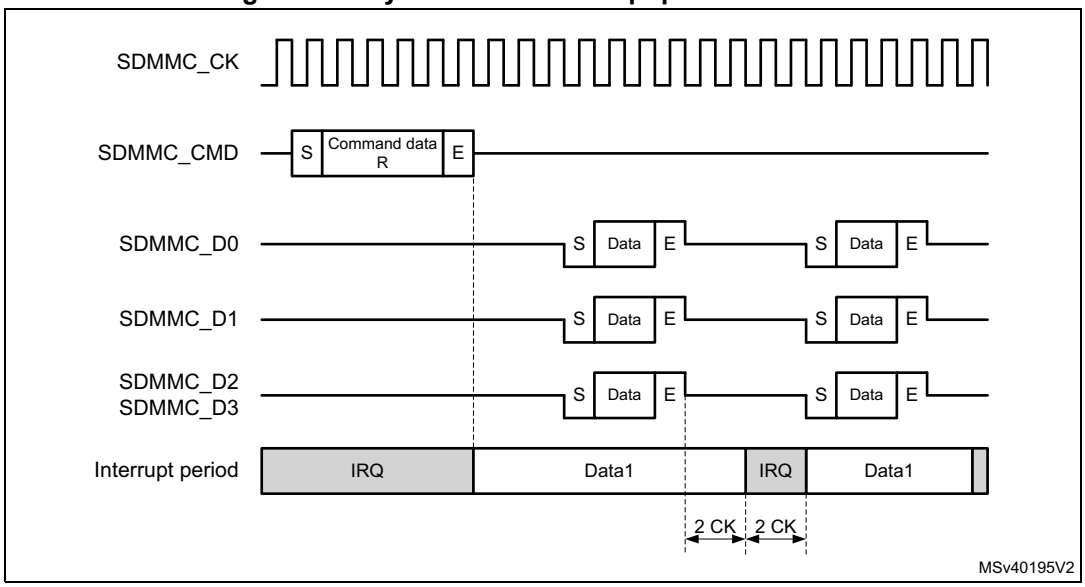
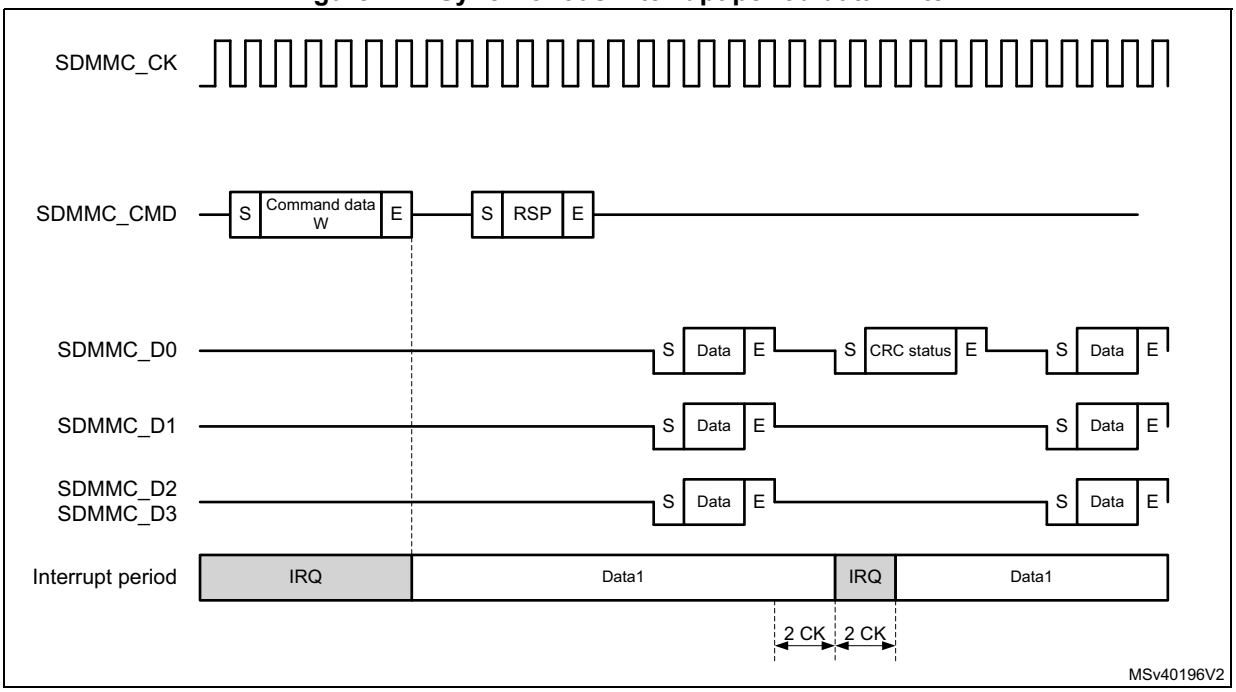


Figure 222. Synchronous interrupt period data write



In SDR50, SDR104, and DDR50, selected by register bit BUSSPEED, due to propagation delay from the card to host, the interrupt period is asynchronous.

- The card interrupt period ends after 0 to 2 SDMMC_CK cycles after the end bit of a command that transfers data block(s) (Command sent with the CMDTRANS bit is set), or when the DTEN bit is set. At the host the interrupt period ends after the end bit of a command that transfers data block(s). A card interrupt issued in the 1 to 2 cycles after the command end bit are not detected by the host during this interrupt period.
- The card interrupt period resumes 2 to 4 SDMMC_CK after the completion of the last data block. The host resumes the interrupt period always 2 cycles after the last data block.
- There is NO interrupt period at the data block gap.

Note: DTEN must not be used to start data transfer with SD and e•MMC cards.

Figure 223. Asynchronous interrupt period data read

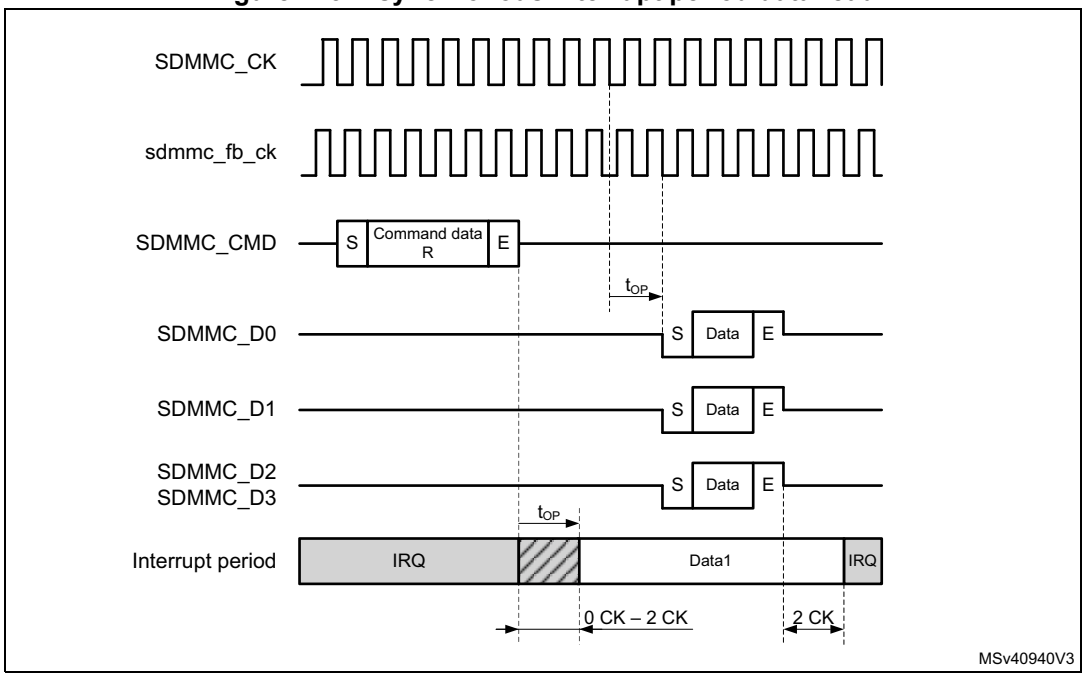
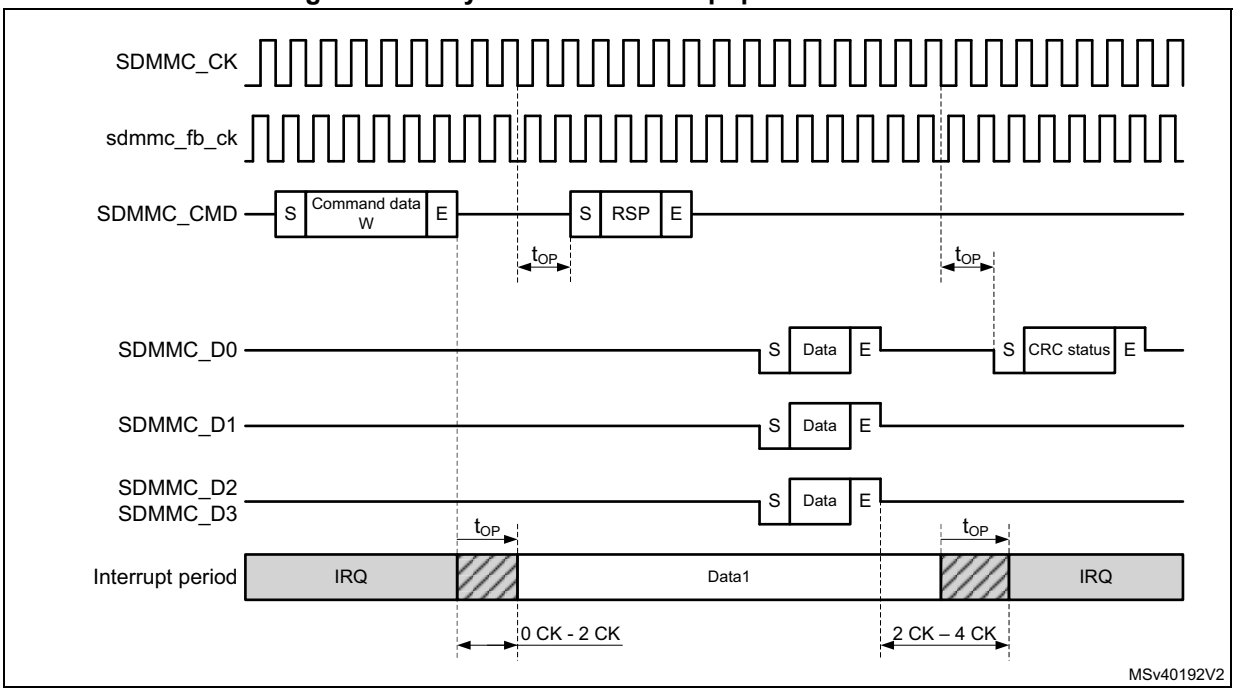


Figure 224. Asynchronous interrupt period data write



When transferring Open-ended multiple block data and using DTMODE “block data transfer ending with STOP_TRANSMISSION command”, the SDMMC masks the interrupt period after the last data block until the end of the CMD12 STOP_TRANSMISSION command.

The interrupt period is applicable for both memory and I/O operations.

In 4-bit mode interrupts can be differentiated from other signaling according *Table 278*.

Table 278. 4-bit mode Start, interrupt, and CRC-status Signaling detection

SDMMC data line	Start	Interrupt	CRC-status
SDMMC_D0	0	1 or CRC-status	0
SDMMC_D1	0	0	X
SDMMC_D2	0	1 or Read Wait	X
SDMMC_D3	0	1	X

SD I/O suspend and resume

This function is NOT supported in SDIO version 4.00 or later.

Within a multifunction SD I/O or a card with both I/O and memory functions, there are multiple devices (I/O and memory) that share access to the *e*•MMC/SD bus. To share access to the host among multiple devices, SD I/O and combo cards optionally implement the concept of suspend/resume. When a card supports suspend/resume, the host can temporarily halt (suspend) a data transfer operation to one function or memory to free the bus for a higher-priority transfer to a different function or memory. After this higher-priority transfer is complete, the original transfer is restarted (resume) where it left off.

To perform the suspend/resume operation on the bus, the host performs the following steps:

1. Determines the function currently using the SDMMC_D[3:0] line(s).
2. Requests the lower-priority or slower transaction to suspend.
3. Waits for the transaction suspension to complete.
4. Begins the higher-priority transaction.
5. Waits for the completion of the higher priority transaction.
6. Restores the suspended transaction.

The card receiving a suspend command responds with its current bus status. Only when the bus has been suspended by the card the bus status indicates suspension completed.

There are different suspend cases conditions:

- Suspend request accepted prior to the start of data transfer.
- Suspend request not accepted, (due to data being transfered at the same time), the host keeps checking the request until it is accepted (data transfer has suspended).
- Suspend request during write busy.
- Suspend request with write multiple.
- Suspend request during Read Wait.

For the host to know if the bus has been released it must check the status of the suspend request, suspension completed.

When the bus status of the suspend request response indicates suspension completed, the card has released the bus. At this time the state of the suspended operation must be saved where after an other operation can start.

The suspend command must be sent with the CMDSUSPEND bit set. This makes possible to start the interrupt period after the suspend command response when the bus is suspended (response bit BS = 0).

The hardware does not save the number of remaining data to be transfered when resuming the suspended operation. It is up to firmware to determine the data that has been transferred and resume with the correct remaining number of data bytes.

While receiving data from the card, the SDMMC can suspend the read operation after the read data block end (DPSM in Wait_R). After receiving the suspend acknowledgment response from the card the following steps must be taken by firmware:

1. The normal receive process must be stopped by setting DTHOLD bit.
   a) The remaining number of data bytes in the FIFO must be read until the receive FIFO is empty (RXFIFOE flag is set), and when IDMAEN = 0 the FIFO must be reset with FIFORST.
2. The confirmation that all data has been read from the FIFO, and that the suspend is completed is indicated by the DHOLD flag.
   a) The remaining number of data bytes (multiple of data blocks) still to be read when resuming the operation must be determined from the remaining number of bytes indicated by the DATACOUNT.

Note: When a DTIMEOUT flag occurs during the suspend procedure, this must be ignored.

To resume receiving data from the card, the following steps must be taken by firmware:

1. The remaining number of data bytes (multiple of data blocks) must be programmed in DATALENGTH.
2. The DPSM must be configured to receive data in the DTDIR bit.
3. The resume command must be sent from the CPSM, with the CMDTRANS bit set and the CMDSUSPEND bit set, which ends the interrupt period when data transfer is resumed (response bit DF = 1) and enabled the DPSM, after which the card resumes sending data.

While sending data to the card, the SDMMC can suspend the write operation after the write data block CRC status end (DPSM in Busy). Before sending the suspend command to the card the following steps must be taken by firmware:

1. Enable DHOLD flag (and DBCKEND flag when IDMAEN = 0)
2. The DPSM must be prevented from start sending a new data block by setting DTHOLD.
3. When IDMAEN = 0: When receiving the DBCKEND flag the data transfer is stopped. Firmware can stop filling the FIFO, after which the FIFO must be reset with FIFORST. Any bytes still in the FIFO need to be rewritten when resuming the operation.
4. When receiving the DHOLD flag the data transfer is stopped. The remaining number of data bytes still to be written when resuming must be determined from the remaining number of bytes indicated by the DATACOUNT.
5. To suspend the card the suspend command must be sent by the CPSM with the CMDSUSPEND bit set. This makes possible to start the interrupt period after the suspend command response when the bus is suspended (response bit BS = 0).

To resume sending data to the card, the following steps must be taken by firmware:

1. The remaining number of data bytes must be programmed in DATALENGTH.
2. The DPSM must be configured for transmission with DTDIR set and enabled by having the CPSM send the resume command with the CMDTRANS bit set and the CMDSUSPEND bit set. This ends the interrupt period and start the data transfer. The DPSM either goes to the Wait_S state when SDMMC_D0 does not signal busy, or goes to the Busy state when busy is signaled.
3. When IDMAEN = 1: The IDMA needs to be reprogrammed for the remaining bytes to be transfered.
4. When IDMAEN = 0: Firmware must start filling the FIFO with the remaining data.

SD I/O Read Wait

There are two methods to pause the data transfer during the block gap:

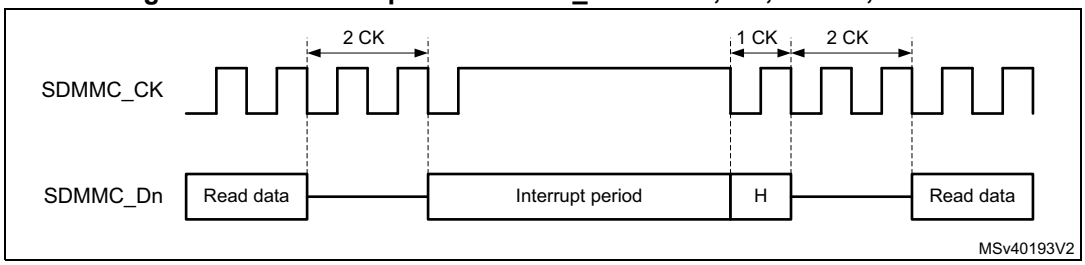
1. Stopping the SDMMC_CK.
2. Using Read Wait signaling on SDMMC_D2.

The SDMMC can perform a Read Wait with register settings according *Table 277*.

Depending the SDMMC operation mode (DS, HS, SDR12, SDR25) or (SDR50, SDR104, DDR) each method has a different characteristic.

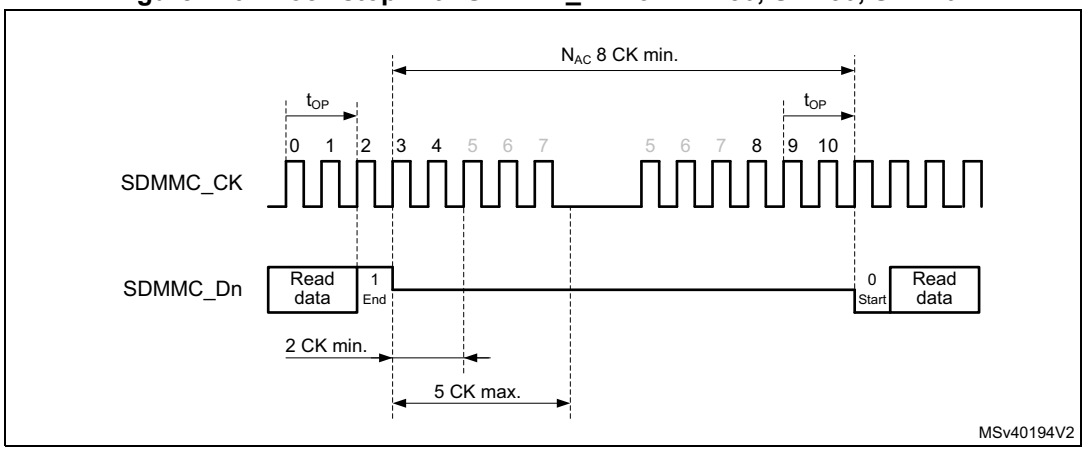
The timing for pause read operation by stopping the SDMMC_CK for DS, HS, SDR12, and SDR25, the SDMMC_CK may be stopped 2 SDMMC_CK cycles after the end bit. When ready the host resumes by restarting clock (see *Figure 225*).

Figure 225. Clock stop with SDMMC_CK for DS, HS, SDR12, SDR25



The timing for pause read operation by stopping the SDMMC_CK for SDR50, SDR104, and DDR50, the SDMMC_CK may be stopped minimum 2 SDMMC_CK cycles and maximum 5 SDMMC_CK cycles, after the end bit. When ready the host resumes by restarting clock, see *Figure 226*. (In DDR50 mode the SDMMC_CK must only be stopped after the falling edge, when the clock line is low.)

Figure 226. Clock stop with SDMMC_CK for DDR50, SDR50, SDR104



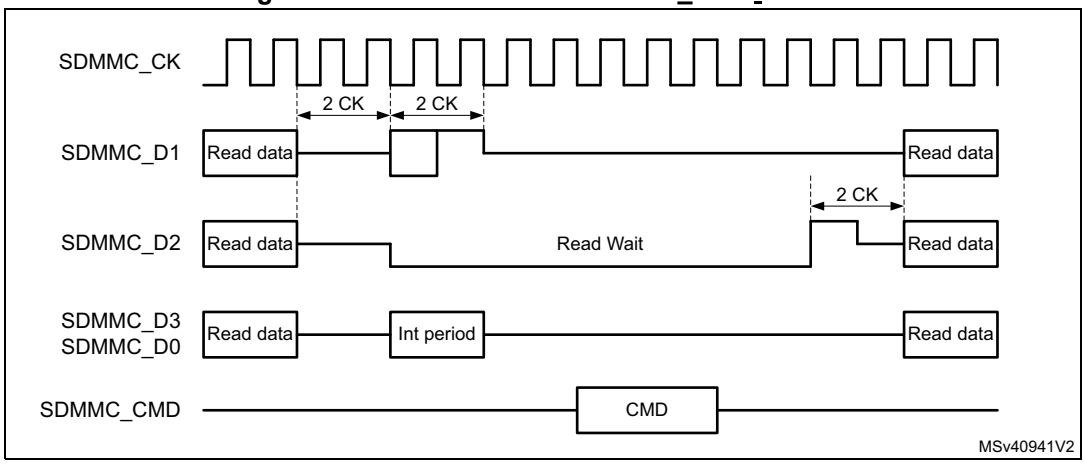
In Read Wait SDMMC_CK clock stopping, when RWSTART is set, the DSPM stops the clock after the end bit of the current received data block CRC. The clock start again after writing 1 to the RWSTOP bit, where after the DPSM waits for a start bit from the card.

As SDMMC_CK is stopped, no command can be issued to the card. During a Read Wait interval, the SDMMC can still detect SDIO interrupts on SDMMC_D1.

The optional Read Wait signaling on SDMMC_D2 (RW) operation is defined only for the SD 1-bit and 4-bit modes. The Read Wait operation enables the host to signal a card that is reading multiple registers (IO_RW_EXTENDED, CMD53) to temporarily stall the data transfer while allowing the host to send commands to any function within the SD I/O device. To determine when a card supports the Read Wait protocol, the host must test capability bits in the internal card registers.

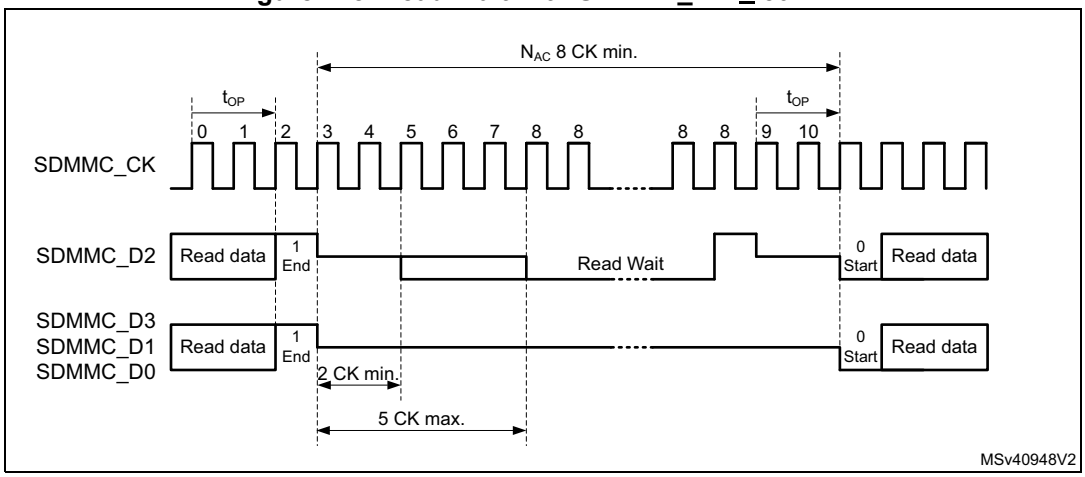
The timing for Read Wait with a SDMMC_CK less then 50MHz (DS, HS, SDR12, SDR25) is based on the interrupt period generated by the card on SDMMC_D1. The host by asserting SDMMC_D2 low during the interrupt period requests the card to enter Read Wait. To exit Read Wait the host must raise SDMMC_D2 high during one SDMMC_CK cycles before making it Hi-Z, see *Figure 227*.

Figure 227. Read Wait with SDMMC_CK < 50 MHz



For SDR50, SDR104 with a SDMMC_CK more than 50MHz, and DDR50, the card treats the Read Wait request on SDMMC_D2 as an asynchronous event. The host by asserting SDMMC_D2 low after minimum 2 SDMMC_CK cycles and maximum 5 SDMMC_CK cycles, request the card to enter Read Wait. To exit Read Wait the host must raise SDMMC_D2 high during one SDMMC_CK cycles before making it Hi-Z. The host must raise SDMMC_D2 on the SDMMC_CK clock (see *Figure 228*).

Figure 228. Read Wait with SDMMC_CK ≥ 50 MHz



In Read Wait SDMMC_D2 signaling, when RWSTART is set, the DPSM drives SDMMC_D2 after the end bit of the current received data block CRC. The Read Wait signaling on SDMMC_D2 is removed when writing 1 to the RWSTOP bit. The DPSM remains in R_W state for two more SDMMC_CK clock cycles to drive SDMMC_D2 to 1 for one clock cycle (in accordance with SDIO specification), where after the DPSM waits for a start bit from the card.

During the Read Wait signaling on SDMMC_D2 commands can be issued to the card. During the Read Wait interval, the SDMMC can detect SDIO interrupts on SDMMC_D1.

28.6.2 CMD12 send timing

CMD12 is used to stop/abort the data transfer, the card data transmission is terminated two clock cycles after the end bit of the Stop Transmission command.

Table 279. CMD12 use cases

Data operation	Stop Transmission command CMD12 Description
SDMMC stream write	The data transfer is stopped/aborted by sending the Stop Transmission command.
SDMMC open ended multiple block write	The data transfer is stopped/aborted by sending the Stop Transmission command. If the card detects an error, the host must abort the operation by sending the Stop Transmission command.
SDMMC block write with predefined block count	The Stop Transmission command is not required at the end of this type of multiple block write. (sending the Stop Transmission command after the card has received the last block is regarded as an illegal command.) If the card detects an error, the host must abort the operation by sending the Stop Transmission command.
SDMMC stream read	The data transfer is stopped/aborted by sending the Stop Transmission command.
SDMMC open ended multiple block read	The data transfer is stopped/aborted by sending the Stop Transmission command. If the card detects an error, the host must abort the operation by sending the Stop Transmission command.
SDMMC block read with predefined block count	The Stop Transmission command is not required at the end of this type of multiple block read. (sending the Stop Transmission command after the card has transmitted the last block is regarded as an illegal command.) Transaction can be aborted by sending the Stop Transmission command. If the card detects an error, the host must abort the operation by sending the Stop Transmission command.

All data write and read commands can be aborted any time by a Stop Transmission command CMD12. The following data abort procedure applies during an ongoing data transfer:

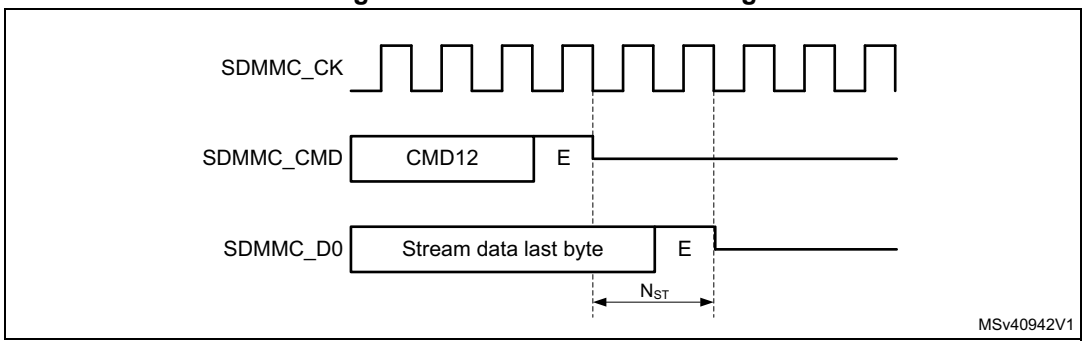
1. Load CMD12 Stop Transmission command in registers and set the CMDSTOP bit.
   – This causes the CPSM Abort signal to be generated when the command is sent to the DPSM.
2. Configure the CPSM to send a command immediately (clear WAITPEND bit).
   – The card, when sending data, stops data transfer 2 cycles after the Stop Transmission command end bit.
   The card when no data is being sent, does not start sending any new data.
   – The host, when sending data, sends one last data bit followed by an end bit after the Stop Transmission command end bit.
   The host when not sending data, does not start sending any new data.
3. When IDMAEN = 0, the FIFO need to be reset with FIFORST.
   – When writing data to the card. On the CMDREND flag, firmware must stop writing data to the FIFO. Subsequently the FIFO must be reset with FIFORST, this flushes the FIFO.
   – When reading data from the card. On the CMDREND flag, firmware must read the remaining data from the FIFO. Subsequently the FIFO must be reset with FIFORST.
4. When IDMAEN = 1, hardware takes care of the FIFO.
   – When writing data to the card. On the CPSM Abort signal, hardware stops the IDMA and subsequently the FIFO is flushed.
   – When reading data from the card. On the CPSM Abort signal, hardware instructs the IDMA to transfer the remaining data from the FIFO to RAM.
5. When the FIFO is empty/reset the DABORT flag is generated.

Stream operation and CMD12

To stop the stream transfer after the last byte to be transfered, the CMD12 end bit timing must be sent aligned with the data stream end of last byte. The following write stream data procedure applies:

1. Initialize the stream data in the DPSM, DTMODE = MCC stream data transfer.
2. Send the WRITE_DATA_STREAM command from the CPSM with CMDTRANS = 1.
3. Preload CMD12 in command registers, with the CMDSTOP bit set.
4. Configure the CPSM to send a command only after a wait pending (WAITPEND = 1) end of last data (according DATALENGTH).
5. Enabling the CPSM to send the STOP_TRANSMISSION command, the stream data end bit and command end bit are aligned.
   – When DATALENGTH > 5 bytes, Command CMD12 is waited in the CPSM to be aligned with the data transfer end bit.
   – When DATALENGTH < 5 bytes, Command CMD12 is started before and the DPSM remains in the Wait_S state to align the data transfer end with the CMD12 end bit.
6. The write stream data can be aborted any time by clearing the WAITPEND bit. This causes the Preloaded CMD12 to be sent immediately and stop the write data stream.

Figure 229. CMD12 stream timing



To stop the read stream transfer after the last byte, the CMD12 end bit timing must occur after the last data stream byte. The following read stream data procedure applies:

1. Wait for all data to be received by the DPSM and read from the FIFO (DATAEND flag).
   – The DPSM does not receive more data than indicated by DATALENGTH, even if the card is sending more data.
2. Send CMD12 by the CPSM.
   – CMD12 stops the card sending data.

Note: The SDMMC does not receive any more data from the card when DATACOUNT = 0, even when the card continues sending data.

Block operation and CMD12

To stop block transfer at the end of the data, the CMD12 end bit must be sent after the last block end bit.

When writing data to the card the CMD12 end bit must be sent after the write data block CRC token end bit. This requires the CMD12 sending to be tied to the data block transmission timing. To stop an Open-ended Multiple block write, the following procedure applies:

1. Before starting the data transfer, set DTMODE to “block data transfer ending with STOP_TRANSMISSION command”.
2. Wait for all data to be sent by the DPSM and the CRC token to be received, (DATAEND flag).
   – The DPSM does not send more data than indicated by DATALENGTH.
3. Send CMD12 by the CPSM.
   – CMD12 sets the card to Idle mode.

When reading data from the card the CMD12 end bit must be sent earliest at the same time as the card read data block last data bit. This requires the CMD12 sending to be tied to the data block reception timing. The following stop Open-ended Multiple block read data block procedure applies:

1. Before starting the data transfer, set DTMODE to “block data transfer ending with STOP_TRANSMISSION command”.
2. Wait for all data to be received by the DPSM and read from the FIFO (DATAEND flag).
   – The DPSM does not receive more data than indicated by DATALENGTH, even if the card is sending more data.
3. Send CMD12 with CMDSTOP bit set by the CPSM.
   – CMD12 stops the Card sending more data and set the card to Idle mode. Any ongoing block transfer is aborted by the Card.

Note: The SDMMC does not receive any more data from the card when DATACOUNT = 0, even when the card continues sending data.

28.6.3 Sleep (CMD5)

The *e*•MMC card may be switched between a Sleep state and a Standby state by CMD5. In the Sleep state the power consumption of the card is minimized and the Vcc power supply may be switched off.

The CMD5 (SLEEP) is used to initiate the state transition from Standby state to Sleep state. The card indicates Busy, pulling down SDMMC_D0, during the transition phase. The Sleep state is reached when the card stops pulling down the SDMMC_DO line.

To set the card into Sleep state the following procedure applies:

1. Enable interrupt on BUSYD0END.
2. Send CMD5 (SLEEP).
3. On BUSYD0END interrupt, card is in Sleep state.
4. Vcc power supply can be switched off.

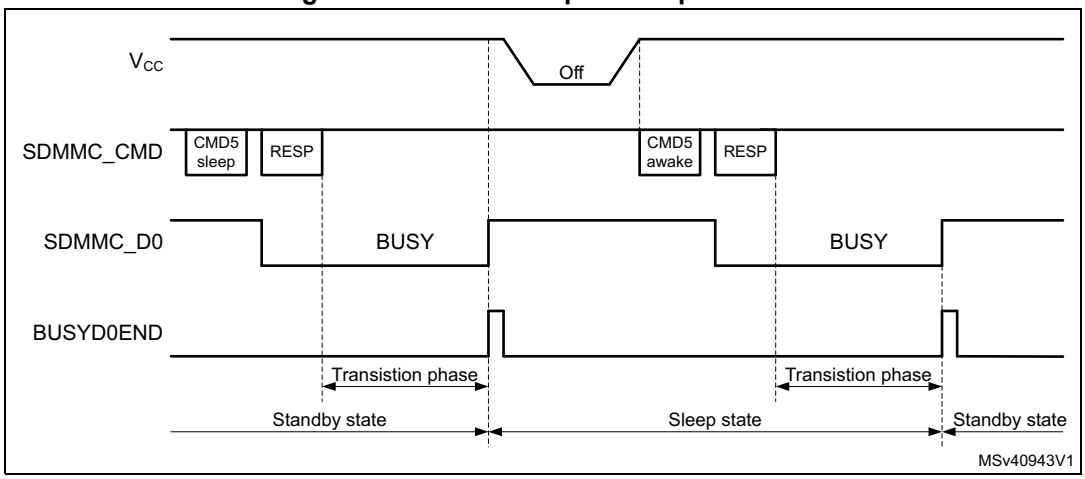
The CMD5 (AWAKE) is used to initiate the state transition from Sleep state to Standby state. The card indicates Busy, pulling down SDMMC_D0, during the transition phase. The Standby state is reached when the card stops pulling down the SDMMC_DO line.

To set the card into Sleep state the following procedure applies:

1. Switch on Vcc power supply and wait unit minimum operating level is reached.
2. Enable interrupt on BUSYD0END.
3. Send CMD5 (AWAKE).
4. On BUSYD0END interrupt card is in Standby state.

The Vcc power supply can be switched off only after the Sleep state has been reached. The Vcc supply must be reinstalled before CMD5 (AWAKE) is sent.

Figure 230. CMD5 Sleep Awake procedure



28.6.4 Interrupt mode (Wait-IRQ)

The host and card enter and exit interrupt mode (Wait-IRQ) simultaneously. In interrupt mode there is no data transfer. The only message allowed is an interrupt service request response from the card or the host. For the interrupt mode to work correctly the SDMMC_CK frequency must be set in accordance with the achievable SDMMC_CMD data rate in Open Drain mode, which depend on the capacitive load and pull-up resistor. The CLKDIV must be set >1, and the SETCLKRX must select either the sdmmc_io_in_ck or SDMMC_CLKin source.

The host must ensure that the card is in Standby state before issuing the CMD40 (GO_IRQ_STATE). While waiting for an interrupt response the SDMMC_CK clock signal must be kept active.

A card in interrupt mode (IRQ state):

- is waiting for an internal card interrupt event. Once the event occurs, the card starts to send the interrupt service request response. The response is sent in open-drain mode.
- while waiting for the internal card interrupt event, the card also monitors the SDMMC_CMD line for a start bit. Upon detection of a start bit the card aborts the interrupt mode and switch to Standby state.

The host in interrupt mode (CPSM Wait state waiting for interrupt):

- is waiting for a card interrupt service request response (start bit).
- while waiting for a card interrupt service request response the host may abort the interrupt mode (by clearing the WAITINT register bit), which causes the host to send a interrupt service request response R5 with RCA = 0x0000 in open-drain mode.

When sending the interrupt service request response, the sender bit-wise monitors the SDMMC_CMD bit stream. The sender whose interrupt service request response bit does not correspond to the bit on the SDMMC_CMD line stops sending. In the case of multiple senders only one successfully sends its full interrupt service request response. If the host sends simultaneously, it loses sending after the transmission bit.

To handle the interrupt mode, the following procedure applies:

1. Set the SDMMC_CK frequency in accordance with the achievable SDMMC_CMD data rate in Open-drain mode, CLKDIV must be set >1, and SETCLKRX must select the sdmmc_io_in_ck.
2. Load CMD40 (GO_IRQ_STATE) in the command registers.
3. Enable wait for interrupt by setting WAITINT register bit.
4. Configure the CPSM to send a command immediately.
   – This causes the CMD40 to be sent and the CPSM to be halted in the Wait state, waiting for a interrupt service request response.
5. To exit the wait for interrupt state (CPSM Wait state):
   – Upon the detection of an interrupt service request response start bit the CPSM moves to the Receive state where the response is received. The complete reception of the response is indicated by the CMDREND or the command CRC error flags.
   – To abort the interrupt mode the host clears the WAITINT register bit, which causes the host to send an interrupt service request response by itself. This moves the CPSM to the Receive state. The complete reception of the response is indicated by the CMDREND or the command CRC error flags.

Note: On a simultaneous send interrupt service request response start bit collision the host loses the bus access after the transmission bit.

28.6.5 Boot operation

In boot operation mode the host can read boot data from the card by either one of the two boot operation functions:

- Normal boot. (keeping CMD line low)
- Alternative boot (sending CMD0 with argument 0xFFFFFFFA)

The boot data can be read according the following configuration options, depending on card register settings:

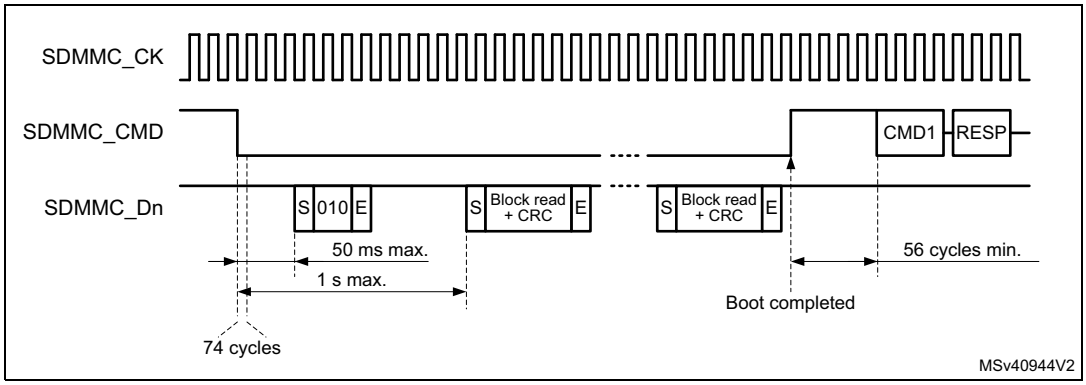
- The partition from which boot data is read (EXT_CSD Byte[179])
- The boot data size (EXT_CSD Byte[226])
- The bus configuration during boot (EXT_CSD Byte[177])
- Receiving boot acknowledgment from the card. (EXT_CSD Byte[179])

If boot acknowledgment is enabled the card send pattern 010 on SDMMC_D0 within 50ms after boot mode has been requested by either CMD line going low or after CMD0 with argument 0xFFFFFFFA. A boot acknowledgment timeout (ACKTIMEOUT) and acknowledgment status (ACKFAIL) is provided.

Normal boot operation

If the SDMMC_CMD line is held low for at least 74 clock cycles after card power-up or reset, before the first command is issued, the card recognizes that boot mode is being initiated. Within 1 second after the CMD line goes low, the card starts to sent the first boot code data on the SDMMC_Dn line(s). The host must keep the SDMMC_CMD line low until after all boot data has been read. The host can terminate boot mode by pulling the SDMMC_CMD line high.

Figure 231. Normal boot mode operation



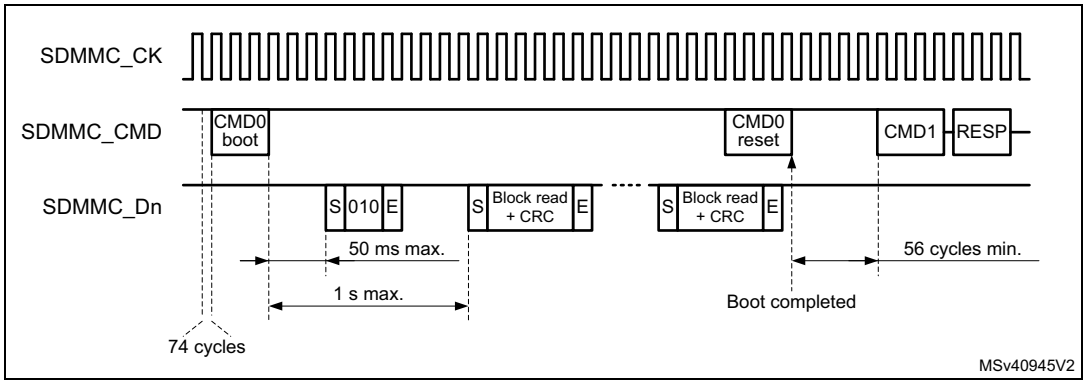
To perform the normal boot procedure the following steps needed:

1. Reset the card.
2. if a boot acknowledgment is requested enable the BOOTACKEN and set the ACKTIME and enable the ACKFAIL and ACKTIMEOUT interrupt.
3. enable the data reception by setting the DPSM in receive mode (DTDIR) and the number of data bytes to be received in DATALENGTH.
4. Enable the DTIMEOUT, DATAEND, and CMDSENT interrupts for end of boot command confirmation.
5. Select the normal boot operation mode in BOOTMODE, and enable boot in BOOTEN. The boot procedure is started by enabling the CPSM with CPSMEN.This causes:
   – the SDMMC_CMD to be driven low. (BOOTMODE = normal boot).
   – the ACK timeout to start.
   – DPSM to be enabled.
6. The incorrect reception of the boot acknowledgment can be detected with ACKFAIL flag or ACKTIMEOUT flag when enabled.
   – when an incorrect boot acknowledgment is received the ACKFAIL flag occurs.
   – when the boot acknowledgment is not received in time the ACKTIMEOUT flag occurs.
7. when all boot data has been received the DATAEND flag occurs.
   – when data CRC fails the DCRCFAIL flag is also generated.
   – when the data timeout occurs the DTIMEOUT flag is also generated.
8. When last data has been received, read data from the FIFO until FIFO is empty after which end of data DATAEND flag is generated.
   – SDMMC has completely received all data and the DPSM is disabled.
9. The boot procedure is terminated by firmware clearing BOOTEN, which causes the SDMMC_CMD line to go high. The CMDSENT flag is generated 56 cycles later to indicate that a new command can be sent.
   – If the boot procedure is aborted by firmware before all data has been received the CPSM Abort signal stops data reception and disables the DPSM which triggers an DABORT flag when enabled.
10. The CMDSENT flag signals the end of the boot procedure and the card is ready to receive a new command.

Alternative boot operation

After card power-up or reset, if the host send CMD0 with the argument 0xFFFFFFFA after 74 clock cycles before CMD0 is issued, the card recognizes that boot mode is being initiated. Within 1 second after the CMD0 with argument 0xFFFFFFFA has been sent, the card starts to send the first boot code data on the SDMMC_Dn line(s). The master terminates boot operation by sending CMD0 (Reset).

Figure 232. Alternative boot mode operation



To perform the alternative boot procedure the following steps needed:

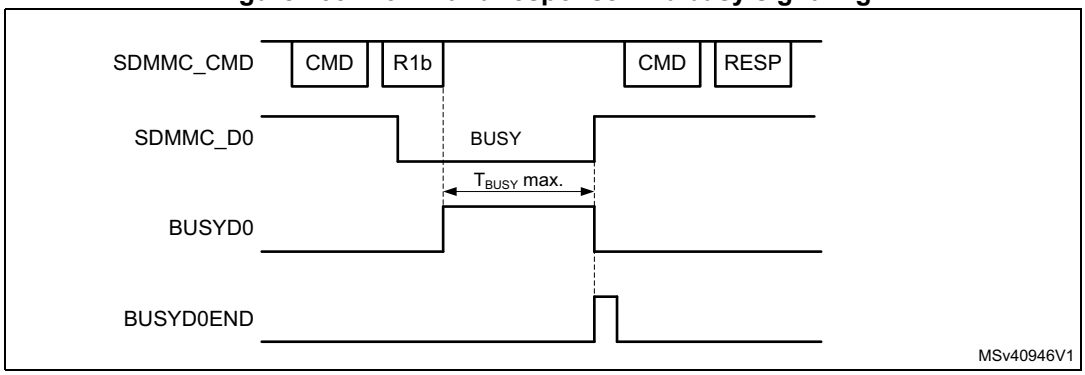
1. Move the SDMMC to power-off state, and reset the card.
2. Move the SDMMC to power-on state. This guarantees the 74 SCDMMC_CK cycles to be clocked before any command.
3. if a boot acknowledgment is requested enable the BOOTACKEN and set the ACKTIME and enable the ACKTIMEOUT flag.
4. enable the data reception by setting the DPSM in receive mode (DTDIR) and the number of data to be received in DATALENGTH. Enable the DTIMEOUT and DATAEND flags.
5. Select the alternative boot operation mode in BOOTMODE, load the CMD0 with the 0xFFFFFFFA argument in the command registers. Enable CMDSENT flag for end of boot command confirmation, and enable boot in BOOTEN. The boot procedure is started by enabling the CPSM with CPSMEN. This causes:
   - the loaded command and argument to be sent out. (BOOTMODE = alternative boot).
   - the ACK timeout to start.
   - DPSM to be enabled.
6. When the command has been sent the CMDSENT flag is generated, at which time the BOOTEN bit must be cleared.
7. the reception of the boot acknowledgment can be detected with ACKFAIL flag when enabled.
   - when the boot acknowledgment is not received in time the ACKTIMEOUT flag occurs.
8. when all boot data has been received the DATAEND flag occurs.
   - when data CRC fails the DCRCFAIL flag is also generated.
   - when the data timeout occurs the DTIMEOUT flag is also generated.

9. When last data has been received, read data from the FIFO until FIFO is empty after which end of data DATAEND flag is generated.
   – SDMMC has completely received all data and the DPSM is disabled.
10. The BOOTEN bit must be cleared, before terminating the boot procedure by sending CMD0 (Reset) with BOOTMODE = alternative boot. This causes the CMDSENT flag to occur 56 cycles after the Command.
   – if the boot procedure is aborted by firmware before all data has been received the CPSM Abort signal stops the data transfer and disable the DPSM which triggers an DABORT flag when enabled.
11. The CMDSENT flag signals the end of the boot procedure and the card is ready to receive a new command. When the RESET command has been sent successfully, the BOOTMODE control bit has to be cleared to terminate the boot operation.

28.6.6 Response R1b handling

When sending commands which have a R1b response the busy signaling is reflected in the BUSYD0 register bit and the release of busy with the BUSYD0END flag. The SDMMC_D0 line is sampled at the end of the R1b response and signaled in the BUSYD0 register bit. The BUSYD0 register bit is reset to not busy when the SDMMC_D0 line release busy, at the same time the BUSYD0END flag is generated.

Figure 233. Command response R1b busy signaling



The expected maximum busy time must be set in the DATATIME register before sending the command. When enabled, the DTIMEOUT flag is set when after the R1b response busy stays active longer then the programmed time.

To detect the SDMMC_D0 busy signaling when sending a Command with R1b response the following procedure applies:

- Enable CMDREND flag.
- Send Command through CPSM.
- On the CMDREND flag check the BUSYD0 register bit.
  – If BUSYD0 signals not busy, signal busy release to firmware
  – If BUSYD0 signals busy, wait for BUSYD0END flag
- On BUSYD0END flag signal busy released to firmware.
- On DTIMEOUT flag busy is active longer then programmed time.

28.6.7 Reset and card cycle power

Reset

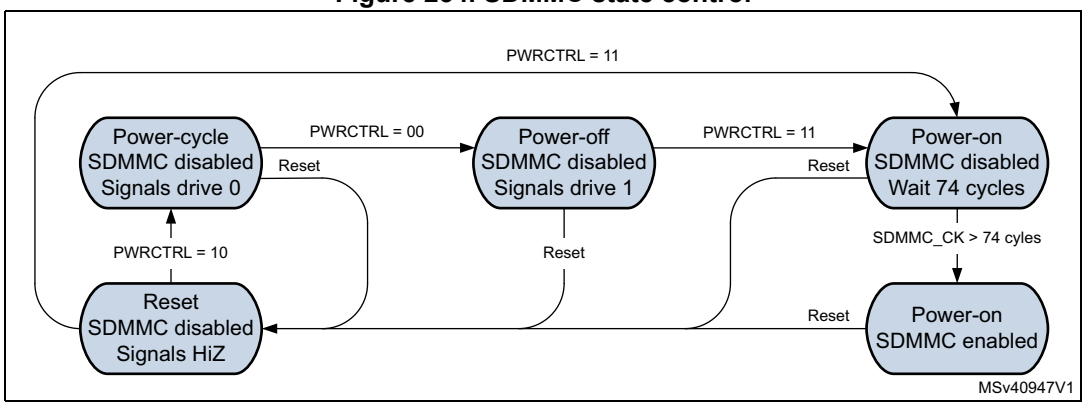
Following reset the SDMMC is in the reset state. In this state the SDMMC is disabled and no command nor data can be transfered. The SDMMC_D[7:0], and SDMMC_CMD are in HiZ and the SDMMC_CK is driven low.

Before moving to the power-on state the SDMMC must be configured.

In the power-on state the SDMMC_CK clock is running. First 74 SDMMC_CK cycles are clocked after which the SDMMC is enabled and command and data can be transfered.

The SDMMC states are controlled by Firmware with the PWRCTL register bits according *Figure 234.*.

Figure 234. SDMMC state control

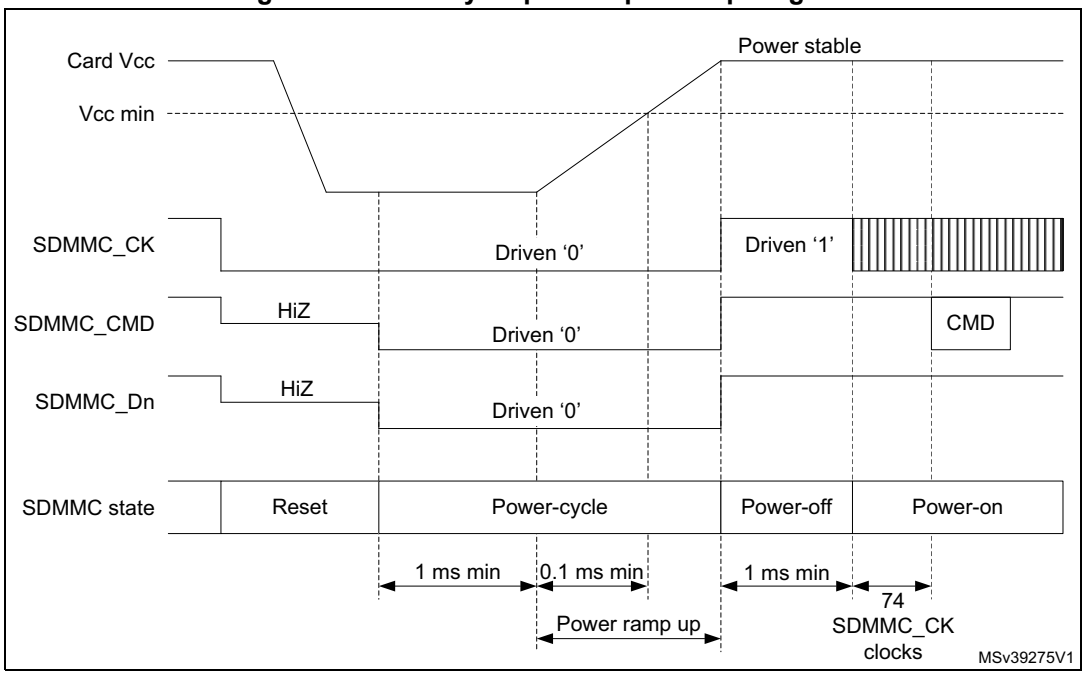


Card cycle power

To perform a card cycle power the following procedure applies:

1. Reset the SDMMC with the RCC.SDMMCxRST register bit. This resets the SDMMC to the reset state and the CPSM and DPSM to the Idle state.
2. Disable the Vcc power to the card.
3. Set the SDMMC in power-cycle state. This makes that the SDMMC_D[7:0], SDMMC_CMD and SDMMC_CK are driven low, to prevent the card from being supplied through the signal lines.
4. After minimum 1 ms enable the Vcc power to the card.
5. After the power ramp period set the SDMMC to the power-off state for minimum 1 ms. The SDMMC_D[7:0], SDMMC_CMD and SDMMC_CK are set to drive 1.
6. After the 1 ms delay set the SDMMC to power-on state in which the SDMMC_CK clock is enabled.
7. After 74 SDMMC_CK cycles the first command can be sent to the card.

Figure 235. Card cycle power / power up diagram



28.7 Hardware flow control

The hardware flow control during data transfer functionality is used to avoid FIFO underrun (TX mode) and overrun (RX mode) errors.

The behavior is to stop SDMMC_CK during data transfer and freeze the SDMMC state machines. The data transfer is stalled when the FIFO is unable to transmit or receive data. The data transfer remains stalled until the transmit FIFO is half full or all data according DATALENGTH has been stored, or until the receive FIFO is half empty. Only state machines clocked by SDMMC_CK are frozen, the AHB interfaces are still alive. The FIFO can thus be filled or emptied even if flow control is activated.

On an IDMA linked list transfer error, the hardware flow control is disabled. As a consequence, depending on when the IDMA linked list transfer error occurs, an underrun or overrun error may also occur (see *Section : IDMA transfer error management*).

To enable hardware flow control during data transfer, the HWFC_EN register bit must be set to 1. After reset hardware flow control is disabled.

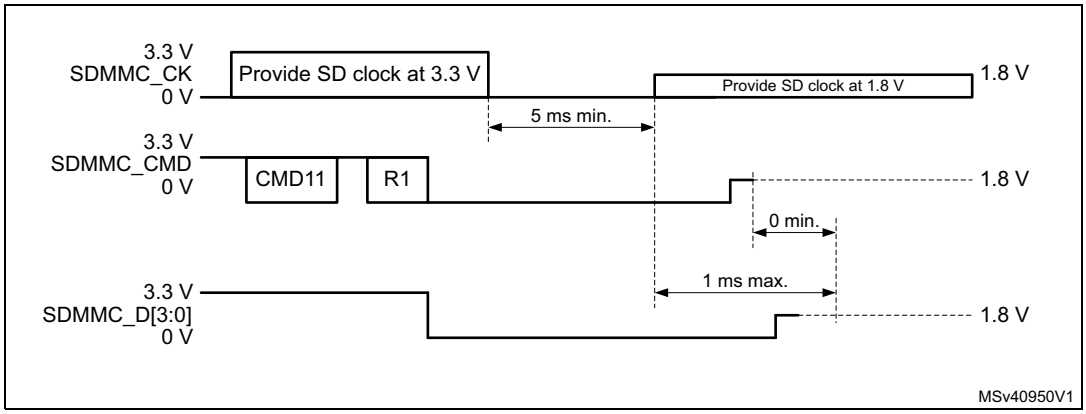
Hardware flow control must only be used when the SDMMC_Dn data is cycle-aligned with the SDMMC_CK. Whenever the sdmmc_fb_ck from the DLYB delay block is used, i.e in the case of SDR104 mode with a t_{OP} and Dt_{OP} delay > 1 cycle, hardware flow control can not be used.

28.8 Ultra-high-speed phase I (UHS-I) voltage switch

UHS-I mode (SDR12, SDR25, SDR50, SDR104, and DDR50) requires the support for 1.8 V signaling. After power up the card starts in 3.3V mode. CMD11 invokes the voltage switch

sequence to the 1.8V mode. When the voltage sequence is completed successfully the card enters UHS-I mode with default SDR12 and card input and output timings are changed.

Figure 236. CMD11 signal voltage switch sequence



To perform the signal voltage switch sequence the following steps are needed:

1. Before starting the Voltage Switch procedure, the SDMMC_CK frequency must be set in the range 100 kHz - 400 kHz.
2. The host starts the Voltage Switch procedure by setting the VSWITCHEN bit before sending the CMD11.
3. The card returns an R1 response.
   - if the response CRC is pass, the Voltage Switch procedure continues the host does no longer drive the CMD and SDMMC_D[3:0] signals until completion of the voltage switch sequence. Some cycles after the response the SDMMC_CK is stopped and the CKSTOP flag is set.
   - if the response CRC is fail (CCRCFAIL flag) or no response is received before the timeout (CTIMEOUT flag), the Voltage Switch procedure is stopped.
4. The card drives CMD and SDMMC_D[3:0] to low at the next clock after the R1 response.
5. The host, after having received the R1 response, may monitor the SDMMC_D0 line using the BUSYD0 register bit. The SDMMC_D0 line is sampled two SDMMC_CK clock cycles after the Response. The Firmware may read the BUSYD0 register bit following the CKSTOP flag.
   - When the BUSYD0 is detected low the host firmware switches the Voltage regulator to 1.8V, after which it instructs the SDMMC to start the timing critical section of the Voltage Switch sequence by setting register bit VSWITCH. The hardware continues to stop the SDMMC_CK by holding it low for at least 5 ms.
   - When the BUSYD0 is detected high the host aborts the Voltage Switch sequence and cycle power the card.
6. The card after detecting SDMMC_CK low begins switching signaling voltage to 1.8 V.
7. The host SDMMC hardware after at least 5 ms restarts the SDMMC_CK.
8. The card within 1 ms from detecting SDMMC_CK transition drives CMD and DAT[3:0] high for at least 1 SDMMC_CK cycle and then stop driving CMD and DAT[3:0].
9. The host SDMMC hardware, 1 ms after the SDMMC_CK has been restarted, the SDMMC_D0 is sampled into BUSYD0 and the VSWEND flag is set.

10. The host, on the VSWEND flag, checks SDMMC_D0 line using the BUSYD0 register bit, to confirm completion of voltage switch sequence:
    – When BUSYD0 is detected high, Voltage Switch has been completed successfully.
    – When BUSYD0 is detected low, Voltage Switch has failed, the host cycles the card power.

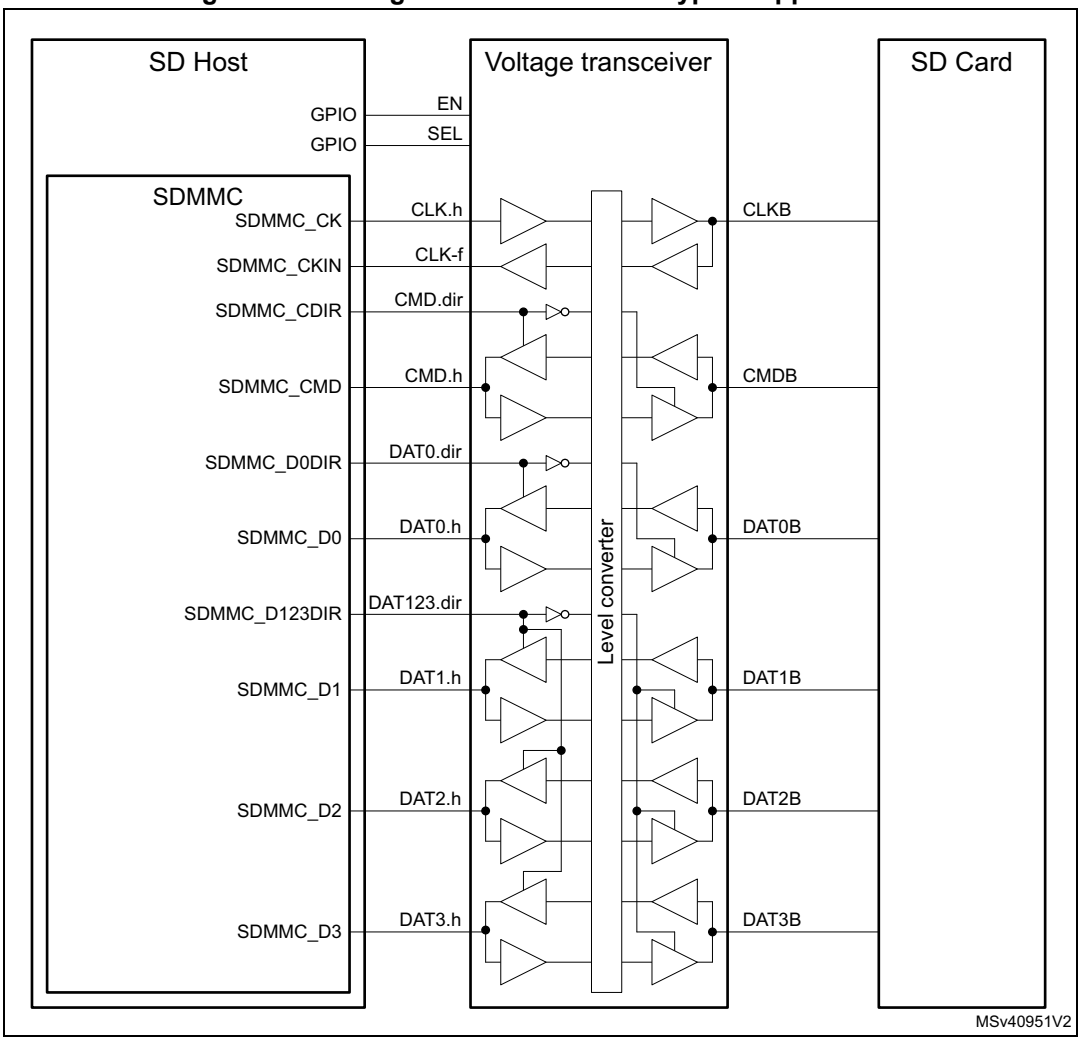
The minimum 5 ms time to stop the SDMMC_CK is derived from the internal un-gated SDMMC_CK clock, which has a maximum frequency of 25 MHz (SD mode), as set by the clock divider CLKDIV. The >5 ms time is counted by 2^{12} cycles (10.24 ms @ 400 kHz). If a lower SDMMC_CK frequency is selected by the clock divider CLKDIV the time for the SDMMC_CK clock to be stopped is longer.

The maximum 1 ms time for the card to drive the SDMMC_Dn and SDMMC_CMD lines high is derived from the internal ungated SDMMC_CK which has a maximum frequency of 25 MHz (SD mode), as set by the clock divider CLKDIV. The SDMMC checks the lines after >1 ms time which is counted by 2^9 cycles (1.28 ms @ 25 MHz). If a lower SDMMC_CK frequency is selected by the clock divider CLKDIV the time to check the lines is longer.

The signal voltage level switch is supported through an external voltage translation transceiver.

Note: For external devices not needing a signal voltage level switch the signal voltage level can be kept static for all SDMMC operations, including UHS-I.

Figure 237. Voltage switch transceiver typical application



To interface with an external driver (a voltage switch transceiver), next to the standard signals the SDMMC uses the following signals:

- **SDMMC_CKIN** feedback input clock
- **SDMMC_CDIR** I/O direction control for the CMD signal
- **SDMMC_D0DIR** I/O direction control for the SDMMC_D0 signal
- **SDMMC_D123DIR** I/O direction control for the SDMMC_D1, SDMMC_D2 and SDMMC_D3 signals

The voltage transceiver signals **EN** and **SEL** are to be handled through general-purpose I/O.

The polarity of the SDMMC_CDIR, SDMMC_D0DIR and SDMMC_D123DIR signals can be selected through SDMMC_POWER.DIRPOL control bit.

28.9 SDMMC interrupts

Table 280. SDMMC interrupts

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit from Sleep mode
SDMMC	Command response CRC fail	CCRCFAIL	CCRCFAILIE	CCRCFAILC	Yes
SDMMC	Data block CRC fail	DCRCFAIL	DCRCFAILIE	DCRCFAILC	Yes
SDMMC	Command response timeout	CTIMEOUT	CTIMEOUTIE	CTIMEOUTC	Yes
SDMMC	Data timeout	DTIMEOUT	DTIMEOUTIE	DTIMEOUTC	Yes
SDMMC	Transmit FIFO underrun	TXUNDERR	TXUNDERRIE	TXUNDERRC	Yes
SDMMC	Receive FIFO overrun	RXOVERR	RXOVERRIE	RXOVERRC	Yes
SDMMC	Command reponse received	CMDREND	CMDRENDIE	CMDRENDC	Yes
SDMMC	Comand sent	CMDSENT	CMDSENTIE	CMDSENTC	Yes
SDMMC	Data transfer ended	DATAEND	DATAENDIE	DATAENDC	Yes
SDMMC	Data transfer hold	DHOLD	DHOLDIE	DHOLDC	Yes
SDMMC	Data block sent or received	DBCKEND	DBCKENDIE	DBCKENDC	Yes
SDMMC	Data transfer aborted	DABORT	DABORTIE	DABORTC	Yes
SDMMC	Transmit FIFO half empty	TXFIFOHE	TXFIFOHEIE	N/A	Yes
SDMMC	Receive FIFO half full	RXFIFOHF	RXFIFOHFIE	N/A	Yes
SDMMC	Transmit FIFO full	TXFIFOF	N/A	N/A	Yes
SDMMC	Receive FIFO full	RXFIFOF	RXFIFOFIE	N/A	Yes
SDMMC	Transmit FIFO empty	TXFIFOE	TXFIFOEIE	N/A	Yes
SDMMC	Receive FIFO empty	RXFIFOE	N/A	N/A	Yes
SDMMC	Command response end of busy	BUSYD0END	BUSYD0ENDIE	BUSYD0ENDC	Yes
SDMMC	SDIO interrupt	SDIOIT	SDIOITIE	SDIOITC	Yes
SDMMC	Boot acknowledgment fail	ACKFAIL	ACKFAILIE	ACKFAILC	Yes
SDMMC	Boot acknowledgment timeout	ACKTIMEOUT	ACKTIMEOUTIE	ACKTIMEOUTC	Yes
SDMMC	Voltage switch timing	VSWEND	VSWENDIE	VSWENDC	Yes
SDMMC	SDMM_CK stopped in voltage switch	CKSTOP	CKSTOPIE	CKSTOPC	Yes
SDMMC	IDMA transfer error	IDMATE	IDMATEIE	IDMATEC	Yes
SDMMC	IDMA buffer transfer complete	IDMABTC	IDMABTCIE	IDMABTCC	Yes

28.10 SDMMC registers

The device communicates to the system via 32-bit control registers accessible via AHB slave interface.

The peripheral registers have to be accessed by words (32-bit). Byte (8-bit) and half-word (16-bit) accesses trigger an AHB bus error.

28.10.1 SDMMC power control register (SDMMC_POWER)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIR POL	VSWI TCHEN	VSWI TCH	PWRCTRL[1:0]	
											rw	rw	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **DIRPOL**: Data and command direction signals polarity selection

This bit can only be written when the SDMMC is in the power-off state (PWRCTRL = 00).

0: Voltage transceiver I/Os driven as output when direction signal is low.

1: Voltage transceiver I/Os driven as output when direction signal is high.

Bit 3 **VSWITCHEN**: Voltage switch procedure enable

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).

This bit is used to stop the SDMMC_CK after the voltage switch command response:

0: SDMMC_CK clock kept unchanged after successfully received command response.

1: SDMMC_CK clock stopped after successfully received command response.

Bit 2 **VSWITCH**: Voltage switch sequence start

This bit is used to start the timing critical section of the voltage switch sequence:

0: Voltage switch sequence not started and not active.

1: Voltage switch sequence started or active.

Bits 1:0 **PWRCTRL[1:0]**: SDMMC state control bits

These bits can only be written when the SDMMC is not in the power-on state (PWRCTRL ≠ 11).

These bits are used to define the functional state of the SDMMC signals:

00: After reset, Reset: the SDMMC is disabled and the clock to the Card is stopped, SDMMC_D[7:0], and SDMMC_CMD are HiZ and SDMMC_CK is driven low. When written 00, power-off: the SDMMC is disabled and the clock to the card is stopped, SDMMC_D[7:0], SDMMC_CMD and SDMMC_CK are driven high.

01: Reserved (When written 01, PWRCTRL value does not change)

10: Power-cycle, the SDMMC is disabled and the clock to the card is stopped, SDMMC_D[7:0], SDMMC_CMD and SDMMC_CK are driven low.

11: Power-on: the card is clocked, The first 74 SDMMC_CK cycles the SDMMC is still disabled. After the 74 cycles the SDMMC is enabled and the SDMMC_D[7:0], SDMMC_CMD and SDMMC_CK are controlled according the SDMMC operation.

Any further write is ignored, PWRCTRL value keeps 11.

28.10.2 SDMMC clock control register (SDMMC_CLKCR)

Address offset: 0x004

Reset value: 0x0000 0000

This register controls the SDMMC_CK output clock, the sdmmc_rx_ck receive clock, and the bus width.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SELCLKRX[1:0]		BUS SPEED	DDR	HWFC_EN	NEG EDGE
										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WID BUS[1:0]		Res.	PWR SAV	Res.	Res.	CLKDIV[9:0]									
rw	rw		rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:20 **SELCLKRX[1:0]**: Receive clock selection

These bits can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0)

00: sdmmc_io_in_ck selected as receive clock

01: SDMMC_CKIN feedback clock selected as receive clock

10: sdmmc_fb_ck tuned feedback clock selected as receive clock

11: Reserved (select sdmmc_io_in_ck)

Bit 19 **BUSSPEED**: Bus speed for selection of SDMMC operating modes

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0)

0: DS, HS, SDR12, SDR25, Legacy compatible, High speed SDR, High speed DDR bus speed mode selected

1: SDR50, DDR50, SDR104, HS200 bus speed mode selected

Bit 18 **DDR**: Data rate signaling selection

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0)

DDR rate must only be selected with 4-bit or 8-bit wide bus mode. (WIDBUS > 00). DDR = 1 has no effect when WIDBUS = 00 (1-bit wide bus).

DDR rate must only be selected with clock division > 1 (CLKDIV > 0).

0: SDR Single data rate signaling

1: DDR double data rate signaling

Bit 17 **HWFC_EN**: Hardware flow control enable

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0)

0: Hardware flow control is disabled

1: Hardware flow control is enabled

When Hardware flow control is enabled, the meaning of the TXFIFOE and RXFIFOF flags change, see SDMMC status register definition in *Section 28.10.11*.

Bit 16 **NEGEDGE**: SDMMC_CK dephasing selection bit for data and command

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0).

When clock division = 1 (CLKDIV = 0), this bit has no effect. Data and Command change on SDMMC_CK falling edge.

0: When clock division >1 (CLKDIV > 0) and DDR = 0:

- Command and data changed on the sdmmc_ker_ck falling edge succeeding the rising edge of SDMMC_CK.
- SDMMC_CK edge occurs on sdmmc_ker_ck rising edge.

When clock division >1 (CLKDIV > 0) and DDR = 1:

- Command changed on the sdmmc_ker_ck falling edge succeeding the rising edge of SDMMC_CK.
- Data changed on the sdmmc_ker_ck falling edge succeeding a SDMMC_CK edge.
- SDMMC_CK edge occurs on sdmmc_ker_ck rising edge.

1: When clock division >1 (CLKDIV > 0) and DDR = 0:

- Command and data changed on the same sdmmc_ker_ck rising edge generating the SDMMC_CK falling edge.

When clock division >1 (CLKDIV > 0) and DDR = 1:

- Command changed on the same sdmmc_ker_ck rising edge generating the SDMMC_CK falling edge.
- Data changed on the SDMMC_CK falling edge succeeding a SDMMC_CK edge.
- SDMMC_CK edge occurs on sdmmc_ker_ck rising edge.

Bits 15:14 **WIDBUS[1:0]**: Wide bus mode enable bit

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0)

00: Default 1-bit wide bus mode: SDMMC_D0 used (Does not support DDR)

01: 4-bit wide bus mode: SDMMC_D[3:0] used

10: 8-bit wide bus mode: SDMMC_D[7:0] used

Bit 13 Reserved, must be kept at reset value.

Bit 12 **PWRSAV**: Power saving configuration bit

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0)

For power saving, the SDMMC_CK clock output can be disabled when the bus is idle by setting PWRSAV:

0: SDMMC_CK clock is always enabled

1: SDMMC_CK is only enabled when the bus is active

Bits 11:10 Reserved, must be kept at reset value.

Bits 9:0 **CLKDIV[9:0]**: Clock divide factor

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0).

This field defines the divide factor between the input clock (sdmmc_ker_ck) and the output clock (SDMMC_CK): SDMMC_CK frequency = sdmmc_ker_ck / [2 * CLKDIV].

0x000: SDMMC_CK frequency = sdmmc_ker_ck / 1 (Does not support DDR)

0x001: SDMMC_CK frequency = sdmmc_ker_ck / 2

0x002: SDMMC_CK frequency = sdmmc_ker_ck / 4

0x0XX: ..

0x080: SDMMC_CK frequency = sdmmc_ker_ck / 256

0xXXX: ..

0x3FF: SDMMC_CK frequency = sdmmc_ker_ck / 2046

Note: While the SD/SDIO card or e•MMC is in identification mode, the SDMMC_CK frequency must be less than 400 kHz.

The clock frequency can be changed to the maximum card bus frequency when relative card addresses are assigned to all cards.

At least seven sdmmc_hclk clock periods are needed between two write accesses to this register. SDMMC_CK can also be stopped during the Read Wait interval for SD I/O cards: in this case the SDMMC_CLKCR register does not control SDMMC_CK.

28.10.3 SDMMC argument register (SDMMC_ARGR)

Address offset: 0x008

Reset value: 0x0000 0000

This register contains a 32-bit command argument, which is sent to a card as part of a command message.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CMDARG[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CMDARG[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CMDARG[31:0]**: Command argument

These bits can only be written by firmware when CPSM is disabled (CPSMEN = 0). Command argument sent to a card as part of a command message. If a command contains an argument, it must be loaded into this register before writing a command to the command register.

28.10.4 SDMMC command register (SDMMC_CMDR)

Address offset: 0x00C

Reset value: 0x0000 0000

This register contains the command index and command type bits. The command index is sent to a card as part of a command message. The command type bits control the command path state machine (CPSM).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMD SUS PEND
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BOOT EN	BOOT MODE	DT HOLD	CPSM EN	WAITP END	WAIT INT	WAITRESP[1:0]		CMD STOP	CMD TRANS	CMDINDEX[5:0]					
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **CMDSUSPEND**: The CPSM treats the command as a Suspend or Resume command and signals interrupt period start/end

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).
CMDSUSPEND = 1 and CMDTRANS = 0 Suspend command, start interrupt period when response bit BS = 0.
CMDSUSPEND = 1 and CMDTRANS = 1 Resume command with data, end interrupt period when response bit DF = 1.

Bit 15 **BOOTEN**: Enable boot mode procedure

0: Boot mode procedure disabled
1: Boot mode procedure enabled

Bit 14 **BOOTMODE**: Select the boot mode procedure to be used

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0)
0: Normal boot mode procedure selected
1: Alternative boot mode procedure selected

Bit 13 **DTHOLD**: Hold new data block transmission and reception in the DPSM

If this bit is set, the DPSM does not move from the Wait_S state to the Send state or from the Wait_R state to the Receive state.

Bit 12 **CPSMEN**: Command path state machine (CPSM) enable bit

This bit is written 1 by firmware, and cleared by hardware when the CPSM enters the Idle state.
If this bit is set, the CPSM is enabled.
When DTEN = 1, no command is transfered nor boot procedure is started. CPSMEN is cleared to 0.
During Read Wait with SDMMC_CK stopped no command is sent and CPSMEN is kept 0.

Bit 11 **WAITPEND**: CPSM waits for end of data transfer (CmdPend internal signal) from DPSM

This bit when set, the CPSM waits for the end of data transfer trigger before it starts sending a command.
WAITPEND is only taken into account when DTMODE = *e*•MMC stream data transfer, WIDBUS = 1-bit wide bus mode, DPSMACT = 1 and DTDIR = from host to card.

Bit 10 **WAITINT**: CPSM waits for interrupt request

If this bit is set, the CPSM disables command timeout and waits for an card interrupt request (Response).
If this bit is cleared in the CPSM Wait state, it causes the abort of the interrupt mode.

Bits 9:8 **WAITRESP[1:0]**: Wait for response bits

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).
They are used to configure whether the CPSM is to wait for a response, and if yes, which kind of response.
00: No response, expect CMDSENT flag
01: Short response, expect CMDREND or CCRCFAIL flag
10: Short response, expect CMDREND flag (No CRC)
11: Long response, expect CMDREND or CCRCFAIL flag

Bit 7 **CMDSTOP**: The CPSM treats the command as a Stop Transmission command and signals abort to the DPSM

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).

If this bit is set, the CPSM issues the abort signal to the DPSM when the command is sent.

Bit 6 **CMDTRANS**: The CPSM treats the command as a data transfer command, stops the interrupt period, and signals DataEnable to the DPSM

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).

If this bit is set, the CPSM issues an end of interrupt period and issues DataEnable signal to the DPSM when the command is sent.

Bits 5:0 **CMDINDEX[5:0]**: Command index

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).

The command index is sent to the card as part of a command message.

Note: 1 At least seven sdmmc_hclk clock periods are needed between two write accesses to this register.

2 MultiMediaCard can send two kinds of response: short responses, 48 bits, or long responses,136 bits. SD card and SD I/O card can send only short responses, the argument can vary according to the type of response: the software distinguishes the type of response according to the send command.

28.10.5 SDMMC command response register (SDMMC_RESPCMDR)

Address offset: 0x010

Reset value: 0x0000 0000

This register contains the command index field of the last command response received. If the command response transmission does not contain the command index field (long or OCR response), the RESPCMD field is unknown, although it must contain 111111b (the value of the reserved field from the response).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RESPCMD[5:0]					
										r	r	r	r	r	r

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:0 **RESPCMD[5:0]**: Response command index

Read-only bitfield. Contains the command index of the last command response received.

28.10.6 SDMMC response x register (SDMMC_RESPxR)

Address offset: 0x010 + 0x004 * x, (x = 1 to 4)

Reset value: 0x0000 0000

These registers contain the status of a card, which is part of the received response.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CARDSTATUS[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CARDSTATUS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CARDSTATUS[31:0]**: Card status according table below
See *Table 281*.

The card status size is 32 or 128 bits, depending on the response type.

Table 281. Response type and SDMMC_RESPxR registers

Register(1)	Short response	Long response
SDMMC_RESP1R	Card status[31:0]	Card status [127:96]
SDMMC_RESP2R	all 0	Card status [95:64]
SDMMC_RESP3R	all 0	Card status [63:32]
SDMMC_RESP4R	all 0	Card status [31:0](2)

1. The most significant bit of the card status is received first.
2. The SDMMC_RESP4R register LSB is always 0.

28.10.7 SDMMC data timer register (SDMMC_DTIMER)

Address offset: 0x024

Reset value: 0x0000 0000

This register contains the data timeout period, in card bus clock periods.

A counter loads the value from this register, and starts decrementing when the data path state machine (DPSM) enters the Wait_R or Busy state. If the timer reaches 0 while the DPSM is in either of these states, the timeout status flag is set.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATATIME[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATATIME[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DATATIME[31:0]**: Data and R1b busy timeout period

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0).

Data and R1b busy timeout period expressed in card bus clock periods.

Note: A data transfer must be written to the data timer register and the data length register before being written to the data control register.

28.10.8 SDMMC data length register (SDMMC_DLENR)

Address offset: 0x028

Reset value: 0x0000 0000

This register contains the number of data bytes to be transferred. The value is loaded into the data counter when data transfer starts.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATALENGTH[24:16]								
							rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATALENGTH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 24:0 **DATALENGTH[24:0]**: Data length value

This register can only be written by firmware when DPSM is inactive (DPSMACT = 0).

Number of data bytes to be transferred.

When DDR = 1 DATALENGTH is truncated to a multiple of 2. (The last odd byte is not transfered)

When DATALENGTH = 0 no data are transfered, when requested by a CPSMEN and CMDTRANS = 1 also no command is transfered. DTEN and CPSMEN are cleared to 0.

Note: For a block data transfer, the value in the data length register must be a multiple of the block size (see SDMMC_DCTRL). A data transfer must be written to the data timer register and the data length register before being written to the data control register.

For an SDMMC multibyte transfer the value in the data length register must be between 1 and 512.

28.10.9 SDMMC data control register (SDMMC_DCTRL)

Address offset: 0x02C

Reset value: 0x0000 0000

This register controls the data path state machine (DPSM).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	FIFO RST	BOOT ACK EN	SDIO EN	RW MOD	RW STOP	RW START	DBLOCKSIZE[3:0]				DTMODE[1:0]		DTDIR	DTEN
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **FIFORST**: FIFO reset, flushes any remaining data

This bit can only be written by firmware when IDMAEN= 0 and DPSM is active (DPSMACT = 1). This bit only takes effect when a transfer error or transfer hold occurs.

0: FIFO not affected.

1: Flush any remaining data and reset the FIFO pointers. This bit is automatically cleared to 0 by hardware when DPSM gets inactive (DPSMACT = 0).

Bit 12 **BOOTACKEN**: Enable the reception of the boot acknowledgment

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).

0: Boot acknowledgment disabled, not expected to be received

1: Boot acknowledgment enabled, expected to be received

Bit 11 **SDIOEN**: SD I/O interrupt enable functions

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).

If this bit is set, the DPSM enables the SD I/O card specific interrupt operation.

Bit 10 **RWMOD**: Read Wait mode

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).

0: Read Wait control using SDMMC_D2

1: Read Wait control stopping SDMMC_CK

Bit 9 **RWSTOP**: Read Wait stop

This bit is written by firmware and auto cleared by hardware when the DPSM moves from the R_W state to the Wait_R or Idle state.

0: No Read Wait stop

1: Enable for Read Wait stop when DPSM is in the R_W state.

Bit 8 **RWSTART**: Read Wait start

If this bit is set, Read Wait operation starts.

Bits 7:4 **DBLOCKSIZE[3:0]**: Data block size

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).
Define the data block length when the block data transfer mode is selected:
0000: Block length = 2^0 = 1 byte
0001: Block length = 2^1 = 2 bytes
0010: Block length = 2^2 = 4 bytes
0011: Block length = 2^3 = 8 bytes
0100: Block length = 2^4 = 16 bytes
0101: Block length = 2^5 = 32 bytes
0110: Block length = 2^6 = 64 bytes
0111: Block length = 2^7 = 128 bytes
1000: Block length = 2^8 = 256 bytes
1001: Block length = 2^9 = 512 bytes
1010: Block length = 2^{10} = 1024 bytes
1011: Block length = 2^{11} = 2048 bytes
1100: Block length = 2^{12} = 4096 bytes
1101: Block length = 2^{13} = 8192 bytes
1110: Block length = 2^{14} = 16384 bytes
1111: Reserved
When DATALENGTH is not a multiple of DBLOCKSIZE, the transfered data is truncated at a multiple of DBLOCKSIZE. (None of the remaining data are transfered.)
When DDR = 1, DBLOCKSIZE = 0000 must not be used. (No data are transfered)

Bits 3:2 **DTMODE[1:0]**: Data transfer mode selection

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).
00: Block data transfer ending on block count.
01: SDIO multibyte data transfer.
10: *e*•MMC Stream data transfer. (WIDBUS must select 1-bit wide bus mode)
11: Block data transfer ending with STOP_TRANSMISSION command (not to be used with DTEN initiated data transfers).

Bit 1 **DTDIR**: Data transfer direction selection

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).
0: From host to card.
1: From card to host.

Bit 0 **DTEN**: Data transfer enable bit

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0). This bit is cleared by hardware when data transfer completes.
This bit must only be used to transfer data when no associated data transfer command is used (must not be used with SD or *e*•MMC cards).
0: Do not start data transfer without CPSM data transfer command.
1: Start data transfer without CPSM data transfer command.

28.10.10 SDMMC data counter register (SDMMC_DCNTR)

Address offset: 0x030

Reset value: 0x0000 0000

This register loads the value from the data length register (see SDMMC_DLENR) when the DPSM moves from the Idle state to the Wait_R or Wait_S state. As data is transferred, the counter decrements the value until it reaches 0. The DPSM then moves to the Idle state and

when there has been no error, and no transmit data transfer hold, the data status end flag (DATAEND) is set.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATACOUNT[24:16]								
							r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATACOUNT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:25 Reserved, must be kept at reset value.

Bits 24:0 **DATACOUNT[24:0]**: Data count value

When read, the number of remaining data bytes to be transferred is returned. Write has no effect.

Note: This register must be read only after the data transfer is complete, or hold. When reading after an error event the read data count value may be different from the real number of data bytes transfered.

28.10.11 SDMMC status register (SDMMC_STAR)

Address offset: 0x034

Reset value: 0x0000 0000

This register is a read-only register. It contains two types of flag:

- Static flags (bits [28, 21, 11:0]): these bits remain asserted until they are cleared by writing to the SDMMC interrupt Clear register (see SDMMC_ICR)
- Dynamic flags (bits [20:12]): these bits change state depending on the state of the underlying logic (for example, FIFO full and empty flags are asserted and deasserted as data while written to the FIFO)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	IDMA BTC	IDMA TE	CK STOP	VSW END	ACK TIME OUT	ACK FAIL	SDIOIT	BUSY D0END	BUSY D0	RX FIFOE	TX FIFOE	RX FIFOF	TX FIFOF
			r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RX FIFO HF	TX FIFO HE	CPSM ACT	DPSM ACT	DA BORT	DBCK END	DHOLD	DATA END	CMD SENT	CMDR END	RX OVERR	TX UNDER R	D TIME OUT	C TIME OUT	DCRC FAIL	CCRC FAIL
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **IDMABTC**: IDMA buffer transfer complete

The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 27 **IDMATE**: IDMA transfer error

The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 26 **CKSTOP**: SDMMC_CK stopped in Voltage switch procedure

The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 25 **VSWEND**: Voltage switch critical timing section completion
The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 24 **ACKTIMEOUT**: Boot acknowledgment timeout
The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 23 **ACKFAIL**: Boot acknowledgment received (boot acknowledgment check fail)
The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 22 **SDIOIT**: SDIO interrupt received
The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 21 **BUSYD0END**: end of SDMMC_D0 Busy following a CMD response detected
This indicates only end of busy following a CMD response. This bit does not signal busy due to data transfer. Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.
0: card SDMMC_D0 signal does NOT signal change from busy to not busy.
1: card SDMMC_D0 signal changed from busy to NOT busy.

Bit 20 **BUSYD0**: Inverted value of SDMMC_D0 line (Busy), sampled at the end of a CMD response and a second time 2 SDMMC_CK cycles after the CMD response
This bit is reset to not busy when the SDMMCD0 line changes from busy to not busy. This bit does not signal busy due to data transfer. This is a hardware status flag only, it does not generate an interrupt.
0: card signals not busy on SDMMC_D0.
1: card signals busy on SDMMC_D0.

Bit 19 **RXFIFOE**: Receive FIFO empty
This is a hardware status flag only, does not generate an interrupt. This bit is cleared when one FIFO location becomes full.

Bit 18 **TXFIFOE**: Transmit FIFO empty
This bit is cleared when one FIFO location becomes full.

Bit 17 **RXFIFOF**: Receive FIFO full
This bit is cleared when one FIFO location becomes empty.

Bit 16 **TXFIFOF**: Transmit FIFO full
This is a hardware status flag only, does not generate an interrupt. This bit is cleared when one FIFO location becomes empty.

Bit 15 **RXFIFOHF**: Receive FIFO half full
There are at least half the number of words in the FIFO. This bit is cleared when the FIFO becomes half+1 empty.

Bit 14 **TXFIFOHE**: Transmit FIFO half empty
At least half the number of words can be written into the FIFO. This bit is cleared when the FIFO becomes half+1 full.

Bit 13 **CPSMACT**: Command path state machine active (not in Idle state)
This is a hardware status flag only, does not generate an interrupt.

Bit 12 **DPSMACT**: Data path state machine active (not in Idle state)
This is a hardware status flag only, does not generate an interrupt.

Bit 11 **DABORT**: Data transfer aborted by CMD12
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 10 **DBCKEND**: Data block sent/received
DBCKEND is set when:
- CRC check passed and DPSM moves to the R_W state
or
- IDMAEN = 0 and transmit data transfer hold and DATACOUNT >0 and DPSM moves to Wait_S.
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 9 **DHOLD**: Data transfer Hold
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 8 **DATAEND**: Data transfer ended correctly
DATAEND is set if data counter DATACOUNT is zero and no errors occur, and no transmit data transfer hold.
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 7 **CMDSENT**: Command sent (no response required)
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 6 **CMDREND**: Command response received (CRC check passed, or no CRC)
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 5 **RXOVERR**: Received FIFO overrun error (masked by hardware when IDMA is enabled)
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 4 **TXUNDERR**: Transmit FIFO underrun error (masked by hardware when IDMA is enabled)
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 3 **DTIMEOUT**: Data timeout
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 2 **CTIMEOUT**: Command response timeout
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.
The Command Timeout period has a fixed value of 64 SDMMC_CK clock periods.

Bit 1 **DCRCFAIL**: Data block sent/received (CRC check failed)
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 0 **CCRCFAIL**: Command response received (CRC check failed)
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Note: FIFO interrupt flags must be masked in SDMMC_MASKR when using IDMA mode.

28.10.12 SDMMC interrupt clear register (SDMMC_ICR)

Address offset: 0x038

Reset value: 0x0000 0000

This register is a write-only register. Writing a bit with 1 clears the corresponding bit in the SDMMC_STAR status register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	IDMA BTCC	IDMA TEC	CK STOPC	VSW ENDC	ACK TIME OUTC	ACK FAILC	SDIO ITC	BUSY D0 ENDC	Res.	Res.	Res.	Res.	Res.
			rw	rw	rw	rw	rw	rw	rw	rw					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	D ABORT C	DBCK ENDC	DHOLD C	DATA ENDC	CMD SENTC	CMDR ENDC	RX OVERR C	TX UNDER RC	D TIME OUTC	C TIME OUTC	DCRC FAILC	CCRC FAILC
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **IDMABTCC**: IDMA buffer transfer complete clear bit
Set by software to clear the IDMABTC flag.
0: IDMABTC not cleared
1: IDMABTC cleared

Bit 27 **IDMATEC**: IDMA transfer error clear bit
Set by software to clear the IDMATE flag.
0: IDMATE not cleared
1: IDMATE cleared

Bit 26 **CKSTOPC**: CKSTOP flag clear bit
Set by software to clear the CKSTOP flag.
0: CKSTOP not cleared
1: CKSTOP cleared

Bit 25 **VSWENDC**: VSWEND flag clear bit
Set by software to clear the VSWEND flag.
0: VSWEND not cleared
1: VSWEND cleared

Bit 24 **ACKTIMEOUTC**: ACKTIMEOUT flag clear bit
Set by software to clear the ACKTIMEOUT flag.
0: ACKTIMEOUT not cleared
1: ACKTIMEOUT cleared

Bit 23 **ACKFAILC**: ACKFAIL flag clear bit
Set by software to clear the ACKFAIL flag.
0: ACKFAIL not cleared
1: ACKFAIL cleared

Bit 22 **SDIOITC**: SDIOIT flag clear bit
Set by software to clear the SDIOIT flag.
0: SDIOIT not cleared
1: SDIOIT cleared

Bit 21 **BUSYD0ENDC**: BUSYD0END flag clear bit
Set by software to clear the BUSYD0END flag.
0: BUSYD0END not cleared
1: BUSYD0END cleared

Bits 20:12 Reserved, must be kept at reset value.

Bit 11 **DABORTC**: DABORT flag clear bit
Set by software to clear the DABORT flag.
0: DABORT not cleared
1: DABORT cleared

Bit 10 **DBCKENDC**: DBCKEND flag clear bit
Set by software to clear the DBCKEND flag.
0: DBCKEND not cleared
1: DBCKEND cleared

Bit 9 **DHOLDC**: DHOLD flag clear bit
Set by software to clear the DHOLD flag.
0: DHOLD not cleared
1: DHOLD cleared

Bit 8 **DATAENDC**: DATAEND flag clear bit
Set by software to clear the DATAEND flag.
0: DATAEND not cleared
1: DATAEND cleared

Bit 7 **CMDSENTC**: CMDSENT flag clear bit
Set by software to clear the CMDSENT flag.
0: CMDSENT not cleared
1: CMDSENT cleared

Bit 6 **CMDRENDC**: CMDREND flag clear bit
Set by software to clear the CMDREND flag.
0: CMDREND not cleared
1: CMDREND cleared

Bit 5 **RXOVERRC**: RXOVERR flag clear bit
Set by software to clear the RXOVERR flag.
0: RXOVERR not cleared
1: RXOVERR cleared

Bit 4 **TXUNDERRC**: TXUNDERR flag clear bit
Set by software to clear TXUNDERR flag.
0: TXUNDERR not cleared
1: TXUNDERR cleared

Bit 3 **DTIMEOUTC**: DTIMEOUT flag clear bit
Set by software to clear the DTIMEOUT flag.
0: DTIMEOUT not cleared
1: DTIMEOUT cleared

Bit 2 **CTIMEOUTC**: CTIMEOUT flag clear bit
Set by software to clear the CTIMEOUT flag.
0: CTIMEOUT not cleared
1: CTIMEOUT cleared

Bit 1 **DCRCFAILC**: DCRCFAIL flag clear bit
Set by software to clear the DCRCFAIL flag.
0: DCRCFAIL not cleared
1: DCRCFAIL cleared

Bit 0 **CCRCFAILC**: CCRCFAIL flag clear bit
Set by software to clear the CCRCFAIL flag.
0: CCRCFAIL not cleared
1: CCRCFAIL cleared

28.10.13 SDMMC mask register (SDMMC_MASKR)

Address offset: 0x03C

Reset value: 0x0000 0000

This register determines which status flags generate an interrupt request by setting the corresponding bit to 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	IDMA BTCIE	Res.	CK STOP IE	VSW ENDIE	ACK TIME OUTIE	ACK FAILIE	SDIO ITIE	BUSY D0 ENDIE	Res.	Res.	TX FIFO EIE	RX FIFO FIE	Res.
			rw		rw	rw	rw	rw	rw	rw			rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RX FIFO HFIE	TX FIFO HEIE	Res.	Res.	DA BORT IE	DBCK ENDIE	DHOLD IE	DATA ENDIE	CMD SENT IE	CMDR ENDIE	RX OVER RIE	TX UNDER RIE	D TIME OUTIE	C TIME OUTIE	DCRC FAILIE	CCRC FAILIE
rw	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **IDMABTCIE**: IDMA buffer transfer complete interrupt enable
Set and cleared by software to enable/disable the interrupt generated when the IDMA has transferred all data belonging to a memory buffer.
0: IDMA buffer transfer complete interrupt disabled
1: IDMA buffer transfer complete interrupt enabled

Bit 27 Reserved, must be kept at reset value.

Bit 26 **CKSTOPIE**: Voltage switch clock stopped interrupt enable
Set and cleared by software to enable/disable interrupt caused by voltage switch clock stopped.
0: Voltage switch clock stopped interrupt disabled
1: Voltage switch clock stopped interrupt enabled

Bit 25 **VSWENDIE**: Voltage switch critical timing section completion interrupt enable
Set and cleared by software to enable/disable the interrupt generated when voltage switch critical timing section completion.
0: Voltage switch critical timing section completion interrupt disabled
1: Voltage switch critical timing section completion interrupt enabled

Bit 24 **ACKTIMEOUTIE**: Acknowledgment timeout interrupt enable
Set and cleared by software to enable/disable interrupt caused by acknowledgment timeout.
0: Acknowledgment timeout interrupt disabled
1: Acknowledgment timeout interrupt enabled

Bit 23 **ACKFAILIE**: Acknowledgment fail interrupt enable
Set and cleared by software to enable/disable interrupt caused by acknowledgment fail.
0: Acknowledgment fail interrupt disabled
1: Acknowledgment fail interrupt enabled

Bit 22 **SDIOITIE**: SDIO mode interrupt received interrupt enable
Set and cleared by software to enable/disable the interrupt generated when receiving the SDIO mode interrupt.
0: SDIO mode interrupt received interrupt disabled
1: SDIO mode interrupt received interrupt enabled

Bit 21 **BUSYD0ENDIE**: BUSYD0END interrupt enable
Set and cleared by software to enable/disable the interrupt generated when SDMMC_D0 signal changes from busy to NOT busy following a CMD response.
0: BUSYD0END interrupt disabled
1: BUSYD0END interrupt enabled

Bits 20:19 Reserved, must be kept at reset value.

Bit 18 **TXFIFOEIE**: Tx FIFO empty interrupt enable
Set and cleared by software to enable/disable interrupt caused by Tx FIFO empty.
0: Tx FIFO empty interrupt disabled
1: Tx FIFO empty interrupt enabled

Bit 17 **RXFIFOFIE**: Rx FIFO full interrupt enable
Set and cleared by software to enable/disable interrupt caused by Rx FIFO full.
0: Rx FIFO full interrupt disabled
1: Rx FIFO full interrupt enabled

Bit 16 Reserved, must be kept at reset value.

Bit 15 **RXFIFOHFIE**: Rx FIFO half full interrupt enable
Set and cleared by software to enable/disable interrupt caused by Rx FIFO half full.
0: Rx FIFO half full interrupt disabled
1: Rx FIFO half full interrupt enabled

Bit 14 **TXFIFOHEIE**: Tx FIFO half empty interrupt enable
Set and cleared by software to enable/disable interrupt caused by Tx FIFO half empty.
0: Tx FIFO half empty interrupt disabled
1: Tx FIFO half empty interrupt enabled

Bits 13:12 Reserved, must be kept at reset value.

Bit 11 **DABORTIE**: Data transfer aborted interrupt enable
Set and cleared by software to enable/disable interrupt caused by a data transfer being aborted.
0: Data transfer abort interrupt disabled
1: Data transfer abort interrupt enabled

Bit 10 **DBCKENDIE**: Data block end interrupt enable
Set and cleared by software to enable/disable interrupt caused by data block end.
0: Data block end interrupt disabled
1: Data block end interrupt enabled

Bit 9 **DHOLDIE**: Data hold interrupt enable
Set and cleared by software to enable/disable the interrupt generated when sending new data is hold in the DPSM Wait_S state.
0: Data hold interrupt disabled
1: Data hold interrupt enabled

Bit 8 **DATAENDIE**: Data end interrupt enable
Set and cleared by software to enable/disable interrupt caused by data end.
0: Data end interrupt disabled
1: Data end interrupt enabled

Bit 7 **CMDSENTIE**: Command sent interrupt enable
Set and cleared by software to enable/disable interrupt caused by sending command.
0: Command sent interrupt disabled
1: Command sent interrupt enabled

Bit 6 **CMDRENDIE**: Command response received interrupt enable
Set and cleared by software to enable/disable interrupt caused by receiving command response.
0: Command response received interrupt disabled
1: command Response received interrupt enabled

Bit 5 **RXOVERRIE**: Rx FIFO overrun error interrupt enable
Set and cleared by software to enable/disable interrupt caused by Rx FIFO overrun error.
0: Rx FIFO overrun error interrupt disabled
1: Rx FIFO overrun error interrupt enabled

Bit 4 **TXUNDERRIE**: Tx FIFO underrun error interrupt enable
Set and cleared by software to enable/disable interrupt caused by Tx FIFO underrun error.
0: Tx FIFO underrun error interrupt disabled
1: Tx FIFO underrun error interrupt enabled

Bit 3 **DTIMEOUTIE**: Data timeout interrupt enable
Set and cleared by software to enable/disable interrupt caused by data timeout.
0: Data timeout interrupt disabled
1: Data timeout interrupt enabled

Bit 2 **CTIMEOUTIE**: Command timeout interrupt enable
Set and cleared by software to enable/disable interrupt caused by command timeout.
0: Command timeout interrupt disabled
1: Command timeout interrupt enabled

Bit 1 **DCRCFAILIE**: Data CRC fail interrupt enable
Set and cleared by software to enable/disable interrupt caused by data CRC failure.
0: Data CRC fail interrupt disabled
1: Data CRC fail interrupt enabled

Bit 0 **CCRCFAILIE**: Command CRC fail interrupt enable
Set and cleared by software to enable/disable interrupt caused by command CRC failure.
0: Command CRC fail interrupt disabled
1: Command CRC fail interrupt enabled

28.10.14 SDMMC acknowledgment timer register (SDMMC_ACKTIMER)

Address offset: 0x040

Reset value: 0x0000 0000

This register contains the acknowledgment timeout period, in SDMMC_CK bus clock periods.

A counter loads the value from this register, and starts decrementing when the data path state machine (DPSM) enters the Wait_Ack state. If the timer reaches 0 while the DPSM is in this states, the acknowledgment timeout status flag is set.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	ACKTIME[24:16]								
							rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACKTIME[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 24:0 **ACKTIME[24:0]**: Boot acknowledgment timeout period
This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).
Boot acknowledgment timeout period expressed in card bus clock periods.

Note: The data transfer must be written to the acknowledgment timer register before being written to the data control register.

28.10.15 SDMMC DMA control register (SDMMC_IDMACTRLR)

Address offset: 0x050

Reset value: 0x0000 0000

The receive and transmit FIFOs can be read or written as 32-bit wide registers. The FIFOs contain 32 entries on 32 sequential addresses. This enables the CPU to use its load and store multiple operands to read from/write to the FIFO.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IDMAB MODE	IDMA EN
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **IDMABMODE**: Buffer mode selection
This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).
0: Single buffer mode.
1: Linked list mode.

Bit 0 **IDMAEN**: IDMA enable
This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).
0: IDMA disabled
1: IDMA enabled

28.10.16 SDMMC IDMA buffer size register (SDMMC_IDMABSIZER)

Address offset: 0x054

Reset value: 0x0000 0000

This register contains the buffer size when in linked list configuration.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IDMABNDT[11]
															rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IDMABNDT[10:0]											Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw					

Bits 31:17 Reserved, must be kept at reset value.

Bits 16:5 **IDMABNDT[11:0]**: Number of bytes per buffer
This 12-bit value must be multiplied by 8 to get the size of the buffer in 32-bit words and by 32 to get the size of the buffer in bytes.
Example: IDMABNDT = 0x001: buffer size = 8 words = 32 bytes.
Example: IDMABNDT = 0x800: buffer size = 16384 words = 64 Kbyte.
These bits can only be written by firmware when DPSM is inactive (DPSMACT = 0).

Bits 4:0 Reserved, must be kept at reset value.

28.10.17 SDMMC IDMA buffer base address register (SDMMC_IDMABASER)

Address offset: 0x058

Reset value: 0x0000 0000

This register contains the memory buffer base address in single buffer configuration and linked list configuration.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IDMABASE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IDMABASE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r

Bits 31:0 **IDMABASE[31:0]**: Buffer memory base address bits [31:2], must be word aligned (bit [1:0] are always 0 and read only)

This register can be written by firmware when DPSM is inactive (DPSMACT = 0), and can dynamically be written by firmware when DPSM active (DPSMACT = 1).

28.10.18 SDMMC IDMA linked list address register (SDMMC_IDMALAR)

Address offset: 0x064

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ULA	ULS	ABR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw													
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IDMALA[13:0]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bit 31 **ULA**: Update SDMMC_IDMALAR from linked list when in linked list mode (SDMMC_IDMACTRLR.IDMABMODE select linked list mode)
This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).
0: SDMMC_IDMALAR is not to be updated, last linked list item.
1: SDMMC_IDMALAR is to be updated from linked list table.

Bit 30 **ULS**: Update SDMMC_IDMABSIZE from the next linked list when in linked list mode (SDMMC_IDMACTRLR.IDMABMODE select linked list mode and ULA = 1)
This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).
0: SDMMC_IDMABSIZER is not to be updated from next linked list table.
1: SDMMC_IDMABSIZER is to be updated from next linked list table.

Bit 29 **ABR**: Acknowledge linked list buffer ready
This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).
This bit is not taken into account when starting the first linked list buffer from the software programmed register information. ABR is only taken into account on subsequent loaded linked list items.
0: Loaded linked list buffer is not ready (this causes a linked list IDMA transfer error to be generated).
1: Loaded linked list buffer ready acknowledge. Linked list buffer data are transfered by IDMA.

Bits 28:16 Reserved, must be kept at reset value.

Bits 15:2 **IDMALA[13:0]**: Word aligned linked list item address offset
Linked list item offset pointer to the base of the next linked list item structure.
Linked list item base address is IDMABA + IDMALA.
These bits can only be written by firmware when DPSM is inactive (DPSMACT = 0).

Bits 1:0 Reserved, must be kept at reset value.

28.10.19 SDMMC IDMA linked list memory base register (SDMMC_IDMABAR)

Address offset: 0x068

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IDMABA[29:14]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IDMABA[13:0]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:2 **IDMABA[29:0]**: Word aligned Linked list memory base address
Linked list memory base pointer.
These bits can only be written by firmware when DPSM is inactive (DPSMACT = 0).

Bits 1:0 Reserved, must be kept at reset value.

28.10.20 SDMMC data FIFO registers x (SDMMC_FIFORx)

Address offset: 0x080 + 0x004 * x, (x =0 to 15)

Reset value: 0x0000 0000

The receive and transmit FIFOs can be only read or written as word (32-bit) wide registers. The FIFOs contain 16 entries on sequential addresses. This enables the CPU to use its load and store multiple operands to read from/write to the FIFO. The FIFO register interface takes care of correct data alignment inside the FIFO, the FIFO register address used by the CPU does matter.

When accessing SDMMC_FIFOR with half word or byte access an AHB bus fault is generated.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FIFODATA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FIFODATA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **FIFODATA[31:0]**: Receive and transmit FIFO data

This register can only be read or written by firmware when the DPSM is active (DPSMACT = 1).

The FIFO data occupies 16 entries of 32-bit words.

28.10.21 SDMMC register map

Table 282. SDMMC register map

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	SDMMC_ POWER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIRPOL	VSWITCHEN	VSWITCH	PWRCTRL[1:0]	
	Reset value																												0	0	0	0	0
0x004	SDMMC_ CLKCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SELCLKRX[1:0]		BUSSPEED	DDR	HWFC_EN	NEGEDGE	WIDBUS[1:0]		Res.	PWRSAV	Res.	Res.	CLKDIV[9:0]									
	Reset value											0	0	0	0	0	0	0	0		0			0	0	0	0	0	0	0	0	0	0
0x008	SDMMC_ ARGR	CMDARG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C	SDMMC_ CMDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMDSUSPEND	BOOTEN	BOOTMODE	DTHOLD	CPSMEN	WAITPEND	WAITINT	WAITRESP[1:0]		CMDSTOP	CMDTRANS	CMDINDEX[5:0]					
	Reset value																																

Table 282. SDMMC register map (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x010	SDMMC_ RESPCMDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RESPCMD[5:0]					
	Reset value																											0	0	0	0	0	0
0x014	SDMMC_ RESP1R	CARDSTATUS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x018	SDMMC_ RESP2R	CARDSTATUS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x01C	SDMMC_ RESP3R	CARDSTATUS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	SDMMC_ RESP4R	CARDSTATUS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	SDMMC_ DTIMER	DATATIME[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x028	SDMMC_ DLENR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATALENGTH[24:0]																								
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x02C	SDMMC_ DCTRLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FIFORST	BOOTACKEN	SDIOEN	RWMOD	RWSTOP	RWSTART	DBLOCK SIZE[3:0]				DTMODE[1:0]		DTDIR	DTEN
	Reset value																			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x030	SDMMC_ DCNTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATACOUNT[24:0]																								
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x034	SDMMC_ STAR	Res.	Res.	Res.	IDMABTC	IDMATE	CKSTOP	VSWEND	ACKTIMEOUT	ACKFAIL	SDIOIT	BUSYD0END	BUSYD0	RXFIFOE	TXFIFOE	RXFIFOF	TXFIFOF	RXFIFOHF	TXFIFOHE	CPSMACT	DPSMACT	DABORT	DBCKEND	DHOLD	DATAEND	CMDSENT	CMDREND	RXOVERR	TXUNDERR	DTIMEOUT	CTIMEOUT	DCRCFAIL	CCRCFAIL
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x038	SDMMC_ ICR	Res.	Res.	Res.	IDMABTCC	IDMATEC	CKSTOPC	VSWENDC	ACKTIMEOUTC	ACKFAILC	SDIOITC	BUSYD0ENDC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DABORTC	DBCKENDC	DHOLDC	DATAENDC	CMDSENTC	CMDRENDC	RXOVERRC	TXUNDERRC	DTIMEOUTC	CTIMEOUTC	DCRCFAILC	CCRCFAILC
	Reset value				0	0	0	0	0	0	0	0										0	0	0	0	0	0	0	0	0	0	0	0
0x03C	SDMMC_ MASKR	Res.	Res.	Res.	IDMABTCIE	Res.	CKSTOPIE	VSWENDIE	ACKTIMEOUTIE	ACKFAILIE	SDIOITIE	BUSYD0ENDIE	Res.	Res.	TXFIFOEIE	RXFIFOFIE	Res.	RXFIFOHFIE	TXFIFOHEIE	Res.	Res.	DABORTIE	DBCKENDIE	DHOLDIE	DATAENDIE	CMDSENTIE	CMDRENDIE	RXOVERRIE	TXUNDERRIE	DTIMEOUTIE	CTIMEOUTIE	DCRCFAILIE	CCRCFAILIE
	Reset value				0		0	0	0	0	0	0			0	0		0	0			0	0	0	0	0	0	0	0	0	0	0	0

Table 282. SDMMC register map (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x040	SDMMC_ ACKTIMER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ACKTIME[24:0]																								
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x044 - 0x04C	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x050	SDMMC_ IDMACTRLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IDMABMODE	IDMAEN
	Reset value																															0	0
0x054	SDMMC_ IDMABSIZER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IDMABNDT[11:0]												Res.	Res.	Res.	Res.	Res.
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0					
0x058	SDMMC_ IDMABASER	IDMABASE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x05C - 0x060	Reserved	Res.																															
0x064	SDMMC_ IDMALAR	ULA	ULS	ABR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IDMALA[13:0]														Res.	Res.
	Reset value	0	0	0														0	0	0	0	0	0	0	0	0	0	0	0	0			
0x068	SDMMC_ IDMABAR	IDMABA[29:0]																														Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
0x06C - 0x07C	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x080 + 0x04 * x, (x=0..15)	SDMMC_ FIFORx	FIFODATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

29 Delay block (DLYB)

29.1 DLYB introduction

The delay block (DLYB) is used to generate an output clock that is dephased from the input clock. The phase of the output clock must be programmed by the user application. The output clock is then used to clock the data received by another peripheral such as an SDMMC or Octo-SPI interface.

The delay is voltage- and temperature-dependent, that may require the application to re-configure and recenter the output clock phase with the receive data.

29.2 DLYB main features

The delay block has the following features:

- Input clock frequency ranging from 25 MHz to the maximum frequency supported by the communication interface (see datasheet)
- Up to 12 oversampling phases.

29.3 DLYB implementation

Table 283. STM32H5E4/5F4 and STM32H5E5/5F5 features

DLYB associated peripheral	DLYBOS1	DLYBOS2	DLYBSD1	DLYBSD2
OCTOSPI1	X	-	-	-
OCTOSPI2	-	X	-	-
SDMMC1	-	-	X	-
SDMMC2	-	-	-	X

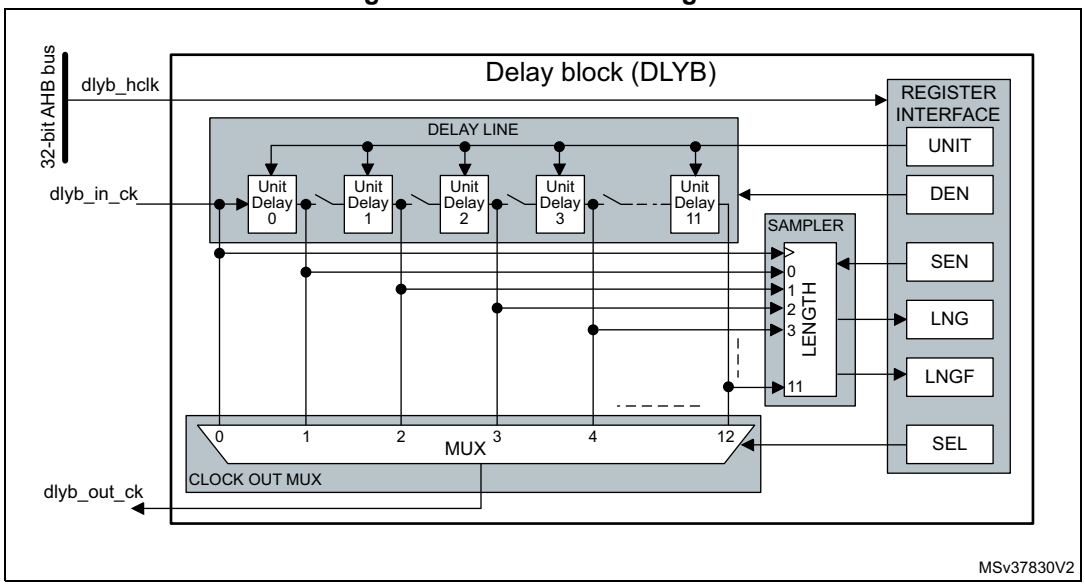
29.4 DLYB functional description

29.4.1 DLYB diagram

The delay block includes the following sub-blocks (shown in the figure below):

- register interface block providing AHB access to the DLYB registers
- delay line supporting the unit delays
- delay line length sampling
- output clock selection multiplexer

Figure 238. DLYB block diagram



29.4.2 DLYB pins and internal signals

Table 284 lists the DLYB internal signals.

Table 284. DLYB internal input/output signals

Signal name	Signal type	Description
dlyb_hclk	Digital input	Delay block register interface clock
dlyb_in_ck	Digital input	Delay block input clock
dlyb_out_ck	Digital output	Delay block output clock

29.4.3 General description

The delay block is enabled by setting the DEN bit in the DLYB control register (DLYB_CR). The length sampler is enabled through the SEN bit in DLYB_CR register.

When the delay block is enabled, the delay added by a unit delay is defined by the UNIT[6:0] field in the DLYB configuration register (DLYB_CFGR).

Note: UNIT[6:0] can be programmed only when the output clock is disabled (SEN = 1).

When the delay block is enabled, the output clock phase is selected through the SEL[3:0] field in DLYB_CFGR register.

Note: SEL can be programmed only when the output clock is disabled (SEN = 1).

The output clock can be de-phased over one input clock period by configuring the delay line length to span one period. The delay line length can be configured by enabling the length sampler through the SEN bit, that gives access to the delay line length (LNG[11:0]) and length valid flag (LNGF) in DLYB_CFGR.

If an output clock delay smaller than one input clock period is needed the delay line length can be reduced. This allows a smaller unit delay providing higher resolution.

Once the delay line length is configured, a dephased output clock can be selected by the output clock multiplexer. This is done through SEL[3:0]. The output clock is only available on the selected phase when SEN is set to 0.

The table below gives a summary of the delay block control.

Table 285. Delay block control

DEN	SEN	UNIT	SEL	LNG	LNGF	Output clock
0	0	Don't care	Don't care	Don't care	Don't care	Enabled (= Input clock)
x	1	Unit delay	Output clock phase	Length	Length flag	Disabled
1	0	Unit delay(1)	Output clock phase(2)	Don't care	Don't care	Enabled (= selected phase)

1. The unit delay can only be changed when SEN = 1.
2. The output clock phase can only be changed when SEN = 1.

29.4.4 Delay line length configuration procedure

LNG[11:0] is used to determine the delay line length with respect to the input clock period. The length must be configured so that one full input clock period is covered by the delay line length.

Note that despite the delay line has 12 unit delay elements, the following procedure description returns a length between 0 and 10, as the upper delay output value is used to ensure that the delay is calibrated over one full input clock cycle. Depending on the clock frequency and UNIT value, unit delay element 10 may also be truncated from the clock cycle length.

A clock input (free running clock) must be present during the whole tuning procedure.

To configure the delay line length to one period of the Input clock, follow the sequence below:

1. Enable the delay block by setting DEN bit to 1.
2. Enable the length sampling by setting SEN bit to 1.
3. Enable all delay cells by setting SEL[3:0] to 12.
4. For UNIT[6:0] = 0 to 127 (this step must be repeated until the delay line length is configured):
   a) Update the UNIT[6:0] value and wait till the length flag LNGF is set to 1.
   b) Read LNG[11:0].

   If (LNG[10:0] > 0) and (LNG[11] or LNG[10] = 0), the delay line length is configured to one input clock period.
5. Determine how many unit delays (N) span one input clock period: for N = 0 to 10, if LNG[N] = 1, the number of unit delays spanning the input clock period = N.
6. Disable the length sampling by clearing SEN to 0.

If an output clock delay smaller than one input clock period is needed the delay line length can be reduced smaller than one input clock period. This allows a smaller unit delay, providing a higher resolution spanning a shorter time interval.

29.4.5 Output clock phase configuration procedure

When the delay line length is configured to one input clock period, the output clock phase can be selected between the unit delays spanning one Input clock period.

Follow the steps below to select the output clock phase:

1. Disable the output clock and enable the access to the phase selection SEL[3:0] bits by setting SEN bit to 1.
2. Program SEL[3:0] with the desired output clock phase value.
3. Enable the output clock on the selected phase by clearing SEN to 0.

Octo-SPI use case:

The delay block is used in conjunction with Octo-SPI interface to allow shifting the input data sampling signal. This sampling signal can be the feedback clock or the data strobe (DQS) signal, which is delivered by certain type of devices. Note that in case DQS is used, the calibration procedure must be performed beforehand with a free running clock, as DQS is a discontinuous signal.

In case of SDR (single data rate) mode the user must typically shift the sampling signal by half period, so that the sampling edges are positioned in the middle of the valid data phase.

In case of DDR (dual data rate) mode, for which data are transitioning at start and middle of period, typical value must be close to N/4, once the calibration is completed.

In case of high frequencies and tight timing constraints, the delay setting granularity (10) might be too coarse. Since in most cases it is not necessary to have a possible delay value covering the whole sampling clock period, the "Unit" value can be overridden by application in order to improve the accuracy of the sampling edge position (example: providing a twice as small “Unit” gives twice better timing accuracy. The counterpart being that the maximum possible delay is divided by 2).

SDMMC use case:

The delay block is used in conjunction with SDMMC interface variable delay. For correct sampling point tuning the delay value must cover a whole SDMMC_CK clock period. After having tuned the delay line length the individual delays are used in the sampling point tuning to find the optimal sampling point.

29.5 DLYB registers

All registers can be accessed in word, half-word and byte access.

29.5.1 DLYB control register (DLYB_CR)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEN	DEN
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **SEN:** Sampler length enable bit
0: Sampler length and register access to UNIT[6:0] and SEL[3:0] disabled, output clock enabled.
1: Sampler length and register access to UNIT[6:0] and SEL[3:0] enabled, output clock disabled.

Bit 0 **DEN:** Delay block enable bit
0: DLYB disabled.
1: DLYB enabled.

29.5.2 DLYB configuration register (DLYB_CFGR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LNGF	Res.	Res.	Res.	LNG[11:0]											
r				r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	UNIT[6:0]							Res.	Res.	Res.	Res.	SEL[3:0]			
	rw	rw	rw	rw	rw	rw	rw					rw	rw	rw	rw

Bit 31 **LNGF:** Length valid flag
This flag indicates when the delay line length value contained in LNG[11:0] is valid after UNIT[6:0] bits changed.
0: Length value in LNG is not valid.
1: Length value in LNG is valid.

Bits 30:28 Reserved, must be kept at reset value.

Bits 27:16 **LNG[11:0]:** Delay line length value
These bits reflect the 12 unit delay values sampled at the rising edge of the input clock. The value is only valid when LNGF = 1.

Bit 15 Reserved, must be kept at reset value.

Bits 14:8 **UNIT[6:0]:** Delay of a unit delay cell.
These bits can only be written when SEN = 1.
Unit delay = initial delay + UNIT[6:0] x delay step

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **SEL[3:0]:** Phase for the output clock.
These bits can only be written when SEN = 1.
Output clock phase = input clock + SEL[3:0] x unit delay

29.5.3 DLYB register map

Table 286. DLYB register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	DLYB_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEN	DEN
	Reset value																															0	0
0x004	DLYB_CFGR	LNGF	Res.	Res.	Res.	LNG[11:0]												Res.	UNIT[6:0]							Res.	Res.	Res.	Res.	SEL[3:0]			
	Reset value	0				0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0					0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

30 Analog-to-digital converters (ADC1/2/3)

30.1 ADC introduction

This section describes the implementation of up to 3 ADCs:

- ADC1 and ADC2 are tightly coupled and can operate in dual mode (ADC1 is master).
- ADC3 is controlled independently.

Each ADC consists of a 12-bit successive approximation analog-to-digital converter.

Each ADC has up to 20 multiplexed channels. A/D conversion of the various channels can be performed in single, continuous, scan or discontinuous mode. The result of the ADC is stored in a left-aligned or right-aligned 16-bit data register.

The ADCs are mapped on the AHB bus to allow fast data handling.

The analog watchdog features allow the application to detect if the input voltage goes outside the user-defined high or low thresholds.

A built-in hardware oversampler allows improving analog performances while off-loading the related computational burden from the CPU.

An efficient low-power mode is implemented to allow very low consumption at low frequency.

30.2 ADC main features

- High-performance features
  - Up to 3 ADCs, out of which two of them can operate in dual mode:
    ADC1 is connected to 18 external channels and to 2 internal channels
    ADC2 is connected to 18 external channels and to 2 internal channels
    ADC3 is connected to 11 external channels and to 7 internal channels
  - 12, 10, 8 or 6-bit configurable resolution
  - ADC conversion time independent from the AHB bus clock frequency
  - Faster conversion time by lowering resolution
  - Manage single-ended or differential inputs
  - AHB slave bus interface to allow fast data handling
  - Self-calibration
  - Channel-wise programmable sampling time
  - Flexible sampling time control
  - Up to 4 injected channels (analog inputs assignment to regular or injected channels is fully configurable)
  - Hardware assistant to prepare the context of the injected channels to allow fast context switching
  - Data alignment with in-built data coherency
  - Data can be managed by DMA for regular channel conversions
  - Data can be routed to ADF/MDF interface for post processing
  - Four dedicated data registers for the injected channels

- Low-power features
  - Speed adaptive low-power mode to reduce ADC consumption when operating at low frequency
  - Allows slow bus frequency application while keeping optimum ADC performance
  - Provides automatic control to avoid ADC overrun in low AHB bus clock frequency application (auto-delayed mode)
- Oversampler
  - 16-bit data register
  - Oversampling ratio adjustable from 2 to 256x
  - Programmable data shift up to 8 bits
- Data preconditioning
  - Offset compensation
- Analog input channels
  - External analog inputs (per ADC):

    Up to 6 fast channels from GPIO pads

    Up to 12 slow channels from GPIO pads
  - 2 channels for the internal temperature sensor (V_{SENSE})
  - 2 channels for the internal reference voltage (V_{REFINT})
  - 2 channels for monitoring the external VBAT power supply pin
  - 2 channels for monitoring the internal V_{DDCORE} supply
  - 1 channel for the internal OPAMP output
  - 2 channels for the DAC outputs
- Start-of-conversion can be initiated:
  - By software for both regular and injected conversions
  - By hardware triggers with configurable polarity (internal timers events or GPIO input events) for both regular and injected conversions
- Conversion modes
  - Each ADC can convert a single channel or can scan a sequence of channels
  - Single mode converts selected inputs once per trigger
  - Continuous mode converts selected inputs continuously
  - Discontinuous mode
- Interrupt generation at ADC ready, the end of sampling, the end of conversion (regular or injected), end of sequence conversion (regular or injected), analog watchdog 1, 2 or 3 or overrun events
- 3 analog watchdogs per ADC
  - Watchdog can perform filtering to ignore out-of-range data
- ADC input range: $V_{SSA} \leq V_{IN} \leq V_{REF+}$

Figure 239 shows the block diagram of one ADC.

30.3 ADC implementation

Table 287. ADC features

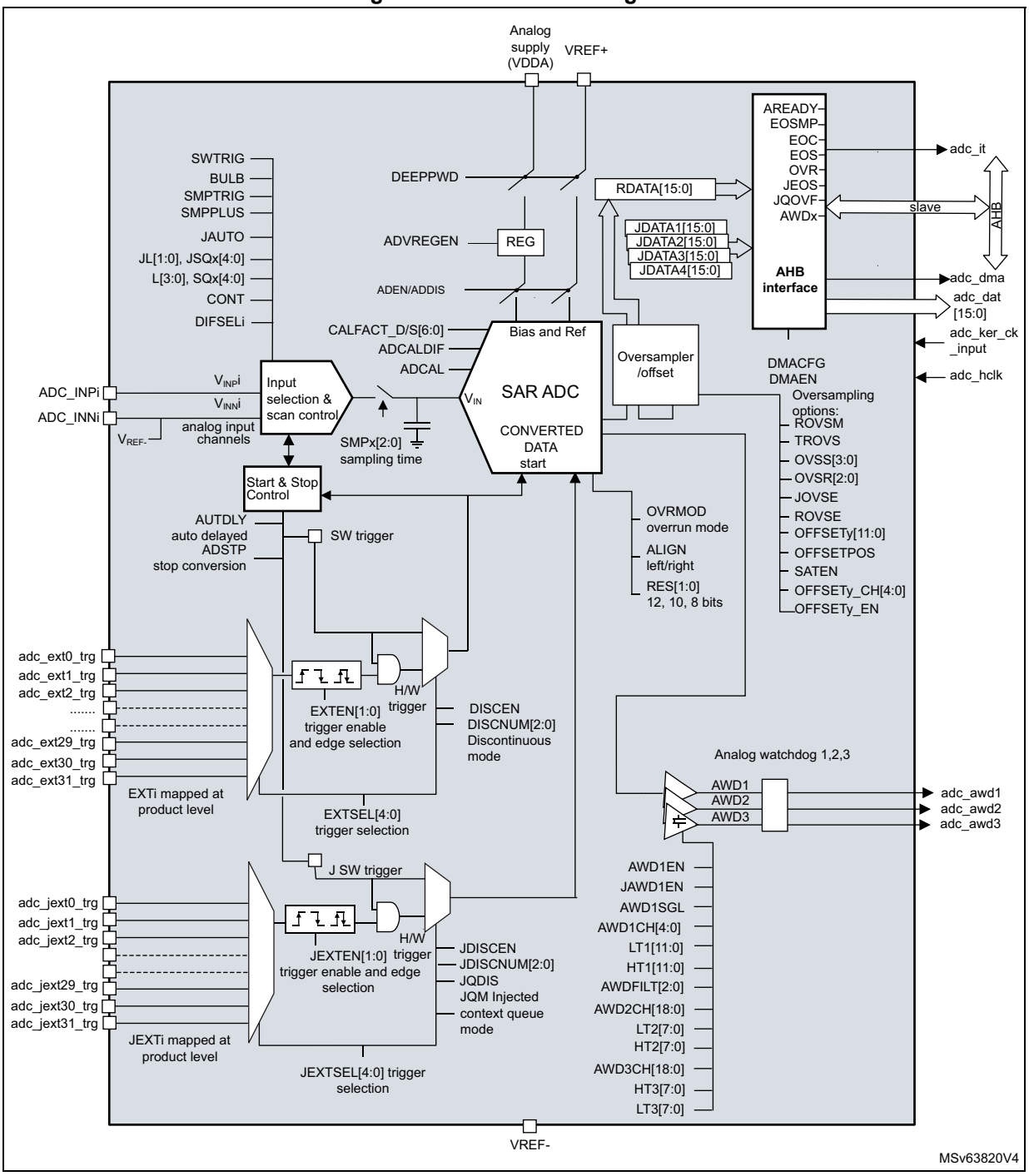
ADC modes/features	ADC1	ADC2	ADC3
Resolution	12 bit		
Maximum sampling speed	5 Msps (12-bit resolution)		
Dual mode operation	X		-
Hardware offset calibration	X		
Hardware linearity calibration	-		
Single-end input	X		
Differential input	X		-
Injected channel conversion	X		
Oversampling	up to x256		
Data register	16 bits		
Data register FIFO depth	3 stages		
DMA support	X		
Parallel data output to ADF/MDF	X		
Offset compensation	X		
Gain compensation	X		
Number of analog watchdog	3		
Option register	X		

30.4 ADC functional description

30.4.1 ADC block diagram

Figure 239 shows the ADC block diagram and *Table 288* gives the ADC pin description.

Figure 239. ADC block diagram



30.4.2 ADC pins and internal signals

Table 288. ADC input/output pins

Pin name	Signal type	Description
VDDA	Input, analog supply	Analog power supply and positive reference voltage for the ADC
VSSA	Input, analog supply ground	Ground for analog power supply, equal to V_{SS}.
VREF+	Input, analog reference positive	The higher/positive reference voltage for the ADC.
VREF−	Input, analog reference negative	The lower/negative reference voltage for the ADC. V_{REF-} is internally connected to V_{SSA}
ADC1/2/3_INNi/INPi	Negative/positive external analog input signals	20 negative/positive external analog input channels (refer to *Section 30.4.4: ADC connectivity* for details)

Table 289. ADC internal input/output signals

Internal signal name	Signal type	Description
$V_{INP}i$	Positive analog input channels	Positive internal analog input channels connected either to ADC1/2/3_INP*i* external channels or to internal channels.
$V_{INN}i$	Negative analog input channels	Negative internal analog input channels connected either to ADC1/2/3_INN*i* external channels or to internal channels
adc_ext_trgi	Inputs	ADC external trigger inputs for regular conversions.These inputs are shared between the ADC master and the ADC slave.
adc_jext_trgi	Inputs	ADC external trigger inputs for the injected conversions. These inputs are shared between the ADC master and the ADC slave.
adc_awdx	Output	Internal analog watchdog output signal connected to on-chip timers. (x = Analog watchdog number 1,2,3)
adc_ker_ck_input	Input	ADC kernel clock
adc_hclk	Input	ADC peripheral clock
adc_it	Output	ADC interrupt
adc_dma	Output	ADC DMA request
adc_dat[15:0]	Output	ADC data outputs

Table 290. ADC interconnection

Signal name	Source/destination
ADC1 V_{INP}[16]	V_{SENSE} (internal temperature sensor output voltage).
ADC1 V_{INP}[17]	V_{REFINT} (output voltage from internal reference voltage).
ADC2 V_{INP}[16]	V_{BAT}/4 (VBAT pin input voltage divided by 4).
ADC2 V_{INP}[17]	V_{DDCORE} (internal digital core voltage).

Table 290. ADC interconnection (continued)

Signal name	Source/destination
ADC3 V_{INP}[14]	V_{BAT}/4 (VBAT pin input voltage divided by 4)
ADC3 V_{INP}[15]	V_{DDCORE} (internal digital core voltage)
ADC3 V_{INP}[16]	V_{SENSE} (internal temperature sensor output voltage)
ADC3 V_{INP}[17]	V_{REFINT} (output voltage from internal reference voltage)
ADC3 V_{INP}[18]	dac1_out1
ADC3 V_{INP}[19]	dac1_out2
adc1_dat[15:0]	mdf_adc1_dat[15:0]
adc2_dat[15:0]	mdf_adc2_dat[15:0]
adc3_dat[15:0]	adf_adc3_dat[15:0]
adc_ext_trg0	tim1_oc1
adc_ext_trg1	tim1_oc2
adc_ext_trg2	tim1_oc3
adc_ext_trg3	tim2_oc2
adc_ext_trg4	tim3_trgo
adc_ext_trg5	tim4_oc4
adc_ext_trg6	exti11
adc_ext_trg7	tim8_trgo
adc_ext_trg8	tim8_trgo2
adc_ext_trg9	tim1_trgo
adc_ext_trg10	tim1_trgo2
adc_ext_trg11	tim2_trgo
adc_ext_trg12	tim4_trgo
adc_ext_trg13	tim6_trgo
adc_ext_trg14	tim15_trgo
adc_ext_trg15	tim3_oc4
adc_ext_trg16	exti15
adc_ext_trg17	reserved
adc_ext_trg18	lptim1_ch1
adc_ext_trg19	lptim2_ch1
adc_ext_trg20	play1_out7
adc_ext_trg21	reserved
adc_ext_trg22	reserved
adc_ext_trg23	reserved
adc_ext_trg24	reserved
adc_ext_trg25	reserved

Table 290. ADC interconnection (continued)

Signal name	Source/destination
adc_ext_trg26	reserved
adc_ext_trg27	reserved
adc_ext_trg28	reserved
adc_ext_trg29	reserved
adc_ext_trg30	reserved
adc_ext_trg31	reserved
adc_jext_trg0	tim1_trgo
adc_jext_trg1	tim1_oc4
adc_jext_trg2	tim2_trgo
adc_jext_trg3	tim2_oc1
adc_jext_trg4	tim3_oc4
adc_jext_trg5	tim4_trgo
adc_jext_trg6	exti15
adc_jext_trg7	tim8_oc4
adc_jext_trg8	tim1_trgo2
adc_jext_trg9	tim8_trgo
adc_jext_trg10	tim8_trgo2
adc_jext_trg11	tim3_oc3
adc_jext_trg12	tim3_trgo
adc_jext_trg13	tim3_oc1
adc_jext_trg14	tim6_trgo
adc_jext_trg15	tim15_trgo
adc_jext_trg16	reserved
adc_jext_trg17	reserved
adc_jext_trg18	lptim1_ch1
adc_jext_trg19	lptim2_ch1
adc_jext_trg20	play1_out9
adc_jext_trg21	reserved
adc_jext_trg22	reserved
adc_jext_trg23	reserved
adc_jext_trg24	reserved
adc_jext_trg25	reserved
adc_jext_trg26	reserved
adc_jext_trg27	reserved
adc_jext_trg28	reserved

Table 290. ADC interconnection (continued)

Signal name	Source/destination
adc_jext_trg29	reserved
adc_jext_trg30	reserved
adc_jext_trg31	reserved

30.4.3 ADC clocks

Dual clock domain architecture

The dual clock-domain architecture means that the ADC clock is independent from the AHB bus clock.

The ADC input clock can be selected between two different clock sources (see *Figure 240: ADC clock scheme*):

1. The ADC clock can be a specific clock source (adc_ker_ck_input), independent and asynchronous with the AHB clock.

   Refer to section *Reset and clock control (RCC)* for more information on how to generate the ADC dedicated clock. To select this scheme, CKMODE[1:0] bits of ADC_CCR register must be set to 00.

2. The ADC clock can be derived from the AHB clock interface divided by a programmable factor of 1, 2 or 4. To select this scheme, CKMODE[1:0] bits of ADC_CCR must be different from 00. The programmable divider factor can be configured through to CKMODE[1:0] bits of ADC_CCR.

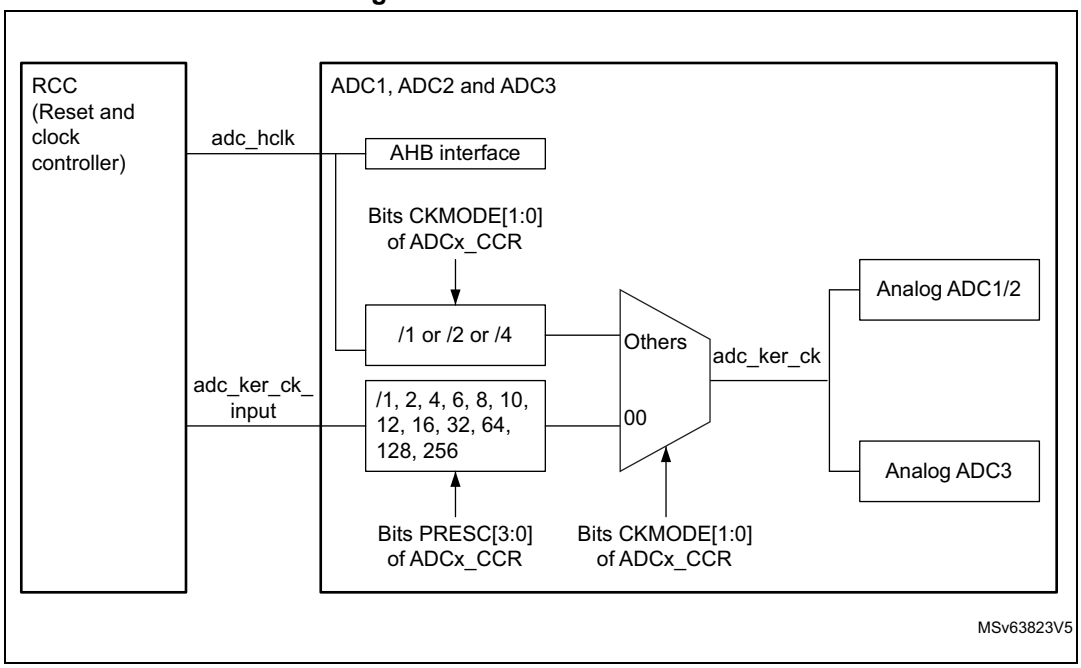
   The prescaling factor of 1 (CKMODE[1:0] = 01) can be used only if the AHB prescaler is set to 1 (HPRE[3:0] = 0xxx in the RCC_CFGR register).

Option **1** has the advantage of achieving the maximum ADC clock frequency whatever the AHB clock scheme selected. The ADC clock can eventually be divided by the following ratio: 1, 2, 4, 6, 8, 12, 16, 32, 64, 128, 256, using the prescaler configured with bits PRESC[3:0] in the ADC_CCR register.

Option **2** has the advantage of bypassing the clock domain resynchronizations. This can be useful when the ADC is triggered by a timer and if the application requires that the ADC is precisely triggered without any uncertainty (otherwise, an uncertainty of the trigger instant is added by the resynchronizations between the two clock domains).

The clock is configured through CKMODE[1:0] bits must be compliant with the operating frequency specified in the device datasheet.

Figure 240. ADC clock scheme



Clock ratio constraint between ADC clock and AHB clock

There are generally no constraints to be respected for the ratio between the ADC clock and the AHB clock except if some injected channels are programmed. In this case, it is mandatory to respect the following ratio:

- $F_{adc_hclk} \geq F_{ADC} / 4$ if the resolution of all channels are 12-bit or 10-bit
- $F_{adc_hclk} \geq F_{ADC} / 3$ if there are some channels with resolutions equal to 8-bit (and none with lower resolutions)
- $F_{adc_hclk} \geq F_{ADC} / 2$ if there are some channels with resolutions equal to 6-bit

Constraints between ADC clocks

When several ADC interfaces are used simultaneously, it is mandatory to use the same clock source from the RCC block without prescaler ratio for all ADC interfaces.

30.4.4 ADC connectivity

ADC inputs are connected to the external channels as well as internal sources as described below.

Figure 241. ADC1 connectivity

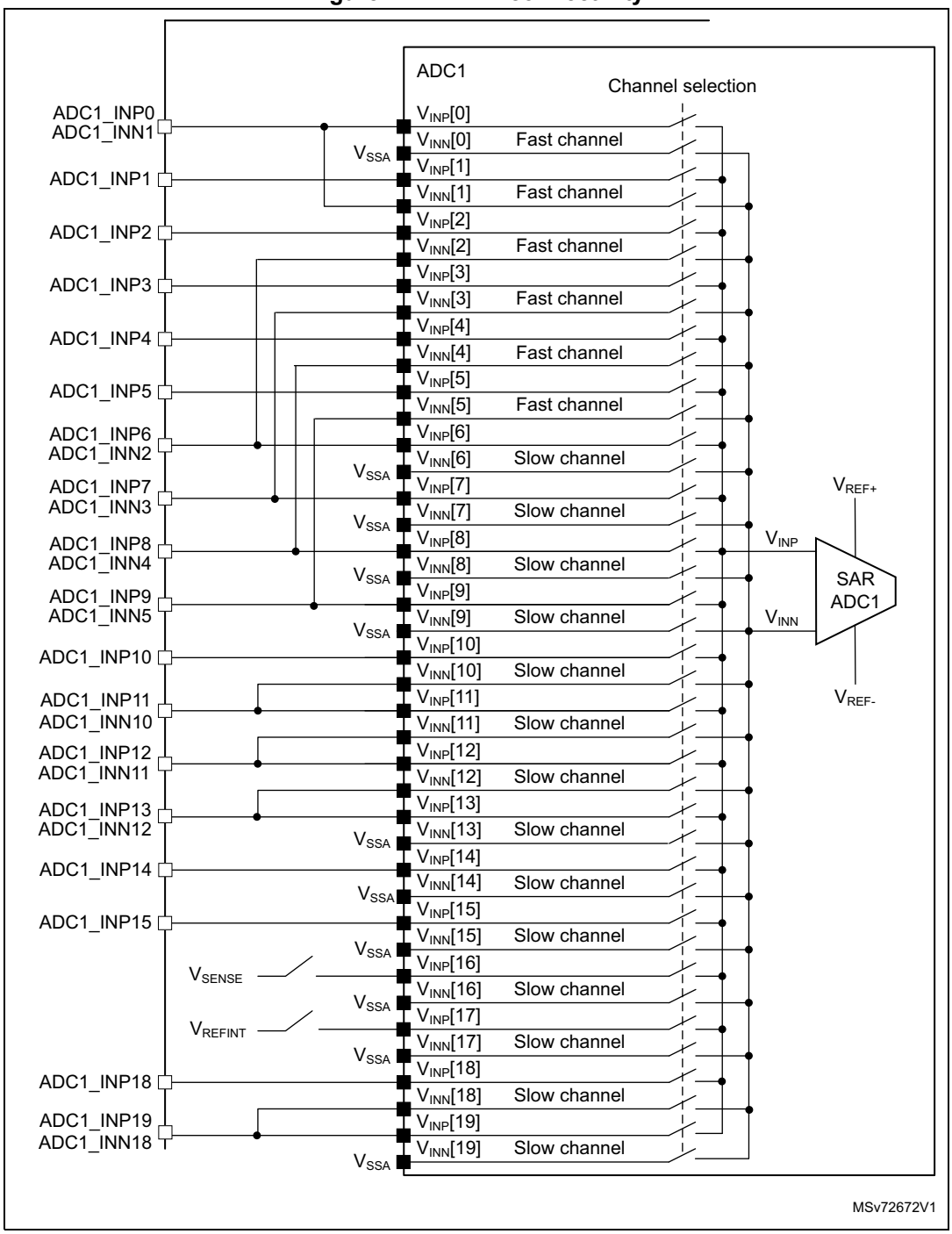


Figure 242. ADC2 connectivity

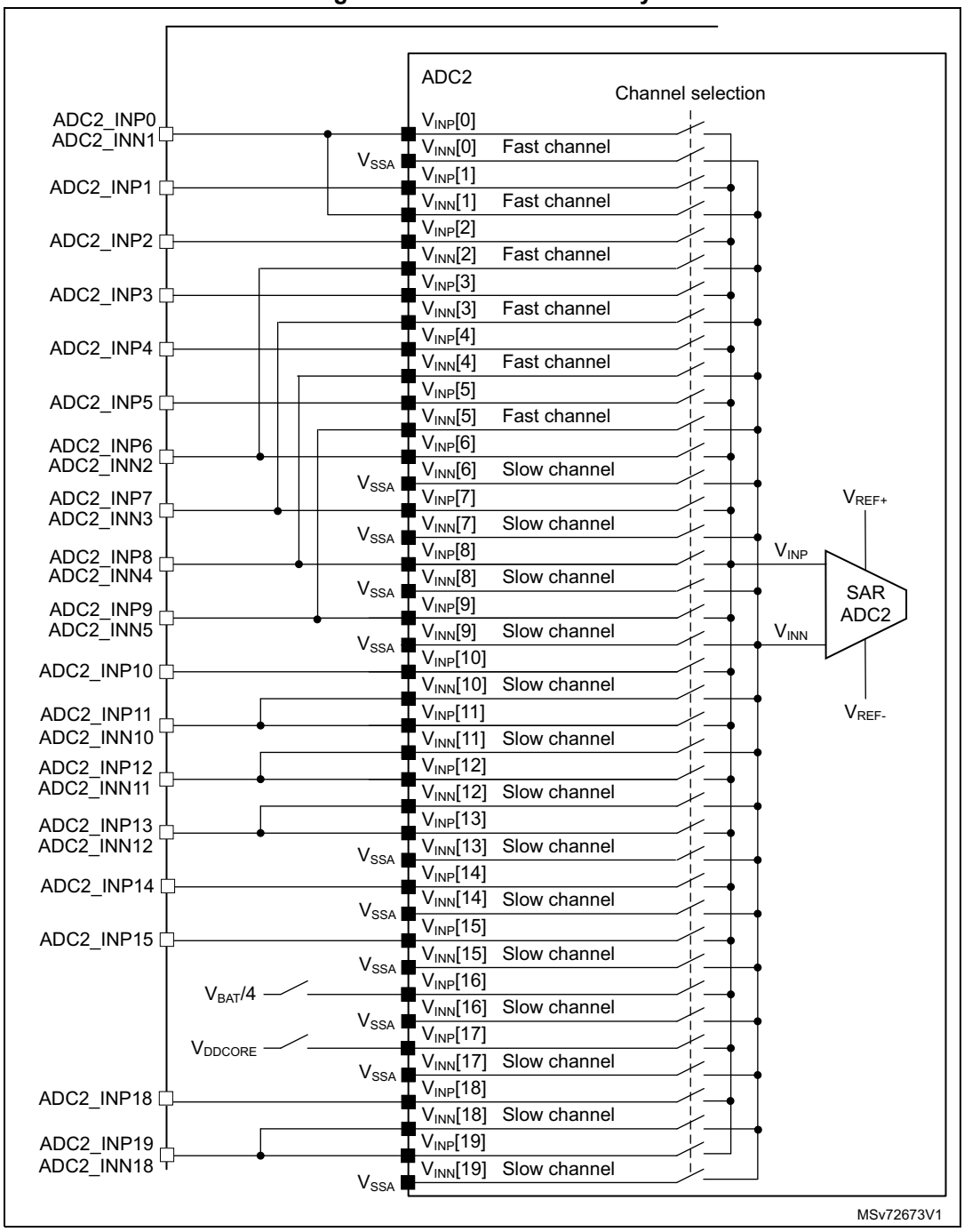
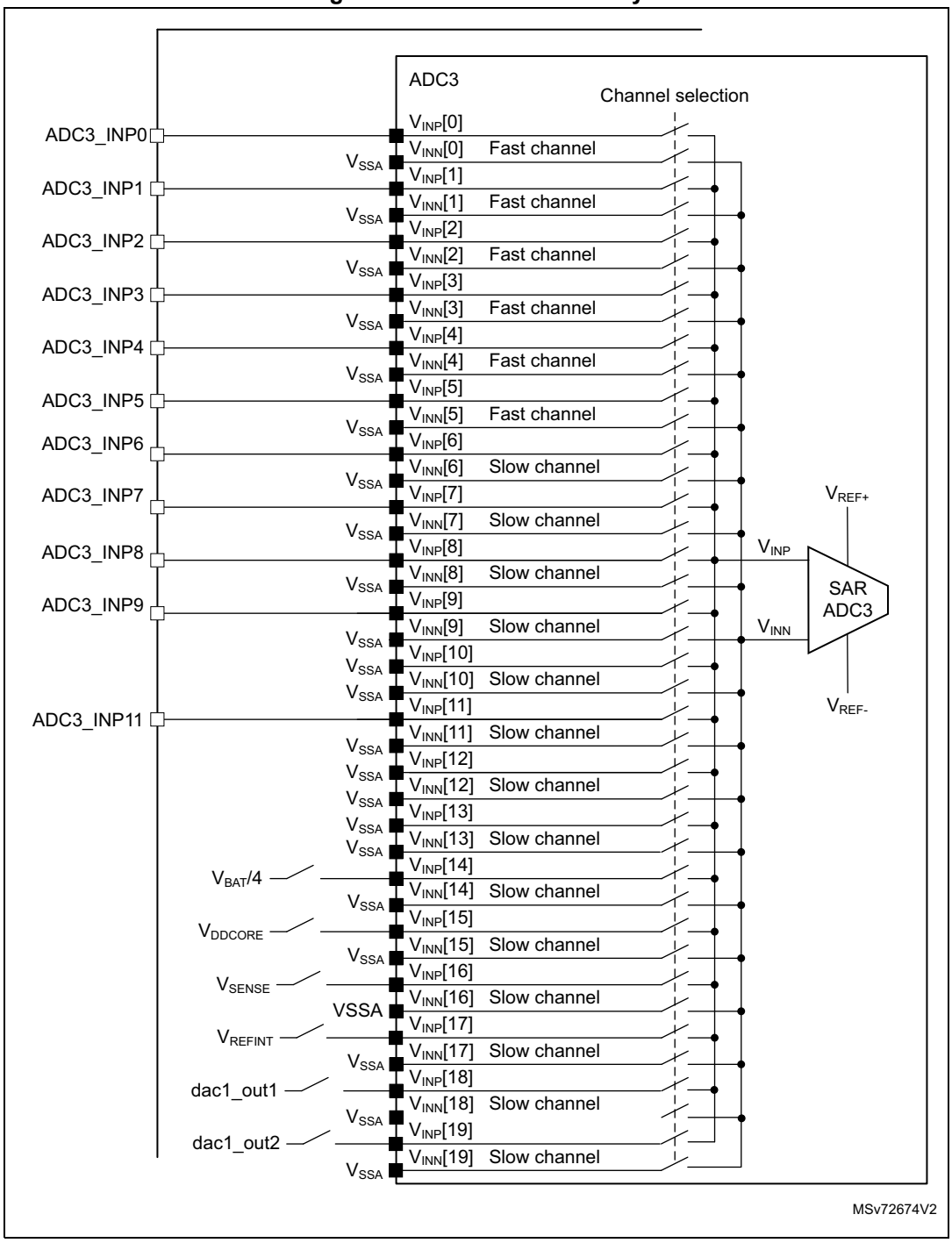


Figure 243. ADC3 connectivity



30.4.5 Slave AHB interface

The ADCs implement an AHB slave port for control/status register and data access. The features of the AHB interface are listed below:

- Word (32-bit) accesses
- Single cycle response
- Response to all read/write accesses to the registers with zero wait states.

The AHB slave interface does not support split/retry requests, and never generates AHB errors.

30.4.6 ADC Deep-power-down mode (DEEPPWD) and ADC voltage regulator (ADVREGEN)

By default, the ADC is in Deep-power-down mode where its supply is internally switched off to reduce the leakage currents (the reset state of bit DEEPPWD is 1 in the ADC_CR register).

To start ADC operations, it is first needed to exit Deep-power-down mode by setting bit DEEPPWD = 0.

Then, it is mandatory to enable the ADC internal voltage regulator by setting the bit ADVREGEN = 1 into ADC_CR register. The software must wait for the startup time of the ADC voltage regulator ($T_{ADCVREG_STUP}$) before launching a calibration or enabling the ADC. This delay must be implemented by software.

For the startup time of the ADC voltage regulator, refer to device datasheet for $T_{ADCVREG_STUP}$ parameter.

When ADC operations are complete, the ADC can be disabled (ADEN = 0). It is possible to save power by also disabling the ADC voltage regulator. This is done by writing bit ADVREGEN = 0.

Then, to save more power by reducing the leakage currents, it is also possible to re-enter in ADC Deep-power-down mode by setting bit DEEPPWD = 1 into ADC_CR register. This is particularly interesting before entering Stop mode.

Note: Writing DEEPPWD = 1 automatically disables the ADC voltage regulator and bit ADVREGEN is automatically cleared.

When the internal voltage regulator is disabled (ADVREGEN = 0), the internal analog calibration is kept.

In ADC Deep-power-down mode (DEEPPWD = 1), the internal analog calibration is lost and it is necessary to either relaunch a calibration or re-apply the calibration factor which was previously saved (refer to *Section 30.4.8: Calibration (ADCAL, ADCALDIF, ADC_CALFACT)*).

30.4.7 Single-ended and differential input channels

Channels can be configured to be either single-ended input or differential input by programming DIFSEL[i] bits in the ADC_DIFSEL register. This configuration must be written while the ADC is disabled (ADEN = 0). Note that the DIFSEL[i] bits corresponding to single-ended channels are always programmed at 0.

In single-ended input mode, the analog voltage to be converted for channel “i” is the difference between the external voltage $V_{INP[i]}$ (positive input) and V_{REF-} (negative input).

In differential input mode, the analog voltage to be converted for channel “i” is the difference between the external voltage $V_{INP[i]}$ (positive input) and $V_{INN[i]}$ (negative input).

The output data for the differential mode is an unsigned data. When $V_{INP[i]}$ equals V_{REF-}, $V_{INN[i]}$ equals V_{REF+} and the output data is 0x000 (12-bit resolution mode). When $V_{INP[i]}$ equals V_{REF+}, $V_{INN[i]}$ equals V_{REF-} and the output data is 0xFFF.

$$\text{Converted value} = \frac{\text{ADC_Full_Scale}}{2} \times \left[1 + \frac{V_{INP} - V_{INN}}{V_{REF+}}\right]$$

When ADC is configured as differential mode, both inputs should be biased at (V_{REF+}) /2 voltage.

The input signals are supposed to be differential (common mode voltage should be fixed).

Internal channels (such as V_{REFINT} and V_{SENSE}) are used in single-ended mode only.

For a complete description of how the input channels are connected for each ADC, refer to *Section 30.4.4: ADC connectivity*.

Caution: When configuring the channel “i” in differential input mode, its negative input voltage $V_{INN[i]}$ is connected to another channel. As a consequence, this channel is no longer usable in single-ended mode or in differential mode and must never be configured to be converted. Some channels are shared between ADC1/ADC2/ADC3: this can make the channel on the other ADC unusable. Only exception is interleaved mode for ADC master and the slave.

30.4.8 Calibration (ADCAL, ADCALDIF, ADC_CALFACT)

Each ADC provides an automatic calibration procedure which drives all the calibration sequence including the power-on/off sequence of the ADC. During the procedure, the ADC calculates a calibration factor which is 7-bit wide and which is applied internally to the ADC until the next ADC power-off. During the calibration procedure, the application must not use the ADC and must wait until calibration is complete.

Calibration is preliminary to any ADC operation. It removes the offset error which may vary from chip to chip due to process or bandgap variation.

The calibration factor to be applied for single-ended input conversions is different from the factor to be applied for differential input conversions:

- Write ADCALDIF = 0 before launching a calibration which is applied for single-ended input conversions.
- Write ADCALDIF = 1 before launching a calibration which is applied for differential input conversions.

The calibration is then initiated by software by setting bit ADCAL = 1. Calibration can only be initiated when the ADC is disabled (when ADEN = 0). ADCAL bit stays at 1 during all the

calibration sequence. It is then cleared by hardware as soon the calibration completes. At this time, the associated calibration factor is stored internally in the analog ADC and also in the bits CALFACT_S[6:0] or CALFACT_D[6:0] of ADC_CALFACT register (depending on single-ended or differential input calibration)

The internal analog calibration is kept if the ADC is disabled (ADEN = 0). However, if the ADC is disabled for extended periods, then it is recommended that a new calibration cycle is run before re-enabling the ADC.

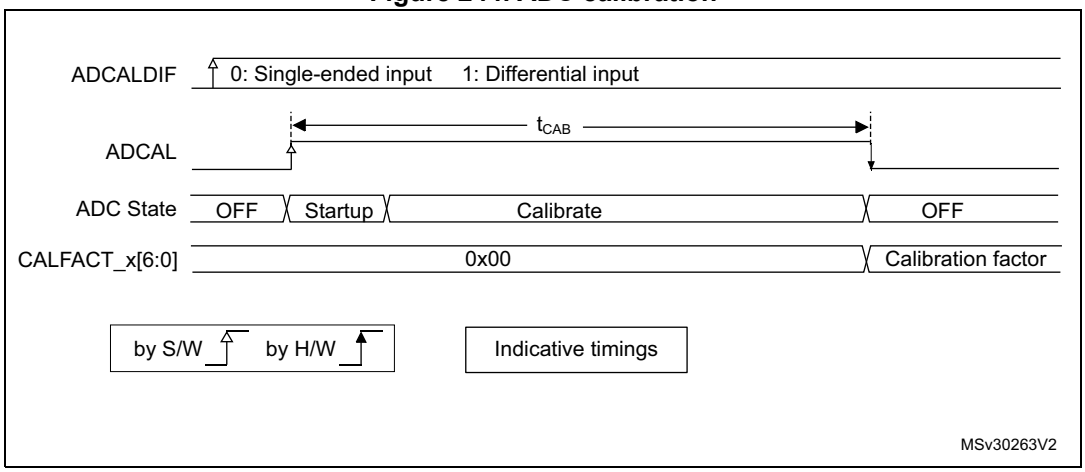
The internal analog calibration is lost each time the power of the ADC is removed (example, when the product enters in Standby or V_{BAT} mode). In this case, to avoid spending time recalibrating the ADC, it is possible to re-write the calibration factor into the ADC_CALFACT register without recalibrating, supposing that the software has previously saved the calibration factor delivered during the previous calibration.

The calibration factor can be written if the ADC is enabled but not converting (ADEN = 1 and ADSTART = 0 and JADSTART = 0). Then, at the next start of conversion, the calibration factor is automatically injected into the analog ADC. This loading is transparent and does not add any cycle latency to the start of the conversion. It is recommended to recalibrate when V_{REF+} voltage changed more than 10%.

Software procedure to calibrate the ADC

1. Ensure DEEPPWD = 0, ADVREGEN = 1 and that ADC voltage regulator startup time has elapsed.
2. Ensure that ADEN = 0.
3. Select the input mode for this calibration by setting ADCALDIF = 0 (single-ended input) or ADCALDIF = 1 (differential input).
4. Set ADCAL = 1.
5. Wait until ADCAL = 0.
6. The calibration factor can be read from ADC_CALFACT register.

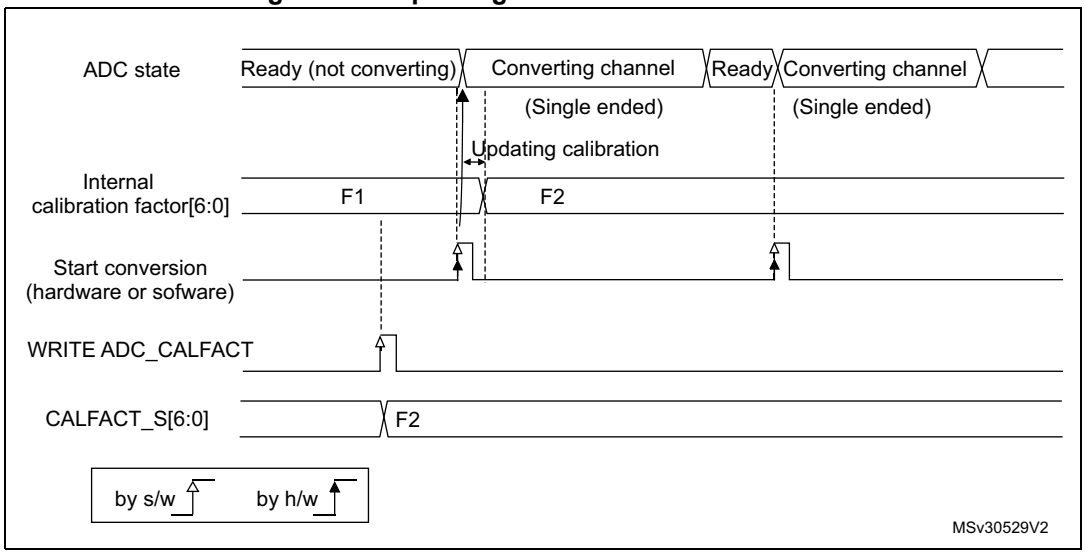
Figure 244. ADC calibration



Software procedure to reinject a calibration factor into the ADC

1. Ensure ADEN = 1 and ADSTART = 0 and JADSTART = 0 (ADC enabled and no conversion is ongoing).
2. Write CALFACT_S and CALFACT_D with the new calibration factors.
3. When a conversion is launched, the calibration factor is injected into the analog ADC only if the internal analog calibration factor differs from the one stored in bits CALFACT_S for single-ended input channel or bits CALFACT_D for differential input channel.

Figure 245. Updating the ADC calibration factor

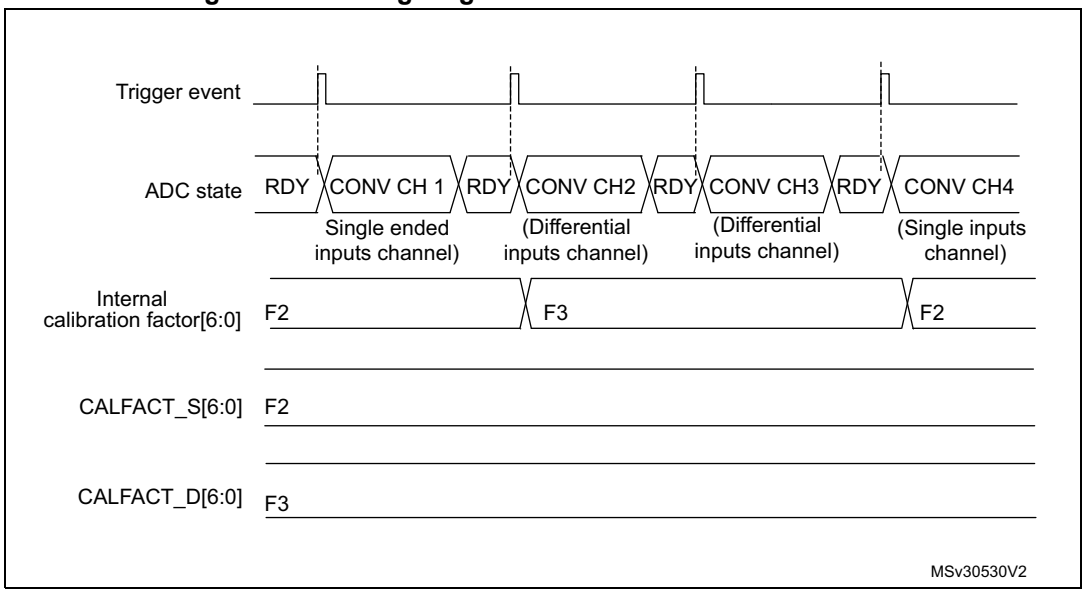


Converting single-ended and differential analog inputs with a single ADC

If the ADC is supposed to convert both differential and single-ended inputs, two calibrations must be performed, one with ADCALDIF = 0 and one with ADCALDIF = 1. The procedure is the following:

1. Disable the ADC.
2. Calibrate the ADC in single-ended input mode (with ADCALDIF = 0). This updates the register CALFACT_S[6:0].
3. Calibrate the ADC in differential input modes (with ADCALDIF = 1). This updates the register CALFACT_D[6:0].
4. Enable the ADC, configure the channels and launch the conversions. Each time there is a switch from a single-ended to a differential inputs channel (and vice-versa), the calibration is automatically injected into the analog ADC.

Figure 246. Mixing single-ended and differential channels



30.4.9 ADC on-off control (ADEN, ADDIS, ADRDY)

First of all, follow the procedure explained in *Section 30.4.6: ADC Deep-power-down mode (DEEPPWD) and ADC voltage regulator (ADVREGEN)*).

Once DEEPPWD = 0 and ADVREGEN = 1, the ADC can be enabled and the ADC needs a stabilization time of t_{STAB} before it starts converting accurately, as shown in *Figure 247*. Two control bits enable or disable the ADC:

- ADEN = 1 enables the ADC. The flag ADRDY is set once the ADC is ready for operation.
- ADDIS = 1 disables the ADC. ADEN and ADDIS are then automatically cleared by hardware as soon as the analog ADC is effectively disabled.

Regular conversion can then start either by setting ADSTART = 1 (refer to *Section 30.4.18: Conversion on external trigger and trigger polarity (EXTSEL, EXTEN,JEXTSEL, JEXTEN)*) or when an external trigger event occurs, if triggers are enabled.

Injected conversions start by setting JADSTART = 1 or when an external injected trigger event occurs, if injected triggers are enabled.

Software procedure to enable the ADC

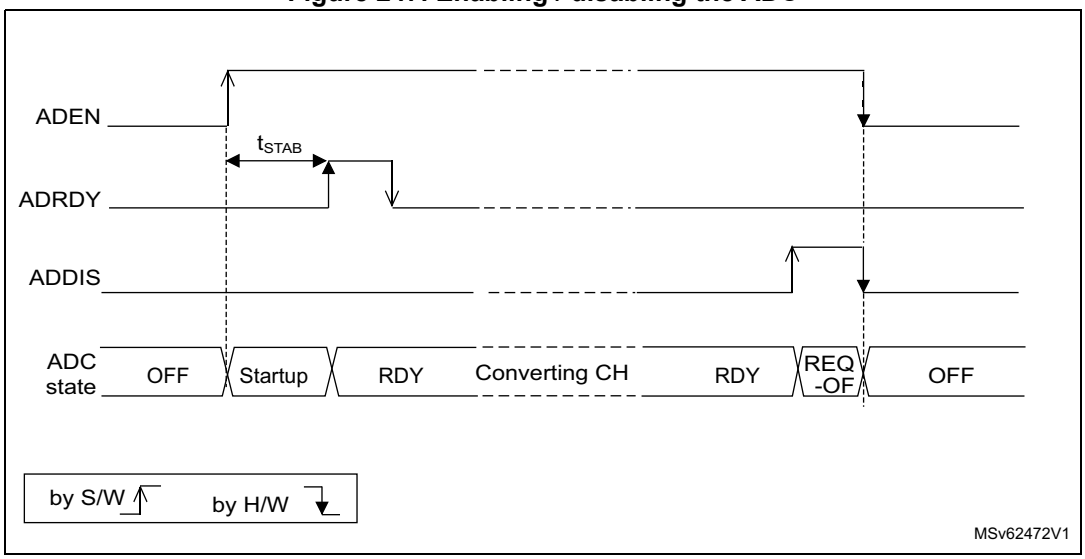
1. Clear the ADRDY bit in the ADC_ISR register by writing ‘1’.
2. Set ADEN = 1.
3. Wait until ADRDY = 1 (ADRDY is set after the ADC startup time). This can be done using the associated interrupt (setting ADRDYIE = 1).
4. Clear the ADRDY bit in the ADC_ISR register by writing ‘1’ (optional).

Caution: ADEN bit cannot be set when ADCAL is set and during four ADC clock cycles after the ADCAL bit is cleared by hardware (end of the calibration).

Software procedure to disable the ADC

1. Check that both ADSTART = 0 and JADSTART = 0 to ensure that no conversion is ongoing. If required, stop any regular and injected conversion ongoing by setting ADSTP = 1 and JADSTP = 1 and then wait until ADSTP = 0 and JADSTP = 0.
2. Set ADDIS = 1.
3. If required by the application, wait until ADEN = 0, until the analog ADC is effectively disabled (ADDIS is automatically reset once ADEN = 0).

Figure 247. Enabling / disabling the ADC



30.4.10 Constraints when writing the ADC control bits

The software is allowed to write the RCC control bits to configure and enable the ADC clock (refer to RCC Section), the DIFSEL[i] control bits in the ADC_DIFSEL register and the control bits ADCAL and ADEN in the ADC_CR register, only if the ADC is disabled (ADEN must be equal to 0).

The software is then allowed to write the control bits ADSTART, JADSTART and ADDIS of the ADC_CR register only if the ADC is enabled and there is no pending request to disable the ADC (ADEN must be equal to 1 and ADDIS to 0).

For all the other control bits of the ADC_CFGR, ADC_SMPRx, ADC_TRy, ADC_SQRy, ADC_JDRy, ADC_OFRy, ADC_OFCHRy and ADC_IER registers:

- For control bits related to configuration of regular conversions, the software is allowed to write them only if the ADC is enabled (ADEN = 1) and if there is no regular conversion ongoing (ADSTART must be equal to 0).
- For control bits related to configuration of injected conversions, the software is allowed to write them only if the ADC is enabled (ADEN = 1) and if there is no injected conversion ongoing (JADSTART must be equal to 0).
- ADC_TRy registers can be modified when an analog-to-digital conversion is ongoing (refer to *Section 30.4.29: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)* for details).

The software is allowed to write the ADSTP or JADSTP control bits of the ADC_CR register only if the ADC is enabled, possibly converting, and if there is no pending request to disable the ADC (ADSTART or JADSTART must be equal to 1 and ADDIS to 0).

The software can write the register ADC_JSQR at any time, when the ADC is enabled (ADEN = 1). Refer to *Section 30.6.16: ADC injected sequence register (ADC_JSQR)* for additional details.

Note: There is no hardware protection to prevent these forbidden write accesses and ADC behavior may become in an unknown state. To recover from this situation, the ADC must be disabled (clear ADEN = 0 as well as all the bits of ADC_CR register).

30.4.11 Channel selection (ADC_SQRy, ADC_JSQR)

The ADC features up to 20 multiplexed channels per ADC, out of which:

- Up to 18 analog inputs coming from GPIO pads (ADC_INP/INN[i]) depending on the products, not all of them are available on GPIO pads.
- Up to 5 internal channels (refer to *Section 30.4.4: ADC connectivity* for details)

  To convert one of the internal analog channels, the corresponding analog sources must first be enabled by programming bits VREFEN, VBATEN or TSEN in the ADC_CCR registers.

Refer to *Table ADC interconnection* in *Section 30.4.2: ADC pins and internal signals* for the connection of the above internal analog inputs to external ADC pins or internal signals.

The conversions can be organized in two groups: regular and injected. A group consists of a sequence of conversions that can be done on any channel and in any order. For instance, it is possible to implement the conversion sequence in the following order: ADC1/2/3_INP/INN3, ADC1/2/3_INP/INN8, ADC1/2/3_INP/INN2, ADC1/2/3_INN/INP2, ADC1/2/3_INP/INN0, ADC1/2/3_INP/INN2, ADC1/2/3_INP/INN2, ADC1/2/3_INP/INN15.

- A **regular group** is composed of up to 16 conversions. The regular channels and their order in the conversion sequence must be selected in the ADC_SQRy registers. The total number of conversions in the regular group must be written in the L[3:0] bits in the ADC_SQR1 register.
- An **injected group** is composed of up to 4 conversions. The injected channels and their order in the conversion sequence must be selected in the ADC_JSQR register. The total number of conversions in the injected group must be written in the L[1:0] bits in the ADC_JSQR register.

ADC_SQRy registers must not be modified while regular conversions can occur. For this, the ADC regular conversions must be first stopped by writing ADSTP = 1 (refer to *Section 30.4.17: Stopping an ongoing conversion (ADSTP, JADSTP)*).

The software is allowed to modify on-the-fly the ADC_JSQR register when JADSTART is set to 1 (injected conversions ongoing) only when the context queue is enabled (JQDIS = 0 in ADC_CFGR register). Refer to *Section 30.4.21: Queue of context for injected conversions*

30.4.12 Channel-wise programmable sampling time (SMPR1, SMPR2)

Before starting a conversion, the ADC must establish a direct connection between the voltage source under measurement and the embedded sampling capacitor of the ADC. This sampling time must be enough for the input voltage source to charge the embedded capacitor to the input voltage level.

Each channel can be sampled with a different sampling time which is programmable using the SMP[2:0] bits in the ADC_SMPR1 and ADC_SMPR2 registers. It is therefore possible to select among the following sampling time values:

- SMP = 000: 2.5 ADC clock cycles
- SMP = 001: 6.5 ADC clock cycles
- SMP = 010: 12.5 ADC clock cycles
- SMP = 011: 24.5 ADC clock cycles
- SMP = 100: 47.5 ADC clock cycles
- SMP = 101: 92.5 ADC clock cycles
- SMP = 110: 247.5 ADC clock cycles
- SMP = 111: 640.5 ADC clock cycles

The total conversion time is calculated as follows:

T_{CONV} = Sampling time + 12.5 ADC clock cycles

Example:

With $F_{adc_ker_ck}$ = 30 MHz and a sampling time of 2.5 ADC clock cycles:

T_{CONV} = (2.5 + 12.5) ADC clock cycles = 15 ADC clock cycles = 500 ns

The ADC notifies the end of the sampling phase by setting the status bit EOSMP (only for regular conversion).

Note: Depending on the ADC conversion mode, the real sampling time can vary compared to the SMP value programmed above, while the equivalent total conversion time (T_{CONV}) does not change:

- *For the first conversion in scan or continuous mode and all the conversions in discontinuous mode, the real sampling time is 0.5 clock cycle less compared to the value configured above.*
- *For the second and subsequent conversions in scan or continuous mode, 0.5 cycle is added to the configured sampling time. This additional 0.5 clock cycle overlaps with the previous conversion cycle.*

Constraints on the sampling time

For each channel, SMP[2:0] bits must be programmed to respect a minimum sampling time as specified in the ADC characteristics section of the datasheets.

Bulb sampling mode

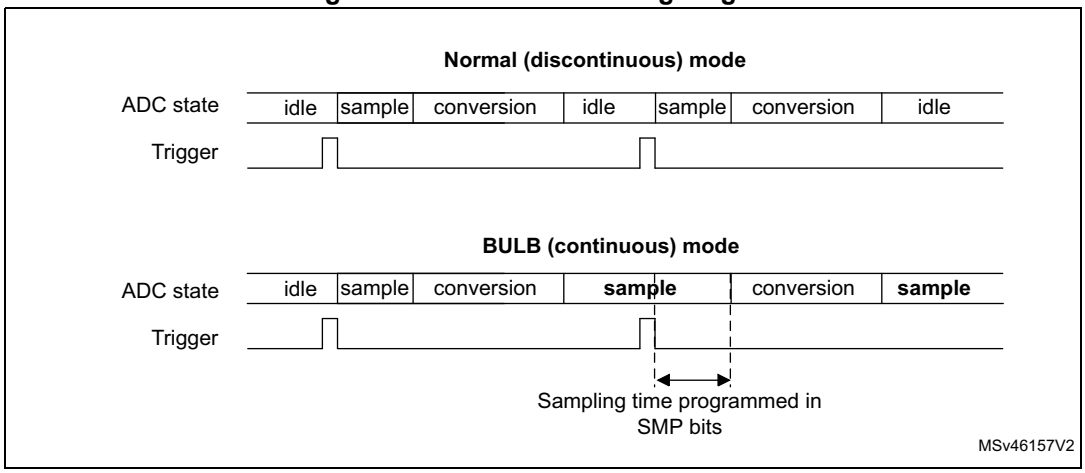
When the BULB bit is set in ADC register, the sampling period starts immediately after the last ADC conversion. A hardware or software trigger starts the conversion after the sampling time has been programmed in ADC_SMPR1 register. The very first ADC conversion, after the ADC is enabled, is performed with the sampling time programmed in SMP bits. The bulb mode is effective starting from the second conversion.

The maximum sampling time is limited (refer to the ADC characteristics section of the datasheet).

The bulb mode is neither compatible with the continuous conversion mode nor with the injected channel conversion.

When the BULB bit is set, it is not allowed to set SMPTRIG bit in ADC_CFGR2.

Figure 248. Bulb mode timing diagram



Sampling time control trigger mode

When the SMPTRIG bit is set, the sampling time programmed though SMPx bits is not applicable. The sampling time is controlled by the trigger signal edge.

When a hardware trigger is selected, each rising edge of the trigger signal starts the sampling period. A falling edge ends the sampling period and starts the conversion.

When a software trigger is selected, the software trigger is not the ADSTART bit in ADC_CR but the SWTRIG bit. SWTRIG bit has to be set to start the sampling period, and the SWTRIG bit has to be cleared to end the sampling period and start the conversion.

The maximum sampling time is limited (refer to the ADC characteristics section of the datasheet).

This mode is neither compatible with the continuous conversion mode, nor with the injected channel conversion.

When SMPTRIG bit is set, it is not allowed to set BULB bit.

I/O analog switch voltage booster

The resistance of the I/O analog switches increases when the V_{DDA} voltage is too low. The sampling time must consequently be adapted accordingly (refer to the device datasheet for the corresponding electrical characteristics). This resistance can be minimized at low V_{DDA}

by enabling an internal voltage booster through BOOSTE bit or by selecting a V_{DD} booster voltage (if V_{DD} > 2.7 V) through the ADV_READY bit of the PWR_PMCR register.

SMPPLUS control bit

The SMPPLUS bit can be used to change the sampling time from 2.5 ADC clock cycles to 3.5 ADC clock cycles.

30.4.13 Single conversion mode (CONT = 0)

In single conversion mode, the ADC performs once all the conversions of the channels. This mode is started with the CONT bit at 0 by either:

- Setting the ADSTART bit in the ADC_CR register (for a regular channel)
- Setting the JADSTART bit in the ADC_CR register (for an injected channel)
- External hardware trigger event (for a regular or injected channel)

Inside the regular sequence, after each conversion is complete:

- The converted data are stored into the 16-bit ADC_DR register
- The EOC (end of regular conversion) flag is set
- An interrupt is generated if the EOCIE bit is set

Inside the injected sequence, after each conversion is complete:

- The converted data are stored into one of the four 16-bit ADC_JDRy registers
- The JEOC (end of injected conversion) flag is set
- An interrupt is generated if the JEOCIE bit is set

After the regular sequence is complete:

- The EOS (end of regular sequence) flag is set
- An interrupt is generated if the EOSIE bit is set

After the injected sequence is complete:

- The JEOS (end of injected sequence) flag is set
- An interrupt is generated if the JEOSIE bit is set

Then the ADC stops until a new external regular or injected trigger occurs or until bit ADSTART or JADSTART is set again.

Note: To convert a single channel, program a sequence with a length of 1.

30.4.14 Continuous conversion mode (CONT = 1)

This mode applies to regular channels only.

In continuous conversion mode, when a software or hardware regular trigger event occurs, the ADC performs once all the regular conversions of the channels and then automatically restarts and continuously converts each conversions of the sequence. This mode is started with the CONT bit at 1 either by external trigger or by setting the ADSTART bit in the ADC_CR register.

Inside the regular sequence, after each conversion is complete:

- The converted data are stored into the 16-bit ADC_DR register
- The EOC (end of conversion) flag is set
- An interrupt is generated if the EOCIE bit is set

After the sequence of conversions is complete:

- The EOS (end of sequence) flag is set
- An interrupt is generated if the EOSIE bit is set

Then, a new sequence restarts immediately and the ADC continuously repeats the conversion sequence.

Note: To convert a single channel, program a sequence with a length of 1.

It is not possible to have both discontinuous mode and continuous mode enabled: it is forbidden to set both DISCEN = 1 and CONT = 1.

Injected channels cannot be converted continuously. The only exception is when an injected channel is configured to be converted automatically after regular channels in continuous mode (using JAUTO bit), refer to Auto-injection mode section).

30.4.15 Starting conversions (ADSTART, JADSTART)

Software starts ADC regular conversions by setting ADSTART = 1.

When ADSTART is set, the conversion starts:

- Immediately: if EXTEN = 0x0 (software trigger)
- At the next active edge of the selected regular hardware trigger: if EXTEN is not equal to 0x0

Software starts ADC injected conversions by setting JADSTART = 1.

When JADSTART is set, the conversion starts:

- Immediately, if JEXTEN = 0x0 (software trigger)
- At the next active edge of the selected injected hardware trigger: if JEXTEN is not equal to 0x0

Note: In auto-injection mode (JAUTO = 1), use ADSTART bit to start the regular conversions followed by the auto-injected conversions (JADSTART must be kept cleared).

ADSTART and JADSTART also provide information on whether any ADC operation is currently ongoing. It is possible to re-configure the ADC while ADSTART = 0 and JADSTART = 0 are both true, indicating that the ADC is idle.

ADSTART is cleared by hardware:

- In single mode with software regular trigger (CONT = 0, EXTSEL = 0x0)
  - At any end of regular conversion sequence (EOS assertion) or at any end of subgroup processing if DISCEN = 1
- In all cases (CONT = x, EXTSEL = x)
  - After execution of the ADSTP procedure asserted by the software.

Note: In continuous mode (CONT = 1), ADSTART is not cleared by hardware with the assertion of EOS because the sequence is automatically relaunched.

When a hardware trigger is selected in single mode (CONT = 0 and EXTSEL # 0x00), ADSTART is not cleared by hardware with the assertion of EOS to help the software which does not need to reset ADSTART again for the next hardware trigger event. This ensures that no further hardware triggers are missed.

JADSTART is cleared by hardware:

- In single mode with software injected trigger (JEXTSEL = 0x0)
  - At any end of injected conversion sequence (JEOS assertion) or at any end of subgroup processing if JDISCEN = 1
- in all cases (JEXTSEL = x)
  - After execution of the JADSTP procedure asserted by the software.

Note: When the software trigger is selected, ADSTART bit should not be set if the EOC flag is still high.

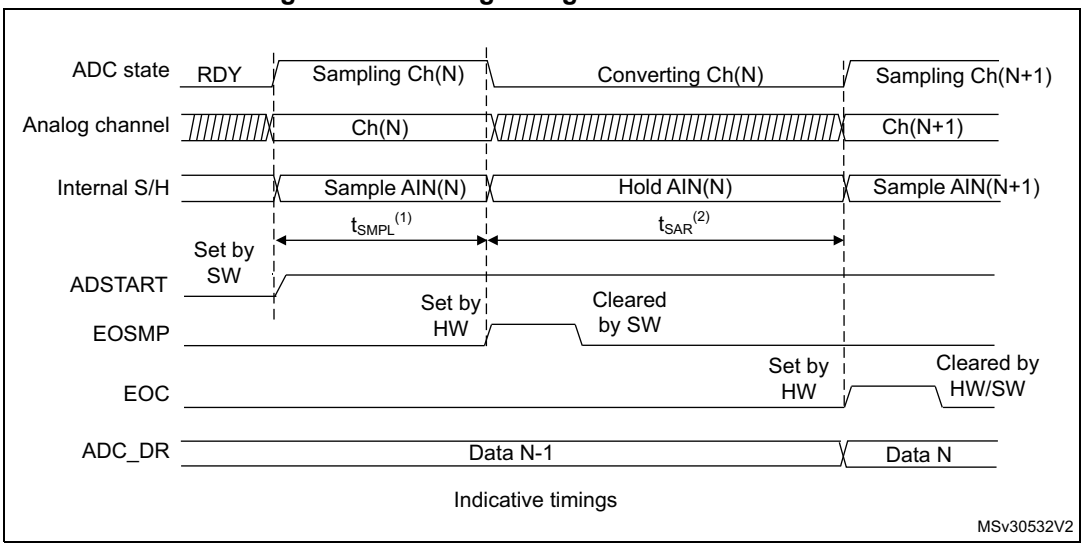
30.4.16 ADC timing

The elapsed time between the start of a conversion and the end of conversion is the sum of the configured sampling time plus the successive approximation time depending on data resolution:

$T_{CONV} = T_{SMPL} + T_{SAR} = [2.5\ _{|min} + 12.5\ _{|12bit}] \times T_{ADC_CLK}$

$T_{CONV} = T_{SMPL} + T_{SAR} = 83.33\ ns\ _{|min} + 416.67\ ns\ _{|12bit} = 500.0\ ns$ (for $F_{ADC_CLK} = 30$ MHz)

Figure 249. Analog-to-digital conversion time



1. T_{SMPL} depends on SMP[2:0].
2. T_{SAR} depends on RES[2:0].

30.4.17 Stopping an ongoing conversion (ADSTP, JADSTP)

The software can decide to stop regular conversions ongoing by setting ADSTP = 1 and injected conversions ongoing by setting JADSTP = 1.

Stopping conversions resets the ongoing ADC operation. Then the ADC can be reconfigured (ex: changing the channel selection or the trigger) ready for a new operation.

Note that it is possible to stop injected conversions while regular conversions are still operating and vice-versa. This allows, for instance, re-configuration of the injected conversion sequence and triggers while regular conversions are still operating (and vice-versa).

When the ADSTP bit is set by software, any ongoing regular conversion is aborted with partial result discarded (ADC_DR register is not updated with the current conversion).

When the JADSTP bit is set by software, any ongoing injected conversion is aborted with partial result discarded (ADC_JDRy register is not updated with the current conversion). The scan sequence is also aborted and reset (meaning that relaunching the ADC would restart a new sequence).

Once this procedure is complete, bits ADSTP/ADSTART (in case of regular conversion), or JADSTP/JADSTART (in case of injected conversion) are cleared by hardware and the software must poll ADSTART (or JADSTART) until the bit is reset before assuming the ADC is completely stopped.

Note: In auto-injection mode (JAUTO = 1), setting ADSTP bit aborts both regular and injected conversions (JADSTP must not be used).

Figure 250. Stopping ongoing regular conversions

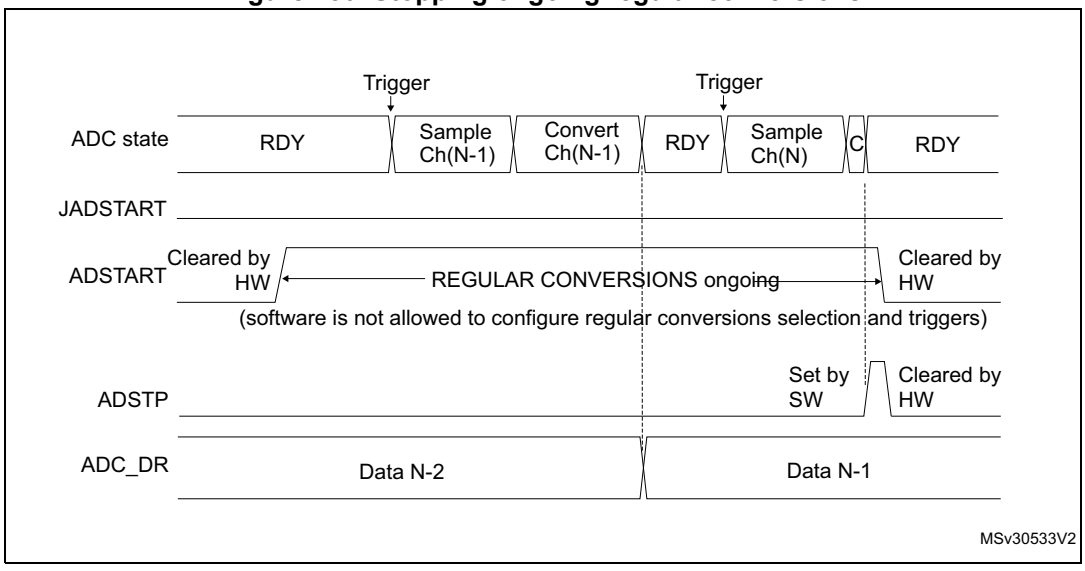
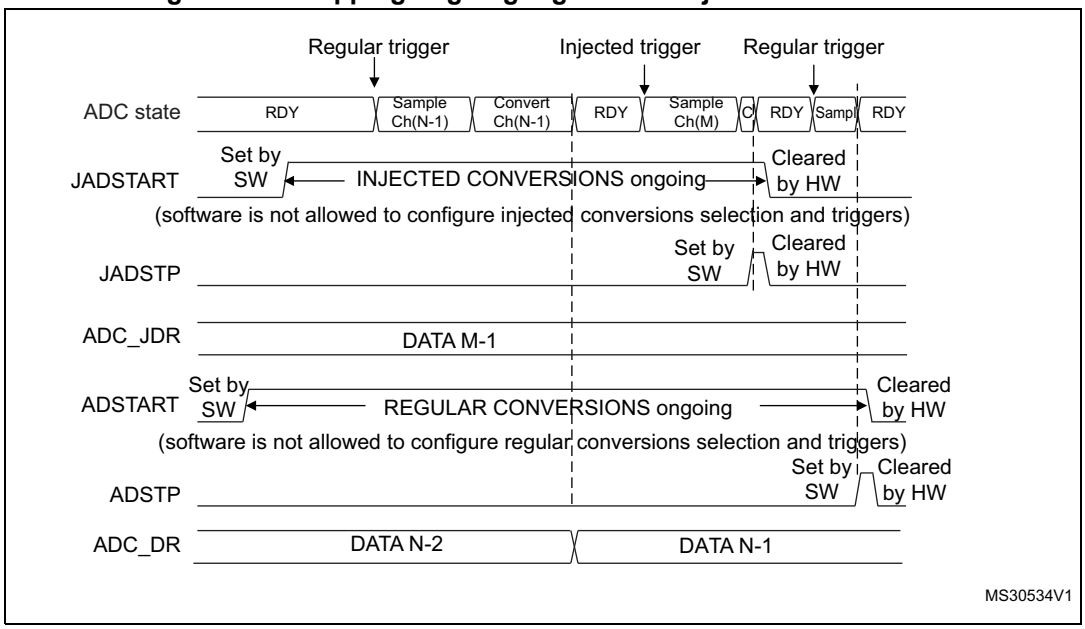


Figure 251. Stopping ongoing regular and injected conversions



30.4.18 Conversion on external trigger and trigger polarity (EXTSEL, EXTEN,JEXTSEL, JEXTEN)

A conversion or a sequence of conversions can be triggered either by software or by an external event (such as timer capture, input pins). If the EXTEN[1:0] control bits (for a regular conversion) or JEXTEN[1:0] bits (for an injected conversion) are different from 0b00, then external events are able to trigger a conversion with the selected polarity.

When the Injected Queue is enabled (bit JQDIS = 0), injected software triggers are not possible.

The regular trigger selection is effective once software has set bit ADSTART = 1 and the injected trigger selection is effective once software has set bit JADSTART = 1.

Any hardware triggers which occur while a conversion is ongoing are ignored.

- If bit ADSTART = 0, any regular hardware triggers which occur are ignored.
- If bit JADSTART = 0, any injected hardware triggers which occur are ignored.

Table 291 provides the correspondence between the EXTEN[1:0] and JEXTEN[1:0] values and the trigger polarity.

Table 291. Configuring the trigger polarity for regular external triggers

EXTEN[1:0]	Source
00	Hardware Trigger detection disabled, software trigger detection enabled
01	Hardware Trigger with detection on the rising edge
10	Hardware Trigger with detection on the falling edge
11	Hardware Trigger with detection on both the rising and falling edges

Note: The polarity of the regular trigger cannot be changed on-the-fly.

Table 292. Configuring the trigger polarity for injected external triggers

JEXTEN[1:0]	Source
00	– If JQDIS = 1 (Queue disabled): Hardware trigger detection disabled, software trigger detection enabled – If JQDIS = 0 (Queue enabled), Hardware and software trigger detection disabled
01	Hardware Trigger with detection on the rising edge
10	Hardware Trigger with detection on the falling edge
11	Hardware Trigger with detection on both the rising and falling edges

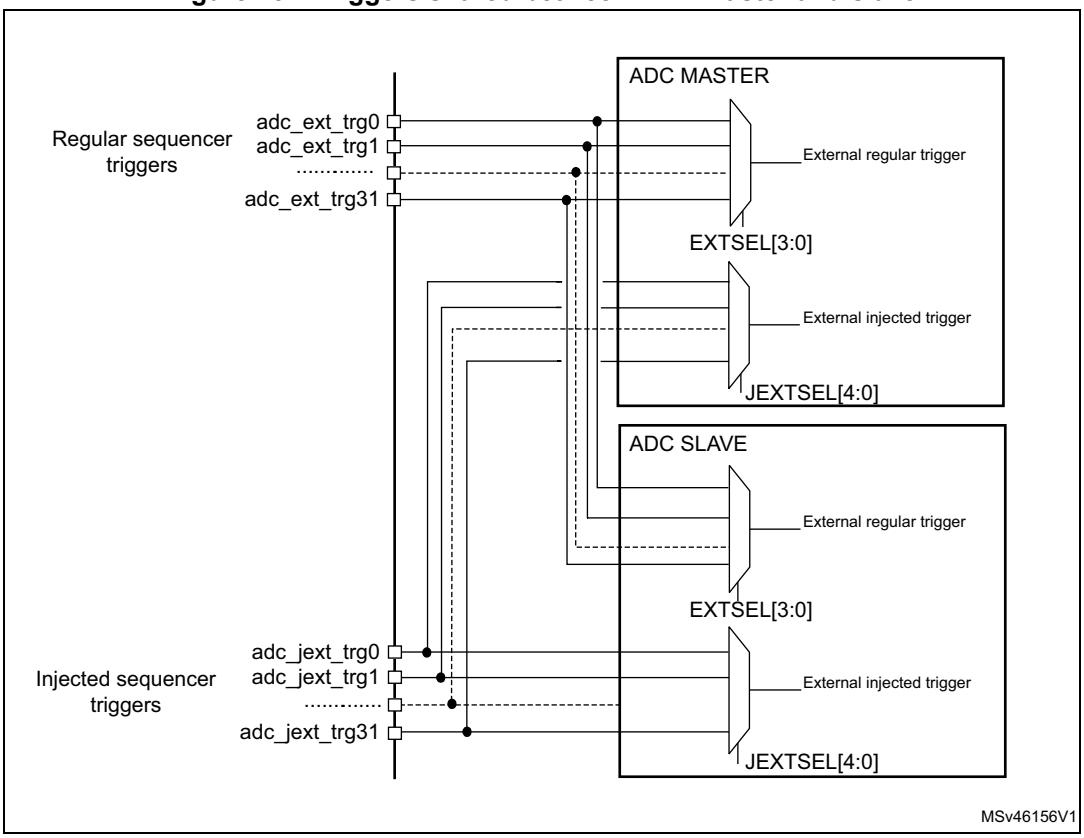
Note: The polarity of the injected trigger can be anticipated and changed on-the-fly when the queue is enabled (JQDIS = 0). Refer to Section 30.4.21: Queue of context for injected conversions.

The EXTSEL and JEXTSEL control bits select which out of 32 possible events can trigger conversion for the regular and injected groups.

A regular group conversion can be interrupted by an injected trigger.

Note: The regular trigger selection cannot be changed on-the-fly. The injected trigger selection can be anticipated and changed on-the-fly. Refer to Section 30.4.21: Queue of context for injected conversions on page 1287.

Figure 252. Triggers shared between ADC master and slave



Refer to Table ADC interconnection in *Section 30.4.2: ADC pins and internal signals* for the list of all the external triggers that can be used for regular conversion.

30.4.19 Injected channel management

Triggered injection mode

To use triggered injection, the JAUTO bit in the ADC_CFGR register must be cleared.

1. Start the conversion of a group of regular channels either by an external trigger or by setting the ADSTART bit in the ADC_CR register.
2. If an external injected trigger occurs, or if the JADSTART bit in the ADC_CR register is set during the conversion of a regular group of channels, the current conversion is reset and the injected channel sequence switches are launched (all the injected channels are converted once).
3. Then, the regular conversion of the regular group of channels is resumed from the last interrupted regular conversion.
4. If a regular event occurs during an injected conversion, the injected conversion is not interrupted but the regular sequence is executed at the end of the injected sequence. *Figure 253* shows the corresponding timing diagram.

Note: When using triggered injection, one must ensure that the interval between trigger events is longer than the injection sequence. For instance, if the sequence length is 30 ADC clock cycles (that is two conversions with a sampling time of 2.5 clock periods), the minimum interval between triggers must be 31 ADC clock cycles.

Auto-injection mode

If the JAUTO bit in the ADC_CFGR register is set, then the channels in the injected group are automatically converted after the regular group of channels. This can be used to convert a sequence of up to 20 conversions programmed in the ADC_SQRy and ADC_JSQR registers.

In this mode, the ADSTART bit in the ADC_CR register must be set to start regular conversions, followed by injected conversions (JADSTART must be kept cleared). Setting the ADSTP bit aborts both regular and injected conversions (JADSTP bit must not be used).

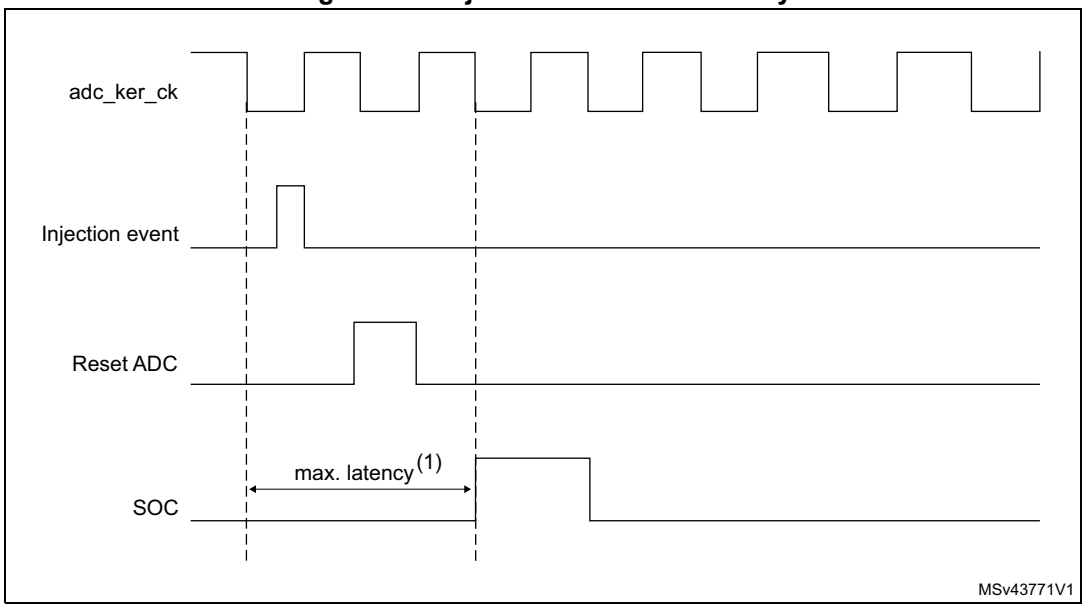
In this mode, external trigger on injected channels must be disabled.

If the CONT bit is also set in addition to the JAUTO bit, regular channels followed by injected channels are continuously converted.

Note: It is not possible to use both the auto-injected and discontinuous modes simultaneously.

When the DMA is used for exporting regular sequencer's data in JAUTO mode, it is necessary to program it in circular mode. If the single-shot mode is selected, the JAUTO sequence is stopped upon DMA Transfer Complete event.

Figure 253. Injected conversion latency



1. The maximum latency value can be found in the electrical characteristics of the device datasheet.

30.4.20 Discontinuous mode (DISCEN, DISCNUM, JDISCEN)

Regular group mode

This mode is enabled by setting the DISCEN bit in the ADC_CFGR register.

It is used to convert a short sequence (subgroup) of n conversions (n ≤ 8) that is part of the sequence of conversions selected in the ADC_SQRy registers. The value of n is specified by writing to the DISCNUM[2:0] bits in the ADC_CFGR register.

When an external trigger occurs, it starts the next n conversions selected in the ADC_SQRy registers until all the conversions in the sequence are done. The total sequence length is defined by the L[3:0] bits in the ADC_SQR1 register.

Example:

- DISCEN = 1, n = 3, channels to be converted = 1, 2, 3, 6, 7, 8, 9, 10, 11
  - 1st trigger: channels converted are 1, 2, 3 (an EOC event is generated at each conversion).
  - 2nd trigger: channels converted are 6, 7, 8 (an EOC event is generated at each conversion).
  - 3rd trigger: channels converted are 9, 10, 11 (an EOC event is generated at each conversion) and an EOS event is generated after the conversion of channel 11.
  - 4th trigger: channels converted are 1, 2, 3 (an EOC event is generated at each conversion).
  - ...
- DISCEN = 0, channels to be converted = 1, 2, 3, 6, 7, 8, 9, 10,11
  - 1st trigger: the complete sequence is converted: channel 1, then 2, 3, 6, 7, 8, 9, 10 and 11. Each conversion generates an EOC event and the last one also generates an EOS event.
  - All the next trigger events relaunch the complete sequence.

Note: The channel numbers referred to in the above example might not be available on all microcontrollers.

When a regular group is converted in discontinuous mode, no rollover occurs (the last subgroup of the sequence can have less than n conversions).

When all subgroups are converted, the next trigger starts the conversion of the first subgroup. In the example above, the 4th trigger reconverts the channels 1, 2 and 3 in the 1st subgroup.

It is not possible to have both discontinuous mode and continuous mode enabled. In this case (if DISCEN = 1, CONT = 1), the ADC behaves as if continuous mode was disabled.

Injected group mode

This mode is enabled by setting the JDISCEN bit in the ADC_CFGR register. It converts the sequence selected in the ADC_JSQR register, channel by channel, after an external injected trigger event. This is equivalent to discontinuous mode for regular channels where ‘n’ is fixed to 1.

When an external trigger occurs, it starts the next channel conversions selected in the ADC_JSQR registers until all the conversions in the sequence are done. The total sequence length is defined by the JL[1:0] bits in the ADC_JSQR register.

Example:

- JDISCEN = 1, channels to be converted = 1, 2, 3
  - 1st trigger: channel 1 converted (a JEOC event is generated)
  - 2nd trigger: channel 2 converted (a JEOC event is generated)
  - 3rd trigger: channel 3 converted and a JEOC event + a JEOS event are generated
  - ...

Note: The channel numbers referred to in the above example might not be available on all microcontrollers.

When all injected channels have been converted, the next trigger starts the conversion of the first injected channel. In the example above, the 4th trigger reconverts the 1st injected channel 1.

It is not possible to use both auto-injected mode and discontinuous mode simultaneously: the bits DISCEN and JDISCEN must be kept cleared by software when JAUTO is set.

30.4.21 Queue of context for injected conversions

A queue of context is implemented to anticipate up to 2 contexts for the next injected sequence of conversions. JQDIS bit of ADC_CFGR register must be reset to enable this feature. Only hardware-triggered conversions are possible when the context queue is enabled.

This context consists of:

- Configuration of the injected triggers (bits JEXTEN[1:0] and JEXTSEL bits in ADC_JSQR register)
- Definition of the injected sequence (bits JSQx[4:0] and JL[1:0] in ADC_JSQR register)

All the parameters of the context are defined into a single register ADC_JSQR and this register implements a queue of 2 buffers, allowing the bufferization of up to 2 sets of parameters:

- The ADC_JSQR register can be written at any moment even when injected conversions are ongoing.
- Each data written into the ADC_JSQR register is stored into the Queue of context.
- At the beginning, the Queue is empty and the first write access into the ADC_JSQR register immediately changes the context and the ADC is ready to receive injected triggers.
- Once an injected sequence is complete, the Queue is consumed and the context changes according to the next ADC_JSQR parameters stored in the Queue. This new context is applied for the next injected sequence of conversions.
- A Queue overflow occurs when writing into register ADC_JSQR while the Queue is full. This overflow is signaled by the assertion of the flag JQOVF. When an overflow occurs, the write access of ADC_JSQR register which has created the overflow is ignored and the queue of context is unchanged. An interrupt can be generated if bit JQOVFIE is set.
- Two possible behaviors are possible when the Queue becomes empty, depending on the value of the control bit JQM of register ADC_CFGR:
  - If JQM = 0, the Queue is empty just after enabling the ADC, but then it can never be empty during run operations: the Queue always maintains the last active context and any further valid start of injected sequence is served according to the last active context.
  - If JQM = 1, the Queue can be empty after the end of an injected sequence or if the Queue is flushed. When this occurs, there is no more context in the queue and hardware triggers are disabled. Therefore, any further hardware injected triggers are ignored until the software re-writes a new injected context into ADC_JSQR register.
- Reading ADC_JSQR register returns the current ADC_JSQR context which is active at that moment. When the ADC_JSQR context is empty, JSQi is read as 0x00.
- The Queue is flushed when stopping injected conversions by setting JADSTP = 1 or when disabling the ADC by setting ADDIS = 1:
  - If JQM = 0, the Queue is maintained with the last active context.
  - If JQM = 1, the Queue becomes empty and triggers are ignored.

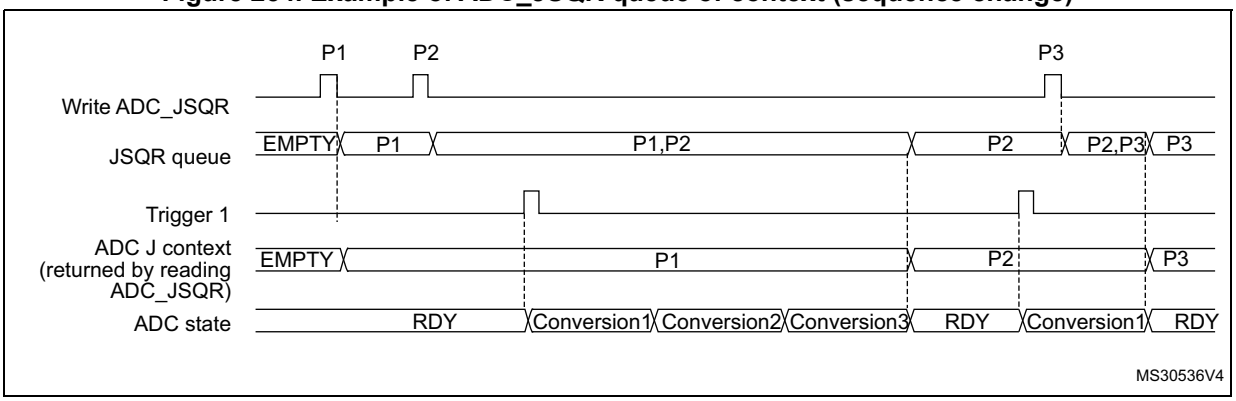
Note: When configured in discontinuous mode (bit JDISCEN = 1), only the last trigger of the injected sequence changes the context and consumes the Queue.The 1st trigger only consumes the queue but others are still valid triggers as shown by the discontinuous mode example below (length = 3 for both contexts):

- *1st trigger, discontinuous. Sequence 1: context 1 consumed, 1st conversion carried out*
- *2nd trigger, disc. Sequence 1: 2nd conversion.*
- *3rd trigger, discontinuous. Sequence 1: 3rd conversion.*
- *4th trigger, discontinuous. Sequence 2: context 2 consumed, 1st conversion carried out.*
- *5th trigger, discontinuous. Sequence 2: 2nd conversion.*
- *6th trigger, discontinuous. Sequence 2: 3rd conversion.*

Behavior when changing the trigger or sequence context

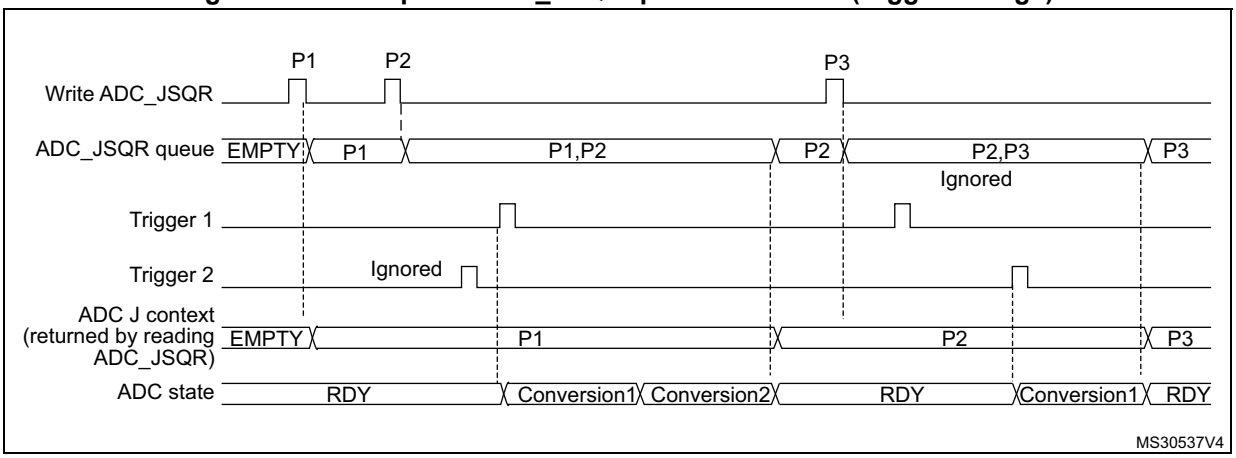
Figure 254 and *Figure 255* show the behavior of the context Queue when changing the sequence or the triggers.

Figure 254. Example of ADC_JSQR queue of context (sequence change)



1. Parameters:
   P1: sequence of 3 conversions, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 4 conversions, hardware trigger 1

Figure 255. Example of ADC_JSQR queue of context (trigger change)

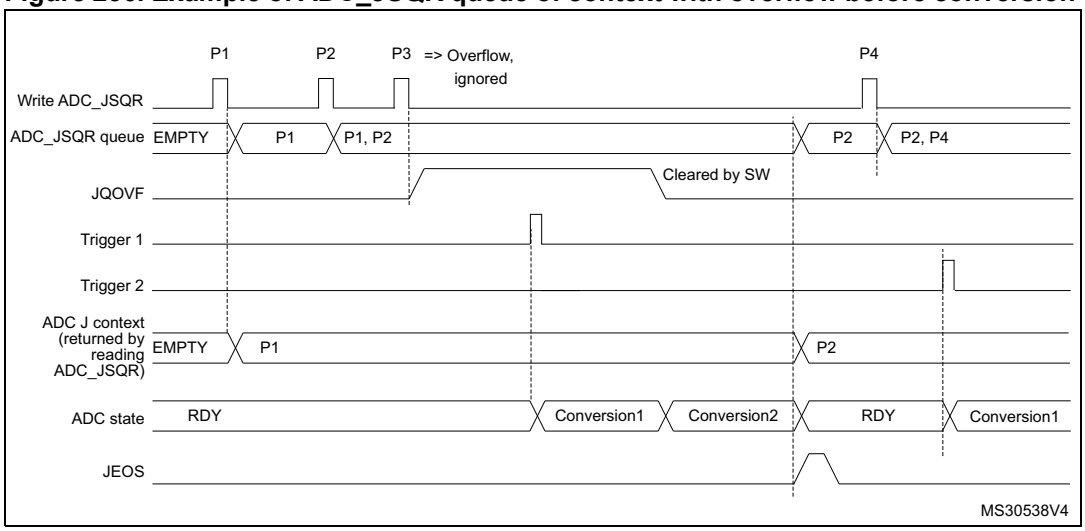


1. Parameters:
   P1: sequence of 2 conversions, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 2
   P3: sequence of 4 conversions, hardware trigger 1

Queue of context: Behavior when a queue overflow occurs

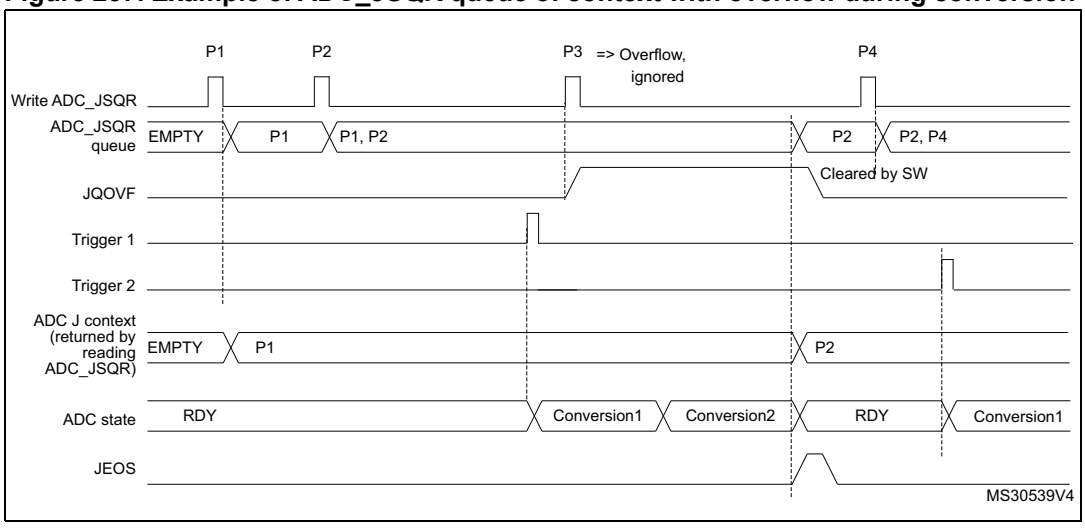
The *Figure 256* and *Figure 257* show the behavior of the context Queue if an overflow occurs before or during a conversion.

Figure 256. Example of ADC_JSQR queue of context with overflow before conversion



1. Parameters:
   P1: sequence of 2 conversions, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 2
   P3: sequence of 3 conversions, hardware trigger 1
   P4: sequence of 4 conversions, hardware trigger 1

Figure 257. Example of ADC_JSQR queue of context with overflow during conversion



1. Parameters:
   P1: sequence of 2 conversions, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 2
   P3: sequence of 3 conversions, hardware trigger 1
   P4: sequence of 4 conversions, hardware trigger 1

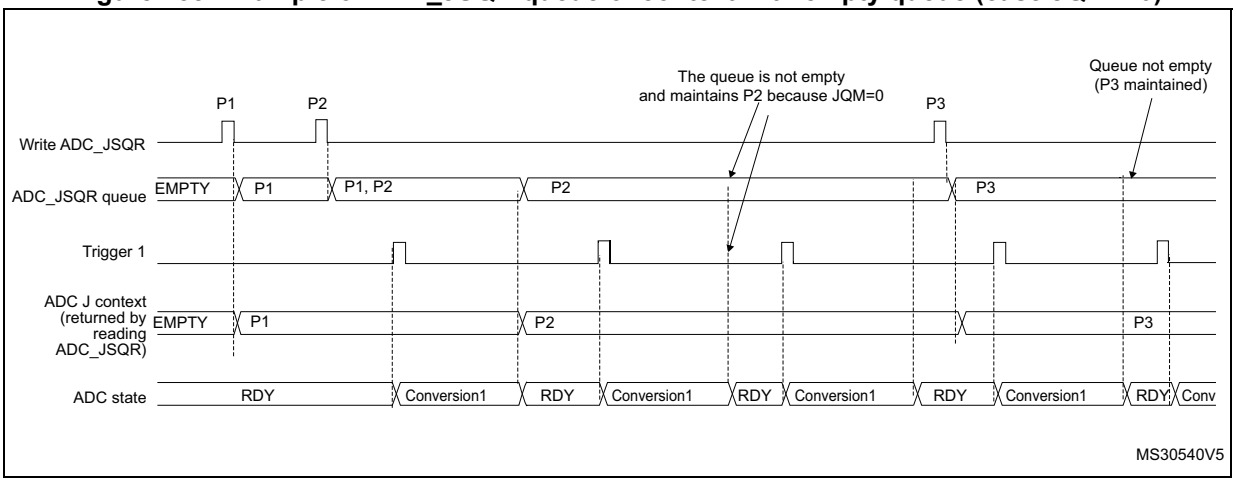
It is recommended to manage the queue overflows as described below:

- After each P context write into ADC_JSQR register, flag JQOVF shows if the write has been ignored or not (an interrupt can be generated).
- Avoid Queue overflows by writing the third context (P3) only once the flag JEOS of the previous context P2 has been set. This ensures that the previous context has been consumed and that the queue is not full.

Queue of context: Behavior when the queue becomes empty

Figure 258 and *Figure 259* show the behavior of the context Queue when the Queue becomes empty in both cases JQM = 0 or 1.

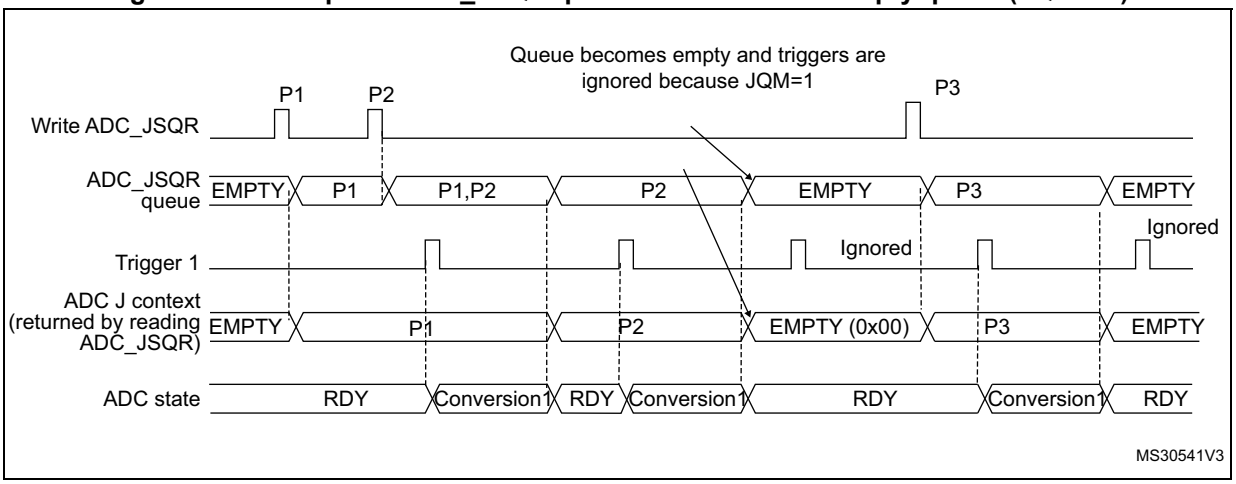
Figure 258. Example of ADC_JSQR queue of context with empty queue (case JQM = 0)



1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Note: When writing P3, the context changes immediately. However, because of internal resynchronization, there is a latency and if a trigger occurs just after or before writing P3, it can happen that the conversion is launched considering the context P2. To avoid this situation, the user must ensure that there is no ADC trigger happening when writing a new context that applies immediately.

Figure 259. Example of ADC_JSQR queue of context with empty queue (JQM = 1)

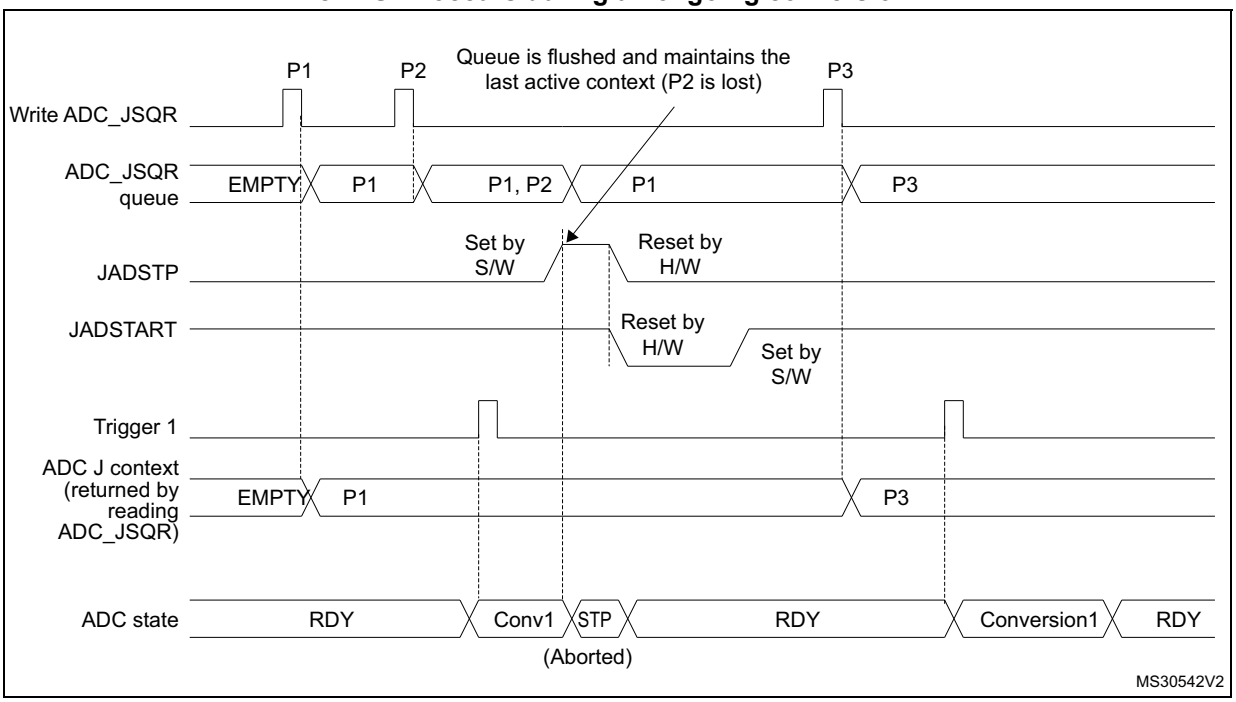


1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Flushing the queue of context

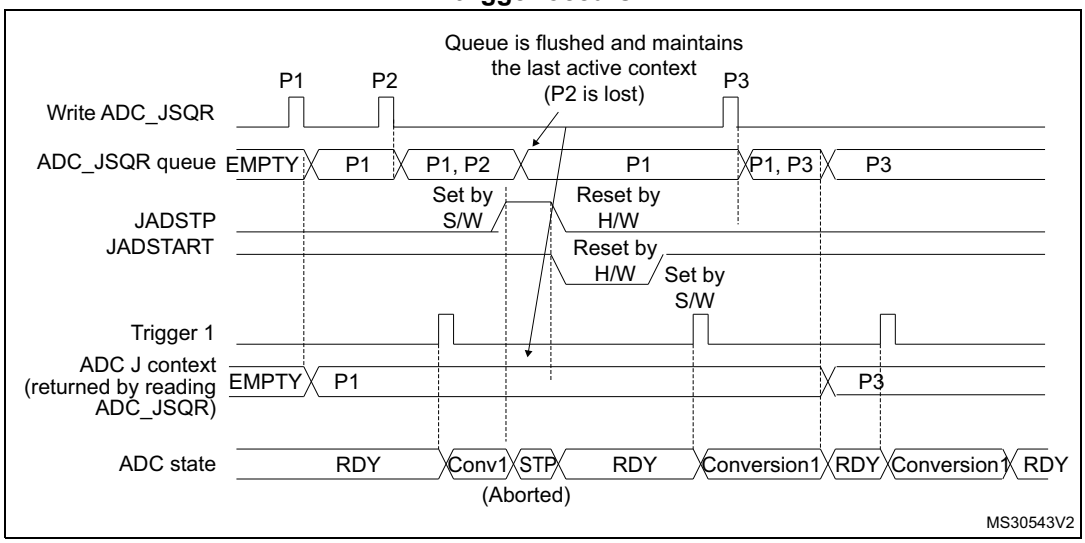
The figures below show the behavior of the context Queue in various situations when the queue is flushed.

Figure 260. Flushing ADC_JSQR queue of context by setting JADSTP = 1 (JQM = 0) - JADSTP occurs during an ongoing conversion.



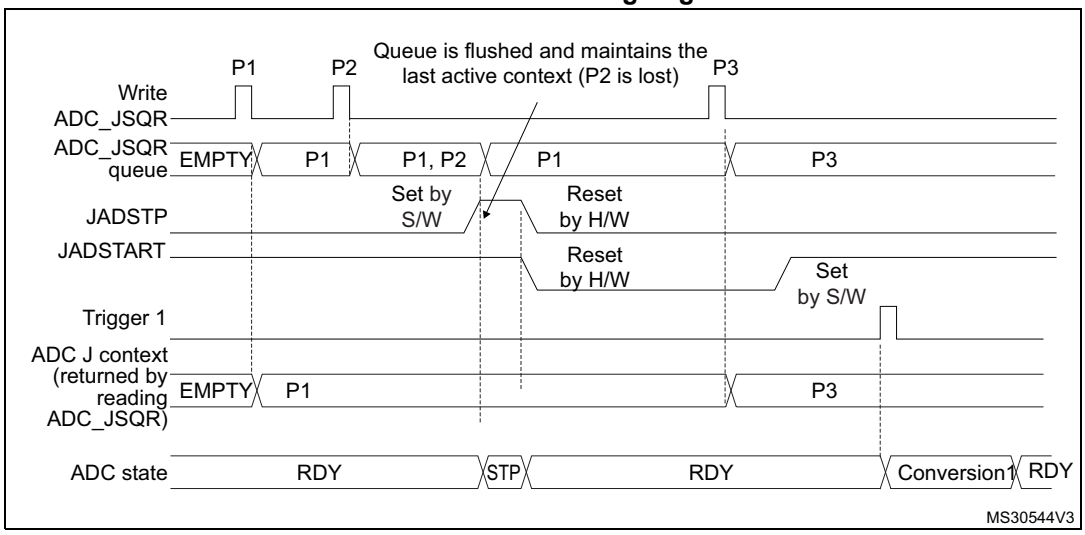
1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 261. Flushing ADC_JSQR queue of context by setting JADSTP = 1 (JQM = 0) - JADSTP occurs during an ongoing conversion and a new trigger occurs



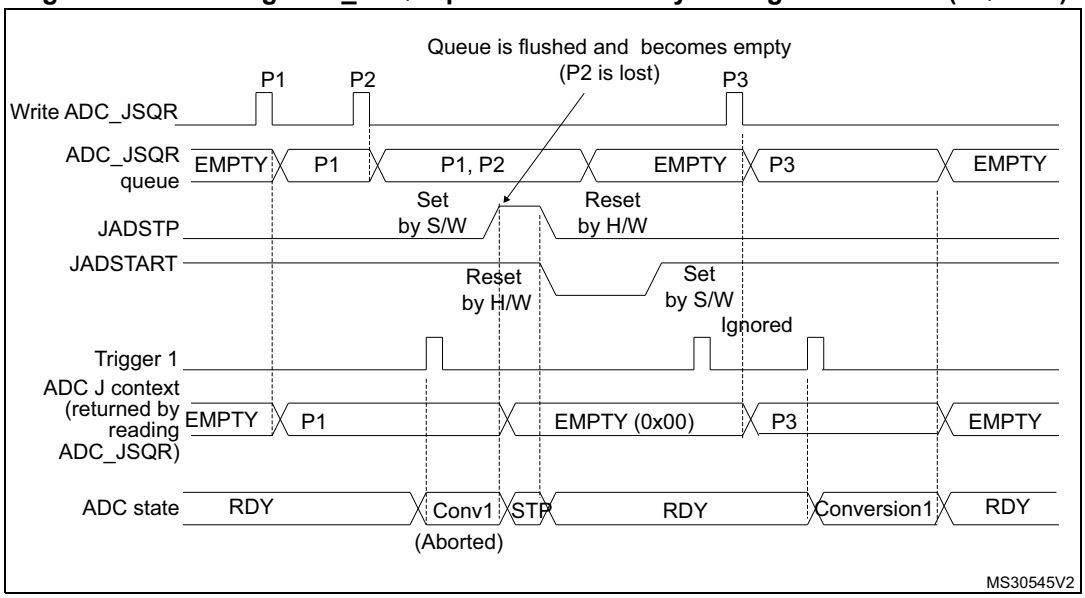
1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 262. Flushing ADC_JSQR queue of context by setting JADSTP = 1 (JQM = 0) - JADSTP occurs outside an ongoing conversion



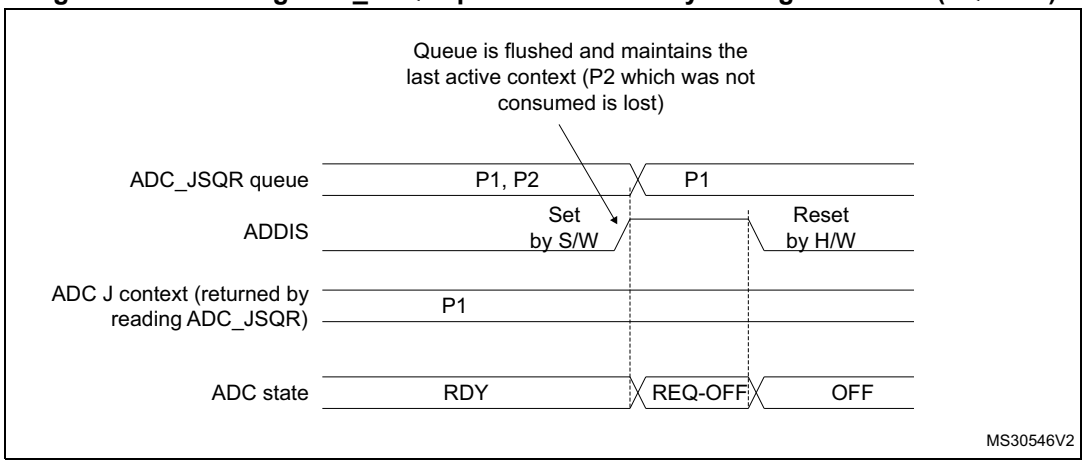
1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 263. Flushing ADC_JSQR queue of context by setting JADSTP = 1 (JQM = 1)



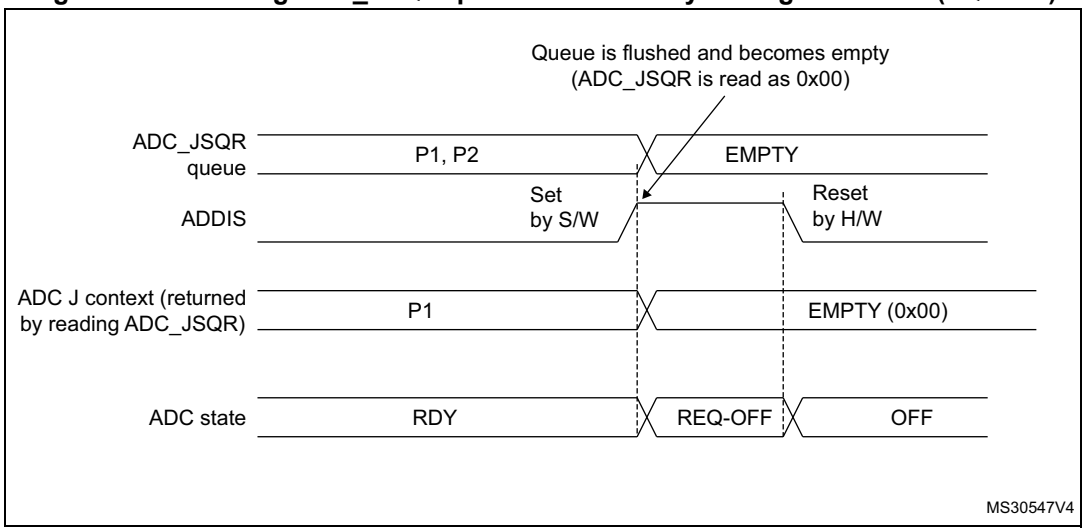
1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 264. Flushing ADC_JSQR queue of context by setting ADDIS = 1 (JQM = 0)



1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 265. Flushing ADC_JSQR queue of context by setting ADDIS = 1 (JQM = 1)



1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Queue of context: Starting the ADC with an empty queue

The following procedure must be followed to start ADC operation with an empty queue, in case the first context is not known at the time the ADC is initialized. This procedure is only applicable when JQM bit is reset:

5. Write a dummy ADC_JSQR with JEXTEN not equal to 0 (otherwise triggering a software conversion)
6. Set JADSTART
7. Set JADSTP
8. Wait until JADSTART is reset
9. Set JADSTART.

Disabling the queue

It is possible to disable the queue by setting bit JQDIS = 1 into the ADC_CFGR register.

30.4.22 Programmable resolution (RES) - fast conversion mode

It is possible to perform faster conversion by reducing the ADC resolution.

The resolution can be configured to be either 12, 10, 8, or 6 bits by programming the control bits RES[1:0]. *Figure 270*, *Figure 271*, *Figure 272* and *Figure 273* show the conversion result format with respect to the resolution as well as to the data alignment.

Lower resolution allows faster conversion time for applications where high-data precision is not required. It reduces the conversion time spent by the successive approximation steps according to *Table 293*.

Table 293. T_{SAR} timings depending on resolution

RES (bits)	T_{SAR} (ADC clock cycles)	T_{SAR} (ns) at F_{ADC} = 30 MHz	T_{CONV} (ADC clock cycles) (with Sampling Time = 2.5 ADC clock cycles)	T_{CONV} (ns) at F_{ADC} = 30 MHz
12	12.5 ADC clock cycles	416.67 ns	15 ADC clock cycles	500.0 ns
10	10.5 ADC clock cycles	350.0 ns	13 ADC clock cycles	433.33 ns
8	8.5 ADC clock cycles	203.33 ns	11 ADC clock cycles	366.67 ns
6	6.5 ADC clock cycles	216.67 ns	9 ADC clock cycles	300.0 ns

30.4.23 End of conversion, end of sampling phase (EOC, JEOC, EOSMP)

The ADC notifies the application for each end of regular conversion (EOC) event and each injected conversion (JEOC) event.

The ADC sets the EOC flag as soon as a new regular conversion data is available in the ADC_DR register. An interrupt can be generated if bit EOCIE is set. EOC flag is cleared by the software either by writing 1 to it or by reading ADC_DR.

The ADC sets the JEOC flag as soon as a new injected conversion data is available in one of the ADC_JDRy register. An interrupt can be generated if bit JEOCIE is set. JEOC flag is cleared by the software either by writing 1 to it or by reading the corresponding ADC_JDRy register.

The ADC also notifies the end of Sampling phase by setting the status bit EOSMP (for regular conversions only). EOSMP flag is cleared by software by writing 1 to it. An interrupt can be generated if bit EOSMPIE is set.

30.4.24 End of conversion sequence (EOS, JEOS)

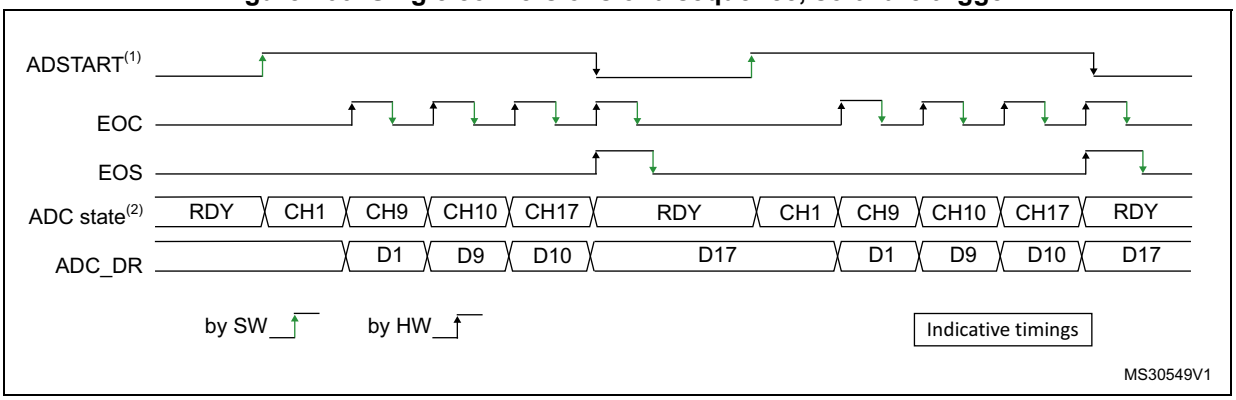
The ADC notifies the application for each end of regular sequence (EOS) and for each end of injected sequence (JEOS) event.

The ADC sets the EOS flag as soon as the last data of the regular conversion sequence is available in the ADC_DR register. An interrupt can be generated if bit EOSIE is set. EOS flag is cleared by the software either by writing 1 to it.

The ADC sets the JEOS flag as soon as the last data of the injected conversion sequence is complete. An interrupt can be generated if bit JEOSIE is set. JEOS flag is cleared by the software either by writing 1 to it.

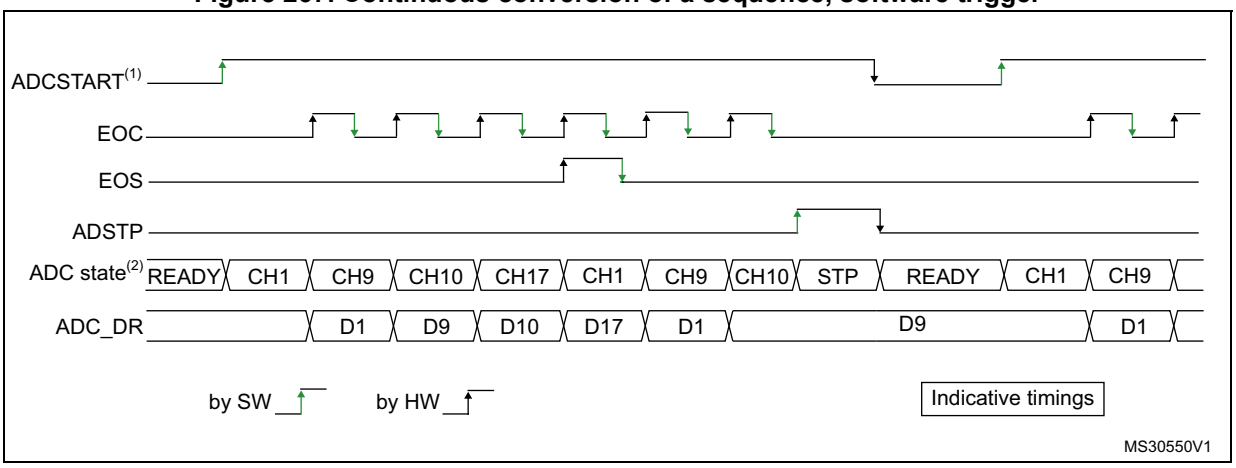
30.4.25 Timing diagrams example (single/continuous modes, hardware/software triggers)

Figure 266. Single conversions of a sequence, software trigger



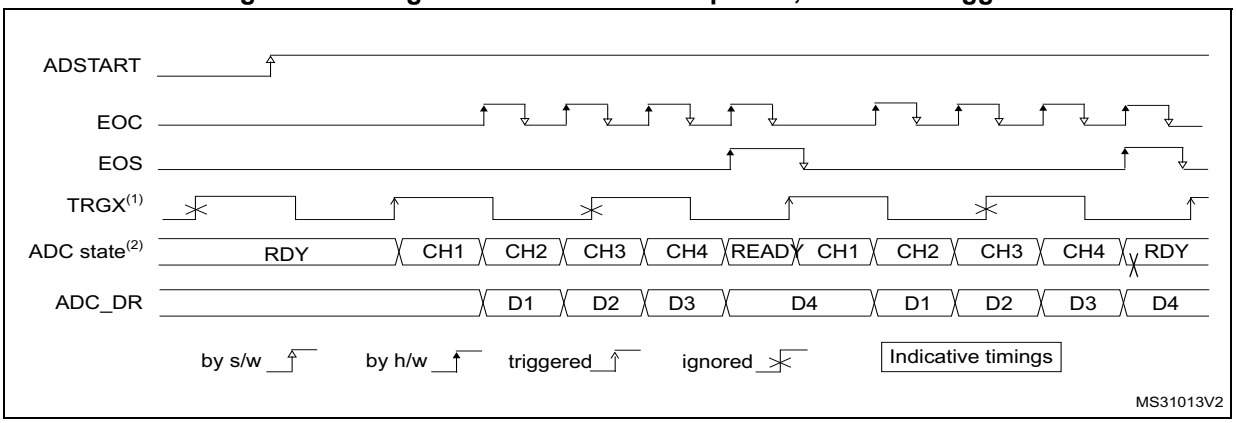
1. EXTEN = 0x0, CONT = 0
2. Channels selected = 1,9, 10, 17; AUTDLY = 0.

Figure 267. Continuous conversion of a sequence, software trigger



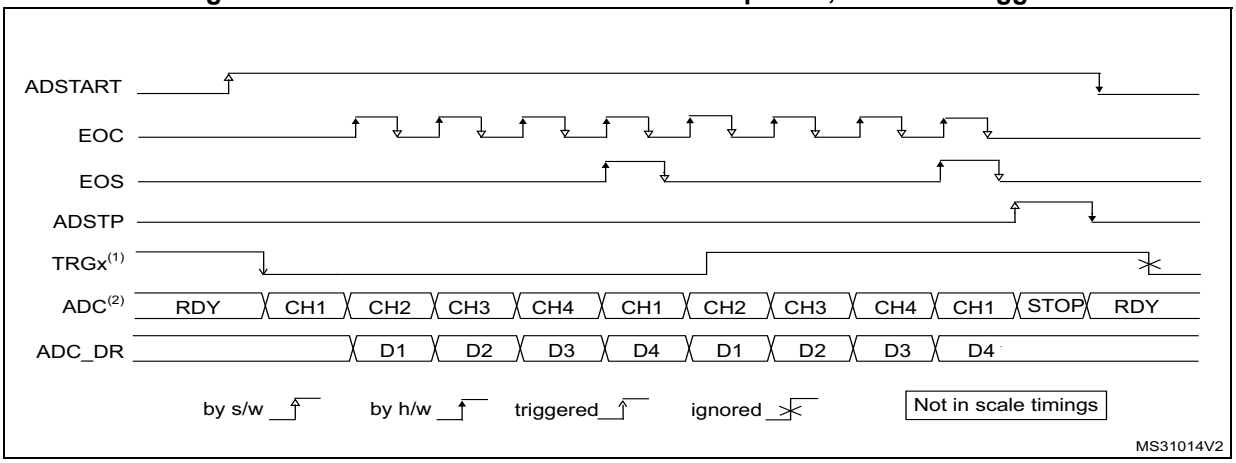
1. EXTEN = 0x0, CONT = 1
2. Channels selected = 1,9, 10, 17; AUTDLY = 0.

Figure 268. Single conversions of a sequence, hardware trigger



1. TRGx (over-frequency) is selected as trigger source, EXTEN = 01, CONT = 0
2. Channels selected = 1, 2, 3, 4; AUTDLY = 0.

Figure 269. Continuous conversions of a sequence, hardware trigger



1. TRGx is selected as trigger source, EXTEN = 10, CONT = 1
2. Channels selected = 1, 2, 3, 4; AUTDLY = 0.

30.4.26 Data management

Data register, data alignment and offset (ADC_DR, OFFSET, OFFSET_CH, ALIGN)

Data and alignment

At the end of each regular conversion channel (when EOC event occurs), the result of the converted data is stored into the ADC_DR data register which is 16 bits wide.

At the end of each injected conversion channel (when JEOC event occurs), the result of the converted data is stored into the corresponding ADC_JDRy data register which is 16 bits wide.

The ALIGN bit in the ADC_CFGR register selects the alignment of the data stored after conversion. Data can be right- or left-aligned as shown in *Figure 270*, *Figure 271*, *Figure 272* and *Figure 273*.

Special case: when left-aligned, the data are aligned on a half-word basis except when the resolution is set to 6-bit. In that case, the data are aligned on a byte basis as shown in *Figure 272* and *Figure 273*.

Note: Left-alignment is not supported in oversampling mode. When ROVSE and/or JOVSE bit is set, the ALIGN bit value is ignored and the ADC only provides right-aligned data.

Offset

An offset y (y = 1,2,3,4) can be applied to a channel by setting the bit OFFSET_EN = 1 into ADC_OFRy register. The channel to which the offset is to be applied is programmed into the bits OFFSET_CH[4:0] of ADC_OFRy register. In this case, the converted value is decreased by the user-defined offset written in the bits OFFSET[11:0]. The result may be a negative value so the read data is signed and the SEXT bit represents the extended sign value.

Note: Offset correction is not supported in oversampling mode. When ROVSE and/or JOVSE bit is set, the value of the OFFSET_EN bit in ADC_OFRy register is ignored (considered as reset).

Table 296 describes how the comparison is performed for all the possible resolutions for analog watchdog 1.

Table 294. Offset computation versus data resolution

Resolution (bits RES[1:0])	Subtraction between raw converted data and offset		Result	Comments
	Raw converted Data, left aligned	Offset		
00: 12-bit	DATA[11:0]	OFFSET[11:0]	Signed 12-bit data	-
01: 10-bit	DATA[11:2],00	OFFSET[11:0]	Signed 10-bit data	The user must configure OFFSET[1:0] to “00”

Table 294. Offset computation versus data resolution (continued)

Resolution (bits RES[1:0])	Subtraction between raw converted data and offset		Result	Comments
	Raw converted Data, left aligned	Offset		
10: 8-bit	DATA[11:4],0000	OFFSET[11:0]	Signed 8-bit data	The user must configure OFFSET[3:0] to “0000”
11: 6-bit	DATA[11:6],000000	OFFSET[11:0]	Signed 6-bit data	The user must configure OFFSET[5:0] to “000000”

When reading data from ADC_DR (regular channel) or from ADC_JDRy (injected channel, y = 1,2,3,4) corresponding to the channel “i”:

- If one of the offsets is enabled (bit OFFSET_EN = 1) for the corresponding channel, the read data is signed.
- If none of the four offsets is enabled for this channel, the read data is not signed.

Figure 270, *Figure 271*, *Figure 272* and *Figure 273* show alignments for signed and unsigned data.

Figure 270. Right alignment (offset disabled, unsigned value)

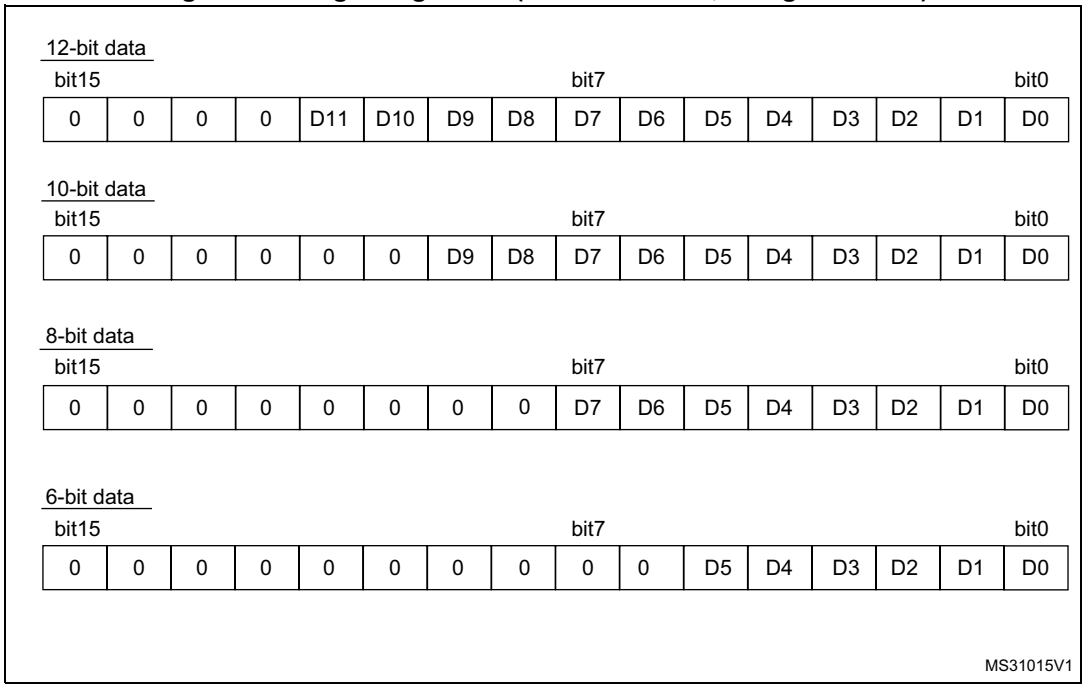


Figure 271. Right alignment (offset enabled, signed value)

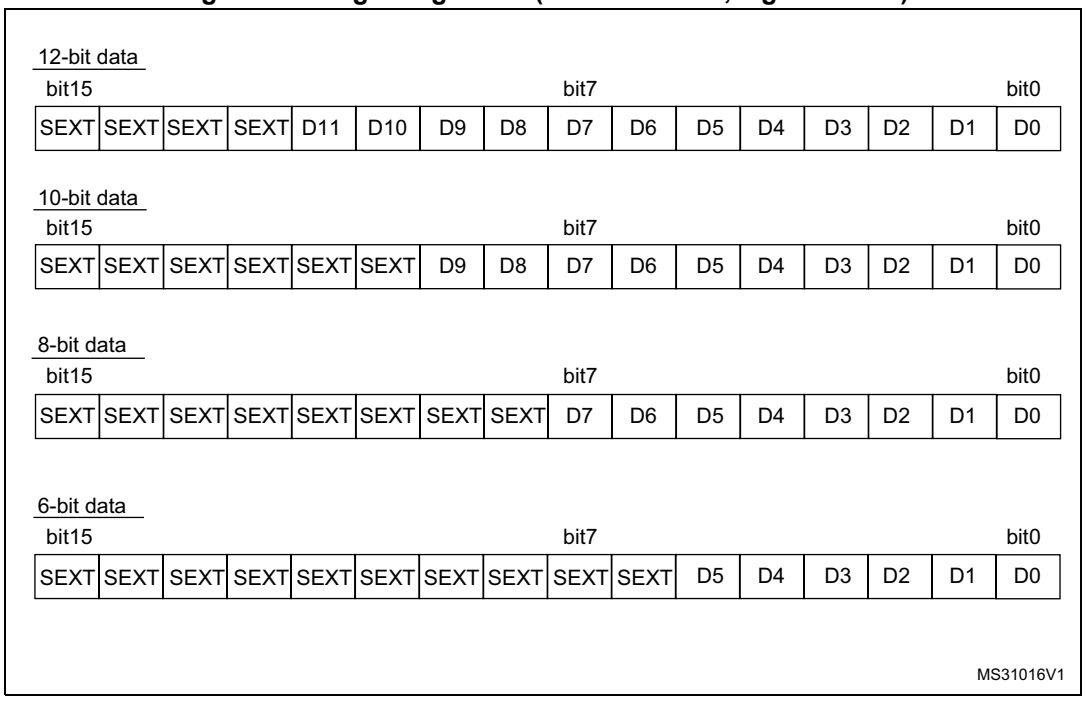


Figure 272. Left alignment (offset disabled, unsigned value)

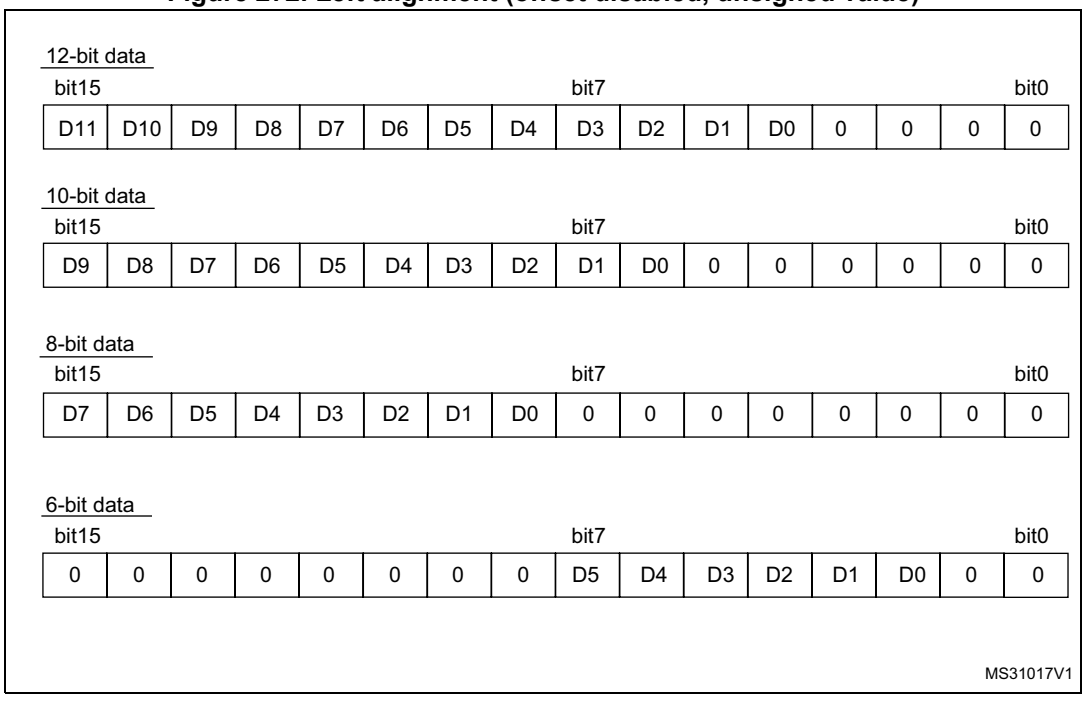
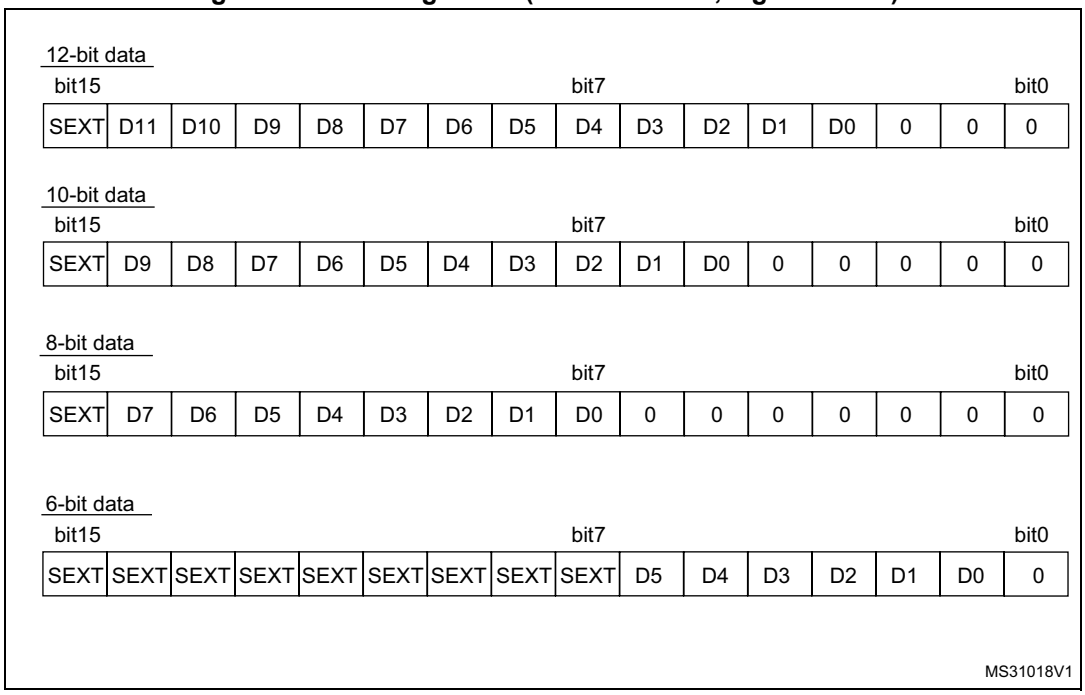


Figure 273. Left alignment (offset enabled, signed value)



Offset compensation

When SATEN bit is set in ADC_OFRy register during offset operation, data are unsigned. All the offset data saturate at 0x000 (in 12-bit mode). When OFFSETPOS bit is set, the offset direction is positive and the data saturate at 0xFFF (in 12-bit mode). In 8-bit mode, data saturate at 0x00 and 0xFF, respectively.

The analog watchdog comparison is performed before the offset compensation.

ADC overrun (OVR, OVRMOD)

The overrun flag (OVR) notifies when the regular converted data has not been read (by the CPU or the DMA) before ADC_DR FIFO (three stages) is overflowed.

The OVR flag is set when a new conversion completes while ADC_CR register FIFO was full. An interrupt is generated if OVRIE bit is set to 1.

When an overrun condition occurs, the ADC is still operating and can continue converting unless the software decides to stop and reset the sequence by setting ADSTP to 1. Since ADC_DR FIFO features three stages, up to three data are stored in the FIFO.

OVR flag is cleared by software by writing 1 to it.

It is possible to configure if data is preserved or overwritten when an overrun event occurs by programming the control bit OVRMOD:

- OVRMOD = 0: The overrun event preserves the data register from being overwritten: the old data is maintained up to ADC_DR FIFO depth (three stages) and the new conversion is discarded and lost. In this mode, ADC_DR FIFO is disabled. If the FIFO is full, any further conversion is performed but the resulting data is also discarded. EOC

is cleared by reading ADC_DR register. However, the FIFO can still contain previously converted data.

- OVRMOD = 1: The data register is overwritten with the last conversion result and the previous unread data is lost. In this mode, ADC_DR FIFO is disabled. If OVR remains at 1, any further conversions is performed normally and the ADC_DR register always contains the latest converted data.

Figure 274. Example of overrun (OVRMOD = 0)

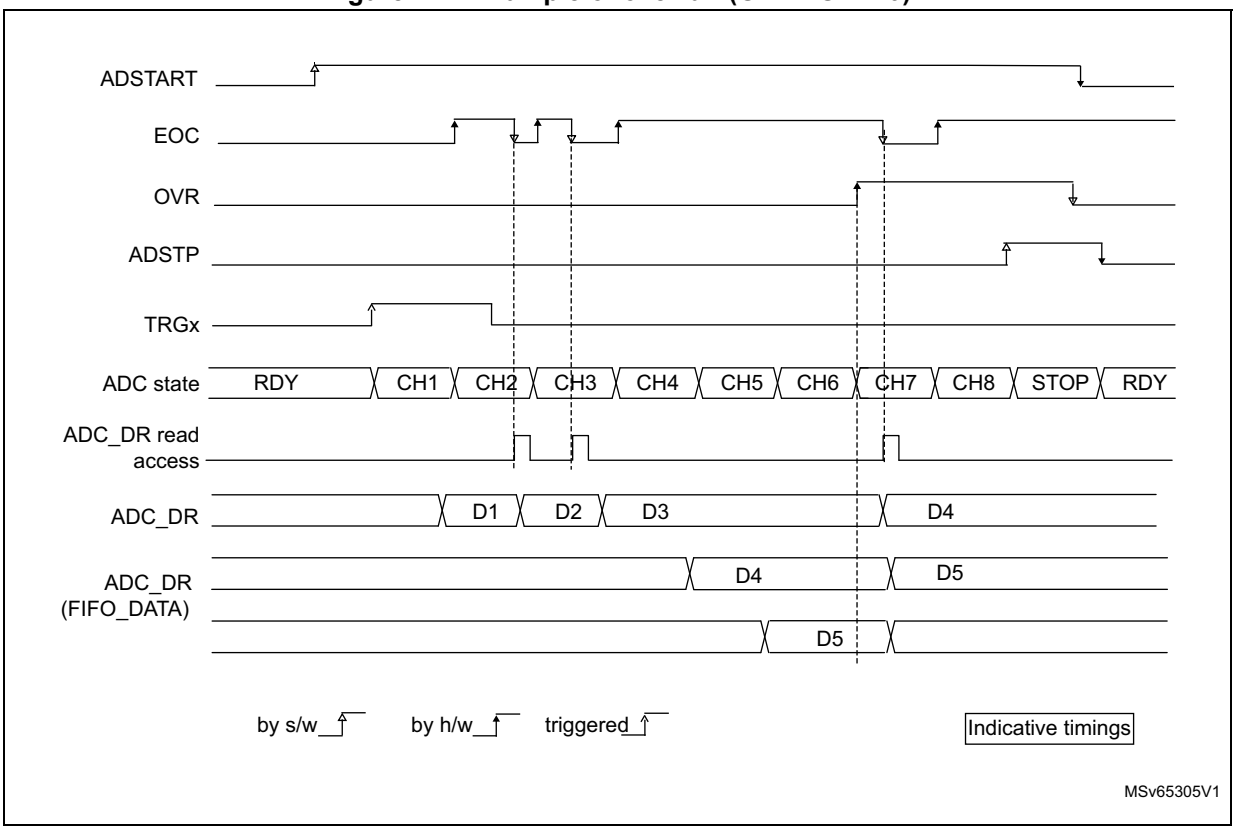
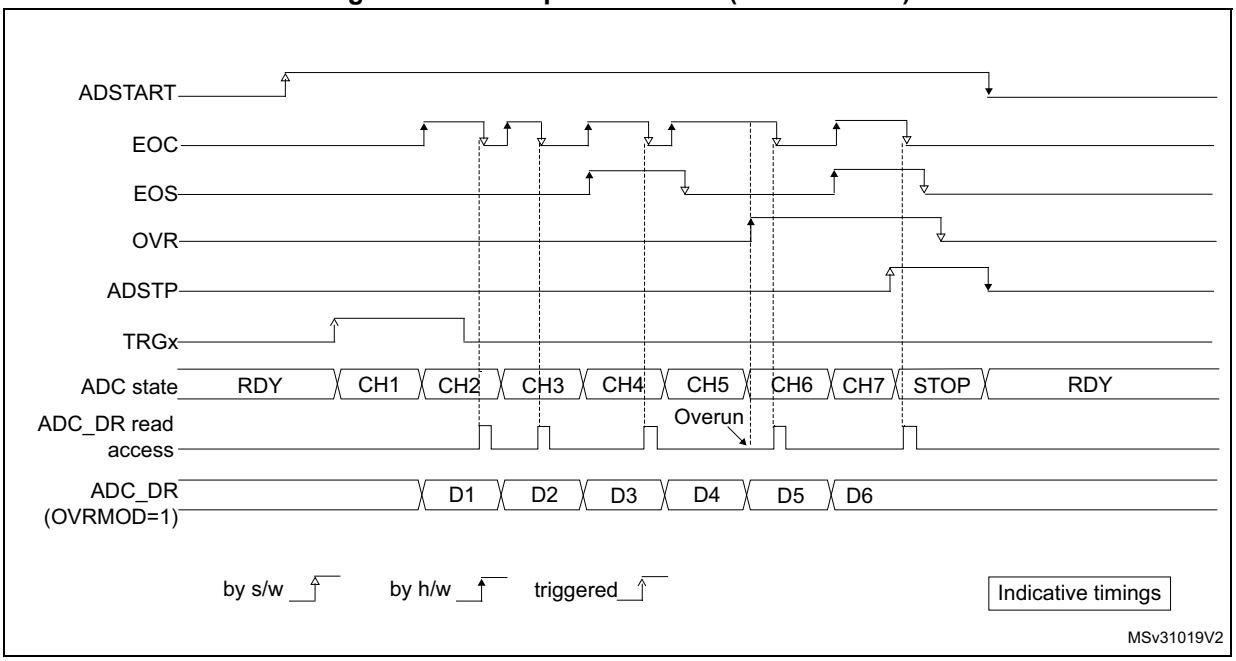


Figure 275. Example of overrun (OVRMOD = 1)



Note: There is no overrun detection on the injected channels since there is a dedicated data register for each of the four injected channels.

Managing a sequence of conversions without using the DMA

If the conversions are slow enough, the conversion sequence can be handled by the software. In this case the software must use the EOC flag and its associated interrupt to handle each data. Each time a conversion is complete, EOC is set and the ADC_DR register can be read. OVRMOD must be configured to 0 to manage overrun events or FIFO overflow as an error.

Managing conversions without using the DMA and without overrun

It may be useful to let the ADC convert one or more channels without reading the data each time (if there is an analog watchdog for instance). In this case, the OVRMOD bit must be configured to 1 and OVR flag should be ignored by the software. An overrun event does not prevent the ADC from continuing to convert and the ADC_DR register always contains the latest conversion.

Managing conversions using the DMA

Since converted channel values are stored into a unique data register, it is useful to use DMA for conversion of more than one channel. This avoids the loss of the data already stored in the ADC_DR register.

When the DMA mode is enabled (DMAEN bit set to 1 in the ADC_CFGR register in single ADC mode or MDMA different from 0b00 in dual ADC mode), a DMA request is generated after each conversion of a channel. This allows the transfer of the converted data from the ADC_DR register to the destination location selected by the software.

Despite this, if an overrun occurs (OVR = 1) because the DMA could not serve the DMA transfer request in time, the ADC stops generating DMA requests and the data corresponding to the new conversion is not transferred by the DMA. Which means that all the data transferred to the RAM can be considered as valid.

Depending on the configuration of OVRMOD bit, the data is either preserved or overwritten (refer to *Section : ADC overrun (OVR, OVRMOD)*).

The DMA transfer requests are blocked until the software clears the OVR bit.

Two different DMA modes are proposed depending on the application use and are configured with bit DMACFG of the ADC_CFGR register in single ADC mode, or with bit DMACFG of the ADC_CCR register in dual ADC mode:

- DMA one shot mode (DMACFG = 0).
  This mode is suitable when the DMA is programmed to transfer a fixed number of data.
- DMA circular mode (DMACFG = 1)
  This mode is suitable when programming the DMA in circular mode.

DMA one shot mode (DMACFG = 0)

In this mode, the ADC generates a DMA transfer request each time a new conversion data is available and stops generating DMA requests once the DMA has reached the last DMA transfer (when a transfer complete interrupt occurs - refer to DMA section) even if a conversion has been started again.

When the DMA transfer is complete (all the transfers configured in the DMA controller have been done):

- The content of the ADC data register is frozen.
- Any ongoing conversion is aborted with partial result discarded.
- No new DMA request is issued to the DMA controller. This avoids generating an overrun error if there are still conversions which are started.
- Scan sequence is stopped and reset.
- The DMA is stopped.

DMA circular mode (DMACFG = 1)

In this mode, the ADC generates a DMA transfer request each time a new conversion data is available in the data register, even if the DMA has reached the last DMA transfer. This allows configuring the DMA in circular mode to handle a continuous analog input data stream.

30.4.27 Managing conversions using the ADF/MDF

The ADC conversion results can be transferred directly to the audio digital filter (ADF/MDF).

In this case, the ADFCFG bit must be set to 1 and DMAEN bit must be cleared to 0.

The ADC transfers all the 16 bits of the regular data register to the ADF/MDF and resets the EOC flag once the transfer is complete.

The data format must be 16-bit signed:

ADC_DR[15:12] = sign extended

ADC_DR[11] = sign

ADC_DR[11:0] = data

To obtain 16-bit signed format in 12-bit ADC mode, the software needs to configure the OFFSET[11:0] to 0x800 after having set OFFSET_EN to 1.

Only right aligned data format is available for the ADF/MDF interface (see *Figure 271: Right alignment (offset enabled, signed value)*).

30.4.28 Dynamic low-power features

Auto-delayed conversion mode (AUTDLY)

The ADC implements an auto-delayed conversion mode controlled by the AUTDLY configuration bit. Auto-delayed conversions are useful to simplify the software as well as to optimize performance of an application clocked at low frequency where there would be risk of encountering an ADC overrun.

When AUTDLY = 1, a new conversion can start only if all the previous data of the same group has been treated:

- For a regular conversion: once the ADC_DR register has been read or if the EOC bit has been cleared (see *Figure 276*).
- For an injected conversion: when the JEOS bit has been cleared (see *Figure 277*).

This is a way to automatically adapt the speed of the ADC to the speed of the system which reads the data.

The delay is inserted after each regular conversion (whatever DISCEN = 0 or 1) and after each sequence of injected conversions (whatever JDISCEN = 0 or 1).

Note: There is no delay inserted between each conversions of the injected sequence, except after the last one.

During a conversion, a hardware trigger event (for the same group of conversions) occurring during this delay is ignored.

Note: This is not true for software triggers where it remains possible during this delay to set the bits ADSTART or JADSTART to restart a conversion: it is up to the software to read the data before launching a new conversion.

No delay is inserted between conversions of different groups (a regular conversion followed by an injected conversion or conversely):

- If an injected trigger occurs during the automatic delay of a regular conversion, the injected conversion starts immediately (see *Figure 277*).
- Once the injected sequence is complete, the ADC waits for the delay (if not ended) of the previous regular conversion before launching a new regular conversion (see *Figure 279*).

The behavior is slightly different in auto-injected mode (JAUTO = 1) where a new regular conversion can start only when the automatic delay of the previous injected sequence of conversion has ended (when JEOS has been cleared). This is to ensure that the software can read all the data of a given sequence before starting a new sequence (see *Figure 280*).

To stop a conversion in continuous auto-injection mode combined with autodelay mode (JAUTO = 1, CONT = 1 and AUTDLY = 1), follow the following procedure:

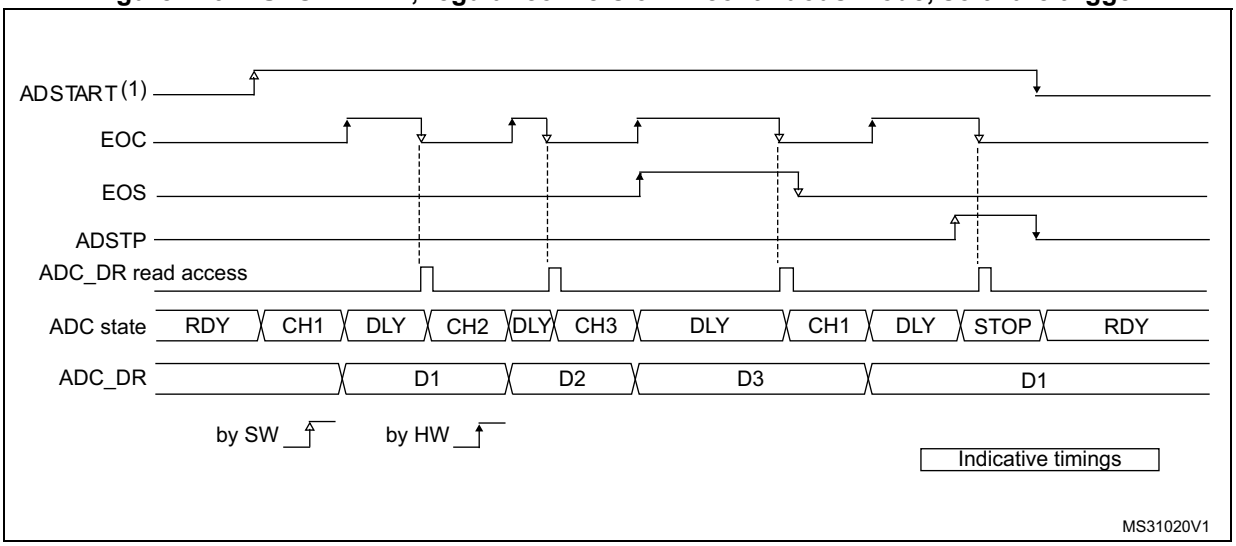
1. Wait until JEOS = 1 (no more conversions are restarted)
2. Clear JEOS,
3. Set ADSTP = 1
4. Read the regular data.

If this procedure is not respected, a new regular sequence can restart if JEOS is cleared after ADSTP has been set.

In AUTDLY mode, a hardware regular trigger event is ignored if it occurs during an already ongoing regular sequence or during the delay that follows the last regular conversion of the sequence. It is however considered pending if it occurs after this delay, even if it occurs during an injected sequence of the delay that follows it. The conversion then starts at the end of the delay of the injected sequence.

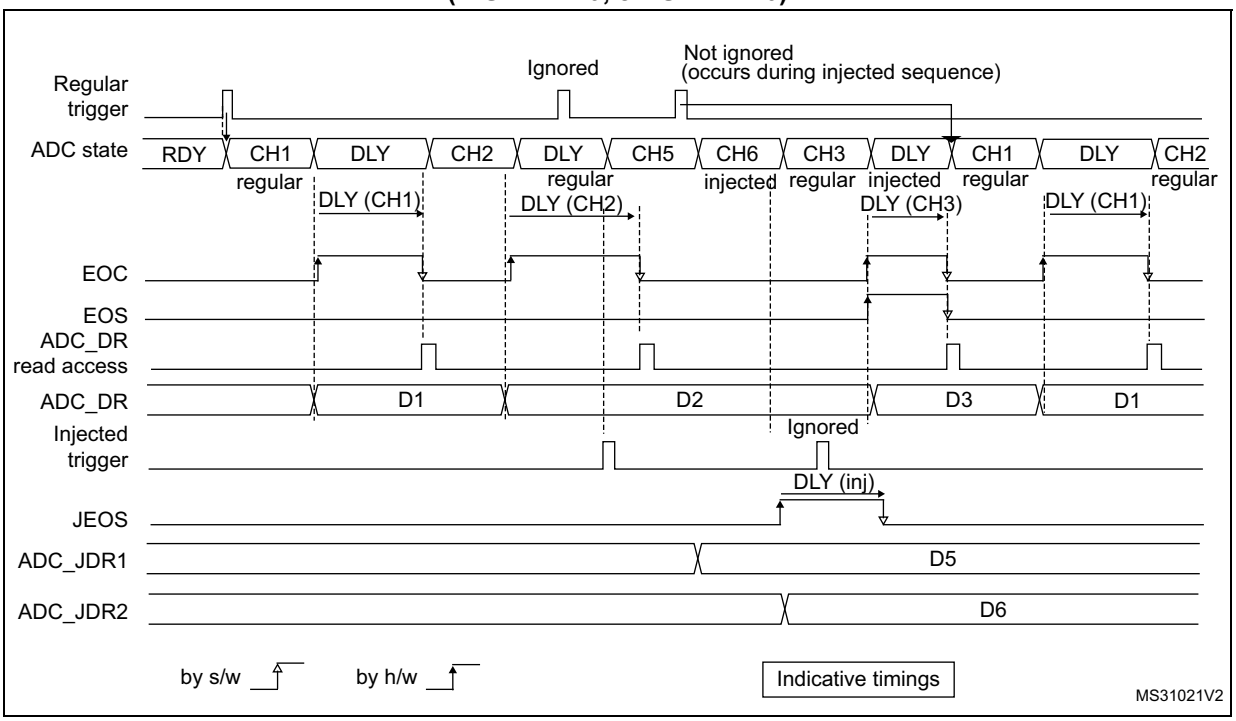
In AUTDLY mode, a hardware injected trigger event is ignored if it occurs during an already ongoing injected sequence or during the delay that follows the last injected conversion of the sequence.

Figure 276. AUTODLY = 1, regular conversion in continuous mode, software trigger



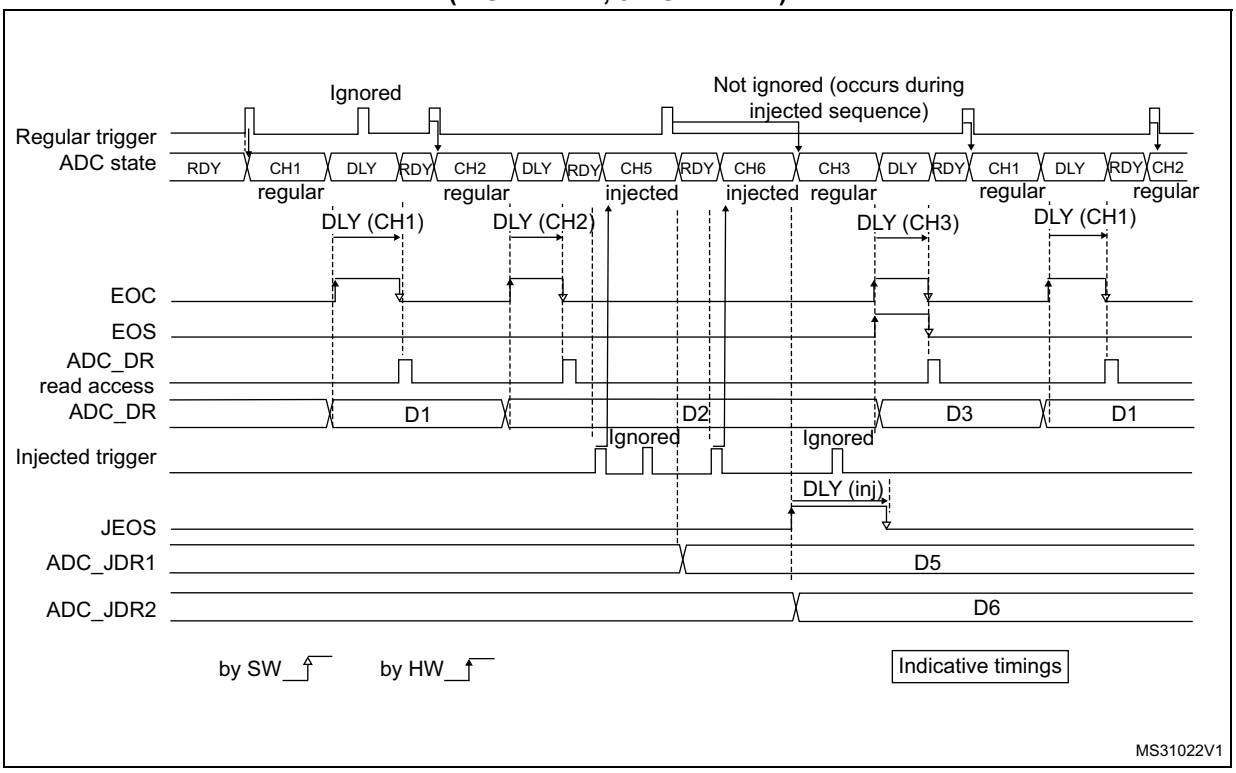
1. AUTDLY = 1
2. Regular configuration: EXTEN=0x0 (SW trigger), CONT = 1, CHANNELS = 1,2,3
3. Injected configuration DISABLED

Figure 277. AUTODLY = 1, regular HW conversions interrupted by injected conversions (DISCEN = 0; JDISCEN = 0)



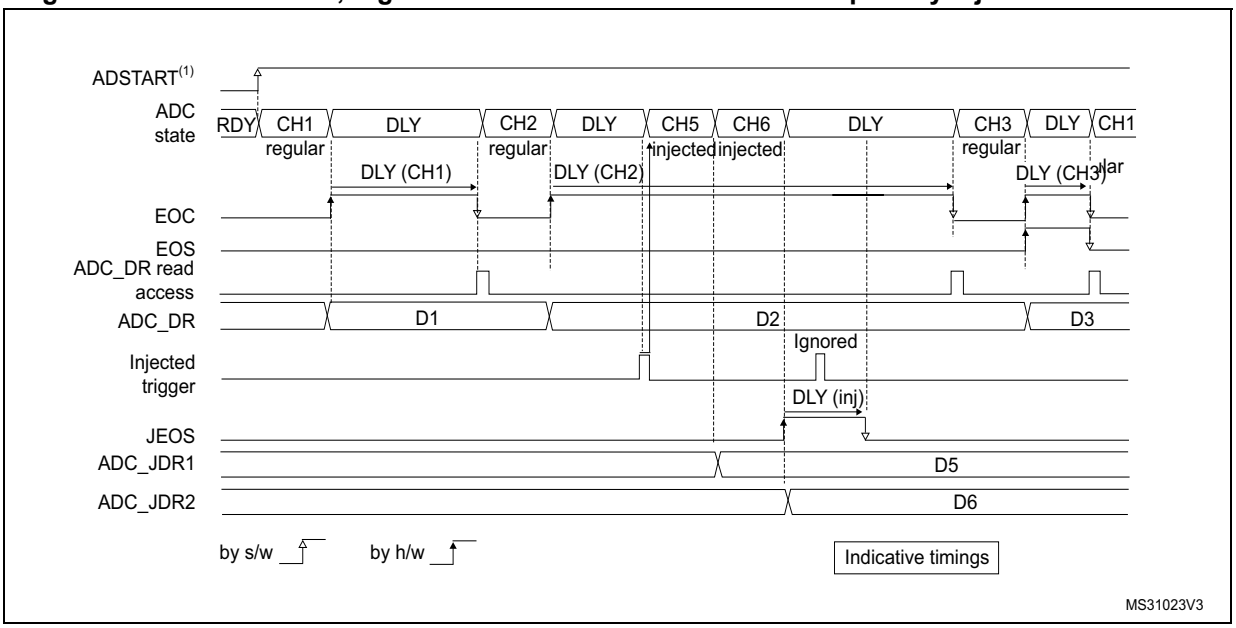
1. AUTDLY = 1
2. Regular configuration: EXTEN=0x1 (HW trigger), CONT = 0, DISCEN = 0, CHANNELS = 1, 2, 3
3. Injected configuration: JEXTEN = 0x1 (HW Trigger), JDISCEN = 0, CHANNELS = 5,6

Figure 278. AUTODLY = 1, regular HW conversions interrupted by injected conversions (DISCEN = 1, JDISCEN = 1)



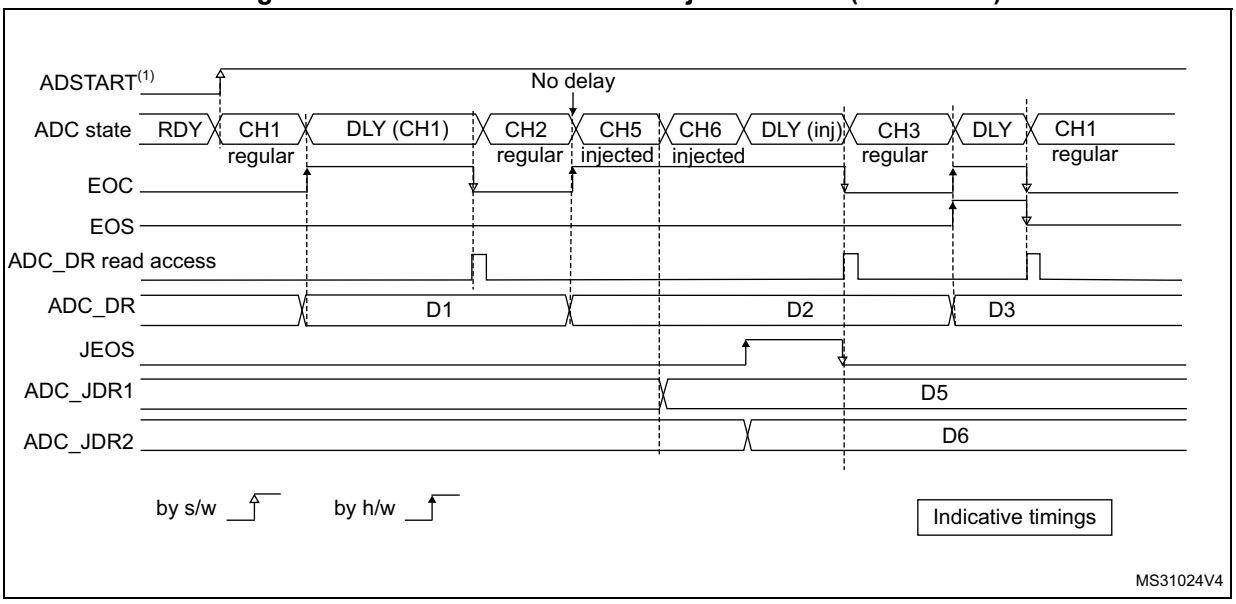
1. AUTDLY = 1
2. Regular configuration: EXTEN = 0x1 (HW trigger), CONT = 0, DISCEN = 1, DISCNUM = 1, CHANNELS = 1, 2, 3.
3. Injected configuration: JEXTEN = 0x1 (HW Trigger), JDISCEN = 1, CHANNELS = 5,6

Figure 279. AUTODLY = 1, regular continuous conversions interrupted by injected conversions



1. AUTDLY = 1
2. Regular configuration: EXTEN = 0x0 (SW trigger), CONT = 1, DISCEN = 0, CHANNELS = 1, 2, 3
3. Injected configuration: JEXTEN = 0x1 (HW Trigger), JDISCEN = 0, CHANNELS = 5,6

Figure 280. AUTODLY = 1 in auto- injected mode (JAUTO = 1)

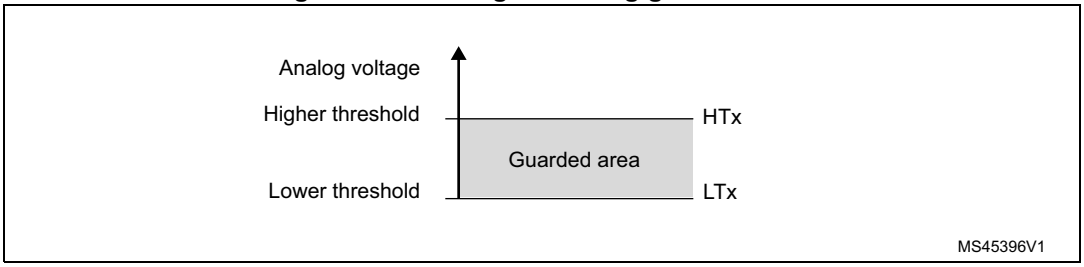


1. AUTDLY = 1
2. Regular configuration: EXTEN = 0x0 (SW trigger), CONT = 1, DISCEN = 0, CHANNELS = 1, 2
3. Injected configuration: JAUTO = 1, CHANNELS = 5,6

30.4.29 Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)

The three AWD analog watchdogs monitor whether some channels remain within a configured voltage range (window).

Figure 281. Analog watchdog guarded area



AWDx flag and interrupt

An interrupt can be enabled for each of the 3 analog watchdogs by setting AWDxIE in the ADC_IER register (x = 1,2,3).

AWDx (x = 1,2,3) flag is cleared by software by writing 1 to it.

The ADC conversion result is compared to the lower and higher thresholds before alignment.

Description of analog watchdog 1

The AWD analog watchdog 1 is enabled by setting the AWD1EN bit in the ADC_CFGR register. This watchdog monitors whether either one selected channel or all enabled channels(1) remain within a configured voltage range (window).

Table 295 shows how the ADC_CFGR registers should be configured to enable the analog watchdog on one or more channels.

Table 295. Analog watchdog channel selection

Channels guarded by the analog watchdog	AWD1SGL bit	AWD1EN bit	JAWD1EN bit
None	x	0	0
All injected channels	0	0	1
All regular channels	0	1	0
All regular and injected channels	0	1	1
Single(1) injected channel	1	0	1
Single(1) regular channel	1	1	0
Single(1) regular or injected channel	1	1	1

1. Selected by the AWD1CH[4:0] bits. The channels must also be programmed to be converted in the appropriate regular or injected sequence.

The AWD1 analog watchdog status bit is set if the analog voltage converted by the ADC is below a lower threshold or above a higher threshold.

These thresholds are programmed in bits HT1[11:0] and LT1[11:0] of the ADC_TR1 register for the analog watchdog 1. When converting data with a resolution of less than 12 bits (according to bits RES[1:0]), the LSB of the programmed thresholds must be kept cleared because the internal comparison is always performed on the full 12-bit raw converted data (left aligned) before the offset compensation stage.

Table 296 describes how the comparison is performed for all the possible resolutions for analog watchdog 1.

Table 296. Analog watchdog 1 comparison

Resolution(bit RES[1:0])	Analog watchdog comparison between:		Comments
	Raw converted data, left aligned	Thresholds	
00: 12-bit	DATA[11:0]	LT1[11:0] and HT1[11:0]	-
01: 10-bit	DATA[11:2],00	LT1[11:0] and HT1[11:0]	User must configure LT1[1:0] and HT1[1:0] to 00
10: 8-bit	DATA[11:4],0000	LT1[11:0] and HT1[11:0]	User must configure LT1[3:0] and HT1[3:0] to 0000
11: 6-bit	DATA[11:6],000000	LT1[11:0] and HT1[11:0]	User must configure LT1[5:0] and HT1[5:0] to 000000

Analog watchdog filter for watchdog 1

When an ADC is configured with only one input channel (selecting several channels in scan mode not allowed), a valid ADC conversion data filter can be configured:

- When the converted data belong to the interval defined in ADC_TR1, the AWD1 flag remains cleared.
- If data are out-of-range a number of times higher than the value specified in AWDFILT bit of ADC_TR1, the AWD1 flag is set an the corresponding interrupt is issued.

Description of analog watchdog 2 and 3

The second and third analog watchdogs are more flexible and can guard several selected channels by programming the corresponding bits in AWDxCH[19:0] (x = 2,3).

The corresponding watchdog is enabled when any bit of AWDxCH[19:0] (x = 2,3) is set.

They are limited to a resolution of 8 bits and only the 8 MSBs of the thresholds can be programmed into HTx[7:0] and LTx[7:0]. *Table 297* describes how the comparison is performed for all the possible resolutions.

Table 297. Analog watchdog 2 and 3 comparison

Resolution (bits RES[1:0])	Analog watchdog comparison between:		Comments
	Raw converted data, left aligned	Thresholds	
00: 12-bit	DATA[11:4]	LTx[7:0] and HTx[7:0]	DATA[3:0] are not relevant for the comparison
01: 10-bit	DATA[11:4]	LTx[7:0] and HTx[7:0]	DATA[3:2] are not relevant for the comparison

Table 297. Analog watchdog 2 and 3 comparison

Resolution (bits RES[1:0])	Analog watchdog comparison between:		Comments
	Raw converted data, left aligned	Thresholds	
10: 8-bit	DATA[11:4]	LTx[7:0] and HTx[7:0]	-
11: 6-bit	DATA[11:6],00	LTx[7:0] and HTx[7:0]	User must configure LTx[1:0] and HTx[1:0] to 00

ADCy_AWDx_OUT signal output generation

Each analog watchdog is associated to an internal hardware signal ADCy_AWDx_OUT (y = ADC number, x = watchdog number) which is directly connected to the ETR input (external trigger) of some on-chip timers. Refer to the on-chip timers section to understand how to select the ADCy_AWDx_OUT signal as ETR.

ADCy_AWDx_OUT is activated when the associated analog watchdog is enabled:

- ADCy_AWDx_OUT is set when a guarded conversion is outside the programmed thresholds.
- ADCy_AWDx_OUT is reset after the end of the next guarded conversion which is inside the programmed thresholds (It remains at 1 if the next guarded conversions are still outside the programmed thresholds).
- ADCy_AWDx_OUT is also reset when disabling the ADC (when setting ADDIS = 1). Note that stopping regular or injected conversions (setting ADSTP = 1 or JADSTP = 1) has no influence on the generation of ADCy_AWDx_OUT.

Note: AWDx flag is set by hardware and reset by software: AWDx flag has no influence on the generation of ADCy_AWDx_OUT (ex: ADCy_AWDx_OUT can toggle while AWDx flag remains at 1 if the software did not clear the flag).

Figure 282. ADCy_AWDx_OUT signal generation (on all regular channels)

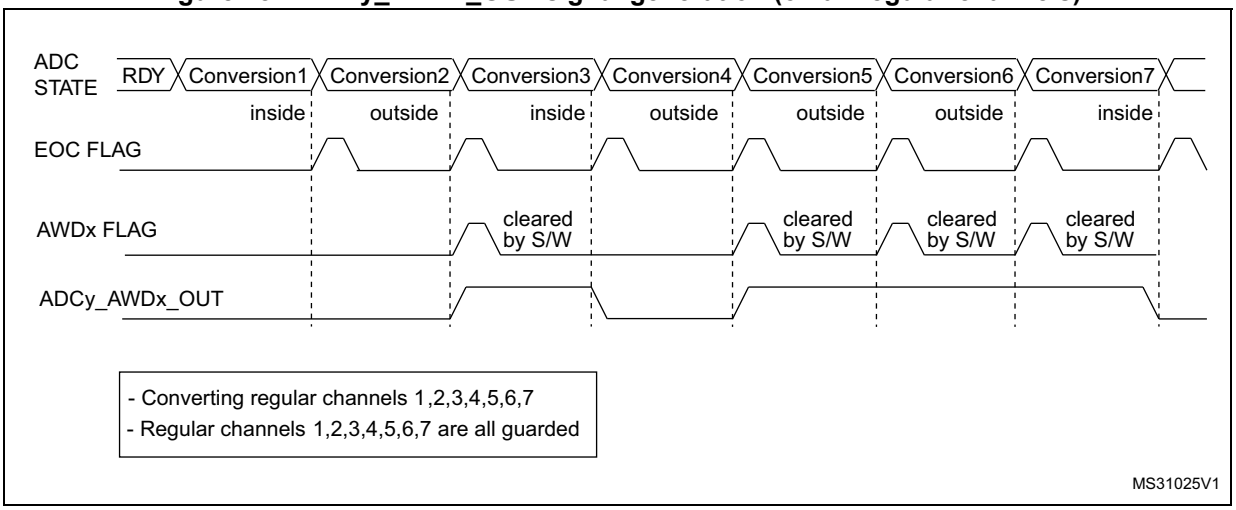


Figure 283. ADCy_AWDx_OUT signal generation (AWDx flag not cleared by software)

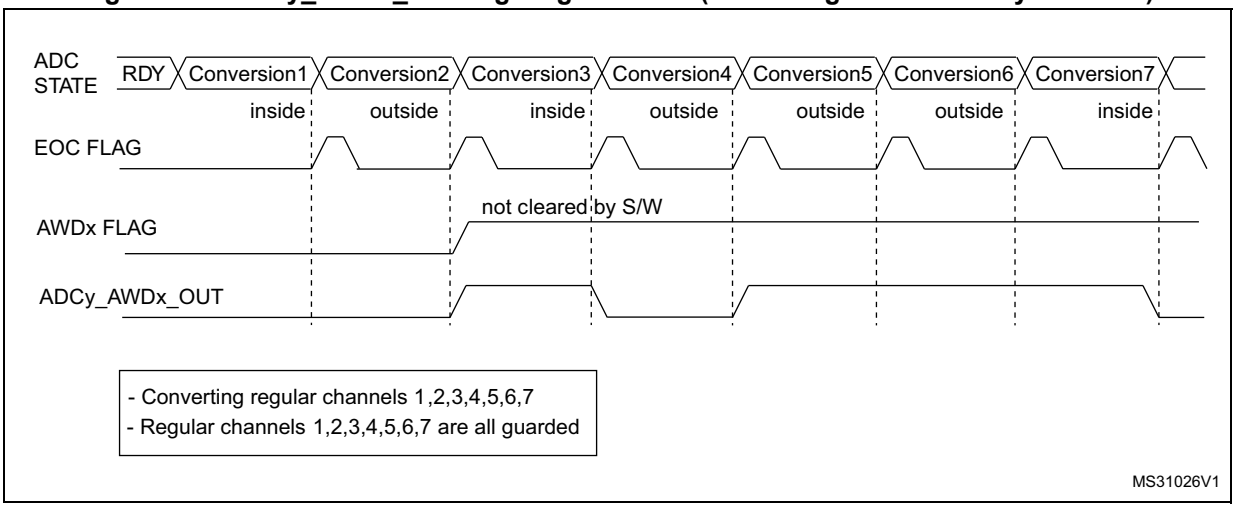


Figure 284. ADCy_AWDx_OUT signal generation (on a single regular channel)

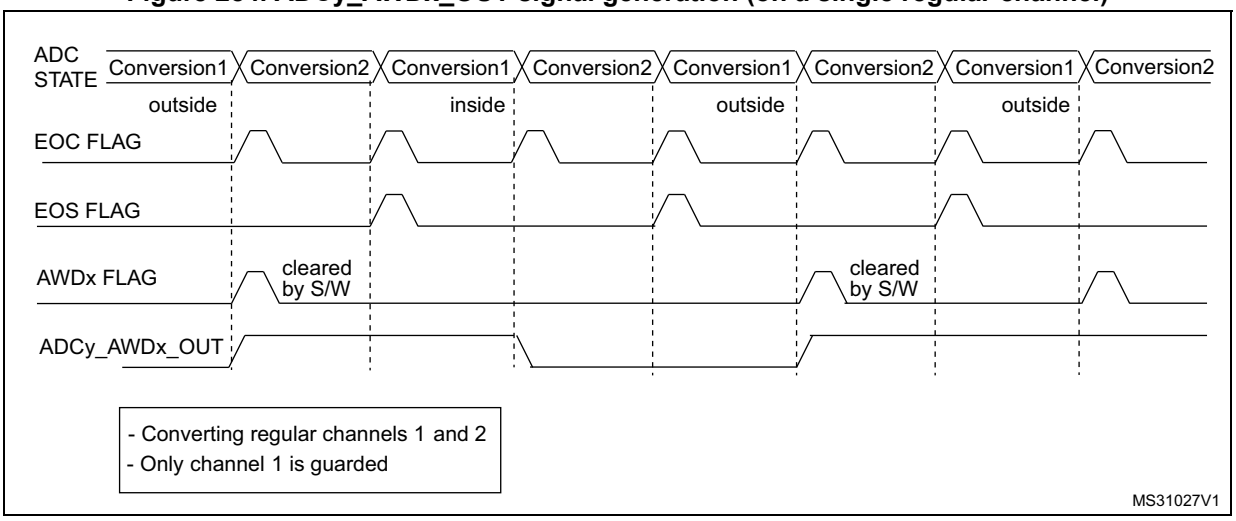
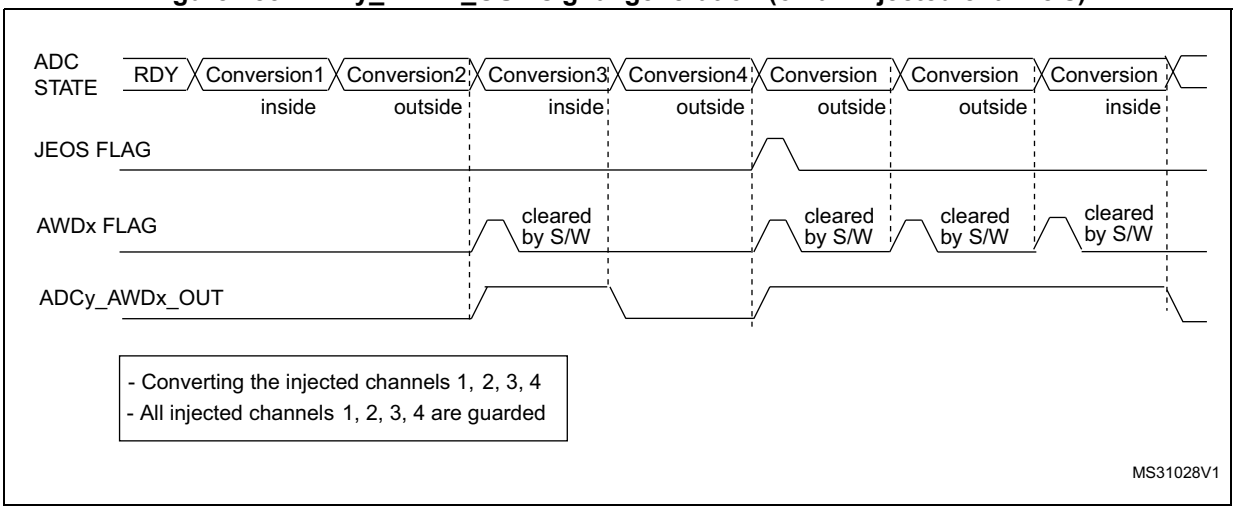


Figure 285. ADCy_AWDx_OUT signal generation (on all injected channels)



Analog watchdog threshold control

LTx[11:0] and HTx[11:0] can be changed when an analog-to-digital conversion is ongoing (that is between the start of conversion and the end of conversion of the ADC internal state). If LTx[11:0] and HTx[11:0] are updated during the ADC conversion of the ADC guarded channel, the watchdog function is masked for this conversion. This masking is removed at the next start of conversion, resulting in a analog watchdog thresholds to be applied from the next ADC conversion. The analog watchdog comparison is performed at each end of conversion. If the current ADC data is out of the new interval, no interrupt and AWDx_OUT signal are issued. The Interrupt and the AWD generation only happen at the end of the conversion which started after the threshold update. If AWD_xOUT is already asserted, programming the new thresholds does not deassert the AWDx_OUT signal.

To update both LTx[11:0] and HTx[11:0] during an ADC conversion, a unique write access to the ADC_TRx register be performed.

Analog watchdog with offset compensation

When the offset compensation is enabled, the analog watchdog compares the threshold before the data compensation.

30.4.30 Oversampler

The oversampling unit performs data pre-processing to offload the CPU. It is able to handle multiple conversions and average them into a single data with increased data width, up to 16-bit.

It provides a result with the following form, where N and M can be adjusted:

$$\text{Result} = \frac{1}{M} \times \sum_{n=0}^{n=N-1} \text{Conversion}(t_n)$$

It allows to perform by hardware the following functions: averaging, data rate reduction, SNR improvement, basic filtering.

The oversampling ratio N is defined using the OVFS[2:0] bits in the ADC_CFGR2 register, and can range from 2x to 256x. The division coefficient M consists of a right bit shift up to 8 bits, and is defined using the OVSS[3:0] bits in the ADC_CFGR2 register.

The summation unit can yield a result up to 20 bits (256x 12-bit results), which is first shifted right. It is then truncated to the 16 least significant bits, rounded to the nearest value using the least significant bits left apart by the shifting, before being finally transferred into the ADC_DR data register.

Note: If the intermediary result after the shifting exceeds 16-bit, the result is truncated as is, without saturation.

Figure 286. 20-bit to 16-bit result truncation

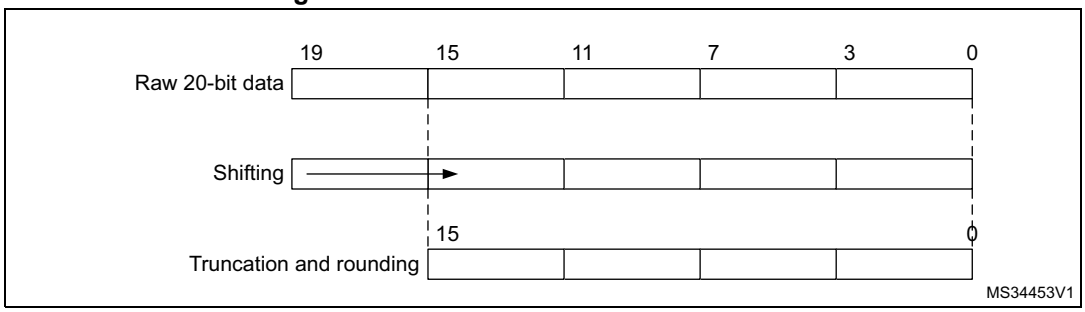


Figure 287 gives a numerical example of the processing, from a raw 20-bit accumulated data to the final 16-bit result.

Figure 287. Numerical example with 5-bit shift and rounding

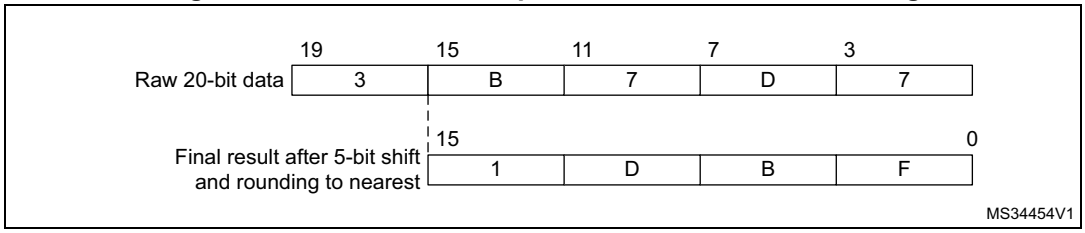


Table 298 gives the data format for the various N and M combinations, for a raw conversion data equal to 0xFFF.

Table 298. Maximum output results versus N and M (gray cells indicate truncation)

Over sampling ratio	Max Raw data	No-shift OVSS = 0000	1-bit shift OVSS = 0001	2-bit shift OVSS = 0010	3-bit shift OVSS = 0011	4-bit shift OVSS = 0100	5-bit shift OVSS = 0101	6-bit shift OVSS = 0110	7-bit shift OVSS = 0111	8-bit shift OVSS = 1000
2x	0x1FFE	0x1FFE	0x0FFF	0x0800	0x0400	0x0200	0x0100	0x0080	0x0040	0x020
4x	0x3FFC	0x3FFC	0x1FFE	0x0FFF	0x0800	0x0400	0x0200	0x0100	0x0080	0x0040
8x	0x7FF8	0x7FF8	0x3FFC	0x1FFE	0x0FFF	0x0800	0x0400	0x0200	0x0100	0x0080
16x	0xFFF0	0xFFF0	0x7FF8	0x3FFC	0x1FFE	0x0FFF	0x0800	0x0400	0x0200	0x0100
32x	0x1FFE0	0xFFE0	0xFFF0	0x7FF8	0x3FFC	0x1FFE	0x0FFF	0x0800	0x0400	0x0200
64x	0x3FFC0	0xFFC0	0xFFE0	0xFFF0	0x7FF8	0x3FFC	0x1FFE	0x0FFF	0x0800	0x0400
128x	0x7FF80	0xFF80	0xFFC0	0xFFE0	0xFFF0	0x7FF8	0x3FFC	0x1FFE	0x0FFF	0x0800
256x	0xFFF00	0xFF00	0xFF80	0xFFC0	0xFFE0	0xFFF0	0x7FF8	0x3FFC	0x1FFE	0x0FFF

There are no changes for conversion timings in oversampled mode: the sample time is maintained equal during the whole oversampling sequence. A new data is provided every N

conversions, with an equivalent delay equal to N x T_{CONV} = N x (t_{SMPL} + t_{SAR}). The flags are set as follow:

- The end of the sampling phase (EOSMP) is set after each sampling phase
- The end of conversion (EOC) occurs once every N conversions, when the oversampled result is available
- The end of sequence (EOS) occurs once the sequence of oversampled data is completed (that is after N x sequence length conversions total)

ADC operating modes supported when oversampling (single ADC mode)

In oversampling mode, most of the ADC operating modes are maintained:

- Single or continuous conversion modes
- ADC conversions start either by software or with triggers
- ADC stop during a conversion (abort)
- Data read via CPU or DMA with overrun detection
- Low-power modes (AUTDLY)
- Programmable resolution: in this case, the reduced conversion values (as per RES[1:0] bits in ADC_CFGR register) are accumulated, truncated, rounded and shifted in the same way as 12-bit conversions are

Note: The alignment mode is not available when working with oversampled data. The ALIGN bit in ADC_CFGR is ignored and the data are always provided right-aligned.

Offset correction is not supported in oversampling mode. When ROVSE and/or JOVSE bit is set, the value of the OFFSET_EN bit in ADC_OFRy register is ignored (considered as reset).

Analog watchdog

The analog watchdog functionality is maintained, with the following difference:

- The RES[1:0] bits are ignored, the comparison is always done by using the full 12-bit values HT1[11:0] and LT1[11:0] for AWD1, and the 8-MSB value of HT2/HT3[7:0] and LT2/LT3[7:0] for AWD2 and AWD3.
- The comparison is done on the most significant 12-bit of the 16-bit oversampled results ADC_DR[15:4] for AWD1, and ADC_DR[15:8] for AWD2 and ADW3

Note: Care must be taken when using high shifting values, this reduces the comparison range. For instance, if the oversampled result is shifted by 4 bits, thus yielding a 12-bit data right-aligned, the effective analog watchdog comparison can only be performed on 8 bits. The comparison is done between ADC_DR[11:4] and HTx[7:0] / LTx[7:0] (AWD1/2/3), with HT1[11:8] and LT1[11:8] kept reset (AWD1 only).

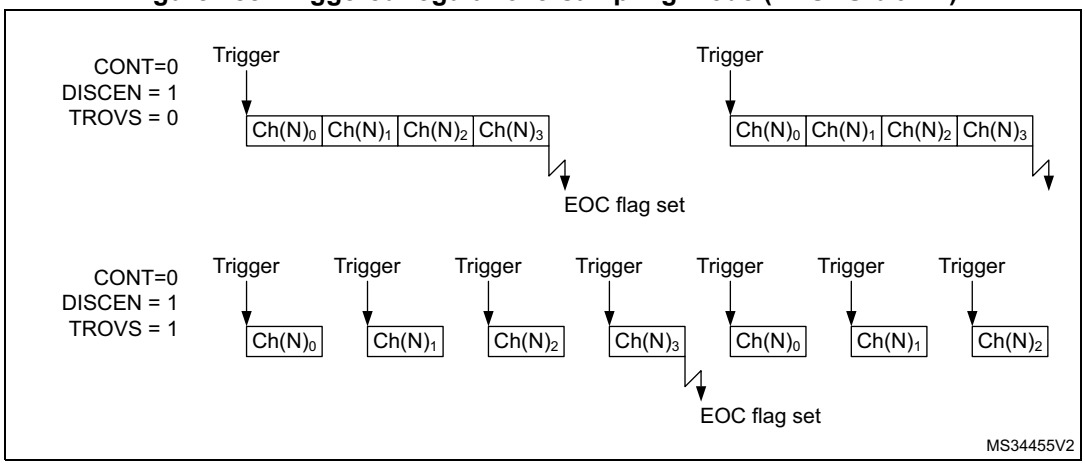
Triggered mode

The averager can also be used for basic filtering purpose. Although not a very powerful filter (slow roll-off and limited stop band attenuation), it can be used as a notch filter to reject constant parasitic frequencies (typically coming from the mains or from a switched mode power supply). For this purpose, a specific discontinuous mode can be enabled with TROVS bit in ADC_CFGR2, to be able to have an oversampling frequency defined by a user and independent from the conversion time itself.

The *Figure 288* below shows how conversions are started in response to triggers during discontinuous mode.

If the TROVS bit is set, the content of the DISCEN bit is ignored and considered as 1.

Figure 288. Triggered regular oversampling mode (TROVS bit = 1)



Injected and regular sequencer management when oversampling

In oversampling mode, it is possible to have differentiated behavior for injected and regular sequencers. The oversampling can be enabled for both sequencers with some limitations if they have to be used simultaneously (this is related to a unique accumulation unit).

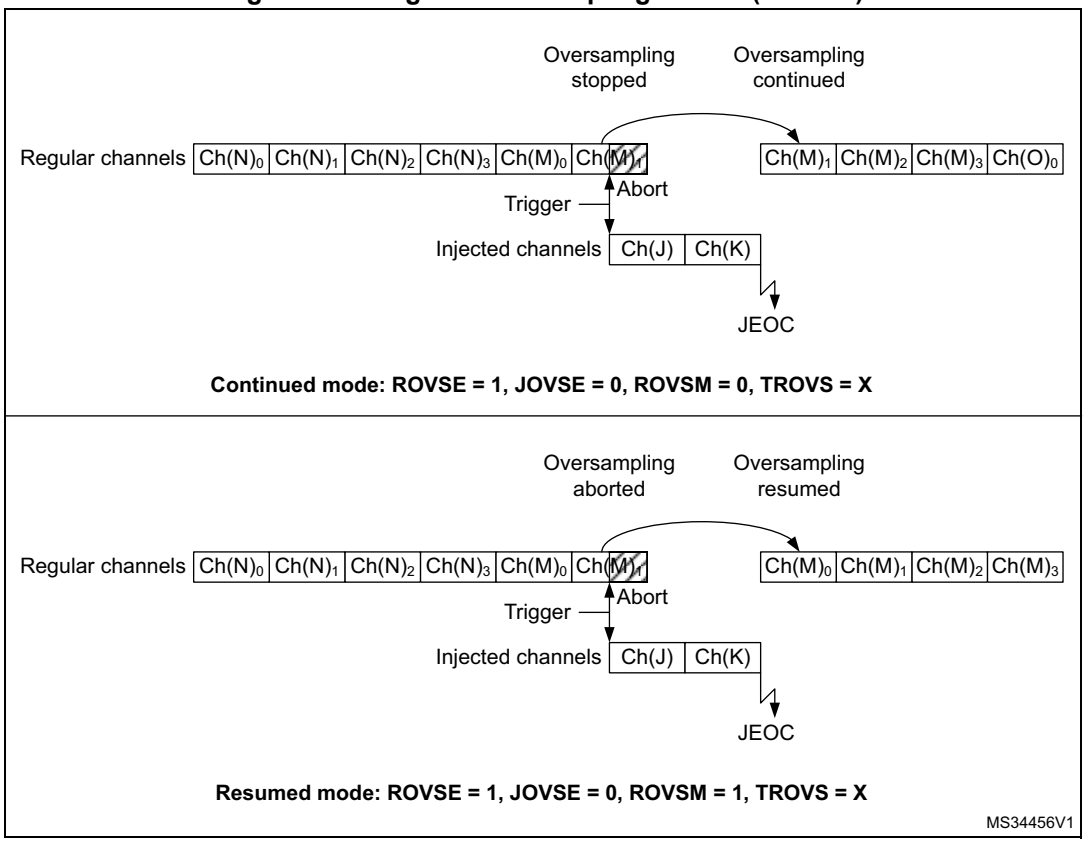
Oversampling regular channels only

The regular oversampling mode bit ROVSM defines how the regular oversampling sequence is resumed if it is interrupted by injected conversion:

- In continued mode, the accumulation restarts from the last valid data (prior to the conversion abort request due to the injected trigger). This ensures that oversampling is complete whatever the injection frequency (providing at least one regular conversion can be completed between triggers);
- In resumed mode, the accumulation restarts from 0 (previous conversions results are ignored). This mode allows to guarantee that all data used for oversampling were converted back-to-back within a single timeslot. Care must be taken to have a injection trigger period above the oversampling period length. If this condition is not respected, the oversampling cannot be completed and the regular sequencer is blocked.

The *Figure 289* gives examples for a 4x oversampling ratio.

Figure 289. Regular oversampling modes (4x ratio)



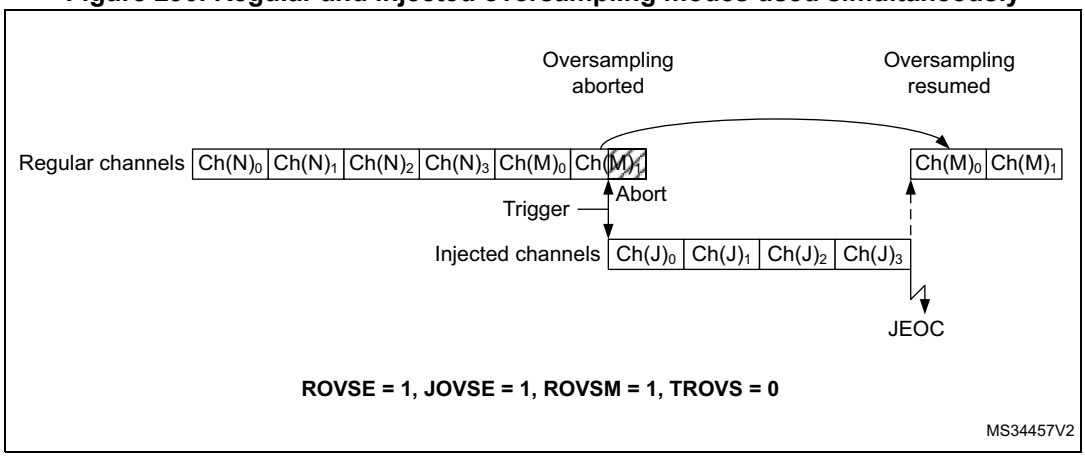
Oversampling Injected channels only

The Injected oversampling mode bit JOVSE enables oversampling solely for conversions in the injected sequencer.

Oversampling regular and Injected channels

It is possible to have both ROVSE and JOVSE bits set. In this case, the regular oversampling mode is forced to resumed mode (ROVSM bit ignored), as represented on *Figure 290* below.

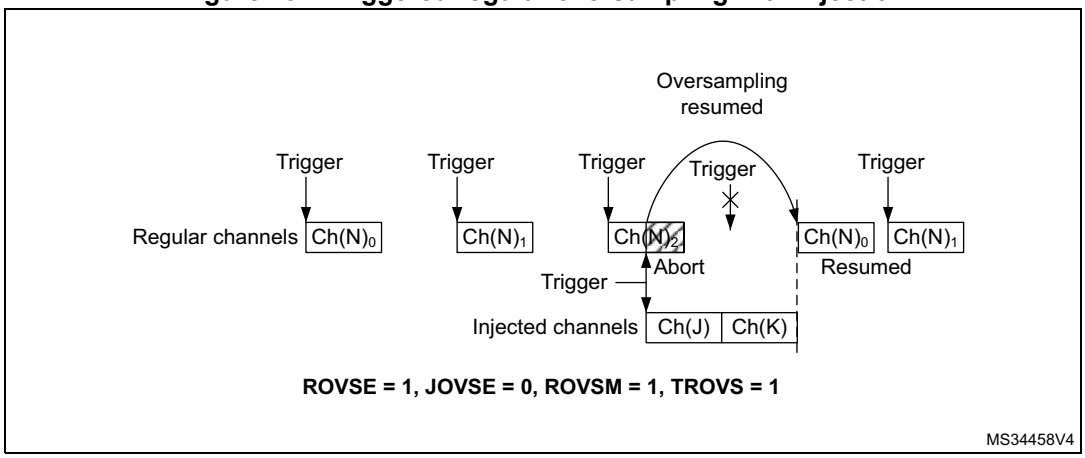
Figure 290. Regular and injected oversampling modes used simultaneously



Triggered regular oversampling with injected conversions

It is possible to have triggered regular mode with injected conversions. In this case, the injected mode oversampling mode must be disabled, and the ROVSM bit is ignored (resumed mode is forced). The JOVSE bit must be reset. The behavior is represented on *Figure 291* below.

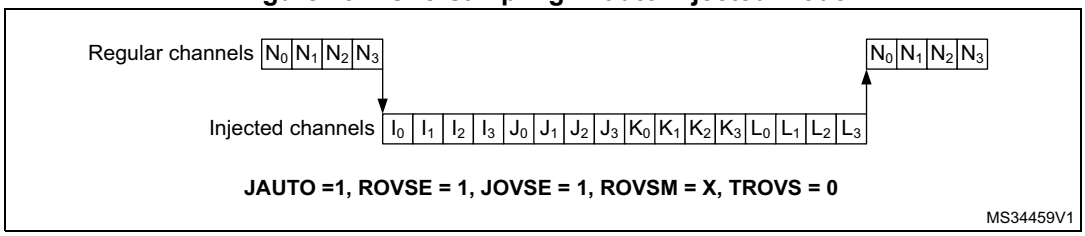
Figure 291. Triggered regular oversampling with injection



Auto-injected mode

It is possible to oversample auto-injected sequences and have all conversions results stored in registers to save a DMA resource. This mode is available only with both regular and injected oversampling active: JAUTO = 1, ROVSE = 1 and JOVSE = 1, other combinations are not supported. The ROVSM bit is ignored in auto-injected mode. The *Figure 292* below shows how the conversions are sequenced.

Figure 292. Oversampling in auto-injected mode



It is possible to have also the triggered mode enabled, using the TROVS bit. In this case, the ADC must be configured as following: JAUTO = 1, DISCEN = 0, JDISCEN = 0, ROVSE = 1, JOVSE = 1 and TROVSE = 1.

Dual ADC modes supported when oversampling

It is possible to have oversampling enabled when working in dual ADC configuration, for the injected simultaneous mode and regular simultaneous mode. In this case, the two ADCs must be programmed with the very same settings (including oversampling).

All other dual ADC modes are not supported when either regular or injected oversampling is enabled (ROVSE = 1 or JOVSE = 1).

Combined modes summary

The *Table 299* below summarizes all combinations, including modes not supported.

Table 299. Oversampler operating modes summary

Regular Oversampling ROVSE	Injected Oversampling JOVSE	Oversampler mode ROVSM 0 = continued 1 = resumed	Triggered Regular mode TROVS	Comment
1	0	0	0	Regular continued mode
1	0	0	1	Not supported
1	0	1	0	Regular resumed mode
1	0	1	1	Triggered regular resumed mode
1	1	0	X	Not supported
1	1	1	0	Injected and regular resumed mode
1	1	1	1	Not supported
0	1	X	X	Injected oversampling

30.4.31 Dual ADC modes

Dual ADC modes can be used in devices with two ADCs or more (see *Figure 293*).

In dual ADC mode the start of conversion is triggered alternately or simultaneously by the ADCx master to the ADC slave, depending on the mode selected by the bits DUAL[4:0] in the ADC_CCR register.

Four possible modes are implemented:

- Injected simultaneous mode
- Regular simultaneous mode
- Interleaved mode
- Alternate trigger mode

It is also possible to use these modes combined in the following ways:

- Injected simultaneous mode + regular simultaneous mode
- Regular simultaneous mode + alternate trigger mode
- Injected simultaneous mode + interleaved mode

In dual ADC mode (when bits DUAL[4:0] in ADC_CCR register are not equal to zero), the bits CONT, AUTDLY, DISCEN, DISCNUM[2:0], JDISCEN, JQM, JAUTO of the ADC_CFGR register are shared between the master and slave ADC: the bits in the slave ADC are always equal to the corresponding bits of the master ADC.

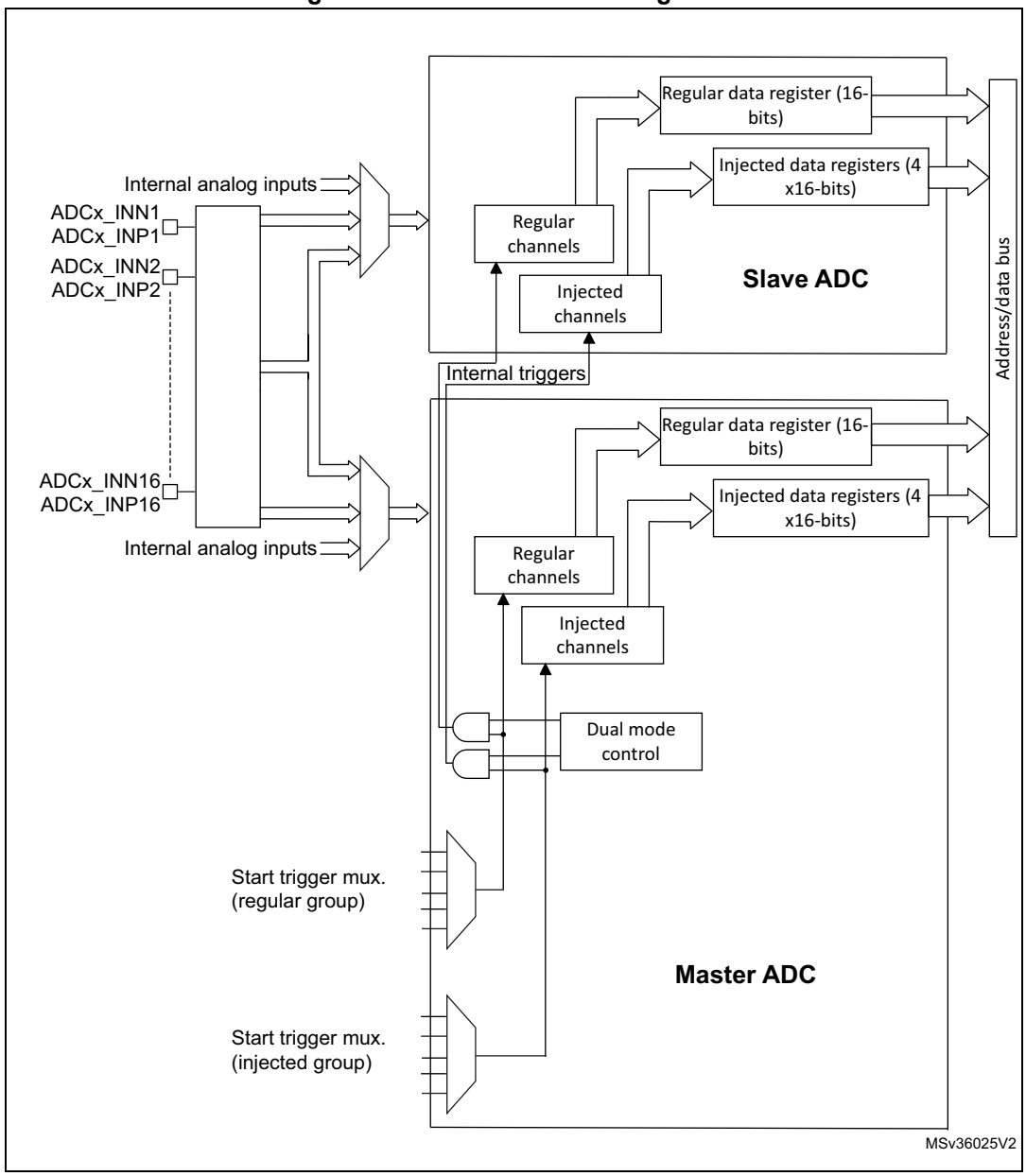
To start a conversion in dual mode, the user must program the bits EXTEN, EXTSEL, JEXTEN, JEXTSEL of the master ADC only, to configure a software or hardware trigger, and a regular or injected trigger. (the bits EXTEN[1:0] and JEXTEN[1:0] of the slave ADC are don’t care).

In regular simultaneous or interleaved modes: once the user sets bit ADSTART or bit ADSTP of the master ADC, the corresponding bit of the slave ADC is also automatically set. However, bit ADSTART or bit ADSTP of the slave ADC is not necessary cleared at the same time as the master ADC bit.

In injected simultaneous or alternate trigger modes: once the user sets bit JADSTART or bit JADSTP of the master ADC, the corresponding bit of the slave ADC is also automatically set. However, bit JADSTART or bit JADSTP of the slave ADC is not necessary cleared at the same time as the master ADC bit.

In dual ADC mode, the converted data of the master and slave ADC can be read in parallel, by reading the ADC common data register (ADC_CDR). The status bits can be also read in parallel by reading the dual-mode status register (ADC_CSR).

Figure 293. Dual ADC block diagram(1)



1. External triggers also exist on slave ADC but are not shown for the purposes of this diagram.
2. The ADC common data register (ADC_CDR) contains both the master and slave ADC regular converted data.

Injected simultaneous mode

This mode is selected by programming bits DUAL[4:0] = 00101

This mode converts an injected group of channels. The external trigger source comes from the injected group multiplexer of the master ADC (selected by the JEXTSEL bits in the ADC_JSQR register).

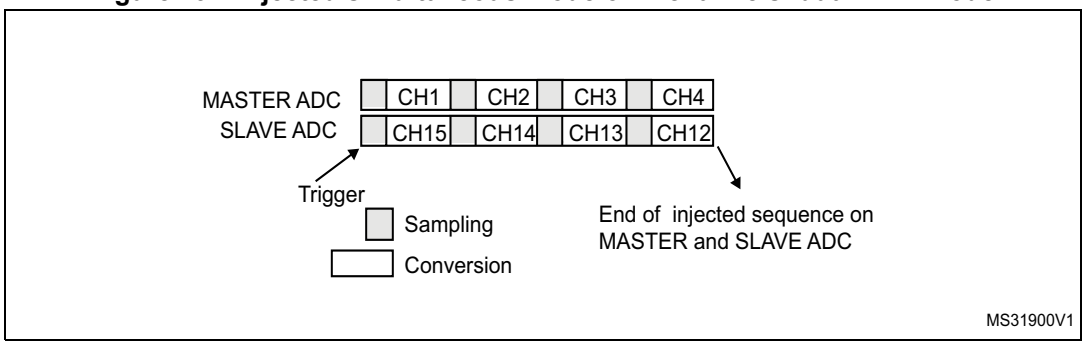
Note: Do not convert the same channel on the two ADCs (no overlapping sampling times for the two ADCs when converting the same channel).

In simultaneous mode, one must convert sequences with the same length or ensure that the interval between triggers is longer than the longer of the 2 sequences. Otherwise, the ADC with the shortest sequence may restart while the ADC with the longest sequence is completing the previous conversions.

Regular conversions can be performed on one or all ADCs. In that case, they are independent of each other and are interrupted when an injected event occurs. They are resumed at the end of the injected conversion group.

- At the end of injected sequence of conversion event (JEOS) on the master ADC, the converted data is stored into the master ADC_JDRy registers and a JEOS interrupt is generated (if enabled)
- At the end of injected sequence of conversion event (JEOS) on the slave ADC, the converted data is stored into the slave ADC_JDRy registers and a JEOS interrupt is generated (if enabled)
- If the duration of the master injected sequence is equal to the duration of the slave injected one (like in *Figure 294*), it is possible for the software to enable only one of the two JEOS interrupt (ex: master JEOS) and read both converted data (from master ADC_JDRy and slave ADC_JDRy registers).

Figure 294. Injected simultaneous mode on 4 channels: dual ADC mode



If JDISCEN = 1, each simultaneous conversion of the injected sequence requires an injected trigger event to occur.

This mode can be combined with AUTDLY mode:

- Once a simultaneous injected sequence of conversions has ended, a new injected trigger event is accepted only if both JEOS bits of the master and the slave ADC have been cleared (delay phase). Any new injected trigger events occurring during the ongoing injected sequence and the associated delay phase are ignored.
- Once a regular sequence of conversions of the master ADC has ended, a new regular trigger event of the master ADC is accepted only if the master data register (ADC_DR) has been read. Any new regular trigger events occurring for the master ADC during the

ongoing regular sequence and the associated delay phases are ignored.
There is the same behavior for regular sequences occurring on the slave ADC.

Regular simultaneous mode with independent injected

This mode is selected by programming bits DUAL[4:0] = 00110.

This mode is performed on a regular group of channels. The external trigger source comes from the regular group multiplexer of the master ADC (selected by the EXTSEL bits in the ADC_CFGR register). A simultaneous trigger is provided to the slave ADC.

In this mode, independent injected conversions are supported. An injection request (either on master or on the slave) aborts the current simultaneous conversions, which are restarted once the injected conversion is completed.

Note: Do not convert the same channel on the two ADCs (no overlapping sampling times for the two ADCs when converting the same channel).

In regular simultaneous mode, one must convert sequences with the same length or ensure that the interval between triggers is longer than the longer conversion time of the 2 sequences. Otherwise, the ADC with the shortest sequence may restart while the ADC with the longest sequence is completing the previous conversions.

Software is notified by interrupts when it can read the data:

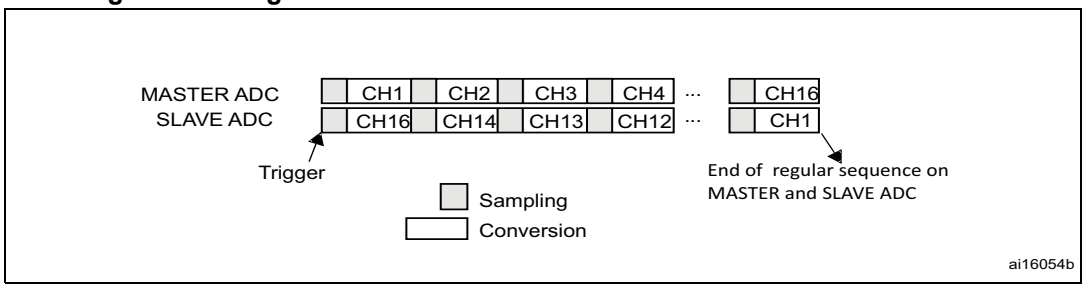
- At the end of each conversion event (EOC) on the master ADC, a master EOC interrupt is generated (if EOCIE is enabled) and software can read the ADC_DR of the master ADC.
- At the end of each conversion event (EOC) on the slave ADC, a slave EOC interrupt is generated (if EOCIE is enabled) and software can read the ADC_DR of the slave ADC.
- If the duration of the master regular sequence is equal to the duration of the slave one (like in *Figure 295*), it is possible for the software to enable only one of the two EOC interrupt (ex: master EOC) and read both converted data from the Common Data register (ADC_CDR).

It is also possible to read the regular data using the DMA. Two methods are possible:

- Using two DMA channels (one for the master and one for the slave). In this case bits MDMA[1:0] must be kept cleared.
  - Configure the DMA master ADC channel to read ADC_DR from the master. DMA requests are generated at each EOC event of the master ADC.
  - Configure the DMA slave ADC channel to read ADC_DR from the slave. DMA requests are generated at each EOC event of the slave ADC.
- Using MDMA mode, which leaves one DMA channel free for other uses:
  - Configure MDMA[1:0] = 0b10 or 0b11 (depending on resolution).
  - A single DMA channel is used (the one of the master). Configure the DMA master ADC channel to read the common ADC register (ADC_CDR)
  - A single DMA request is generated each time both master and slave EOC events have occurred. At that time, the slave ADC converted data is available in the upper half-word of the ADC_CDR 32-bit register and the master ADC converted data is available in the lower half-word of ADC_CDR register.
  - Both EOC flags are cleared when the DMA reads the ADC_CDR register.

Note: In MDMA mode (MDMA[1:0] = 0b10 or 0b11), the user must program the same number of conversions in the master's sequence as in the slave's sequence. Otherwise, the remaining conversions does not generate a DMA request.

Figure 295. Regular simultaneous mode on 16 channels: dual ADC mode



If DISCEN = 1 then each “n” simultaneous conversions of the regular sequence require a regular trigger event to occur (“n” is defined by DISCNUM).

This mode can be combined with AUTDLY mode:

- Once a simultaneous conversion of the sequence has ended, the next conversion in the sequence is started only if the common data register, ADC_CDR (or the regular data register of the master ADC) has been read (delay phase).
- Once a simultaneous regular sequence of conversions has ended, a new regular trigger event is accepted only if the common data register (ADC_CDR) has been read (delay phase). Any new regular trigger events occurring during the ongoing regular sequence and the associated delay phases are ignored.

It is possible to use the DMA to handle data in regular simultaneous mode combined with AUTDLY mode, assuming that multiple-DMA mode is used: bits MDMA must be set to 0b10 or 0b11.

When regular simultaneous mode is combined with AUTDLY mode, it is mandatory for the user to ensure that:

- The number of conversions in the master’s sequence is equal to the number of conversions in the slave’s.
- For each simultaneous conversions of the sequence, the length of the conversion of the slave ADC is inferior to the length of the conversion of the master ADC. Note that the length of the sequence depends on the number of channels to convert and the sampling time and the resolution of each channels.

Note: This combination of regular simultaneous mode and AUTDLY mode is restricted to the use case when only regular channels are programmed: it is forbidden to program injected channels in this combined mode.

Interleaved mode with independent injected

This mode is selected by programming bits DUAL[4:0] = 00111.

This mode can be started only on a regular group (usually one channel). The external trigger source comes from the regular channel multiplexer of the master ADC.

After an external trigger occurs:

- The master ADC starts immediately.
- The slave ADC starts after a delay of several-ADC clock cycles after the sampling phase of the master ADC has complete.

The minimum delay which separates two conversions in interleaved mode is configured in the DELAY bits in the ADC_CCR register. This delay starts counting one half cycle after the end of the sampling phase of the master conversion. This way, an ADC cannot start a

conversion if the complementary ADC is still sampling its input (only one ADC can sample the input signal at a given time).

- The minimum possible DELAY is 1 to ensure that there is at least one cycle time between the opening of the analog switch of the master ADC sampling phase and the closing of the analog switch of the slave ADC sampling phase.
- The maximum DELAY is equal to the number of cycles corresponding to the selected resolution. However the user must properly calculate this delay to ensure that an ADC does not start a conversion while the other ADC is still sampling its input.

If the CONT bit is set on both master and slave ADCs, the selected regular channels of both ADCs are continuously converted.

The software is notified by interrupts when it can read the data at the end of each conversion event (EOC) on the slave ADC. A slave and master EOC interrupts are generated (if EOCIE is enabled) and the software can read the ADC_DR of the slave/master ADC.

Note: It is possible to enable only the EOC interrupt of the slave and read the common data register (ADC_CDR). But in this case, the user must ensure that the duration of the conversions are compatible to ensure that inside the sequence, a master conversion is always followed by a slave conversion before a new master conversion restarts. It is recommended to use the MDMA mode.

It is also possible to have the regular data transferred by DMA. In this case, individual DMA requests on each ADC cannot be used and it is mandatory to use the MDMA mode, as following:

- Configure MDMA[1:0] = 0b10 or 0b11 (depending on resolution).
- A single DMA channel is used (the one of the master). Configure the DMA master ADC channel to read the common ADC register (ADC_CDR).
- A single DMA request is generated each time both master and slave EOC events have occurred. At that time, the slave ADC converted data is available in the upper half-word of the ADC_CDR 32-bit register and the master ADC converted data is available in the lower half-word of ADC_CCR register.
- Both EOC flags are cleared when the DMA reads the ADC_CCR register.

Figure 296. Interleaved mode on one channel in continuous conversion mode: dual ADC mode

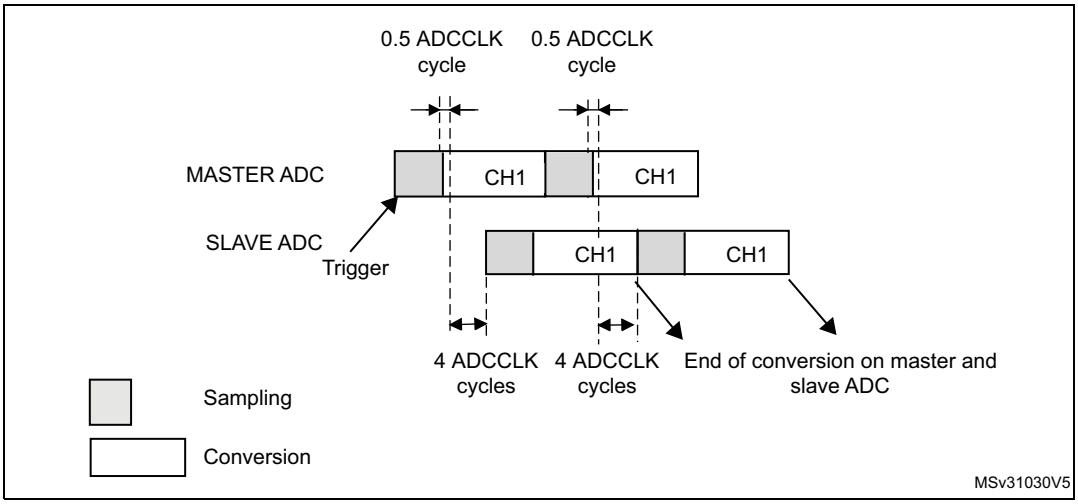
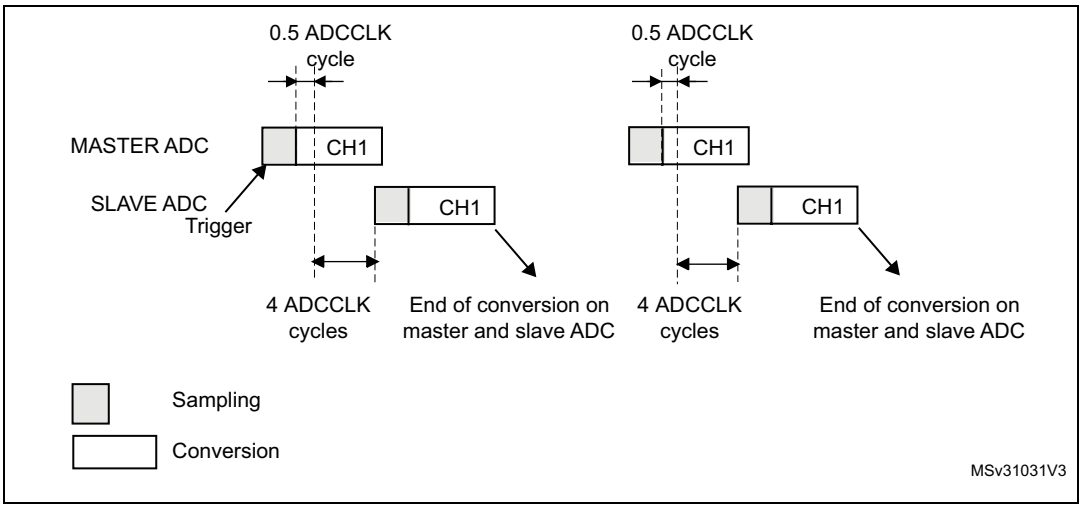


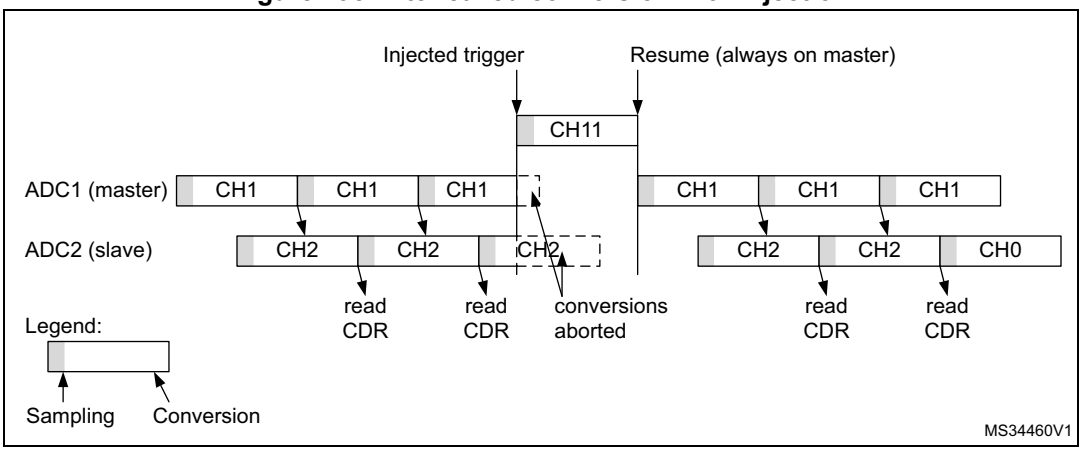
Figure 297. Interleaved mode on 1 channel in single conversion mode: dual ADC mode



If DISCEN = 1, each “n” simultaneous conversions (“n” is defined by DISCNUM) of the regular sequence require a regular trigger event to occur.

In this mode, injected conversions are supported. When injection is done (either on master or on slave), both the master and the slave regular conversions are aborted and the sequence is restarted from the master (see *Figure 298* below).

Figure 298. Interleaved conversion with injection



Alternate trigger mode

This mode is selected by programming bits DUAL[4:0] = 01001.

This mode can be started only on an injected group. The source of external trigger comes from the injected group multiplexer of the master ADC.

This mode is only possible when selecting hardware triggers: JEXTEN must not be 0x0.

Injected discontinuous mode disabled (JDISCEN = 0 for both ADC)

1. When the 1st trigger occurs, all injected master ADC channels in the group are converted.
2. When the 2nd trigger occurs, all injected slave ADC channels in the group are converted.
3. And so on.

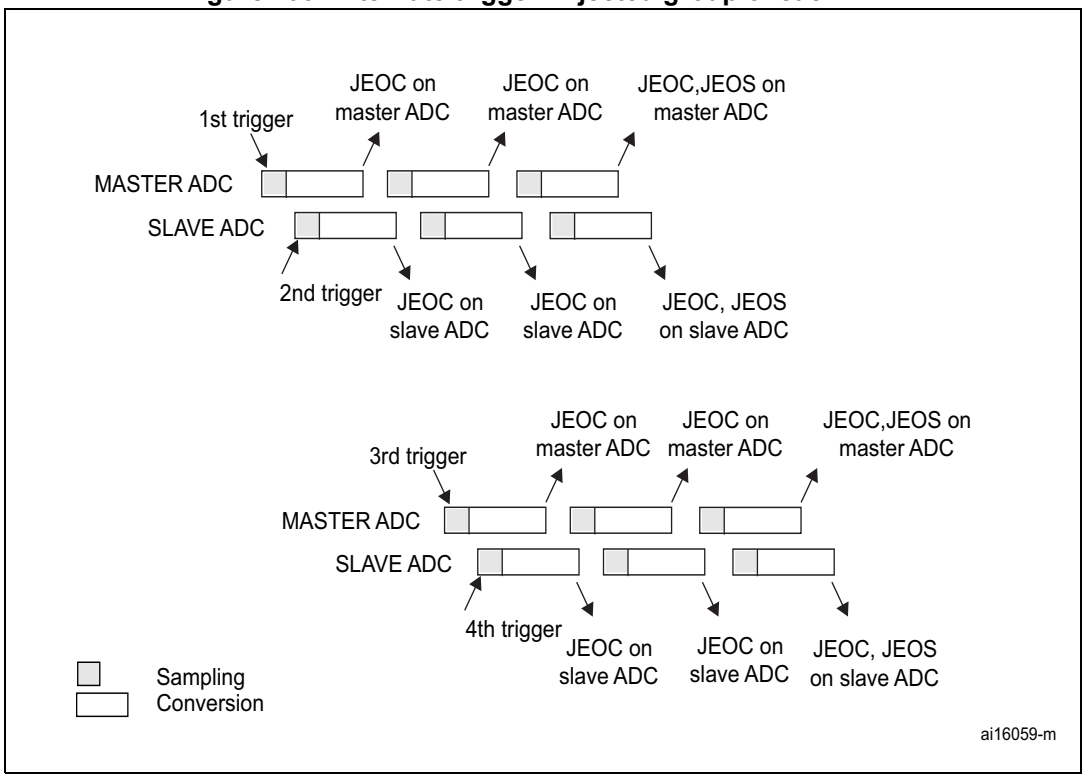
A JEOS interrupt, if enabled, is generated after all injected channels of the master ADC in the group have been converted.

A JEOS interrupt, if enabled, is generated after all injected channels of the slave ADC in the group have been converted.

JEOC interrupts, if enabled, can also be generated after each injected conversion.

If another external trigger occurs after all injected channels in the group have been converted then the alternate trigger process restarts by converting the injected channels of the master ADC in the group.

Figure 299. Alternate trigger: injected group of each ADC



Note: Regular conversions can be enabled on one or all ADCs. In this case the regular conversions are independent of each other. A regular conversion is interrupted when the ADC has to perform an injected conversion. It is resumed when the injected conversion is finished.

The time interval between 2 trigger events must be greater than or equal to 1 ADC clock period. The minimum time interval between 2 trigger events that start conversions on the same ADC is the same as in the single ADC mode.

Injected discontinuous mode enabled (JDISCEN = 1 for both ADC)

If the injected discontinuous mode is enabled for both master and slave ADCs:

- When the 1st trigger occurs, the first injected channel of the master ADC is converted.
- When the 2nd trigger occurs, the first injected channel of the slave ADC is converted.
- And so on.

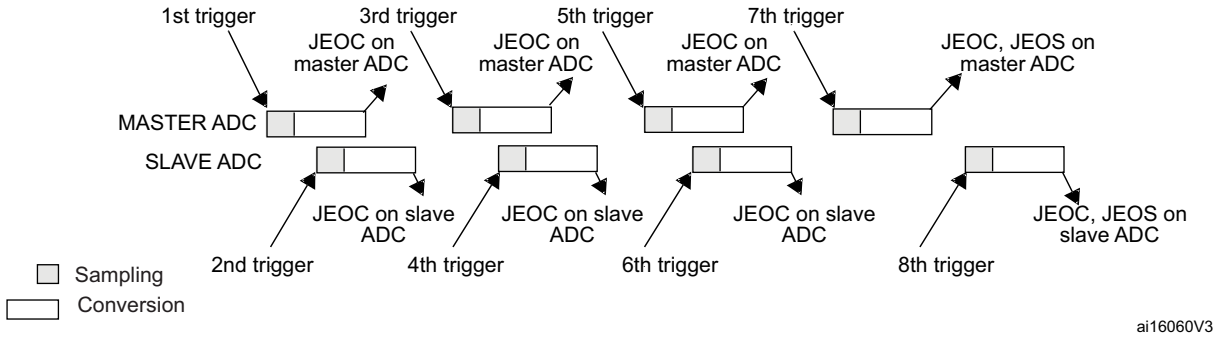
A JEOS interrupt, if enabled, is generated after all injected channels of the master ADC in the group have been converted.

A JEOS interrupt, if enabled, is generated after all injected channels of the slave ADC in the group have been converted.

JEOC interrupts, if enabled, can also be generated after each injected conversions.

If another external trigger occurs after all injected channels in the group have been converted then the alternate trigger process restarts.

Figure 300. Alternate trigger: 4 injected channels (each ADC) in discontinuous mode



Combined regular/injected simultaneous mode

This mode is selected by programming bits DUAL[4:0] = 00001.

It is possible to interrupt the simultaneous conversion of a regular group to start the simultaneous conversion of an injected group.

Note: In combined regular/injected simultaneous mode, one must convert sequences with the same length or ensure that the interval between triggers is longer than the long conversion time of the 2 sequences. Otherwise, the ADC with the shortest sequence may restart while the ADC with the longest sequence is completing the previous conversions.

Combined regular simultaneous + alternate trigger mode

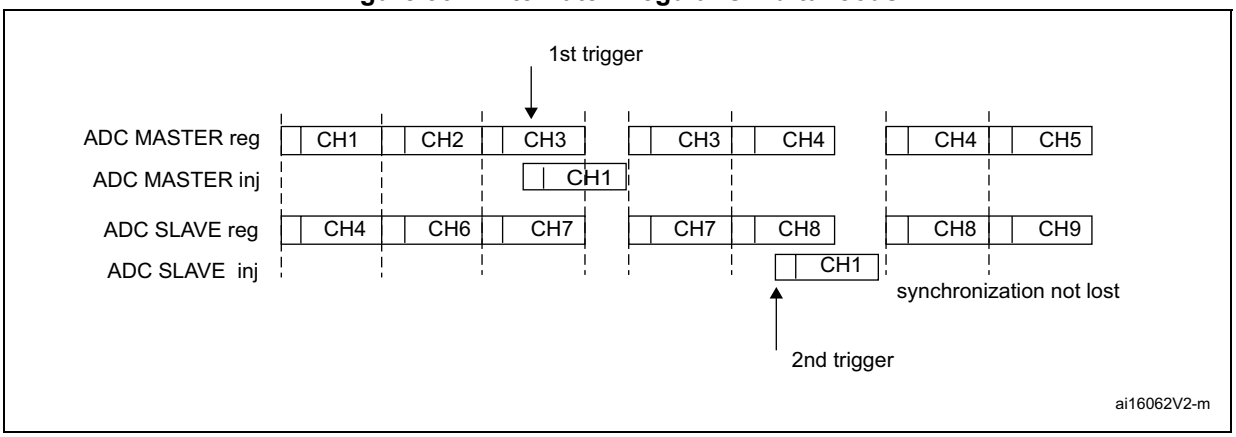
This mode is selected by programming bits DUAL[4:0] = 00010.

It is possible to interrupt the simultaneous conversion of a regular group to start the alternate trigger conversion of an injected group. *Figure 301* shows the behavior of an alternate trigger interrupting a simultaneous regular conversion.

The injected alternate conversion is immediately started after the injected event. If a regular conversion is already running, in order to ensure synchronization after the injected conversion, the regular conversion of all (master/slave) ADCs is stopped and resumed synchronously at the end of the injected conversion.

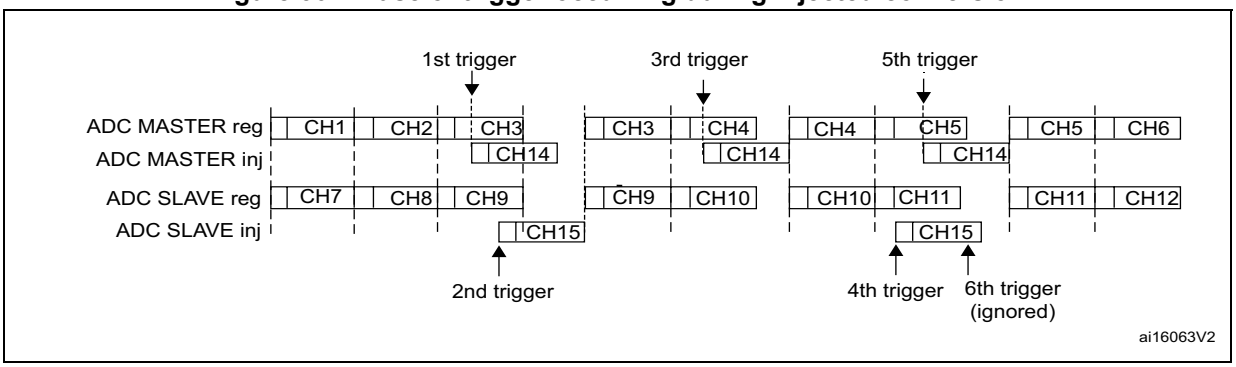
Note: In combined regular simultaneous + alternate trigger mode, one must convert sequences with the same length or ensure that the interval between triggers is longer than the long conversion time of the 2 sequences. Otherwise, the ADC with the shortest sequence may restart while the ADC with the longest sequence is completing the previous conversions.

Figure 301. Alternate + regular simultaneous



If a trigger occurs during an injected conversion that has interrupted a regular conversion, the alternate trigger is served. *Figure 302* shows the behavior in this case (note that the 6th trigger is ignored because the associated alternate conversion is not complete).

Figure 302. Case of trigger occurring during injected conversion



Combined injected simultaneous plus interleaved

This mode is selected by programming bits DUAL[4:0] = 00011

It is possible to interrupt an interleaved conversion with a simultaneous injected event.

In this case the interleaved conversion is interrupted immediately and the simultaneous injected conversion starts. At the end of the injected sequence the interleaved conversion is resumed. When the interleaved regular conversion resumes, the first regular conversion which is performed is alway the master's one. *Figure 303*, *Figure 304* and *Figure 305* show the behavior using an example.

Caution: In this mode, it is mandatory to use the Common Data Register to read the regular data with a single read access. On the contrary, master-slave data coherency is not guaranteed.

Figure 303. Interleaved single channel CH0 with injected sequence CH11, CH12

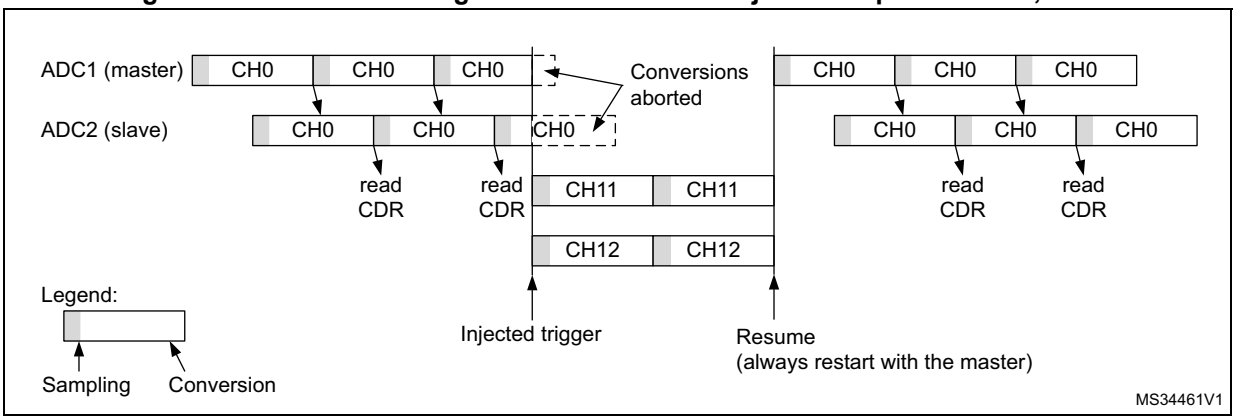


Figure 304. Two Interleaved channels (CH1, CH2) with injected sequence CH11, CH12 - case 1: Master interrupted first

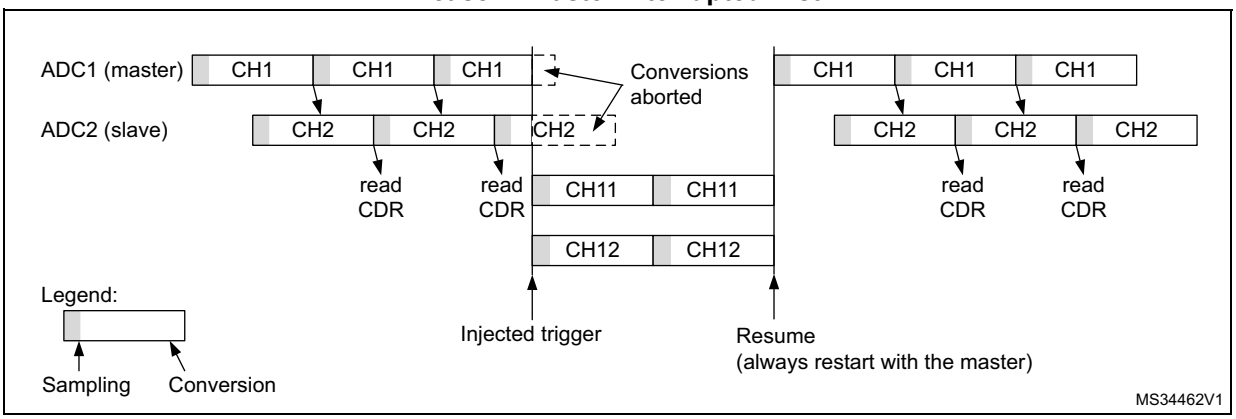
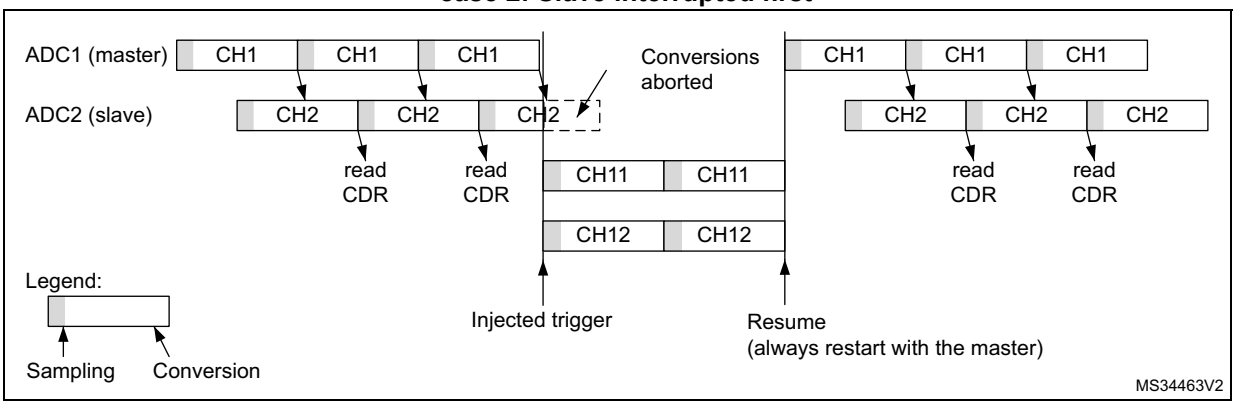


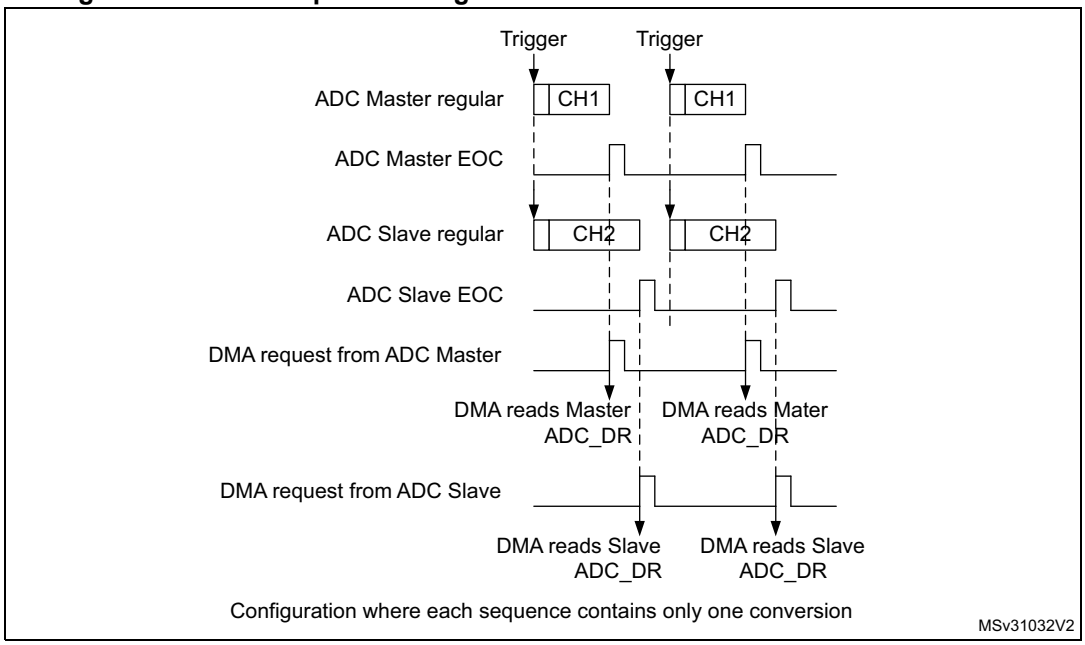
Figure 305. Two Interleaved channels (CH1, CH2) with injected sequence CH11, CH12 - case 2: Slave interrupted first



DMA requests in dual ADC mode

In all dual ADC modes, it is possible to use two DMA channels (one for the master, one for the slave) to transfer the data, like in single mode (refer to *Figure 306: DMA Requests in regular simultaneous mode when MDMA = 0b00*).

Figure 306. DMA Requests in regular simultaneous mode when MDMA = 0b00



In simultaneous regular and interleaved modes, it is also possible to save one DMA channel and transfer both data using a single DMA channel. For this MDMA bits must be configured in the ADC_CCR register:

- **MDMA = 0b10**: A single DMA request is generated each time both master and slave EOC events have occurred. At that time, two data items are available and the 32-bit register ADC_CDR contains the two half-words representing two ADC-converted data items. The slave ADC data take the upper half-word and the master ADC data take the lower half-word.
  This mode is used in interleaved mode and in regular simultaneous mode when resolution is 10-bit or 12-bit.

  Example:

  Interleaved dual mode: a DMA request is generated each time 2 data items are available:

  1st DMA request: ADC_CDR[31:0] = SLV_ADC_DR[15:0] | MST_ADC_DR[15:0]

  2nd DMA request: ADC_CDR[31:0] = SLV_ADC_DR[15:0] | MST_ADC_DR[15:0]

Figure 307. DMA requests in regular simultaneous mode when MDMA = 0b10

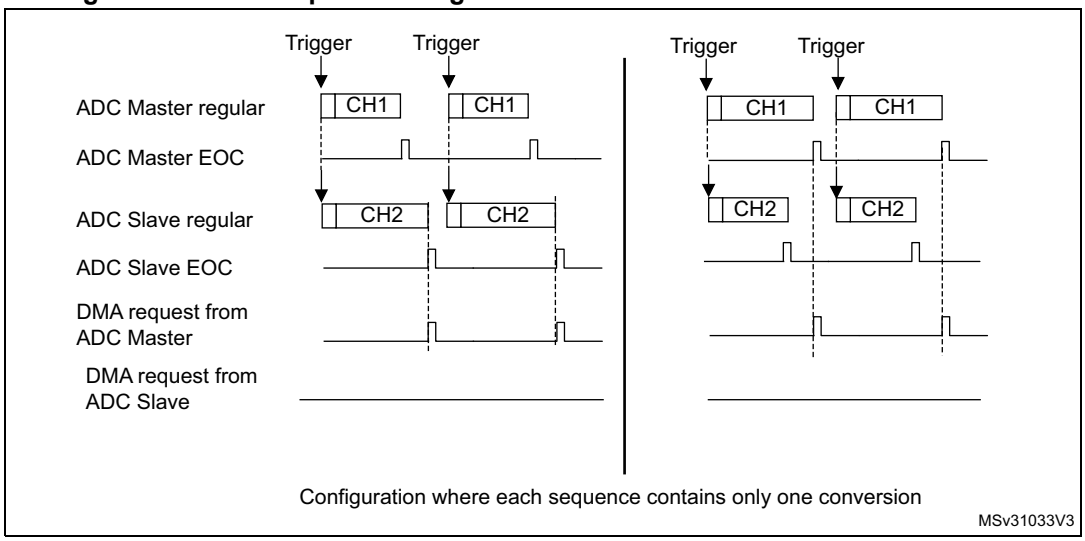
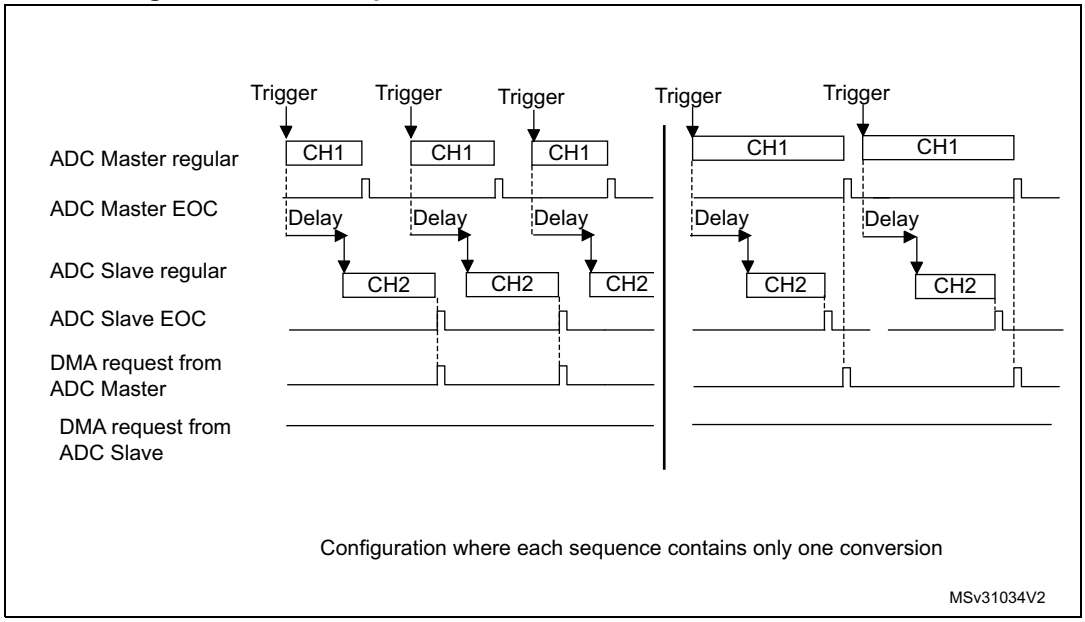


Figure 308. DMA requests in interleaved mode when MDMA = 0b10



Note: When using MDMA mode, the user must take care to configure properly the duration of the master and slave conversions so that a DMA request is generated and served for reading both data (master + slave) before a new conversion is available.

- **MDMA = 0b11**: This mode is similar to the MDMA = 0b10. The only differences are that on each DMA request (two data items are available), two bytes representing two ADC converted data items are transferred as a half-word.

  This mode is used in interleaved and regular simultaneous mode when resolution is 6-bit or when resolution is 8-bit and data is not signed (offsets must be disabled for all the involved channels).

  Example:

  Interleaved dual mode: a DMA request is generated each time 2 data items are available:

  1st DMA request: ADC_CDR[15:0] = SLV_ADC_DR[7:0] | MST_ADC_DR[7:0]

  2nd DMA request: ADC_CDR[15:0] = SLV_ADC_DR[7:0] | MST_ADC_DR[7:0]

Overrun detection

In dual ADC mode (when DUAL[4:0] is not equal to b00000), if an overrun is detected on one of the ADCs, the DMA requests are no longer issued to ensure that all the data transferred to the RAM are valid (this behavior occurs whatever the MDMA configuration). It may happen that the EOC bit corresponding to one ADC remains set because the data register of this ADC contains valid data.

DMA one shot mode/ DMA circular mode when MDMA mode is selected

When MDMA mode is selected (0b10 or 0b11), bit DMACFG of the ADC_CCR register must also be configured to select between DMA one shot mode and circular mode, as explained in section *Section : Managing conversions using the DMA* (bits DMACFG of master and slave ADC_CFGR are not relevant).

Stopping the conversions in dual ADC modes

The user must set the control bits ADSTP/JADSTP of the master ADC to stop the conversions of both ADC in dual ADC mode. The other ADSTP control bit of the slave ADC has no effect in dual ADC mode.

Once both ADC are effectively stopped, the bits ADSTART/JADSTART of the master and slave ADCs are both cleared by hardware.

30.4.32 Temperature sensor

The temperature sensor can be used to measure the junction temperature (Tj) of the device.

The temperature sensor is internally connected to the ADC input channels which are used to convert the sensor output voltage to a digital value (see *Table: ADC interconnection* in *Section 30.4.2: ADC pins and internal signals* for more details). When not in use, the sensor can be put in power down mode. It support the temperature range –40 to 125 °C.

Figure 309 shows the block diagram of connections between the temperature sensor and the ADC.

The temperature sensor output voltage changes linearly with temperature. The offset of this line varies from chip to chip due to process variation (up to 45 °C from one chip to another).

The uncalibrated internal temperature sensor is more suited for applications that detect temperature variations instead of absolute temperatures. To improve the accuracy of the temperature sensor measurement, calibration values are stored in system memory for each device by ST during production.

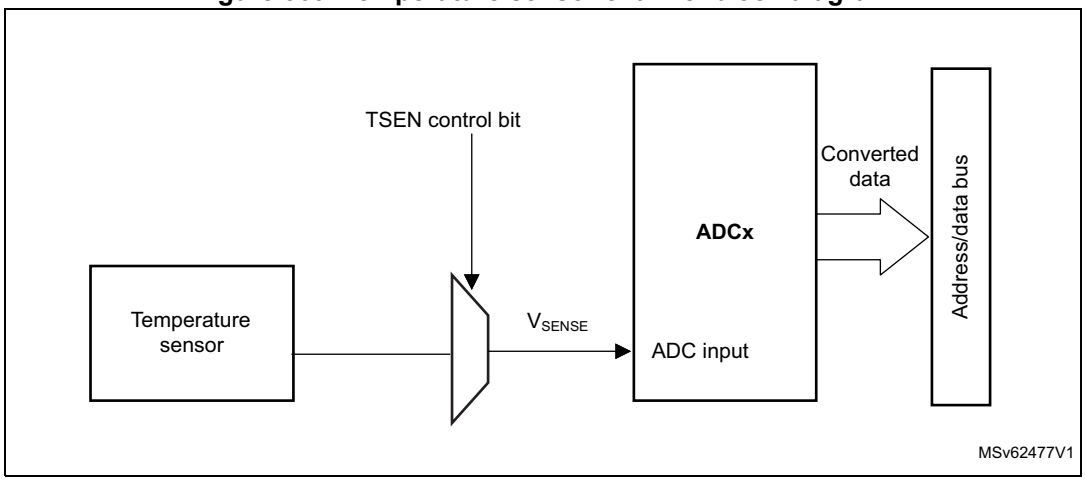
During the manufacturing process, the calibration data of the temperature sensor and the internal voltage reference are stored in the system memory area. The user application can then read them and use them to improve the accuracy of the temperature sensor or the internal reference (refer to the datasheet for additional information).

The temperature sensor is internally connected to the ADC input channel which is used to convert the sensor's output voltage to a digital value. Refer to the electrical characteristics section of the device datasheet for the sampling time value to be applied when converting the internal temperature sensor.

When not in use, the sensor can be put in power-down mode.

Figure 309 shows the block diagram of the temperature sensor.

Figure 309. Temperature sensor channel block diagram



Reading the temperature

To use the sensor:

1. Select the ADC input channels that is connected to V_{SENSE}.
2. Program with the appropriate sampling time (refer to electrical characteristics section of the device datasheet).
3. Set the bit in the ADC_CCR register to wake up the temperature sensor from power-down mode.
4. Start the ADC conversion.
5. Read the resulting V_{SENSE} data in the ADC data register.
6. Calculate the actual temperature using the following formula:

$$\text{Temperature (in °C)} = \frac{\text{TS_CAL2_TEMP} - \text{TS_CAL1_TEMP}}{\text{TS_CAL2} - \text{TS_CAL1}} \times (\text{TS_DATA} - \text{TS_CAL1}) + \text{TS_CAL1_TEMP}$$

where:

- TS_CAL2 is the temperature sensor calibration value acquired at TS_CAL2_TEMP.
- TS_CAL1 is the temperature sensor calibration value acquired at TS_CAL1_TEMP.
- TS_DATA is the actual temperature sensor output value converted by ADC.

  Refer to the device datasheet for more information about TS_CAL1 and TS_CAL2 calibration points.

Note: The sensor has a startup time after waking from power-down mode before it can output V_{SENSE} at the correct level. The ADC also has a startup time after power-on, so to minimize the delay, the ADEN and bits should be set at the same time.

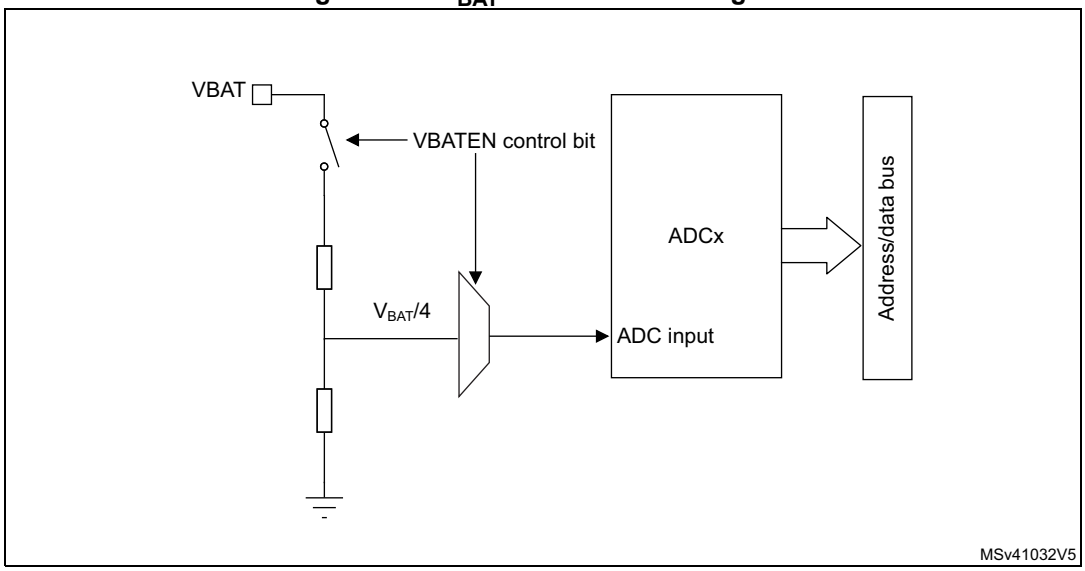
30.4.33 V_{BAT} supply monitoring

The VBATEN bit in the ADC_CCR register is used to switch to the battery voltage. As the V_{BAT} voltage could be higher than V_{DDA}, to ensure the correct operation of the ADC, the V_{BAT} pin is internally connected to a bridge divider by 4. This bridge is automatically enabled when VBATEN is set, to connect $V_{BAT}/4$ to the ADC input channels (see *Table: ADC interconnection* in *Section 30.4.2: ADC pins and internal signals* for more details). As a consequence, the converted digital value is one third of the V_{BAT} voltage. To prevent any unwanted consumption on the battery, it is recommended to enable the bridge divider only when needed, for ADC conversion.

Refer to the electrical characteristics of the device datasheet for the sampling time value to be applied when converting the $V_{BAT}/4$ voltage.

Figure 310 shows the block diagram of the V_{BAT} sensing feature.

Figure 310. V_{BAT} channel block diagram



1. The VBATEN bit must be set to enable the conversion of internal channel for V_{BAT}/4.

30.4.34 Monitoring the internal voltage reference

It is possible to monitor the internal voltage reference (V_{REFINT}) to have a reference point for evaluating the ADC V_{REF+} voltage level.

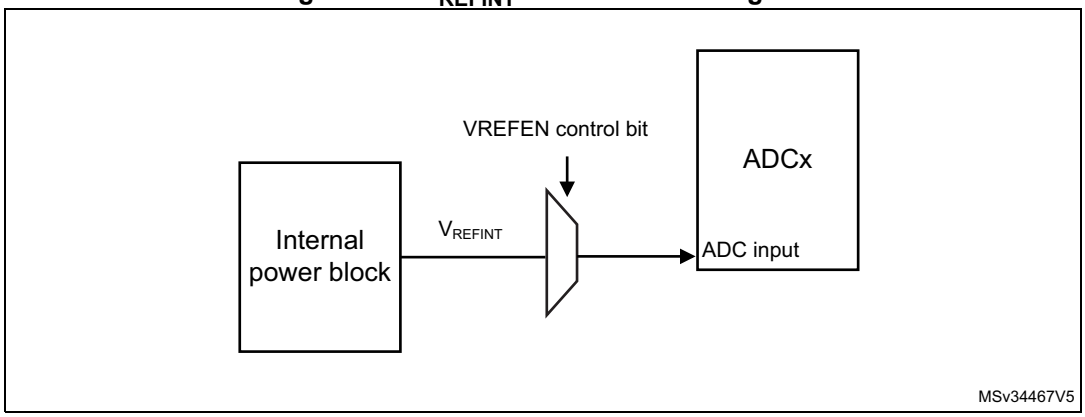
Refer to *Table: ADC interconnection* in *Section 30.4.2: ADC pins and internal signals* for details on the ADC input channels to which the internal voltage reference is internally connected.

Refer to the electrical characteristics section of the product datasheet for the sampling time value to be applied when converting the internal voltage reference voltage.

Figure 311 shows the block diagram of the V_{REFINT} sensing feature.

Note: V_{REFINT} must not be converted by two ADCs at the same time.

Figure 311. V_{REFINT} channel block diagram



1. The VREFEN bit into ADC_CCR register must be set to enable the conversion of internal channels (V_{REFINT}).

Calculating the actual V_{REF+} voltage using the internal reference voltage

V_{REF+} voltage may be subject to variations or not precisely known. The embedded internal reference voltage V_{REFINT} and its calibration data acquired by the ADC during the manufacturing process at V_{REF+_charac} can be used to evaluate the actual V_{REF+} voltage level.

The following formula gives the actual V_{REF+} voltage supplying the device:

$$V_{REF+} = V_{REF+_Charac} \times VREFINT_CAL / VREFINT_DATA$$

Where:

- V_{REF+_Charac} is the value of V_{REF+} voltage characterized at V_{REFINT} during the manufacturing process. It is specified in the device datasheet.
- VREFINT_CAL is the VREFINVREFINT_CAL is the VREFINT calibration value
- VREFINT_DATA is the actual VREFINT output value converted by ADC

Converting a supply-relative ADC measurement to an absolute voltage value

The ADC is designed to deliver a digital value corresponding to the ratio between V_{REF+} and the voltage applied on the converted channel.

For applications where V_{REF+} value is unknown and ADC converted values are right-aligned. In this case, it is necessary to convert this ratio into a voltage independent from V_{REF+}:

$$V_{CHANNELx} = \frac{V_{REF+}}{FULL_SCALE} \times ADC_DATA$$

By replacing V_{REF+} by the formula provided above, the absolute voltage value is given by the following formula

$$V_{CHANNELx} = \frac{V_{REF+_Charac} \times VREFINT_CAL \times ADC_DATA}{VREFINT_DATA \times FULL_SCALE}$$

Where:

- V_{REF+_Charac} is the value of V_{REF+} voltage characterized at V_{REFINT} during the manufacturing process.
- VREFINT_CAL is the VREFINT calibration value
- ADC_DATA is the value measured by the ADC on channel x (right-aligned)
- VREFINT_DATA is the actual VREFINT output value converted by the ADC
- FULL_SCALE is the maximum digital value of the ADC output. For example with 12-bit resolution, it is 2^{12} - 1 = 4095 or with 8-bit resolution, 2^8 - 1 = 255.

Note: If ADC measurements are done using an output format other than 12-bit right-aligned, all the parameters must first be converted to a compatible format before the calculation is done.

30.4.35 Monitoring the supply voltage

ADC2/3 is connected to the internal supply voltage. To use the ADC to measure this voltage, enable the connection through ADC option register.

30.5 ADC interrupts

For each ADC, an interrupt can be generated:

- After ADC power-up, when the ADC is ready (flag ADRDY)
- On the end of any conversion for regular groups (flag EOC)
- On the end of a sequence of conversion for regular groups (flag EOS)
- On the end of any conversion for injected groups (flag JEOC)
- On the end of a sequence of conversion for injected groups (flag JEOS)
- When an analog watchdog detection occurs (flag AWD1, AWD2 and AWD3)
- When the end of sampling phase occurs (flag EOSMP)
- When the data overrun occurs (flag OVR)
- When the injected sequence context queue overflows (flag JQOVF)

Separate interrupt enable bits are available for flexibility.

Table 300. ADC interrupts

Interrupt vector	Interrupt event	Event flag	Enable Control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop, Standby mode
ADC	ADC ready	ADRDY	ADRDYIE	Set by hardware and cleared by software	Yes	No
	End of conversion of a regular group	EOC	EOCIE			
	End of conversion sequence of a regular group	EOS	EOSIE			
	End of conversion of an injected group	JEOC	JEOCIE			
	End of conversion sequence of an injected group	JEOS	JEOSIE			
	Analog watchdog 1 status bit is set	AWD1	AWD1IE			
	Analog watchdog 2 status bit is set	AWD2	AWD2IE			
	Analog watchdog 3 status bit is set	AWD3	AWD3IE			
	End of sampling phase	EOSMP	EOSMPIE			
	Overrun	OVR	OVRIE			
	Injected context queue overflows	JQOVF	JQOVFIE			

30.6 ADC registers (for each ADC)

Refer to *Section 1.2 on page 128* for a list of abbreviations used in register descriptions.

30.6.1 ADC interrupt and status register (ADC_ISR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	JQOVF	AWD3	AWD2	AWD1	JEOS	JEOC	OVR	EOS	EOC	EOSMP	ADRDY
					rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **JQOVF**: Injected context queue overflow

This bit is set by hardware when an Overflow of the Injected Queue of Context occurs. It is cleared by software writing 1 to it. Refer to *Section 30.4.21: Queue of context for injected conversions* for more information.

0: No injected context queue overflow occurred (or the flag event was already acknowledged and cleared by software)

1: Injected context queue overflow has occurred

Bit 9 **AWD3**: Analog watchdog 3 flag

This bit is set by hardware when the converted voltage crosses the values programmed in the fields LT3[7:0] and HT3[7:0] of ADC_TR3 register. It is cleared by software writing 1 to it.

0: No analog watchdog 3 event occurred (or the flag event was already acknowledged and cleared by software)

1: Analog watchdog 3 event occurred

Bit 8 **AWD2**: Analog watchdog 2 flag

This bit is set by hardware when the converted voltage crosses the values programmed in the fields LT2[7:0] and HT2[7:0] of ADC_TR2 register. It is cleared by software writing 1 to it.

0: No analog watchdog 2 event occurred (or the flag event was already acknowledged and cleared by software)

1: Analog watchdog 2 event occurred

Bit 7 **AWD1**: Analog watchdog 1 flag

This bit is set by hardware when the converted voltage crosses the values programmed in the fields LT1[11:0] and HT1[11:0] of ADC_TR1 register. It is cleared by software. writing 1 to it.

0: No analog watchdog 1 event occurred (or the flag event was already acknowledged and cleared by software)

1: Analog watchdog 1 event occurred

Bit 6 **JEOS:** Injected channel end of sequence flag

This bit is set by hardware at the end of the conversions of all injected channels in the group. It is cleared by software writing 1 to it.

0: Injected conversion sequence not complete (or the flag event was already acknowledged and cleared by software)

1: Injected conversions complete

Bit 5 **JEOC:** Injected channel end of conversion flag

This bit is set by hardware at the end of each injected conversion of a channel when a new data is available in the corresponding ADC_JDRy register. It is cleared by software writing 1 to it or by reading the corresponding ADC_JDRy register

0: Injected channel conversion not complete (or the flag event was already acknowledged and cleared by software)

1: Injected channel conversion complete

Bit 4 **OVR**: ADC overrun

This bit is set by hardware when an overrun occurs on a regular channel, meaning that a new conversion has completed while the EOC flag was already set. It is cleared by software writing 1 to it.

0: No overrun occurred (or the flag event was already acknowledged and cleared by software)

1: Overrun has occurred

Bit 3 **EOS**: End of regular sequence flag

This bit is set by hardware at the end of the conversions of a regular sequence of channels. It is cleared by software writing 1 to it.

0: Regular Conversions sequence not complete (or the flag event was already acknowledged and cleared by software)

1: Regular Conversions sequence complete

Bit 2 **EOC**: End of conversion flag

This bit is set by hardware at the end of each regular conversion of a channel when a new data is available in the ADC_DR register. It is cleared by software writing 1 to it or by reading the ADC_DR register

0: Regular channel conversion not complete (or the flag event was already acknowledged and cleared by software)

1: Regular channel conversion complete

Bit 1 **EOSMP**: End of sampling flag

This bit is set by hardware during the conversion of any channel (only for regular channels), at the end of the sampling phase.

0: not at the end of the sampling phase (or the flag event was already acknowledged and cleared by software)

1: End of sampling phase reached

Bit 0 **ADRDY**: ADC ready

This bit is set by hardware after the ADC has been enabled (ADEN = 1) and when the ADC reaches a state where it is ready to accept conversion requests.

It is cleared by software writing 1 to it.

0: ADC not yet ready to start conversion (or the flag event was already acknowledged and cleared by software)

1: ADC is ready to start conversion

30.6.2 ADC interrupt enable register (ADC_IER)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	JQOVFIE	AWD3IE	AWD2IE	AWD1IE	JEOSIE	JEOCIE	OVRIE	EOSIE	EOCIE	EOSMP IE	ADRDY IE
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **JQOVFIE**: Injected context queue overflow interrupt enable

This bit is set and cleared by software to enable/disable the Injected Context Queue Overflow interrupt.

0: Injected Context Queue Overflow interrupt disabled

1: Injected Context Queue Overflow interrupt enabled. An interrupt is generated when the JQOVF bit is set.

Note: The software is allowed to write this bit only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 9 **AWD3IE**: Analog watchdog 3 interrupt enable

This bit is set and cleared by software to enable/disable the analog watchdog 2 interrupt.

0: Analog watchdog 3 interrupt disabled

1: Analog watchdog 3 interrupt enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 8 **AWD2IE**: Analog watchdog 2 interrupt enable

This bit is set and cleared by software to enable/disable the analog watchdog 2 interrupt.

0: Analog watchdog 2 interrupt disabled

1: Analog watchdog 2 interrupt enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 7 **AWD1IE**: Analog watchdog 1 interrupt enable

This bit is set and cleared by software to enable/disable the analog watchdog 1 interrupt.

0: Analog watchdog 1 interrupt disabled

1: Analog watchdog 1 interrupt enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 6 **JEOSIE**: End of injected sequence of conversions interrupt enable

This bit is set and cleared by software to enable/disable the end of injected sequence of conversions interrupt.

0: JEOS interrupt disabled

1: JEOS interrupt enabled. An interrupt is generated when the JEOS bit is set.

Note: The software is allowed to write this bit only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 5 **JEOCIE**: End of injected conversion interrupt enable

This bit is set and cleared by software to enable/disable the end of an injected conversion interrupt.

0: JEOC interrupt disabled.

1: JEOC interrupt enabled. An interrupt is generated when the JEOC bit is set.

Note: The software is allowed to write this bit only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 4 **OVRIE**: Overrun interrupt enable

This bit is set and cleared by software to enable/disable the Overrun interrupt of a regular conversion.

0: Overrun interrupt disabled

1: Overrun interrupt enabled. An interrupt is generated when the OVR bit is set.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 3 **EOSIE**: End of regular sequence of conversions interrupt enable

This bit is set and cleared by software to enable/disable the end of regular sequence of conversions interrupt.

0: EOS interrupt disabled

1: EOS interrupt enabled. An interrupt is generated when the EOS bit is set.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 2 **EOCIE**: End of regular conversion interrupt enable

This bit is set and cleared by software to enable/disable the end of a regular conversion interrupt.

0: EOC interrupt disabled.

1: EOC interrupt enabled. An interrupt is generated when the EOC bit is set.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 1 **EOSMPIE**: End of sampling flag interrupt enable for regular conversions

This bit is set and cleared by software to enable/disable the end of the sampling phase interrupt for regular conversions.

0: EOSMP interrupt disabled.

1: EOSMP interrupt enabled. An interrupt is generated when the EOSMP bit is set.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 0 **ADRDYIE**: ADC ready interrupt enable

This bit is set and cleared by software to enable/disable the ADC Ready interrupt.

0: ADRDY interrupt disabled

1: ADRDY interrupt enabled. An interrupt is generated when the ADRDY bit is set.

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

30.6.3 ADC control register (ADC_CR)

Address offset: 0x08

Reset value: 0x2000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADCAL	ADCALDIF	DEEPPWD	ADVREGEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rs	rw	rw	rw												
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JADSTP	ADSTP	JADSTART	ADSTART	ADDIS	ADEN
										rs	rs	rs	rs	rs	rs

Bit 31 **ADCAL**: ADC calibration

This bit is set by software to start the calibration of the ADC. Program first the bit ADCALDIF to determine if this calibration applies for single-ended or Differential inputs mode.

It is cleared by hardware after calibration is complete.

0: Calibration complete

1: Write 1 to calibrate the ADC. Read at 1 means that a calibration in progress.

Note: The software is allowed to launch a calibration by setting ADCAL only when ADEN = 0.

The software is allowed to update the calibration factor by writing ADC_CALFACT only when ADEN = 1 and ADSTART = 0 and JADSTART = 0 (ADC enabled and no conversion is ongoing)

Bit 30 **ADCALDIF**: Differential mode for calibration

This bit is set and cleared by software to configure the single-ended or Differential inputs mode for the calibration.

0: Writing ADCAL launches a calibration in single-ended inputs mode.

1: Writing ADCAL launches a calibration in Differential inputs mode.

Note: The software is allowed to write this bit only when the ADC is disabled and is not calibrating (ADCAL = 0, JADSTART = 0, JADSTP = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0).

Bit 29 **DEEPPWD**: Deep-power-down enable

This bit is set and cleared by software to put the ADC in Deep-power-down mode.

0: ADC not in Deep-power down

1: ADC in Deep-power-down (default reset state)

Note: The software is allowed to write this bit only when the ADC is disabled (ADCAL = 0, JADSTART = 0, JADSTP = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0).

Bit 28 **ADVREGEN**: ADC voltage regulator enable

This bits is set by software to enable the ADC voltage regulator.

Before performing any operation such as launching a calibration or enabling the ADC, the ADC voltage regulator must first be enabled and the software must wait for the regulator start-up time.

0: ADC Voltage regulator disabled

1: ADC Voltage regulator enabled.

For more details about the ADC voltage regulator enable and disable sequences, refer to *Section 30.4.6: ADC Deep-power-down mode (DEEPPWD) and ADC voltage regulator (ADVREGEN)*.

The software can program this bit field only when the ADC is disabled (ADCAL = 0, JADSTART = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0).

Bits 27:6 Reserved, must be kept at reset value.

Bit 5 **JADSTP**: ADC stop of injected conversion command

This bit is set by software to stop and discard an ongoing injected conversion (JADSTP Command).

It is cleared by hardware when the conversion is effectively discarded and the ADC injected sequence and triggers can be re-configured. The ADC is then ready to accept a new start of injected conversions (JADSTART command).

0: No ADC stop injected conversion command ongoing

1: Write 1 to stop injected conversions ongoing. Read 1 means that an ADSTP command is in progress.

Note: The software is allowed to set JADSTP only when JADSTART = 1 and ADDIS = 0 (ADC is enabled and eventually converting an injected conversion and there is no pending request to disable the ADC)

In auto-injection mode (JAUTO = 1), setting ADSTP bit aborts both regular and injected conversions (do not use JADSTP)

Bit 4 **ADSTP**: ADC stop of regular conversion command

This bit is set by software to stop and discard an ongoing regular conversion (ADSTP Command).

It is cleared by hardware when the conversion is effectively discarded and the ADC regular sequence and triggers can be re-configured. The ADC is then ready to accept a new start of regular conversions (ADSTART command).

0: No ADC stop regular conversion command ongoing

1: Write 1 to stop regular conversions ongoing. Read 1 means that an ADSTP command is in progress.

Note: The software is allowed to set ADSTP only when ADSTART = 1 and ADDIS = 0 (ADC is enabled and eventually converting a regular conversion and there is no pending request to disable the ADC).

In auto-injection mode (JAUTO = 1), setting ADSTP bit aborts both regular and injected conversions (do not use JADSTP).

In dual ADC regular simultaneous mode and interleaved mode, the bit ADSTP of the master ADC must be used to stop regular conversions. The other ADSTP bit is inactive.

Bit 3 **JADSTART**: ADC start of injected conversion

This bit is set by software to start ADC conversion of injected channels. Depending on the configuration bits JEXTEN, a conversion immediately starts (software trigger configuration) or once an injected hardware trigger event occurs (hardware trigger configuration).

It is cleared by hardware:

– in single conversion mode when software trigger is selected (JEXTSEL = 0x0): at the assertion of the End of Injected Conversion Sequence (JEOS) flag.

– in all cases: after the execution of the JADSTP command, at the same time that JADSTP is cleared by hardware.

0: No ADC injected conversion is ongoing.

1: Write 1 to start injected conversions. Read 1 means that the ADC is operating and eventually converting an injected channel.

Note: The software is allowed to set JADSTART only when ADEN = 1 and ADDIS = 0 (ADC is enabled and there is no pending request to disable the ADC).

In auto-injection mode (JAUTO = 1), regular and auto-injected conversions are started by setting bit ADSTART (JADSTART must be kept cleared)

Bit 2 **ADSTART**: ADC start of regular conversion

This bit is set by software to start ADC conversion of regular channels. Depending on the configuration bits EXTEN, a conversion immediately starts (software trigger configuration) or once a regular hardware trigger event occurs (hardware trigger configuration).

It is cleared by hardware:

– in single conversion mode when software trigger is selected (EXTSEL = 0x0): at the assertion of the End of Regular Conversion Sequence (EOS) flag.

– in all cases: after the execution of the ADSTP command, at the same time that ADSTP is cleared by hardware.

0: No ADC regular conversion is ongoing.

1: Write 1 to start regular conversions. Read 1 means that the ADC is operating and eventually converting a regular channel.

Note: The software is allowed to set ADSTART only when ADEN = 1 and ADDIS = 0 (ADC is enabled and there is no pending request to disable the ADC)

In auto-injection mode (JAUTO = 1), regular and auto-injected conversions are started by setting bit ADSTART (JADSTART must be kept cleared)

Bit 1 **ADDIS**: ADC disable command

This bit is set by software to disable the ADC (ADDIS command) and put it into power-down state (OFF state).

It is cleared by hardware once the ADC is effectively disabled (ADEN is also cleared by hardware at this time).

0: no ADDIS command ongoing

1: Write 1 to disable the ADC. Read 1 means that an ADDIS command is in progress.

Note: The software is allowed to set ADDIS only when ADEN = 1 and both ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing)

Bit 0 **ADEN**: ADC enable control

This bit is set by software to enable the ADC. The ADC is effectively ready to operate once the flag ADRDY has been set.

It is cleared by hardware when the ADC is disabled, after the execution of the ADDIS command.

0: ADC is disabled (OFF state)

1: Write 1 to enable the ADC.

Note: The software is allowed to set ADEN only when all bits of ADC_CR registers are 0 (ADCAL = 0, JADSTART = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0) except for bit ADVREGEN which must be 1 (and the software must have wait for the startup time of the voltage regulator)

30.6.4 ADC configuration register (ADC_CFGR)

Address offset: 0x0C

Reset value: 0x8000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
JQDIS	AWD1CH[4:0]					JAUTO	JAWD1EN	AWD1EN	AWD1SGL	JQM	JDISCEN	DISCNUM[2:0]			DISCEN
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ALIGN	AUTDLY	CONT	OVRMOD	EXTEN[1:0]		EXTSEL4	EXTSEL3	EXTSEL2	EXTSEL1	EXTSEL0	RES[1:0]		ADFCFG	DMACFG	DMAEN
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **JQDIS**: Injected queue disable

This bit is set and cleared by software to disable the injected queue mechanism:

0: Injected queue enabled

1: Injected queue disabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no regular nor injected conversion is ongoing).

A set or reset of JQDIS bit causes the injected queue to be flushed and the ADC_JSQR register is cleared.

Bits 30:26 **AWD1CH[4:0]**: Analog watchdog 1 channel selection

These bits are set and cleared by software. They select the input channel to be guarded by the analog watchdog.

00000: ADC analog input channel 0 monitored by AWD1

00001: ADC analog input channel 1 monitored by AWD1

.....

10011: ADC analog input channel 19 monitored by AWD1

others: reserved, must not be used

Note: Some channels are not connected physically. Keep the corresponding AWD1CH[4:0] setting to the reset value.

The channel selected by AWD1CH must be also selected into the SQi or JSQi bits.

The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 25 **JAUTO:** Automatic injected group conversion

This bit is set and cleared by software to enable/disable automatic injected group conversion after regular group conversion.

0: Automatic injected group conversion disabled

1: Automatic injected group conversion enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no regular nor injected conversion is ongoing).

When dual mode is enabled (DUAL bits in ADC_CCR register are not equal to zero), the bit JAUTO of the slave ADC is no more writable and its content is equal to the bit JAUTO of the master ADC.

Bit 24 **JAWD1EN**: Analog watchdog 1 enable on injected channels

This bit is set and cleared by software

0: Analog watchdog 1 disabled on injected channels

1: Analog watchdog 1 enabled on injected channels

Note: The software is allowed to write this bit only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 23 **AWD1EN**: Analog watchdog 1 enable on regular channels

This bit is set and cleared by software

0: Analog watchdog 1 disabled on regular channels

1: Analog watchdog 1 enabled on regular channels

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 22 **AWD1SGL**: Enable the watchdog 1 on a single channel or on all channels

This bit is set and cleared by software to enable the analog watchdog on the channel identified by the AWD1CH[4:0] bits or on all the channels

0: Analog watchdog 1 enabled on all channels

1: Analog watchdog 1 enabled on a single channel

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 21 **JQM**: ADC_JSQR queue mode

This bit is set and cleared by software.

It defines how an empty Queue is managed.

0: ADC_JSQR mode 0: The Queue is never empty and maintains the last written configuration into ADC_JSQR.

1: ADC_JSQR mode 1: The Queue can be empty and when this occurs, the software and hardware triggers of the injected sequence are both internally disabled just after the completion of the last valid injected sequence.

Refer to *Section 30.4.21: Queue of context for injected conversions* for more information.

Note: The software is allowed to write this bit only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

When dual mode is enabled (DUAL bits in ADC_CCR register are not equal to zero), the bit JQM of the slave ADC is no more writable and its content is equal to the bit JQM of the master ADC.

Bit 20 **JDISCEN:** Discontinuous mode on injected channels

This bit is set and cleared by software to enable/disable discontinuous mode on the injected channels of a group.

0: Discontinuous mode on injected channels disabled

1: Discontinuous mode on injected channels enabled

Note: The software is allowed to write this bit only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

It is not possible to use both auto-injected mode and discontinuous mode simultaneously: the bits DISCEN and JDISCEN must be kept cleared by software when JAUTO is set.

When dual mode is enabled (bits DUAL of ADC_CCR register are not equal to zero), the bit JDISCEN of the slave ADC is no more writable and its content is equal to the bit JDISCEN of the master ADC.

Bits 19:17 **DISCNUM[2:0]:** Discontinuous mode channel count

These bits are written by software to define the number of regular channels to be converted in discontinuous mode, after receiving an external trigger.

000: 1 channel

001: 2 channels

...

111: 8 channels

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

When dual mode is enabled (DUAL bits in ADC_CCR register are not equal to zero), the bits DISCNUM[2:0] of the slave ADC are no more writable and their content is equal to the bits DISCNUM[2:0] of the master ADC.

Bit 16 **DISCEN**: Discontinuous mode for regular channels

This bit is set and cleared by software to enable/disable discontinuous mode for regular channels.

0: Discontinuous mode for regular channels disabled

1: Discontinuous mode for regular channels enabled

Note: It is not possible to have both discontinuous mode and continuous mode enabled: it is forbidden to set both DISCEN = 1 and CONT = 1.

It is not possible to use both auto-injected mode and discontinuous mode simultaneously: the bits DISCEN and JDISCEN must be kept cleared by software when JAUTO is set.

The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

When dual mode is enabled (DUAL bits in ADC_CCR register are not equal to zero), the bit DISCEN of the slave ADC is no more writable and its content is equal to the bit DISCEN of the master ADC.

Bit 15 **ALIGN**: Data alignment

This bit is set and cleared by software to select right or left alignment. Refer to *Section : Data register, data alignment and offset (ADC_DR, OFFSET, OFFSET_CH, ALIGN)*.

0: Right alignment

1: Left alignment

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 14 **AUTDLY**: Delayed conversion mode

This bit is set and cleared by software to enable/disable the Auto Delayed Conversion mode.

0: Auto-delayed conversion mode off

1: Auto-delayed conversion mode on

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

When dual mode is enabled (DUAL bits in ADC_CCR register are not equal to zero), the bit AUTDLY of the slave ADC is no more writable and its content is equal to the bit AUTDLY of the master ADC.

Bit 13 **CONT**: Single / continuous conversion mode for regular conversions

This bit is set and cleared by software. If it is set, regular conversion takes place continuously until it is cleared.

0: Single conversion mode

1: Continuous conversion mode

Note: It is not possible to have both discontinuous mode and continuous mode enabled: it is forbidden to set both DISCEN = 1 and CONT = 1.

The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

When dual mode is enabled (DUAL bits in ADC_CCR register are not equal to zero), the bit CONT of the slave ADC is no more writable and its content is equal to the bit CONT of the master ADC.

Bit 12 **OVRMOD**: Overrun mode

This bit is set and cleared by software and configure the way data overrun is managed.

0: ADC_DR register is preserved with the old data when an overrun is detected.

1: ADC_DR register is overwritten with the last conversion result when an overrun is detected.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bits 11:10 **EXTEN[1:0]**: External trigger enable and polarity selection for regular channels

These bits are set and cleared by software to select the external trigger polarity and enable the trigger of a regular group.

00: Hardware trigger detection disabled (conversions can be launched by software)

01: Hardware trigger detection on the rising edge

10: Hardware trigger detection on the falling edge

11: Hardware trigger detection on both the rising and falling edges

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bits 9:5 **EXTSEL[4:0]**: External trigger selection for regular group

These bits select the external event used to trigger the start of conversion of a regular group:

00000: adc_ext_trg0
00001: adc_ext_trg1
00010: adc_ext_trg2
00011: adc_ext_trg3
00100: adc_ext_trg4
00101: adc_ext_trg5
00110: adc_ext_trg6
00111: adc_ext_trg7
...
11111: adc_ext_trg31

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bits 4:3 **RES[1:0]**: Data resolution

These bits are written by software to select the resolution of the conversion.

00: 12-bit
01: 10-bit
10: 8-bit
11: 6-bit

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 2 **ADFCFG**: ADF mode configuration

This bit is set and cleared by software to enable the ADF mode. It is effective only when DMAEN = 0.

0: ADF mode disabled
1: ADF mode enabled

Note: To make sure no conversion is ongoing, the software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0.

Bit 1 **DMACFG**: Direct memory access configuration

This bit is set and cleared by software to select between two DMA modes of operation and is effective only when DMAEN = 1.

0: DMA One Shot mode selected
1: DMA Circular mode selected

For more details, refer to *Section : Managing conversions using the DMA*

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

In dual-ADC modes, this bit is not relevant and replaced by control bit DMACFG of the ADC_CCR register.

Bit 0 **DMAEN**: Direct memory access enable

This bit is set and cleared by software to enable the generation of DMA requests. This allows to use the DMA to manage automatically the converted data. For more details, refer to *Section : Managing conversions using the DMA*.

0: DMA disabled
1: DMA enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

In dual-ADC modes, this bit is not relevant and replaced by control bits MDMA[1:0] of the ADC_CCR register.

30.6.5 ADC configuration register 2 (ADC_CFGR2)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	SMPTRIG	BULB	SWTRIG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
				rw	rw	rw									

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	ROVSM	TROVS	OVSS[3:0]				OVSR[2:0]			JOVSE	ROVSE
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **SMPTRIG**: Sampling time control trigger mode

This bit is set and cleared by software to enable the sampling time control trigger mode.

0: Sampling time control trigger mode disabled

1: Sampling time control trigger mode enabled

The sampling time starts on the trigger rising edge, and the conversion on the trigger falling edge.

EXTEN bit should be set to 01. BULB bit must not be set when the SMPTRIG bit is set.

When EXTEN bit is set to 00, set SWTRIG to start the sampling and clear SWTRIG bit to start the conversion.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bit 26 **BULB**: Bulb sampling mode

This bit is set and cleared by software to enable the bulb sampling mode.

0: Bulb sampling mode disabled

1: Bulb sampling mode enabled. The sampling period starts just after the previous end of conversion.

SAMPTRIG bit must not be set when the BULB bit is set.

The very first ADC conversion is performed with the sampling time specified in SMPx bits.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bit 25 **SWTRIG**: Software trigger bit for sampling time control trigger mode

This bit is set and cleared by software to enable the bulb sampling mode.

0: Software trigger starts the conversion for sampling time control trigger mode

1: Software trigger starts the sampling for sampling time control trigger mode

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bits 24:17 Reserved, must be kept at reset value.

Bits 16:11 Reserved, must be kept at reset value.

Bit 10 **ROVSM**: Regular oversampling mode

This bit is set and cleared by software to select the regular oversampling mode.

0: Continued mode: When injected conversions are triggered, the oversampling is temporary stopped and continued after the injection sequence (oversampling buffer is maintained during injected sequence)

1: Resumed mode: When injected conversions are triggered, the current oversampling is aborted and resumed from start after the injection sequence (oversampling buffer is zeroed by injected sequence start)

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bit 9 **TROVS**: Triggered Regular oversampling

This bit is set and cleared by software to enable triggered oversampling

0: All oversampled conversions for a channel are done consecutively following a trigger

1: Each oversampled conversion for a channel needs a new trigger

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bits 8:5 **OVSS[3:0]**: Oversampling shift

This bitfield is set and cleared by software to define the right shifting applied to the raw oversampling result.

0000: No shift

0001: Shift 1-bit

0010: Shift 2-bits

0011: Shift 3-bits

0100: Shift 4-bits

0101: Shift 5-bits

0110: Shift 6-bits

0111: Shift 7-bits

1000: Shift 8-bits

Other codes reserved

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bits 4:2 **OVSR[2:0]**: Oversampling ratio

This bitfield is set and cleared by software to define the oversampling ratio.

000: 2x

001: 4x

010: 8x

011: 16x

100: 32x

101: 64x

110: 128x

111: 256x

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bit 1 **JOVSE**: Injected oversampling Enable

This bit is set and cleared by software to enable injected oversampling.

0: Injected oversampling disabled

1: Injected oversampling enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing)

Bit 0 **ROVSE**: Regular oversampling Enable

This bit is set and cleared by software to enable regular oversampling.

0: Regular oversampling disabled

1: Regular oversampling enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing)

30.6.6 ADC sample time register 1 (ADC_SMPR1)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SMPPLUS	Res.	SMP9[2:0]			SMP8[2:0]			SMP7[2:0]			SMP6[2:0]			SMP5[2:1]	
rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SMP5[0]	SMP4[2:0]			SMP3[2:0]			SMP2[2:0]			SMP1[2:0]			SMP0[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **SMPPLUS:** Addition of one clock cycle to the sampling time.

1: 2.5 ADC clock cycle sampling time becomes 3.5 ADC clock cycles for the ADC_SMPR1 and ADC_SMPR2 registers.

0: The sampling time remains set to 2.5 ADC clock cycles remains

To make sure no conversion is ongoing, the software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0.

Bit 30 Reserved, must be kept at reset value.

Bits 29:0 **SMPx[2:0]:** Channel x sampling time selection (x = 9 to 0)

These bits are written by software to select the sampling time individually for each channel. During sample cycles, the channel selection bits must remain unchanged.

000: 2.5 ADC clock cycles

001: 6.5 ADC clock cycles

010: 12.5 ADC clock cycles

011: 24.5 ADC clock cycles

100: 47.5 ADC clock cycles

101: 92.5 ADC clock cycles

110: 247.5 ADC clock cycles

111: 640.5 ADC clock cycles

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Some channels are not connected physically. Keep the corresponding SMPx[2:0] setting to the reset value.

30.6.7 ADC sample time register 2 (ADC_SMPR2)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	SMP19[2:0]			SMP18[2:0]			SMP17[2:0]			SMP16[2:0]			SMP15[2:1]	
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SMP15[0]	SMP14[2:0]			SMP13[2:0]			SMP12[2:0]			SMP11[2:0]			SMP10[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:0 **SMPx[2:0]:** Channel x sampling time selection (x = 19 to 10)

These bits are written by software to select the sampling time individually for each channel. During sampling cycles, the channel selection bits must remain unchanged.

000: 2.5 ADC clock cycles
001: 6.5 ADC clock cycles
010: 12.5 ADC clock cycles
011: 24.5 ADC clock cycles
100: 47.5 ADC clock cycles
101: 92.5 ADC clock cycles
110: 247.5 ADC clock cycles
111: 640.5 ADC clock cycles

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Some channels are not connected physically. Keep the corresponding SMPx[2:0] setting to the reset value.

30.6.8 ADC watchdog threshold register 1 (ADC_TR1)

Address offset: 0x20

Reset value: 0x0FFF 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	HT1[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	AWDFILT[2:0]			LT1[11:0]											
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **HT1[11:0]**: Analog watchdog 1 higher threshold

These bits are written by software to define the higher threshold for the analog watchdog 1.

Refer to *Section 30.4.29: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)*

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **AWDFILT[2:0]**: Analog watchdog filtering parameter

This bit is set and cleared by software.

000: No filtering

001: two consecutive detection generates an AWDx flag or an interrupt

...

111: Eight consecutive detection generates an AWDx flag or an interrupt

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bits 11:0 **LT1[11:0]**: Analog watchdog 1 lower threshold

These bits are written by software to define the lower threshold for the analog watchdog 1.

Refer to *Section 30.4.29: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)*

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

30.6.9 ADC watchdog threshold register 2 (ADC_TR2)

Address offset: 0x24

Reset value: 0x00FF 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HT2[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LT2[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **HT2[7:0]**: Analog watchdog 2 higher threshold

These bits are written by software to define the higher threshold for the analog watchdog 2.

Refer to *Section 30.4.29: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)*

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **LT2[7:0]**: Analog watchdog 2 lower threshold

These bits are written by software to define the lower threshold for the analog watchdog 2.

Refer to *Section 30.4.29: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)*

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

30.6.10 ADC watchdog threshold register 3 (ADC_TR3)

Address offset: 0x28

Reset value: 0x00FF 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HT3[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LT3[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **HT3[7:0]**: Analog watchdog 3 higher threshold

These bits are written by software to define the higher threshold for the analog watchdog 3.

Refer to *Section 30.4.29: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)*

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **LT3[7:0]**: Analog watchdog 3 lower threshold

These bits are written by software to define the lower threshold for the analog watchdog 3.

This watchdog compares the 8-bit of LT3 with the 8 MSB of the converted data.

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

30.6.11 ADC regular sequence register 1 (ADC_SQR1)

Address offset: 0x30

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	SQ4[4:0]					Res.	SQ3[4:0]					Res.	SQ2[4]
			rw	rw	rw	rw	rw		rw	rw	rw	rw	rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SQ2[3:0]				Res.	SQ1[4:0]					Res.	Res.	L[3:0]			
rw	rw	rw	rw		rw	rw	rw	rw	rw			rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:24 **SQ4[4:0]:** 4th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 4th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 23 Reserved, must be kept at reset value.

Bits 22:18 **SQ3[4:0]:** 3rd conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 3rd in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 17 Reserved, must be kept at reset value.

Bits 16:12 **SQ2[4:0]:** 2nd conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 2nd in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 11 Reserved, must be kept at reset value.

Bits 10:6 **SQ1[4:0]:** 1st conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 1st in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bits 5:4 Reserved, must be kept at reset value.

Bits 3:0 **L[3:0]:** Regular channel sequence length

These bits are written by software to define the total number of conversions in the regular channel conversion sequence.

0000: 1 conversion
0001: 2 conversions
...
1111: 16 conversions

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Note: Some channels are not connected physically and must not be selected for conversion.

30.6.12 ADC regular sequence register 2 (ADC_SQR2)

Address offset: 0x34

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	SQ9[4:0]					Res.	SQ8[4:0]					Res.	SQ7[4]
			rw	rw	rw	rw	rw		rw	rw	rw	rw	rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SQ7[3:0]				Res.	SQ6[4:0]					Res.	SQ5[4:0]				
rw	rw	rw	rw		rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:24 **SQ9[4:0]:** 9th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 9th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 23 Reserved, must be kept at reset value.

Bits 22:18 **SQ8[4:0]:** 8th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 8th in the regular conversion sequence

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 17 Reserved, must be kept at reset value.

Bits 16:12 **SQ7[4:0]:** 7th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 7th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 11 Reserved, must be kept at reset value.

Bits 10:6 **SQ6[4:0]:** 6th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 6th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **SQ5[4:0]:** 5th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 5th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Note: Some channels are not connected physically and must not be selected for conversion.

30.6.13 ADC regular sequence register 3 (ADC_SQR3)

Address offset: 0x38

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	SQ14[4:0]					Res.	SQ13[4:0]					Res.	SQ12[4]
			rw	rw	rw	rw	rw		rw	rw	rw	rw	rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SQ12[3:0]				Res.	SQ11[4:0]					Res.	SQ10[4:0]				
rw	rw	rw	rw		rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:24 **SQ14[4:0]:** 14th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 14th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 23 Reserved, must be kept at reset value.

Bits 22:18 **SQ13[4:0]:** 13th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 13th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 17 Reserved, must be kept at reset value.

Bits 16:12 **SQ12[4:0]:** 12th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 12th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 11 Reserved, must be kept at reset value.

Bits 10:6 **SQ11[4:0]:** 11th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 11th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **SQ10[4:0]:** 10th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 10th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Note: Some channels are not connected physically and must not be selected for conversion.

30.6.14 ADC regular sequence register 4 (ADC_SQR4)

Address offset: 0x3C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	SQ16[4:0]					Res.	SQ15[4:0]				
					rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:6 **SQ16[4:0]:** 16th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 16th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **SQ15[4:0]:** 15th conversion in regular sequence

These bits are written by software with the channel number (0 to 19) assigned as the 15th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Note: Some channels are not connected physically and must not be selected for conversion.

30.6.15 ADC regular data register (ADC_DR)

Address offset: 0x40

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **RDATA[15:0]**: Regular data converted

These bits are read-only. They contain the conversion result from the last converted regular channel. The data are left- or right-aligned as described in *Section 30.4.26: Data management*.

30.6.16 ADC injected sequence register (ADC_JSQR)

Address offset: 0x4C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
JSQ4[4:0]					Res.	JSQ3[4:0]					Res.	JSQ2[4:1]			
rw	rw	rw	rw	rw		rw	rw	rw	rw	rw		rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JSQ2[0]	Res.	JSQ1[4:0]					JEXTEN[1:0]		JEXTSEL[4:0]					JL[1:0]	
rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 **JSQ4[4:0]:** 4th conversion in the injected sequence

These bits are written by software with the channel number (0 to 19) assigned as the 4th in the injected conversion sequence.

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 26 Reserved, must be kept at reset value.

Bits 25:21 **JSQ3[4:0]:** 3rd conversion in the injected sequence

These bits are written by software with the channel number (0 to 19) assigned as the 3rd in the injected conversion sequence.

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 20 Reserved, must be kept at reset value.

Bits 19:15 **JSQ2[4:0]:** 2nd conversion in the injected sequence

These bits are written by software with the channel number (0 to 19) assigned as the 2nd in the injected conversion sequence.

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 14 Reserved, must be kept at reset value.

Bits 13:9 **JSQ1[4:0]:** 1st conversion in the injected sequence

These bits are written by software with the channel number (0 to 19) assigned as the 1st in the injected conversion sequence.

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bits 8:7 **JEXTEN[1:0]**: External trigger enable and polarity selection for injected channels

These bits are set and cleared by software to select the external trigger polarity and enable the trigger of an injected group.

00: If JQDIS = 0 (queue enabled), hardware and software trigger detection disabled. Otherwise, the queue is disabled as well as hardware trigger detection (conversions can be launched by software)

01: Hardware trigger detection on the rising edge

10: Hardware trigger detection on the falling edge

11: Hardware trigger detection on both the rising and falling edges

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

If JQM = 1 and if the Queue of Context becomes empty, the software and hardware triggers of the injected sequence are both internally disabled (refer to Section 30.4.21: Queue of context for injected conversions)

Bits 6:2 **JEXTSEL[4:0]**: External Trigger Selection for injected group

These bits select the external event used to trigger the start of conversion of an injected group:

00000: adc_jext_trg0

00001: adc_jext_trg1

00010: adc_jext_trg2

00011: adc_jext_trg3

00100: adc_jext_trg4

00101: adc_jext_trg5

00110: adc_jext_trg6

00111: adc_jext_trg7

...

11111: adc_jext_trg31

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bits 1:0 **JL[1:0]:** Injected channel sequence length

These bits are written by software to define the total number of conversions in the injected channel conversion sequence.

00: 1 conversion

01: 2 conversions

10: 3 conversions

11: 4 conversions

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Note: Some channels are not connected physically and must not be selected for conversion.

30.6.17 ADC offset y register (ADC_OFRy)

Address offset: 0x60 + 0x04 * (y -1), (y = 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OFFSET_EN	OFFSET_CH[4:0]					SATEN	OFFSETPOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	OFFSET[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **OFFSET_EN:** Offset y enable

This bit is written by software to enable or disable the offset programmed into bits OFFSET[11:0].

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bits 30:26 **OFFSET_CH[4:0]:** Channel selection for the data offset y

These bits are written by software to define the channel to which the offset programmed into bits OFFSET[11:0] applies.

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Some channels are not connected physically and must not be selected for the data offset y.

If OFFSET_EN is set, it is not allowed to select the same channel for different ADC_OFRy registers.

Bit 25 **SATEN**: Saturation enable

This bit is set and cleared by software to enable the saturation at 0x000 and 0xFFF for the offset function.

0: No saturation control, offset result can be signed

1: Saturation enabled, offset result unsigned and saturated at 0x000 and 0xFFF

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 24 **OFFSETPOS**: Positive offset

This bit is set and cleared by software to enable the positive offset.

0: Negative offset

1: Positive offset

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bits 23:12 Reserved, must be kept at reset value.

Bits 11:0 **OFFSET[11:0]:** Data offset y for the channel programmed into bits OFFSET_CH[4:0]

These bits are written by software to define the offset to be subtracted from the raw converted data when converting a channel (can be regular or injected). The channel to which applies the data offset must be programmed in the bits OFFSET_CH[4:0]. The conversion result can be read from in the ADC_DR (regular conversion) or from in the ADC_JDRyi registers (injected conversion).

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

If several offset (OFFSET) point to the same channel, only the offset with the lowest x value is considered for the subtraction.
Ex: if OFFSET1_CH[4:0] = 4 and OFFSET2_CH[4:0] = 4, this is OFFSET1[11:0] which is subtracted when converting channel 4.

30.6.18 ADC injected channel y data register (ADC_JDRy)

Address offset: 0x80 + 0x04 * (y - 1), (y = 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JDATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **JDATA[15:0]:** Injected data

These bits are read-only. They contain the conversion result from injected channel y. The data are left -or right-aligned as described in *Section 30.4.26: Data management*.

30.6.19 ADC analog watchdog 2 configuration register (ADC_AWD2CR)

Address offset: 0xA0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWD2CH[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AWD2CH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **AWD2CH[19:0]**: Analog watchdog 2 channel selection

These bits are set and cleared by software. They enable and select the input channels to be guarded by the analog watchdog 2.

AWD2CH[i] = 0: ADC analog input channel i is not monitored by AWD2

AWD2CH[i] = 1: ADC analog input channel i is monitored by AWD2

When AWD2CH[19:0] = 000..0, the analog Watchdog 2 is disabled

Note: The channels selected by AWD2CH must be also selected into the SQi or JSQi bits.

The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Some channels are not connected physically and must not be selected for the analog watchdog.

30.6.20 ADC analog watchdog 3 configuration register (ADC_AWD3CR)

Address offset: 0xA4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWD3CH[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AWD3CH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **AWD3CH[19:0]**: Analog watchdog 3 channel selection

These bits are set and cleared by software. They enable and select the input channels to be guarded by the analog watchdog 3.

AWD3CH[i] = 0: ADC analog input channel i is not monitored by AWD3

AWD3CH[i] = 1: ADC analog input channel i is monitored by AWD3

When AWD3CH[19:0] = 000..0, the analog Watchdog 3 is disabled

Note: The channels selected by AWD3CH must be also selected into the SQi or JSQi bits.

The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Some channels are not connected physically and must not be selected for the analog watchdog.

30.6.21 ADC Differential mode selection register (ADC_DIFSEL)

Address offset: 0xB0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIFSEL[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIFSEL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **DIFSEL[19:0]:** Differential mode for channels 19 to 0.

These bits are set and cleared by software. They allow to select if a channel is configured as single-ended or Differential mode.

DIFSEL[i] = 0: ADC analog input channel is configured in single-ended mode

DIFSEL[i] = 1: ADC analog input channel i is configured in Differential mode

Note: The DIFSEL bits corresponding to channels that are either connected to a single-ended I/O port or to an internal channel must be kept their reset value (single-ended input mode).

The software is allowed to write these bits only when the ADC is disabled (ADCAL = 0, JADSTART = 0, JADSTP = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0).

30.6.22 ADC calibration factors (ADC_CALFACT)

Address offset: 0xB4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CALFACT_D[6:0]						
									rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CALFACT_S[6:0]						
									rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:16 **CALFACT_D[6:0]**: Calibration Factors in differential mode

These bits are written by hardware or by software.

Once a differential inputs calibration is complete, they are updated by hardware with the calibration factors.

Software can write these bits with a new calibration factor. If the new calibration factor is different from the current one stored into the analog ADC, it is then applied once a new differential calibration is launched.

Note: The software is allowed to write these bits only when ADEN = 1, ADSTART = 0 and JADSTART = 0 (ADC is enabled and no calibration is ongoing and no conversion is ongoing).

Bits 15:7 Reserved, must be kept at reset value.

Bits 6:0 **CALFACT_S[6:0]**: Calibration Factors In single-ended mode

These bits are written by hardware or by software.

Once a single-ended inputs calibration is complete, they are updated by hardware with the calibration factors.

Software can write these bits with a new calibration factor. If the new calibration factor is different from the current one stored into the analog ADC, it is then applied once a new single-ended calibration is launched.

Note: The software is allowed to write these bits only when ADEN = 1, ADSTART = 0 and JADSTART = 0 (ADC is enabled and no calibration is ongoing and no conversion is ongoing).

30.6.23 ADC option register (ADC_OR)

Address offset: 0xC8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OP0
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **OP0**: Option bit 0
For ADC1:
0: INP0/INN1 GPIO switch control disabled (for both ADC1 and ADC2)
1: INP0/INN1 GPIO switch control enabled (for both ADC1 and ADC2)
For ADC2:
0: V_{DDCORE} channel disabled (for both ADC2 and ADC3)
1: V_{DDCORE} channel enabled (for both ADC2 and ADC3)
For ADC3:
0: INP0 GPIO switch control disabled
1: INP0 GPIO switch control enabled

Note: ADC_OR register might be reserved on some ADC instances. Refer to Section 30.3: ADC implementation.

30.7 ADC common registers

These registers define the control and status registers common to master and slave ADCs:

30.7.1 ADC common status register (ADC_CSR)

Address offset: 0x300

Reset value: 0x0000 0000

This register provides an image of the status bits of the different ADC. Nevertheless it is read-only and does not allow to clear the different status bits. Instead each status bit must be cleared by writing 0 to it in the corresponding ADC_ISR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	JQOVF_SLV	AWD3_SLV	AWD2_SLV	AWD1_SLV	JEOS_SLV	JEOC_SLV	OVR_SLV	EOS_SLV	EOC_SLV	EOSMP_SLV	ADRDY_SLV
					r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	JQOVF_MST	AWD3_MST	AWD2_MST	AWD1_MST	JEOS_MST	JEOC_MST	OVR_MST	EOS_MST	EOC_MST	EOSMP_MST	ADRDY_MST
					r	r	r	r	r	r	r	r	r	r	r

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **JQOVF_SLV:** Injected Context Queue Overflow flag of the slave ADC
This bit is a copy of the JQOVF bit in the corresponding ADC_ISR register.

Bit 25 **AWD3_SLV:** Analog watchdog 3 flag of the slave ADC
This bit is a copy of the AWD3 bit in the corresponding ADC_ISR register.

Bit 24 **AWD2_SLV:** Analog watchdog 2 flag of the slave ADC
This bit is a copy of the AWD2 bit in the corresponding ADC_ISR register.

Bit 23 **AWD1_SLV:** Analog watchdog 1 flag of the slave ADC
This bit is a copy of the AWD1 bit in the corresponding ADC_ISR register.

Bit 22 **JEOS_SLV:** End of injected sequence flag of the slave ADC
This bit is a copy of the JEOS bit in the corresponding ADC_ISR register.

Bit 21 **JEOC_SLV:** End of injected conversion flag of the slave ADC
This bit is a copy of the JEOC bit in the corresponding ADC_ISR register.

Bit 20 **OVR_SLV:** Overrun flag of the slave ADC
This bit is a copy of the OVR bit in the corresponding ADC_ISR register.

Bit 19 **EOS_SLV:** End of regular sequence flag of the slave ADC. This bit is a copy of the EOS bit in the corresponding ADC_ISR register.

Bit 18 **EOC_SLV:** End of regular conversion of the slave ADC
This bit is a copy of the EOC bit in the corresponding ADC_ISR register.

Bit 17 **EOSMP_SLV:** End of Sampling phase flag of the slave ADC
This bit is a copy of the EOSMP2 bit in the corresponding ADC_ISR register.

Bit 16 **ADRDY_SLV:** Slave ADC ready
This bit is a copy of the ADRDY bit in the corresponding ADC_ISR register.

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **JQOVF_MST:** Injected Context Queue Overflow flag of the master ADC
This bit is a copy of the JQOVF bit in the corresponding ADC_ISR register.

Bit 9 **AWD3_MST:** Analog watchdog 3 flag of the master ADC
This bit is a copy of the AWD3 bit in the corresponding ADC_ISR register.

Bit 8 **AWD2_MST:** Analog watchdog 2 flag of the master ADC
This bit is a copy of the AWD2 bit in the corresponding ADC_ISR register.

Bit 7 **AWD1_MST:** Analog watchdog 1 flag of the master ADC
This bit is a copy of the AWD1 bit in the corresponding ADC_ISR register.

Bit 6 **JEOS_MST:** End of injected sequence flag of the master ADC
This bit is a copy of the JEOS bit in the corresponding ADC_ISR register.

Bit 5 **JEOC_MST:** End of injected conversion flag of the master ADC
This bit is a copy of the JEOC bit in the corresponding ADC_ISR register.

Bit 4 **OVR_MST:** Overrun flag of the master ADC
This bit is a copy of the OVR bit in the corresponding ADC_ISR register.

Bit 3 **EOS_MST:** End of regular sequence flag of the master ADC
This bit is a copy of the EOS bit in the corresponding ADC_ISR register.

Bit 2 **EOC_MST:** End of regular conversion of the master ADC
This bit is a copy of the EOC bit in the corresponding ADC_ISR register.

Bit 1 **EOSMP_MST:** End of Sampling phase flag of the master ADC
This bit is a copy of the EOSMP bit in the corresponding ADC_ISR register.

Bit 0 **ADRDY_MST:** Master ADC ready
This bit is a copy of the ADRDY bit in the corresponding ADC_ISR register.

30.7.2 ADC common control register (ADC_CCR)

Address offset: 0x308

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	VBATEN	TSEN	VREFEN	PRESC[3:0]				CKMODE[1:0]	
							rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MDMA[1:0]		DMACFG	Res.	DELAY[3:0]				Res.	Res.	Res.	DUAL[4:0]				
rw	rw	rw		rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **VBATEN**: VBAT enable

This bit is set and cleared by software to control.

0: V_{BAT} channel disabled

1: V_{BAT} channel enabled

Bit 23 **TSEN**: V_{SENSE} enable

This bit is set and cleared by software to control V_{SENSE}.

0: Temperature sensor channel disabled

1: Temperature sensor channel enabled

Bit 22 **VREFEN**: V_{REFINT} enable

This bit is set and cleared by software to enable/disable the V_{REFINT} channel.

0: V_{REFINT} channel disabled

1: V_{REFINT} channel enabled

Bits 21:18 **PRESC[3:0]**: ADC prescaler

These bits are set and cleared by software to select the frequency of the clock to the ADC. The clock is common for all the ADCs.

0000: input ADC clock not divided
0001: input ADC clock divided by 2
0010: input ADC clock divided by 4
0011: input ADC clock divided by 6
0100: input ADC clock divided by 8
0101: input ADC clock divided by 10
0110: input ADC clock divided by 12
0111: input ADC clock divided by 16
1000: input ADC clock divided by 32
1001: input ADC clock divided by 64
1010: input ADC clock divided by 128
1011: input ADC clock divided by 256
other: reserved

Note: The software is allowed to write these bits only when the ADC is disabled (ADCAL = 0, JADSTART = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0). The ADC prescaler value is applied only when CKMODE[1:0] = 0b00.

Bits 17:16 **CKMODE[1:0]:** ADC clock mode

These bits are set and cleared by software to define the ADC clock scheme (which is common to both master and slave ADCs):

00: adc_ker_ck (x = 1/2/3) (Asynchronous clock mode), generated at product level (refer to *Section 6: Reset and clock control (RCC)*)

01: adc_hclk/1 (Synchronous clock mode). This configuration must be enabled only if the AHB clock prescaler is set to 1 (HPRE[3:0] = 0XXX in RCC_CFGR register) and if the system clock has a 50% duty cycle.

10: adc_hclk/2 (Synchronous clock mode)

11: adc_hclk/4 (Synchronous clock mode)

In all synchronous clock modes, there is no jitter in the delay from a timer trigger to the start of a conversion.

Note: The software is allowed to write these bits only when the ADCs are disabled (ADCAL = 0, JADSTART = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0).

Bits 15:14 **MDMA[1:0]:** Direct memory access mode for dual ADC mode

This bitfield is set and cleared by software. Refer to the DMA controller section for more details.

00: MDMA mode disabled

01: Reserved

10: MDMA mode enabled for 12 and 10-bit resolution

11: MDMA mode enabled for 8 and 6-bit resolution

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 13 **DMACFG**: DMA configuration (for dual ADC mode)

This bit is set and cleared by software to select between two DMA modes of operation and is effective only when DMAEN = 1.

0: DMA One Shot mode selected

1: DMA Circular mode selected

For more details, refer to *Section : Managing conversions using the DMA*

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 12 Reserved, must be kept at reset value.

Bits 11:8 **DELAY[3:0]:** Delay between 2 sampling phases

These bits are set and cleared by software. These bits are used in dual interleaved modes. Refer to *Table 301* for the value of ADC resolution versus DELAY bits values.

Note: The software is allowed to write these bits only when the ADCs are disabled (ADCAL = 0, JADSTART = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0).

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **DUAL[4:0]:** Dual ADC mode selection

These bits are written by software to select the operating mode. 00000 corresponds to Independent mode. Values 00001 to 01001 correspond to dual mode, master and slave ADCs working together.

00000: Independent mode
00001: Combined regular simultaneous + injected simultaneous mode
00010: Combined regular simultaneous + alternate trigger mode
00011: Combined interleaved mode + injected simultaneous mode
00100: Reserved
00101: Injected simultaneous mode only
00110: Regular simultaneous mode only
00111: Interleaved mode only
01001: Alternate trigger mode only
Others: Reserved, must not be used

Note: The software is allowed to write these bits only when the ADCs are disabled (ADCAL = 0, JADSTART = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0).

Table 301. DELAY bits versus ADC resolution

DELAY bits	12-bit resolution	10-bit resolution	8-bit resolution	6-bit resolution
0000	1 * $T_{adc_ker_ck}$	1 * $T_{adc_ker_ck}$	1 * $T_{adc_ker_ck}$	1 * $T_{adc_ker_ck}$
0001	2 * $T_{adc_ker_ck}$	2 * $T_{adc_ker_ck}$	2 * $T_{adc_ker_ck}$	2 * $T_{adc_ker_ck}$
0010	3 * $T_{adc_ker_ck}$	3 * $T_{adc_ker_ck}$	3 * $T_{adc_ker_ck}$	3 * $T_{adc_ker_ck}$
0011	4 * $T_{adc_ker_ck}$	4 * $T_{adc_ker_ck}$	4 * $T_{adc_ker_ck}$	4 * $T_{adc_ker_ck}$
0100	5 * $T_{adc_ker_ck}$	5 * $T_{adc_ker_ck}$	5 * $T_{adc_ker_ck}$	5 * $T_{adc_ker_ck}$
0101	6 * $T_{adc_ker_ck}$	6 * $T_{adc_ker_ck}$	6 * $T_{adc_ker_ck}$	6 * $T_{adc_ker_ck}$
0110	7 * $T_{adc_ker_ck}$	7 * $T_{adc_ker_ck}$	7 * $T_{adc_ker_ck}$	6 * $T_{adc_ker_ck}$
0111	8 * $T_{adc_ker_ck}$	8 * $T_{adc_ker_ck}$	8 * $T_{adc_ker_ck}$	6 * $T_{adc_ker_ck}$
1000	9 * $T_{adc_ker_ck}$	9 * $T_{adc_ker_ck}$	8 * $T_{adc_ker_ck}$	6 * $T_{adc_ker_ck}$
1001	10 * $T_{adc_ker_ck}$	10 * $T_{adc_ker_ck}$	8 * $T_{adc_ker_ck}$	6 * $T_{adc_ker_ck}$
1010	11 * $T_{adc_ker_ck}$	10 * $T_{adc_ker_ck}$	8 * $T_{adc_ker_ck}$	6 * $T_{adc_ker_ck}$
1011	12 * $T_{adc_ker_ck}$	10 * $T_{adc_ker_ck}$	8 * $T_{adc_ker_ck}$	6 * $T_{adc_ker_ck}$
others	12 * $T_{adc_ker_ck}$	10 * $T_{adc_ker_ck}$	8 * $T_{adc_ker_ck}$	6 * $T_{adc_ker_ck}$

30.7.3 ADC common regular data register for dual mode (ADC_CDR)

Address offset: 0x30C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDATA_SLV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDATA_MST[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **RDATA_SLV[15:0]:** Regular data of the slave ADC

In dual mode, these bits contain the regular data of the slave ADC. Refer to *Section 30.4.31: Dual ADC modes*.

The data alignment is applied as described in *Section : Data register, data alignment and offset (ADC_DR, OFFSET, OFFSET_CH, ALIGN)*)

Bits 15:0 **RDATA_MST[15:0]**: Regular data of the master ADC.

In dual mode, these bits contain the regular data of the master ADC. Refer to *Section 30.4.31: Dual ADC modes*.

The data alignment is applied as described in *Section : Data register, data alignment and offset (ADC_DR, OFFSET, OFFSET_CH, ALIGN)*)

In MDMA = 0b11 mode, bits 15:8 contains SLV_ADC_DR[7:0], bits 7:0 contains MST_ADC_DR[7:0].

30.8 ADC register map

The following table summarizes the ADC registers.

Table 302. ADC global register map

Offset	Register
0x000 - 0x0B4	Master ADC1/3
0x0B8 - 0x0FC	Reserved
0x100 - 0x1B4	Slave ADC2
0x1B8 - 0x2FC	Reserved
0x300 - 0x3FC	Master and slave ADCs common registers

Table 303. ADC register map and reset values for each ADC (offset = 0x000 for master ADC, 0x100 for slave ADC)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**ADC_ISR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JQOVF	AWD3	AWD2	AWD1	JEOS	JEOC	OVR	EOS	EOC	EOSMP	ADRDY
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x04	**ADC_IER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JQOVFIE	AWD3IE	AWD2IE	AWD1IE	JEOSIE	JEOCIE	OVRIE	EOSIE	EOCIE	EOSMPIE	ADRDYIE
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x08	**ADC_CR**	ADCAL	ADCALDIF	DEEPPWD	ADVREGEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JADSTP	ADSTP	JADSTART	ADSTART	ADDIS	ADEN
	Reset value	0	0	1	0																							0	0	0	0	0	0
0x0C	**ADC_CFGR**	JQDIS	AWD1CH[4:0]					JAUTO	JAWD1EN	AWD1EN	AWD1SGL	JQM	JDISCEN	DISCNUM[2:0]			DISCEN	ALIGN	AUTDLY	CONT	OVRMOD	EXTEN[1:0]		EXTSEL4	EXTSEL3	EXTSEL2	EXTSEL1	EXTSEL0	RES[1:0]		ADFCFG	DMACFG	DMAEN
	Reset value	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	**ADC_CFGR2**	Res.	Res.	Res.	Res.	SMPTRIG	BULB	SWTRIG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ROVSM	TROVS	OVSS[3:0]					OVSR[2:0]		JOVSE	ROVSE
	Reset value					0	0	0															0	0	0	0	0	0	0	0	0	0	0
0x14	**ADC_SMPR1**	SMPPLUS	Res.	SMP9 [2:0]			SMP8 [2:0]			SMP7 [2:0]			SMP6 [2:0]			SMP5 [2:0]			SMP4 [2:0]			SMP3 [2:0]			SMP2 [2:0]			SMP1 [2:0]			SMP0 [2:0]		
	Reset value	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	**ADC_SMPR2**	Res.	Res.	SMP19 [2:0]			SMP18 [2:0]			SMP17 [2:0]			SMP16 [2:0]			SMP15 [2:0]			SMP14 [2:0]			SMP13 [2:0]			SMP12 [2:0]			SMP11 [2:0]			SMP10 [2:0]		
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	Reserved	Res.																															
0x20	**ADC_TR1**	Res.	Res.	Res.	Res.	HT1[11:0]												Res.	AWDFILT [2:0]			LT1[11:0]											
	Reset value					1	1	1	1	1	1	1	1	1	1	1	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 303. ADC register map and reset values for each ADC (offset = 0x000 for master ADC, 0x100 for slave ADC) (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x24	**ADC_TR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HT2[[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LT2[7:0]							
	Reset value									1	1	1	1	1	1	1	1									0	0	0	0	0	0	0	0
0x28	**ADC_TR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HT3[[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LT3[7:0]							
	Reset value									1	1	1	1	1	1	1	1									0	0	0	0	0	0	0	0
0x2C	Reserved	Res.																															
0x30	**ADC_SQR1**	Res.	Res.	Res.	SQ4[4:0]					Res.	SQ3[4:0]					Res.	SQ2[4:0]					Res.	SQ1[4:0]			Res.	Res.	L[3:0]					
	Reset value				0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0			0	0	0	0
0x34	**ADC_SQR2**	Res.	Res.	Res.	SQ9[4:0]					Res.	SQ8[4:0]					Res.	SQ7[4:0]					Res.	SQ6[4:0]			Res.	SQ5[4:0]						
	Reset value				0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0
0x38	**ADC_SQR3**	Res.	Res.	Res.	SQ14[4:0]					Res.	SQ13[4:0]					Res.	SQ12[4:0]					Res.	SQ11[4:0]			Res.	SQ10[4:0]						
	Reset value				0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0
0x3C	**ADC_SQR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SQ16[4:0]			Res.	SQ15[4:0]						
	Reset value																						0	0	0	0	0		0	0	0	0	0
0x40	**ADC_DR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	regular RDATA[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x44-0x48	Reserved	Res.																															
0x4C	**ADC_JSQR**	JSQ4[4:0]					Res.	JSQ3[4:0]					Res.	JSQ2[4:0]				Res.	JSQ1[4:0]				JEXTEN[1:0]		JEXTSEL[4:0]					JL[1:0]			
	Reset value	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x50-0x5C	Reserved	Res.																															
0x60	**ADC_OFR1**	OFFSET_EN	OFFSET_CH[4:0]					SATEN	OFFSETPOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OFFSET[11:0]											
	Reset value	0	0	0	0	0	0	0	0													0	0	0	0	0	0	0	0	0	0	0	0
0x64	**ADC_OFR2**	OFFSET_EN	OFFSET_CH[4:0]					SATEN	OFFSETPOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OFFSET[11:0]											
	Reset value	0	0	0	0	0	0	0	0													0	0	0	0	0	0	0	0	0	0	0	0
0x68	**ADC_OFR3**	OFFSET_EN	OFFSET_CH[4:0]					SATEN	OFFSETPOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OFFSET[11:0]											
	Reset value	0	0	0	0	0	0	0	0													0	0	0	0	0	0	0	0	0	0	0	0
0x6C	**ADC_OFR4**	OFFSET_EN	OFFSET_CH[4:0]					SATEN	OFFSETPOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OFFSET[11:0]											
	Reset value	0	0	0	0	0	0	0	0													0	0	0	0	0	0	0	0	0	0	0	0
0x70-0x7C	Reserved	Res.																															

Table 303. ADC register map and reset values for each ADC (offset = 0x000 for master ADC, 0x100 for slave ADC) (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x80	**ADC_JDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JDATA1[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x84	**ADC_JDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JDATA2[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x88	**ADC_JDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JDATA3[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x8C	**ADC_JDR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JDATA4[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x90-0x9C	Reserved	Res.																															
0xA0	**ADC_AWD2CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWD2CH[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xA4	**ADC_AWD3CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWD3CH[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xA8-0xAC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0xB0	**ADC_DIFSEL**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIFSEL[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xB4	**ADC_CALFACT**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CALFACT_D[6:0]							Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CALFACT_S[6:0]						
	Reset value										0	0	0	0	0	0	0										0	0	0	0	0	0	0
0xB8-0xC4	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0xC8	**ADC_OR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OP0
	Reset value																																0
0xCC-0xFC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Table 304. ADC register map and reset values (master and slave ADC common registers)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x300	**ADC_CSR**	Res.	Res.	Res.	Res.	Res.	JQOVF_SLV	AWD3_SLV	AWD2_SLV	AWD1_SLV	JEOS_SLV	JEOC_SLV	OVR_SLV	EOS_SLV	EOC_SLV	EOSMP_SLV	ADRDY_SLV	Res.	Res.	Res.	Res.	Res.	JQOVF_MST	AWD3_MST	AWD2_MST	AWD1_MST	JEOS_MST	JEOC_MST	OVR_MST	EOS_MST	EOC_MST	EOSMP_MST	ADRDY_MST
							slave ADC2																master ADC1										
	Reset value						0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x304	Reserved	Res.																															
0x308	**ADC_CCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VBATEN	TSEN	VREFEN	PRESC[3:0]				CKMODE[1:0]		MDMA[1:0]		DMACFG	Res.	DELAY[3:0]				Res.	Res.	Res.	DUAL[4:0]				
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0				0	0	0	0	0

Table 304. ADC register map and reset values (master and slave ADC common registers) (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x30C	**ADC_CDR**	RDATA_SLV[15:0]																RDATA_MST[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x310-0x3EC	Reserved	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

31 Digital temperature sensor (DTS)

31.1 DTS introduction

The device embeds a sensor that converts the temperature into a square wave which frequency is proportional to the temperature. The frequency is measured either with the PCLK or the LSE clock.

31.2 DTS main features

The temperature sensor block main features are the following:

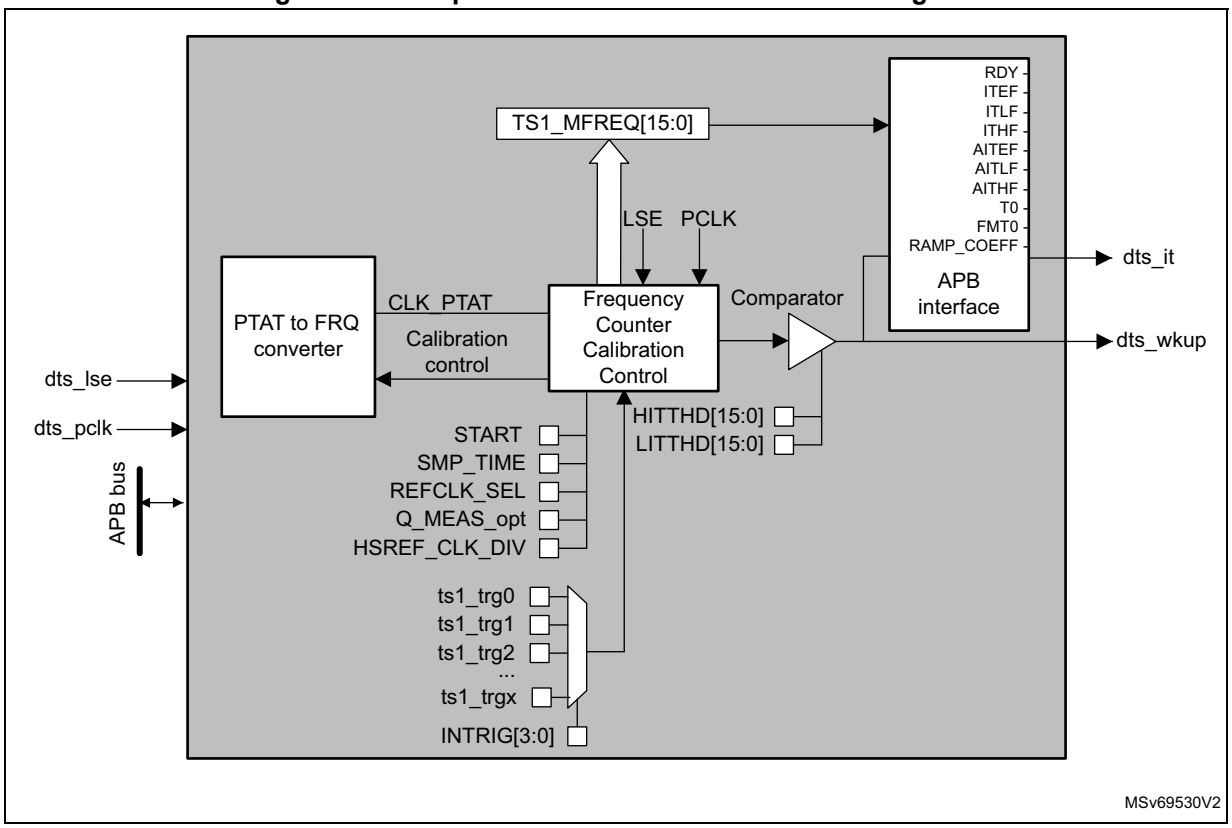
- Start of measurement triggered by software or 4 hardware sources
- Programmable sampling time to increase temperature measurement precision
- Counter synchronized on LSE or PCLK clock
- Temperature watchdog on low and high threshold
- Interrupt generation when the temperature is lower or higher than predefined thresholds and at the end of measurement.
- Asynchronous wake-up signal generation when the temperature is higher/lower than a predefined threshold (LSE mode only)
- Quick measurement using LSE clock

31.3 DTS functional description

31.3.1 DTS block diagram

The temperature sensor block diagram is shown in *Figure 312*.

Figure 312. Temperature sensor functional block diagram



31.3.2 DTS internal signals

Table 305. DTS internal input/output signals

Signal name	Signal type	Description
dts_lse	Digital input	LSE clock
dts_pclk	Digital input	APB clock
dts_it	Digital output	Temperature sensor interrupt
dts_wkup	Digital output	Temperature sensor wake-up

31.3.3 DTS block operation

The analog part of the temperature sensor outputs a frequency that is proportional to the absolute temperature (CLK_PTAT). The frequency measurement is based on the PCLK or the LSE clock.

Before each measurement, the temperature sensor performs a calibration of the frequency generation blocks.

31.3.4 Operating modes

Several operating modes can be selected by setting the REFCLK_SEL bit in *Temperature sensor configuration register 1 (DTS_CFGR1)*:

- PCLK only (REFCLK_SEL = 0)

  The temperature sensor registers can be accessed. The interface can consequently be reconfigured and the measurement sequence is performed using PCLK clock
- PCLK and LSE (REFCLK_SEL = 1)

  The temperature sensor registers can be accessed. The interface can consequently be reconfigured and the measurement sequence is performed using the LSE clock.
- LSE only (REFCLK_SEL = 1) and PCLK OFF

  The registers cannot be accessed. The measurement can be performed using the LSE clock. This mode is used to exit from Sleep mode by using hardware triggers and the asynchronous interrupt line.

31.3.5 Calibration

The temperature sensor must run the calibration prior to any frequency measurement. The calibration is performed automatically when the temperature measurement is triggered except for quick measurement mode (Q_MEAS_OPT set to 1 in DTS_CFGR1).

31.3.6 Prescaler

When a calibration is ongoing, the counter clock must be slower than 1 MHz. This is achieved by the PCLK clock prescaler embedded in the temperature sensor.

During the temperature measurement period, the prescaler is bypassed.

- When PCLK is used as reference clock (REFCLK_SEL set to 0 in DTS_CFGR1), a prescaler is used. Its division ratio must be configured up to 127 (refer to the HSREF_CLK_DIV[6:0] register definition for the divider setting).
- When LSE is used as reference clock (REFCLK_SEL set to 1 in DTS_CFGR1), the timebase is equal to 2 LSE periods. In this case, no prescaler is used.

31.3.7 Temperature measurement principles

The analog part of temperature sensor outputs a signal (CLK_PTAT) which FM(T) frequency is temperature-dependent.

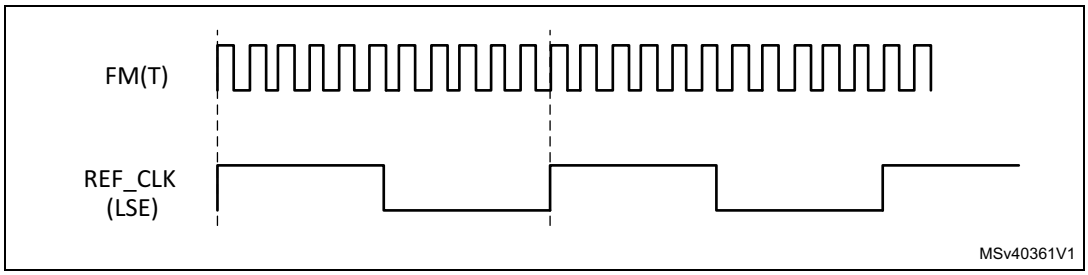
Either PCLK or LSE can be selected as reference clock (REF_CLK) through the REFCLK_SEL bit in DTS_CFGR1.

The counting method depends on the REF_CLK frequency. This is due to the fact that two counters are implemented in the temperature sensor block:

- For low REF_CLK frequencies, a counting of FM(T) cycles is performed during one or several REF_CLK cycles.
- For high REF_CLK frequencies, a counting of REF_CLK cycles is performed during one or several FM(T) cycles.

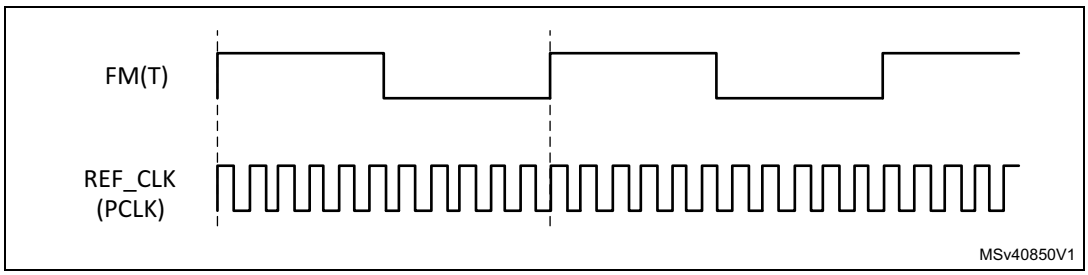
This counter behavior is shown in *Figure 313* and *Figure 314*.

Figure 313. Method for low REF_CLK frequencies



1. To increase the precision, FM(T) measurement can be done on several LSE periods.

Figure 314. Method for high REF_CLK frequencies



1. To increase the precision, PCLK measurement can be done on several FM(T) periods.

The counting result is stored in the DTS_DR register (see *Temperature sensor data register (DTS_DR)*.

Once the FM(T) frequency has been obtained, the corresponding temperature can be calculated by software using the following formula:

- When PCLK is used:

$$T = T_0 + ((F_{PCLK} / TS1_MFREQ) \times TS1_SMP_TIME - 100 \times TS1_FMT0) / TS1_RAMP_COEFF$$

where

T0 (factory calibration temperature) is equal to 30 °C.

TS1_FMT0 is measured and stored in the DTS_T0VALR1 register. It is expressed in hundreds of Hertz.

TS1_RAMP_COEFF is measured during tests in factory and stored in DTS_RAMPVALR register. This value is expressed in Hz/°C.

- When the LSE clock is used

$$T = T_0 + ((F_{LSE} \times TS1_MFREQ / TS1_SMP_TIME) - (100 \times TS1_FMT0)) / TS1_RAMP_COEFF$$

31.3.8 Sampling time

The sampling period can be increased to improve measurement accuracy. This is useful when the reference frequency (REF_CLK) is close to the FM(T) frequency. The default value is one REF_CLK cycle in LSE mode, and one FM(T) cycle in PCLK mode.

The sampling time is configured through TS1_SMP_TIME bits in DTS_CFGR1 register (see *Table 306*).

Table 306. Sampling time configuration

TS1_SMP_TIME[3:0]	LSE or FM(T) clock cycle(s)
0000	1
0001	1
0010	2
0011	3
0100	4
0101	5
0110	6
0111	7
1000	8
1001	9
1010	10
1011	11
1100	12
1101	13
1110	14
1111	15

31.3.9 Quick measurement mode

If a high precision is not required, the calibration step included in each measurement sequence can be skipped by setting Q_MEAS_OPT to 1 in the DTS_CFGR1 register. This method must used only when the LSE clock is selected as reference clock (LSREF_CLK set to 1). This mode can reduce the measurement time.

31.3.10 Trigger input

The temperature measurement can be triggered either by software or by an external event. The trigger source can be selected through TS1_INTRIG[3:0] bits in DTS_CFGR1.

Table 307. Trigger configuration

Name	TS1_INTRIG[3:0]				Comment
N.A	0	0	0	0	No hardware trigger
ts1_trg0	0	0	0	1	lptim1_ch1
ts1_trg1	0	0	1	0	lptim2_ch1
ts1_trg2	0	0	1	1	lptim3_ch1
ts1_trg3	0	1	0	0	exti13
ts1_trg4	0	1	0	1	play1_out13
ts1_trg5	0	1	1	0	Reserved
ts1_trg6	0	1	1	1	
ts1_trg7	1	0	0	0	
ts1_trg8	1	0	0	1	
ts1_trg9	1	0	1	0	
ts1_trg10	1	0	1	1	
ts1_trg11	1	1	0	0	
ts1_trg12	1	1	0	1	
ts1_trg13	1	1	1	0	
ts1_trg14	1	1	1	1	

Note: Hardware triggers are active only on the rising edge.

The temperature sensor can only capture a hardware trigger rising edge when TS1_RDY bit is set (see Section 31.3.11: On-off control and ready flag), otherwise the trigger is ignored.

If a trigger source changes on-the-fly, the new trigger source signal must be low. If the new source signal is high, the temperature sensor detects a rising edge and start the measurement sequence.

31.3.11 On-off control and ready flag

The DTS block can be enabled by setting TS1_EN bit in DTS_CFGR1 register. The TS1_RDY flag in the *Temperature sensor status register (DTS_SR)* indicate that the DTS block is ready for temperature measurement: when TS1_RDY bit is set to 1, the measurement can be started. Once a measurement has started, TS1_RDY bit is reset. New measurement requests are then ignored. Once the measurement is finished, TS1_RDY bit is set again to indicate the sensor is ready to start a new measurement.

31.3.12 Temperature measurement sequence

Start of measurement can be triggered by software or hardware.

Software trigger

The software trigger is selected when TS1_INTRIG_SEL[3:0] is set to ‘0000’ in DTS_CFGR1.

If TS1_RDY is set to 1, writing TS1_START bit to 1 in DTS_CFGR1 starts the measurement.

If TS1_RDY equals 0, the software trigger does not start until TS1_RDY is set.

If TS1_START bit is kept at 1 once the measurement is finished, then the TS1_RDY flag become 1 and the measurement restarts.

Hardware trigger

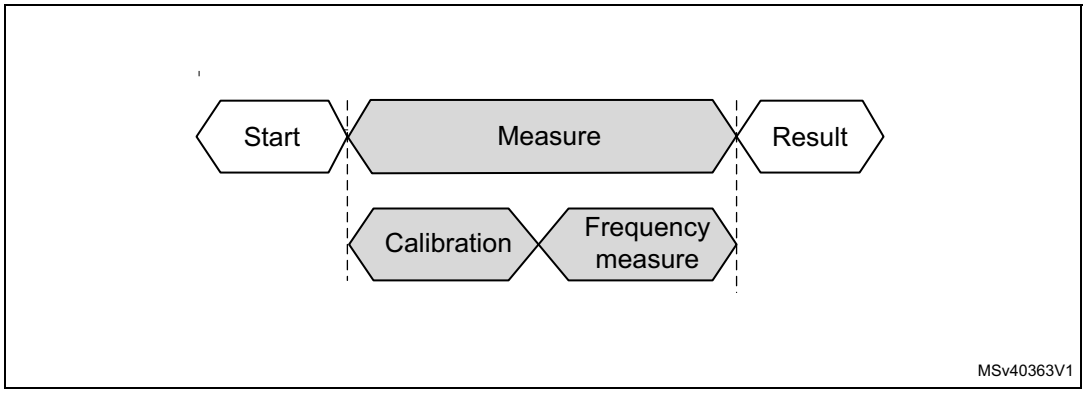
TS1_INTRIG_SEL[3:0] bits allow selecting one hardware trigger out of 4. If TS1_RDY is set to 1, a rising edge on the trigger signal starts the measurement. When TS1_RDY is 0, the rising edge is ignored.

Temperature measurement sequence

One measurement contains two steps: the calibration of the analog blocks and the measurement. The calibration automatically starts when the measurement is triggered (see *Section 31.3.5: Calibration*). The measurement period depends on the following DTS_CFGR1 bits:

- the reference clock selected through REFCLK_SEL bit
- the divider ratio configured by HSREF_CLK_DIV bits
- the sampling time defined by TS1_SMP_TIME bits.

Figure 315. Temperature sensor sequence



31.4 DTS low-power modes

Table 308. Temperature sensor behavior in low-power modes

Mode	Description
Sleep	Only works in LSE mode. DTS interrupt causes the device to exit from Sleep mode.
Stop	Only works in LSE mode. DTS interrupt cause the device to exit from Stop mode.

31.5 DTS interrupts

There are two ways to use the DTS block as an interrupt source.The DTS interrupt line can be connected to the EXTI controller (see *Section 31.5.3: Asynchronous wake-up*) or to the CPU NVIC (see *Section 31.5.2: Synchronous interrupt*).

31.5.1 Temperature window comparator

The DTS_ITR1 register allows defining the high and low threshold that are used for temperature comparison. If the temperature data is equal or higher than TS1_HITTHD, or equal or lower than TS1_LITTHD bit, an interrupt is generated and the corresponding flag, TS1_ ITLF, TS1_ITHF, TS1_AITLF and TS1_AITHF, is set in the DTS_SR register (see *Section 31.6.6*).

31.5.2 Synchronous interrupt

A global interrupt output line is available on the DTS block. The interrupt can be generated at the end of measurement and/or when the measurement result is equal/higher or equal/lower than a predefined threshold (see *Section 31.5.1: Temperature window comparator*).

Three interrupt events can be select via 3 bits in DTS_ITENR register (see *Section 31.6.7*). All combinations of interrupts are allowed.

The TS1_ITEF, TS1_ITLF and TS1_ITHF flags in the DTS_SR register reflect the interrupt event. They can be reset with the correspond bits of the DTS_ICIFR register (see *Section 31.6.8*).

31.5.3 Asynchronous wake-up

The DTS block also provides an asynchronous interrupt line. It is used only when the LSE is selected as reference clock (REFCLK_SEL=1).

This line can generate a signal that wakes up the system from Sleep mode at the end of measurement and/or when the measurement result is equal/higher or equal/lower than a predefined threshold (see *Section 31.5.1: Temperature window comparator*).

Three asynchronous wake-up events can be selected via 3 bits in DTS_ITENR register. All combination of interrupts are allowed.

The TS1_AITEF, TS1_AITLF and TS1_AITHF flags in the DTS_SR register reflect the interrupt status. They can be reset with the correspond bits of the DTS_ICIFR register.

The following table shows the interrupt bits an the their description.

Table 309. Interrupt control bits

Interrupt event	Interrupt flag	Enable control bit	Interrupt clear bit	Exit from Sleep mode	Synchronous/ Asynchronous
At the end of measurement	TS1_ITEF in DTS_SR	TS1_ITEEN in DTS_ITENR	TS1_CITEF in DTS_ICIFR	NO	Synchronous on PCLK
When the measure is equal or exceeds the low threshold	TS1_ITLF in DTS_SR	TS1_ITLEN in DTS_ITENR	TS1_CITLF in DTS_ICIFR	NO	
When the measure is equal or exceeds the high threshold	TS1_ITHF in DTS_SR	TS1_ITHEN in DTS_ITENR	TS1_CITHF in DTS_ICIFR	NO	
At the end of measurement	TS1_AITEF in DTS_SR	TS1_AITEEN in DTS_ITENR	TS1_CAITEF in DTS_ICIFR	YES	Asynchronous
When the measure is equal or exceeds the low threshold	TS1_AITLF in DTS_SR	TS1_AITLEN in DTS_ITENR	TS1_CAITLF in DTS_ICIFR	YES	
When the measure is equal or exceeds the high threshold	TS1_AITHF in DTS_SR	TS1_AITHEN in DTS_ITENR	TS1_CAITHF in DTS_ICIFR	YES	

31.6 DTS registers

The registers of this peripheral can only be accessed by-word (32-bit).

31.6.1 Temperature sensor configuration register 1 (DTS_CFGR1)

DTS_CFGR1 is the configuration register for temperature sensor 1.

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	HSREF_CLK_DIV[6:0]							Res.	Res.	Q_MEAS_OPT	REFCLK_SEL	TS1_SMP_TIME[3:0]			
	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TS1_INTRIG_SEL[3:0]				Res.	Res.	Res.	TS1_START	Res.	Res.	Res.	TS1_EN
				rw	rw	rw	rw				rw				rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **HSREF_CLK_DIV[6:0]**: High speed clock division ratio

These bits are set and cleared by software. They can be used to define the division ratio for the main clock in order to obtain the internal frequency lower than 1 MHz required for the calibration. They are applicable only for calibration when PCLK is selected as reference clock (REFCLK_SEL=0).

0000000: No divider

0000001: No divider

0000010: 1/2 division ratio

...

1111111: 1/127 division ratio

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **Q_MEAS_OPT**: Quick measurement option bit

This bit is set and cleared by software. It is used to increase the measurement speed by suppressing the calibration step. It is effective only when the LSE clock is used as reference clock (REFCLK_SEL=1).

0: Measurement with calibration

1: Measurement without calibration

Bit 20 **REFCLK_SEL**: Reference clock selection bit

This bit is set and cleared by software. It indicates whether the reference clock is the high speed clock (PCLK) or the low speed clock (LSE).

0: High speed reference clock (PCLK)

1: Low speed reference clock (LSE)

Bits 19:16 **TS1_SMP_TIME[3:0]**: Sampling time for temperature sensor 1

These bits allow increasing the sampling time to improve measurement precision.

When the PCLK clock is selected as reference clock (REFCLK_SEL = 0), the measurement is performed at TS1_SMP_TIME period of CLK_PTAT.

When the LSE is selected as reference clock (REFCLK_SEL = 1), the measurement is performed at TS1_SMP_TIME period of LSE.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TS1_INTRIG_SEL[3:0]**: Input trigger selection bit for temperature sensor 1

These bits are set and cleared by software. They select which input triggers a temperature measurement. Refer to *Section 31.3.10: Trigger input*.

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **TS1_START:** Start frequency measurement on temperature sensor 1

This bit is set and cleared by software.

0: No software trigger.

1: Software trigger for a frequency measurement. (only if TS1 is ready).

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **TS1_EN:** Temperature sensor 1 enable bit

This bit is set and cleared by software.

0: Temperature sensor 1 disabled

1: Temperature sensor 1 enabled

Note: Once enabled, the temperature sensor is active after a specific delay time. The TS1_RDY flag is set when the sensor is ready.

31.6.2 Temperature sensor T0 value register 1 (DTS_T0VALR1)

DTS_T0VALR1 contains the value of the factory calibration temperature (T0) for temperature sensor 1. The reset value is factory trimmed.

Address offset: 0x08

Reset value: 0x000X XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_T0[1:0]	
														r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TS1_FMT0[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:16 **TS1_T0[1:0]**: Engineering value of the T0 temperature for temperature sensor 1.
00: 30 °C
01: 130 °C
Others: Reserved, must not be used.

Bits 15:0 **TS1_FMT0[15:0]**: Engineering value of the frequency measured at T0 for temperature sensor 1
This value is expressed in 0.1 kHz.

31.6.3 Temperature sensor ramp value register (DTS_RAMPVALR)

The DTS_RAMPVALR is the ramp coefficient for the temperature sensor. The reset value is factory trimmed.

Address offset: 0x10

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TS1_RAMP_COEFF[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **TS1_RAMP_COEFF[15:0]**: Engineering value of the ramp coefficient for the temperature sensor 1.
This value is expressed in Hz/°C.

31.6.4 Temperature sensor interrupt threshold register 1 (DTS_ITR1)

DTS_ITR1 contains the threshold values for sensor 1.

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TS1_HITTHD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TS1_LITTHD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **TS1_HITTHD[15:0]:** High interrupt threshold for temperature sensor 1
These bits are set and cleared by software. They indicate the highest value than can be reached before raising an interrupt signal.

Bits 15:0 **TS1_LITTHD[15:0]:** Low interrupt threshold for temperature sensor 1
These bits are set and cleared by software. They indicate the lowest value than can be reached before raising an interrupt signal.

31.6.5 Temperature sensor data register (DTS_DR)

The DTS_DR contains the number of REF_CLK cycles used to compute the FM(T) frequency.

Address offset: 0x1C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TS1_MFREQ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **TS1_MFREQ[15:0]**: Value of the counter output value for temperature sensor 1

31.6.6 Temperature sensor status register (DTS_SR)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TS1_RDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_AITHF	TS1_AITLF	TS1_AITEF	Res.	TS1_ITHF	TS1_ITLF	TS1_ITEF
r									r	r	r		r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **TS1_RDY:** Temperature sensor 1 ready flag
This bit is set and reset by hardware.
It indicates that a measurement is ongoing.
0: Temperature sensor 1 busy
1: Temperature sensor 1 ready

Bits 14:7 Reserved, must be kept at reset value.

Bit 6 **TS1_AITHF:** Asynchronous interrupt flag for high threshold on temperature sensor 1
This bit is set by hardware when the high threshold is reached.
It is cleared by software by writing 1 to the TS1_CAITHF bit in the DTS_ICIFR register.
0: High threshold not reached on temperature sensor 1
1: High threshold reached on temperature sensor 1
Note: This bit is active only when the TS1_AITHFEN bit is set

Bit 5 **TS1_AITLF:** Asynchronous interrupt flag for low threshold on temperature sensor 1
This bit is set by hardware when the low threshold is reached.
It is cleared by software by writing 1 to the TS1_CAITLF bit in the DTS_ICIFR register.
0: Low threshold not reached on temperature sensor 1
1: Low threshold reached on temperature sensor 1
Note: This bit is active only when the TS1_AITLFEN bit is set

Bit 4 **TS1_AITEF:** Asynchronous interrupt flag for end of measure on temperature sensor 1
This bit is set by hardware when a temperature measure is done.
It is cleared by software by writing 1 to the TS1_CAITEF bit in the DTS_ICIFR register.
0: End of measure not detected on temperature sensor 1
1: End of measure detected on temperature sensor 1
Note: This bit is active only when the TS1_AITEFEN bit is set

Bit 3 Reserved, must be kept at reset value.

Bit 2 **TS1_ITHF:** Interrupt flag for high threshold on temperature sensor 1, synchronized on PCLK
This bit is set by hardware when the high threshold is set and reached.
It is cleared by software by writing 1 to the TS1_CITHF bit in the DTS_ICIFR register.
0: High threshold not reached on temperature sensor 1
1: High threshold reached on temperature sensor 1
Note: This bit is active only when the TS1_ITHFEN bit is set

Bit 1 **TS1_ITLF:** Interrupt flag for low threshold on temperature sensor 1, synchronized on PCLK.
This bit is set by hardware when the low threshold is set and reached.
It is cleared by software by writing 1 to the TS1_CITLF bit in the DTS_ICIFR register.
0: Low threshold not reached on temperature sensor 1
1: Low threshold reached on temperature sensor 1
Note: This bit is active only when the TS1_ITLFEN bit is set

Bit 0 **TS1_ITEF:** Interrupt flag for end of measurement on temperature sensor 1, synchronized on PCLK.
This bit is set by hardware when a temperature measure is done.
It is cleared by software by writing 1 to the TS2_CITEF bit in the DTS_ICIFR register.
0: No end of measurement detected on temperature sensor 1
1: End of measure detected on temperature sensor 1
Note: This bit is active only when the TS1_ITEFEN bit is set

31.6.7 Temperature sensor interrupt enable register (DTS_ITENR)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_ AITHEN	TS1_ AITLEN	TS1_ AITEEN	Res.	TS1_ ITHEN	TS1_ ITLEN	TS1_ ITEEN
									rw	rw	rw		rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **TS1_AITHEN:** Asynchronous interrupt enable flag on high threshold for temperature sensor 1.
This bit are set and cleared by software.
It enables the asynchronous interrupt when the temperature is above the high threshold (only when REFCLK_SEL= 1")
0: Asynchronous interrupt on high threshold disabled for temperature sensor 1
1: Asynchronous interrupt on high threshold enabled for temperature sensor 1

Bit 5 **TS1_AITLEN:** Asynchronous interrupt enable flag for low threshold on temperature sensor 1.
This bit are set and cleared by software.
It enables the asynchronous interrupt when the temperature is below the low threshold (only when REFCLK_SEL= 1)
0: Asynchronous interrupt on low threshold disabled for temperature sensor 1
1: Asynchronous interrupt on low threshold enabled for temperature sensor 1

Bit 4 **TS1_AITEEN:** Asynchronous interrupt enable flag for end of measurement on temperature sensor 1

This bit are set and cleared by software.
It enables the asynchronous interrupt for end of measurement (only when REFCLK_SEL = 1).
0: Asynchronous interrupt for end of measurement disabled on temperature sensor 1
1: Asynchronous interrupt for end of measurement enabled on temperature sensor 1

Bit 3 Reserved, must be kept at reset value.

Bit 2 **TS1_ITHEN:** Interrupt enable flag for high threshold on temperature sensor 1, synchronized on PCLK.

This bit are set and cleared by software.
It enables the interrupt when the measure reaches or is above the high threshold.
0: Synchronous interrupt for high threshold disabled on temperature sensor 1
1: Synchronous interrupt for high threshold enabled on temperature sensor 1

Bit 1 **TS1_ITLEN:** Interrupt enable flag for low threshold on temperature sensor 1, synchronized on PCLK.

This bit are set and cleared by software.
It enables the synchronous interrupt when the measure reaches or is below the low threshold.
0: Synchronous interrupt for low threshold disabled on temperature sensor 1
1: Synchronous interrupt for low threshold enabled on temperature sensor 1

Bit 0 **TS1_ITEEN:** Interrupt enable flag for end of measurement on temperature sensor 1, synchronized on PCLK.

This bit are set and cleared by software.
It enables the synchronous interrupt for end of measurement.
0: Synchronous interrupt for end of measurement disabled on temperature sensor 1
1: Synchronous interrupt for end of measurement enabled on temperature sensor 1

31.6.8 Temperature sensor clear interrupt flag register (DTS_ICIFR)

DTS_ICIFR is the control register for the interrupt flags.

Address offset: 0x28

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_ CAITHF	TS1_ CAITLF	TS1_ CAITEF	Res.	TS1_ CITHF	TS1_ CITLF	TS1_ CITEF
									rc_w1	rc_w1	rc_w1		rc_w1	rc_w1	rc_w1

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **TS1_CAITHF:** Asynchronous interrupt clear flag for high threshold on temperature sensor 1
Writing 1 to this bit clears the TS1_AITHF flag in the DTS_SR register.

Bit 5 **TS1_CAITLF:** Asynchronous interrupt clear flag for low threshold on temperature sensor 1
Writing 1 to this bit clears the TS1_AITLF flag in the DTS_SR register.

Bit 4 **TS1_CAITEF:** Write once bit. Clear the asynchronous IT flag for End Of Measure for thermal sensor 1.
Writing 1 clears the TS1_AITEF flag of the DTS_SR register.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **TS1_CITHF:** Interrupt clear flag for high threshold on temperature sensor 1
Writing this bit to 1 clears the TS1_ITHF flag in the DTS_SR register.

Bit 1 **TS1_CITLF:** Interrupt clear flag for low threshold on temperature sensor 1
Writing 1 to this bit clears the TS1_ITLF flag in the DTS_SR register.

Bit 0 **TS1_CITEF:** Interrupt clear flag for end of measurement on temperature sensor 1
Writing 1 to this bit clears the TS1_ITEF flag in the DTS_SR register.

31.6.9 Temperature sensor option register (DTS_OR)

The DTS_OR contains general-purpose option bits.

Address offset: 0x2C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TS_OP 31	TS_OP 30	TS_OP 29	TS_OP 28	TS_OP 27	TS_OP 26	TS_OP 25	TS_OP 24	TS_OP 23	TS_OP 22	TS_OP 21	TS_OP 20	TS_OP 19	TS_OP 18	TS_OP 17	TS_OP 16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TS_OP 15	TS_OP 14	TS_OP 13	TS_OP 12	TS_OP 11	TS_OP 10	TS_OP 9	TS_OP 8	TS_OP 7	TS_OP 6	TS_OP 5	TS_OP 4	TS_OP 3	TS_OP 2	TS_OP 1	TS_OP 0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TS_OP[31:0]:** general purpose option bits

31.6.10 DTS register map

The following table summarizes the temperature sensor registers.

Table 310. DTS register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	DTS_ CFGR1	Res.	HSREF_CLK_DIV [6:0]							Res.	Res.	Q_MEAS_OPT	REFCLK_SEL	TS1_ SMP_TIME [3:0]				Res.	Res.	Res.	Res.	TS1_ INTRIG_SEL [3:0]				Res.	Res.	Res.	TS1_START	Res.	Res.	Res.	TS1_EN
	Reset value		0	0	0	0	0	0	0			0	0	0	0	0	0					0	0	0	0				0				0
0x04	Reserved																																
0x08	DTS_ T0VALR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_T0[1:0]		TS1_FMT0[15:0]															
	Reset value															X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x0C	Reserved																																
0x10	DTS_ RAMPVALR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_RAMP_COEFF[15:0]															
	Reset value																	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x14	DTS_ITR1	TS1_HITTHD[15:0]																TS1_LITTHD[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	Reserved																																
0x1C	DTS_DR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_MFREQ[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	DTS_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_RDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_AITHF	TS1_AITLF	TS1_AITEF	Res.	TS1_ITHF	TS1_ITLF	TS1_ITEF
	Reset value																	0									0	0	0		0	0	0
0x24	DTS_ITENR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_AITHEN	TS1_AITLEN	TS1_AITEEN	Res.	TS1_ITHEN	TS1_ITLEN	TS1_ITEEN
	Reset value																										0	0	0		0	0	0
0x28	DTS_ICIFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_CAITHF	TS1_CAITLF	TS1_CAITEF	Res.	TS1_CITHF	TS1_CITLF	TS1_CITEF
	Reset value																										0	0	0		0	0	0

Table 310. DTS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x2C	DTS_OR	TS_OP31	TS_OP30	TS_OP29	TS_OP28	TS_OP27	TS_OP26	TS_OP25	TS_OP24	TS_OP23	TS_OP22	TS_OP21	TS_OP20	TS_OP19	TS_OP18	TS_OP17	TS_OP16	TS_OP15	TS_OP14	TS_OP13	TS_OP12	TS_OP11	TS_OP10	TS_OP9	TS_OP8	TS_OP7	TS_OP6	TS_OP5	TS_OP4	TS_OP3	TS_OP2	TS_OP1	TS_OP0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

32 Digital-to-analog converter (DAC)

32.1 DAC introduction

The DAC module is a 12-bit, voltage output digital-to-analog converter. The DAC can be configured in 8- or 12-bit mode and may be used in conjunction with the DMA controller. In 12-bit mode, the data can be left- or right-aligned. The DAC features two output channels, each with its own converter. In dual DAC channel mode, conversions can be done independently or simultaneously when both channels are grouped together for synchronous update operations. An input reference pin, VREF+ (shared with others analog peripherals) is available for better resolution. An internal reference can also be set on the same input. Refer to *voltage reference buffer (VREFBUF)* section.

The DACx_OUTy pin can be used as general purpose input/output (GPIO) when the DAC output is disconnected from output pad and connected to on chip peripheral. The DAC output buffer can be optionally enabled to obtain a high drive output current. An individual calibration can be applied on each DAC output channel. The DAC output channels support a low power mode, the sample and hold mode.

32.2 DAC main features

The DAC main features are the following (see *Figure 316: Dual-channel DAC block diagram*):

- One DAC interface, maximum two output channels
- Left or right data alignment in 12-bit mode
- Synchronized update capability
- Noise-wave and Triangular-wave generation
- Dual DAC channel for independent or simultaneous conversions
- DMA capability for each channel including DMA underrun error detection
- Double data DMA capability to reduce the bus activity
- External triggers for conversion
- DAC output channel buffered/unbuffered modes
- Buffer offset calibration
- Each DAC output can be disconnected from the DACx_OUTy output pin
- DAC output connection to on-chip peripherals
- Sample and hold mode for low power operation in Stop mode
- Input voltage reference from VREF+ pin or internal VREFBUF reference

Figure 316 shows the block diagram of a DAC channel and *Table 312* gives the pin description.

32.3 DAC implementation

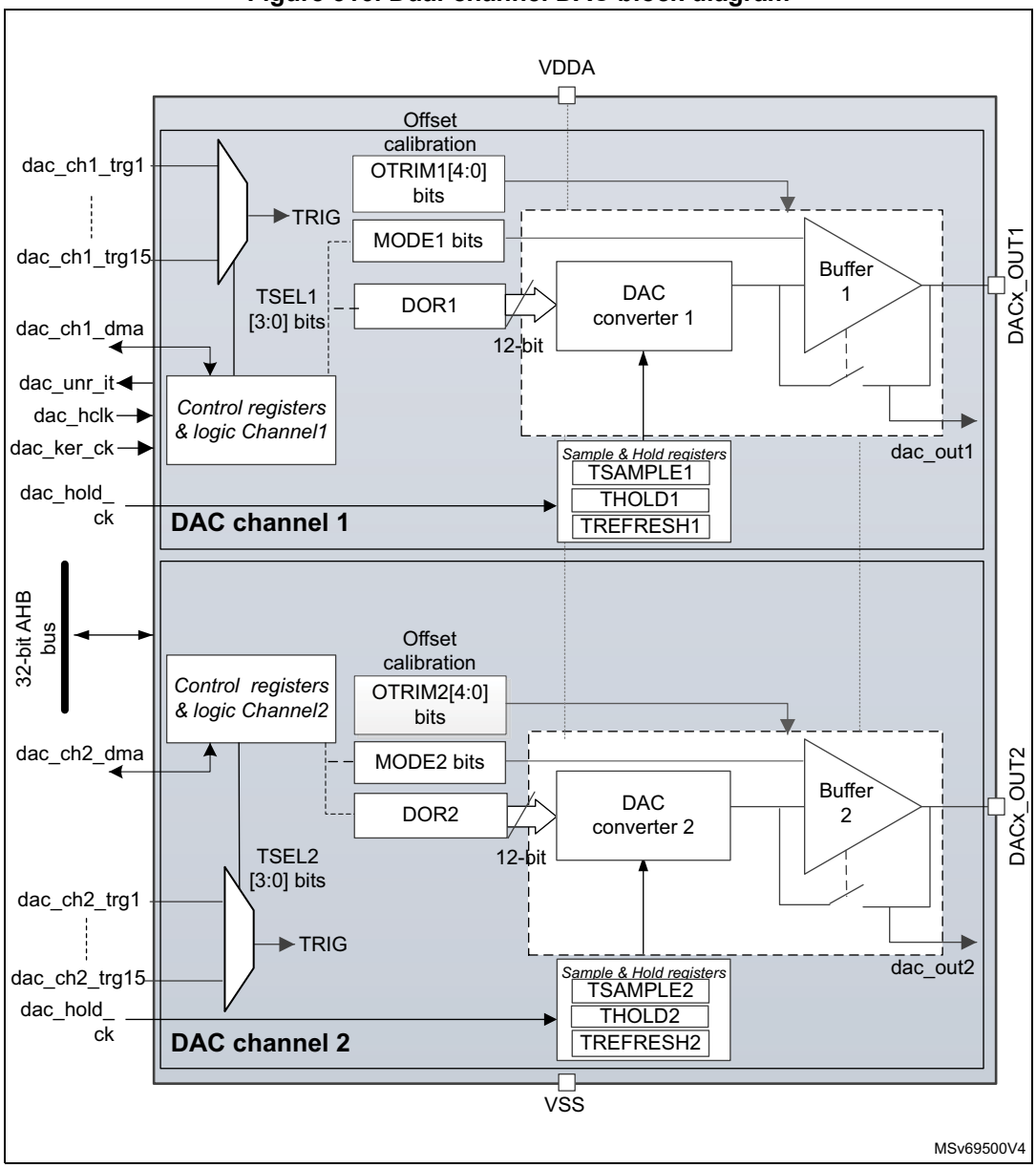
Table 311. DAC features

DAC features	DAC1
Dual channel	X
Output buffer	X
I/O connection	DAC1_OUT1 on PA4, DAC1_OUT2 on PA5
Maximum sampling time	1 Msps
Autonomous mode	-
VREF+ pin	X

32.4 DAC functional description

32.4.1 DAC block diagram

Figure 316. Dual-channel DAC block diagram



1. MODEx bits in the DAC_MCR control the output mode and allow switching between the normal mode in buffer/unbuffered configuration and the sample and hold mode.
2. Refer to *Section 32.3: DAC implementation* for channel2 availability.

32.4.2 DAC pins and internal signals

The DAC includes:

- Up to two output channels
- The DACx_OUTy can be disconnected from the output pin and used as an ordinary GPIO
- The dac_outx can use an internal pin connection to on-chip peripherals such as comparator, operational amplifier and ADC (if available).
- DAC output channel buffered or non buffered
- Sample and hold block and registers operational in Stop mode, using the LSI/LSE clock source (dac_hold_ck) for static conversion.

The DAC includes up to two separate output channels. Each output channel can be connected to on-chip peripherals such as comparator, operational amplifier and ADC (if available). In this case, the DAC output channel can be disconnected from the DACx_OUTy output pin and the corresponding GPIO can be used for another purpose.

The DAC output can be buffered or not. The sample and hold block and its associated registers can run in Stop mode using the LSI/LSE clock source (dac_hold_ck).

Table 312. DAC input/output pins

Pin name	Signal type	Remarks
VREF+	Input, analog positive reference	The higher/positive reference voltage for the DAC, $V_{REF+} \leq V_{DDAmax}$ (refer to the product datasheet)
VDDA	Input, analog supply	Analog power supply
VSSA	Input, analog supply ground	Ground for analog power supply
DACx_OUTy	Analog output signal	DACx channely analog output

Table 313. DAC internal input/output signals

Internal signal name	Signal type	Description
dac_ch1_dma	Bidirectional	DAC channel1 DMA request/acknowledge
dac_ch2_dma	Bidirectional	DAC channel2 DMA request/acknowledge
dac_ch1_trgx (x = 1 to 15)	Inputs	DAC channel1 trigger inputs
dac_ch2_trgx (x = 1 to 15)	Inputs	DAC channel2 trigger inputs
dac_unr_it	Output	DAC underrun interrupt
dac_hclk	Input	DAC peripheral clock
dac_ker_ck	Input	DAC kernel clock
dac_hold_ck	Input	DAC low-power clock used in sample and hold mode
dac_out1	Analog output	DAC channel1 output for on-chip peripherals
dac_out2	Analog output	DAC channel2 output for on-chip peripherals

Table 314. DAC interconnection

Signal name	Source	Source type
dac_hold_ck	ck_lsi or ck_lse	LSI or LSE clock selected in the RCC
dac_chx_trg1 (x = 1, 2)	tim1_trgo	Internal signal from on-chip timer
dac_chx_trg2 (x = 1, 2)	tim2_trgo	Internal signal from on-chip timer
dac_chx_trg3 (x = 1, 2)	tim4_trgo	Internal signal from on-chip timer
dac_chx_trg4 (x = 1, 2)	tim5_trgo	Internal signal from on-chip timer
dac_chx_trg5 (x = 1, 2)	tim6_trgo	Internal signal from on-chip timer
dac_chx_trg6 (x = 1, 2)	tim7_trgo	Internal signal from on-chip timer
dac_chx_trg7 (x = 1, 2)	tim8_trgo	Internal signal from on-chip timer
dac_chx_trg8 (x = 1, 2)	tim15_trgo	Internal signal from on-chip timer
dac_chx_trg11 (x = 1, 2)	lptim1_ch1	Internal signal from on-chip timer
dac_chx_trg12 (x = 1, 2)	lptim2_ch1	Internal signal from on-chip timer
dac_chx_trg13 (x = 1, 2)	exti9	External pin
dac_chx_trg14 (x = 1, 2)	play1_out11	Internal signal from PLAY1
dac_chx_trg15 (x = 1, 2)	play1_out12	Internal signal from PLAY1

32.4.3 DAC clocks

Two clock sources can be used to update the DAC:

- dac_hclk: DAC peripheral clock (AHB clock)
- dac_ker_ck: DAC kernel clock: this clock can be used to synchronize DAC and ADC.
- dac_hold_ck: low-power clock used in sample and hold mode

The DAC clock is selected in the RCC.

32.4.4 DAC channel enable

Each DAC channel can be powered on by setting its corresponding ENx bit in the DAC_CR register. The DAC channel is then enabled after a t_{WAKEUP} startup time.

DACxRDY bit is set in the DAC_SR register when the DAC interface is ready to accept data. Writing new data or asserting the trigger is not allowed when ENx bit is set while DACxRDY signal is reset.

Note: The ENx bit enables the analog DAC channelx only. The DAC channelx digital interface is enabled even if the ENx bit is reset.

32.4.5 DAC data format

Depending on the selected configuration mode, the data have to be written into the specified register as described below:

- Single DAC channel

  There are three possibilities:

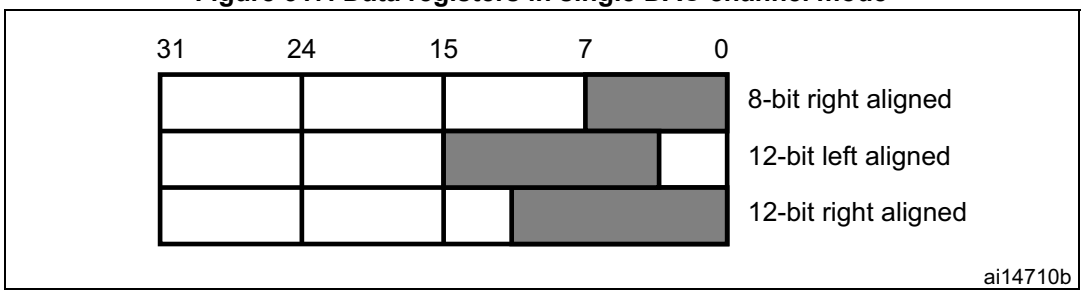
  – 8-bit right alignment: the software has to load data into the DAC_DHR8Rx[7:0] bits (stored into the DHRx[11:4] bits)

  – 12-bit left alignment: the software has to load data into the DAC_DHR12Lx [15:4] bits (stored into the DHRx[11:0] bits)

  – 12-bit right alignment: the software has to load data into the DAC_DHR12Rx [11:0] bits (stored into the DHRx[11:0] bits)

Depending on the loaded DAC_DHRyyyx register, the data written by the user is shifted and stored into the corresponding DAC_DHRx (data holding registerx, which are internal non-memory-mapped registers). The DAC_DHRx register is then loaded into the DAC_DORx register either automatically, by software trigger or by an external event trigger.

Figure 317. Data registers in single DAC channel mode



- Dual DAC channels (when available)

  There are three possibilities:

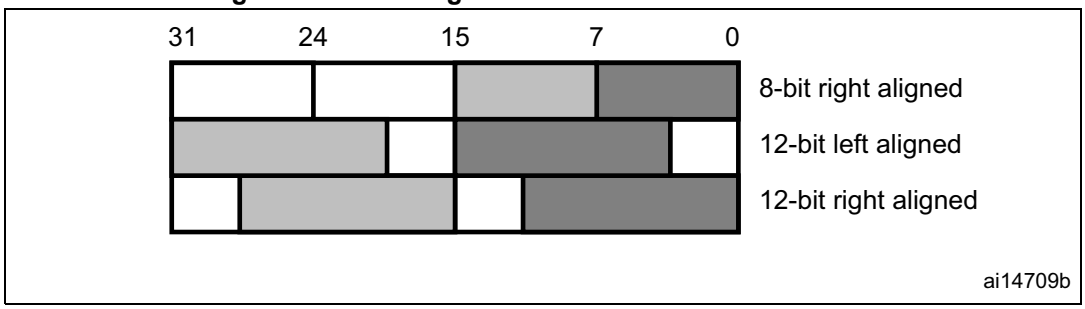
  – 8-bit right alignment: data for DAC channel1 to be loaded into the DAC_DHR8RD [7:0] bits (stored into the DHR1[11:4] bits) and data for DAC channel2 to be loaded into the DAC_DHR8RD [15:8] bits (stored into the DHR2[11:4] bits)

  – 12-bit left alignment: data for DAC channel1 to be loaded into the DAC_DHR12LD [15:4] bits (stored into the DHR1[11:0] bits) and data for DAC channel2 to be loaded into the DAC_DHR12LD [31:20] bits (stored into the DHR2[11:0] bits)

  – 12-bit right alignment: data for DAC channel1 to be loaded into the DAC_DHR12RD [11:0] bits (stored into the DHR1[11:0] bits) and data for DAC channel2 to be loaded into the DAC_DHR12RD [27:16] bits (stored into the DHR2[11:0] bits)

Depending on the loaded DAC_DHRyyyD register, the data written by the user is shifted and stored into DHR1 and DHR2 (data holding registers, which are internal non-memory-mapped registers). The DHR1 and DHR2 registers are then loaded into the DAC_DOR1 and DOR2 registers, respectively, either automatically, by software trigger or by an external event trigger.

Figure 318. Data registers in dual DAC channel mode



Signed/unsigned data

DAC input data are unsigned: 0x000 corresponds to the minimum value and 0xFFF to the maximum value for 12-bit mode.

The DAC can also handle signed input data in 2's complement format. This is done by setting SINFORMATx bit in the DAC_MCR register.

When SINFORMATx bit is set, the MSB of the data written to DAC_DHRx registers is inverted when it is copied to the DAC_DORx register, and the DAC interface can accept signed data (Q1.15, Q1.11 or Q1.7 format). DAC_DHR12Lx register can be used to store 16-bit signed data in the data holding registers. The 12 MSBs of 16-bit data are used for the DAC output data and the MSB is inverted. The four LSBs are simply ignored.

Table 315. Data format (case of 12-bit data)

SINFORMATx bit	DATA written to DAC_DHRx register	DATA transfered to DAC_DORx register
0	0x000	0x000
0	0xFFF	0xFFF
1	0x7FF	0xFFF
1	0x000	0x800
1	0xFFF	0x7FF
1	0x800	0x000

32.4.6 DAC conversion

The DAC_DORx cannot be written directly and any data transfer to the DAC channelx must be performed by loading the DAC_DHRx register (write operation to DAC_DHR8Rx, DAC_DHR12Lx, DAC_DHR12Rx, DAC_DHR8RD, DAC_DHR12RD or DAC_DHR12LD).

Data stored in the DAC_DHRx register are automatically transferred to the DAC_DORx register after one dac_hclk clock cycle, if no hardware trigger is selected (TENx bit in DAC_CR register is reset). However, when a hardware trigger is selected (TENx bit in DAC_CR register is set) and a trigger occurs, the transfer is performed three dac_hclk clock cycles after the trigger signal.

When DAC_DORx is loaded with the DAC_DHRx contents, the analog output voltage becomes available after a time $t_{SETTLING}$ that depends on the power supply voltage and the analog output load.

To synchronize DAC and ADC, the same clock source can be used for both peripherals. This is done by selecting the dac_ker_ck clock instead of the dac_hclk clock (AHB clock) in the RCC.

HFSEL bits of DAC_MCR must be set when dac_ker_ck clock speed is faster than 80 MHz.

Refer to Table *HFSEL description* below for the limitation of the DAC_DORx update rate depending on HFSEL bits and dac_hclk or dac_ker_ck clock frequency.

If the data is updated or a software/hardware trigger event occurs during the non-allowed period, the peripheral behavior is unpredictable.

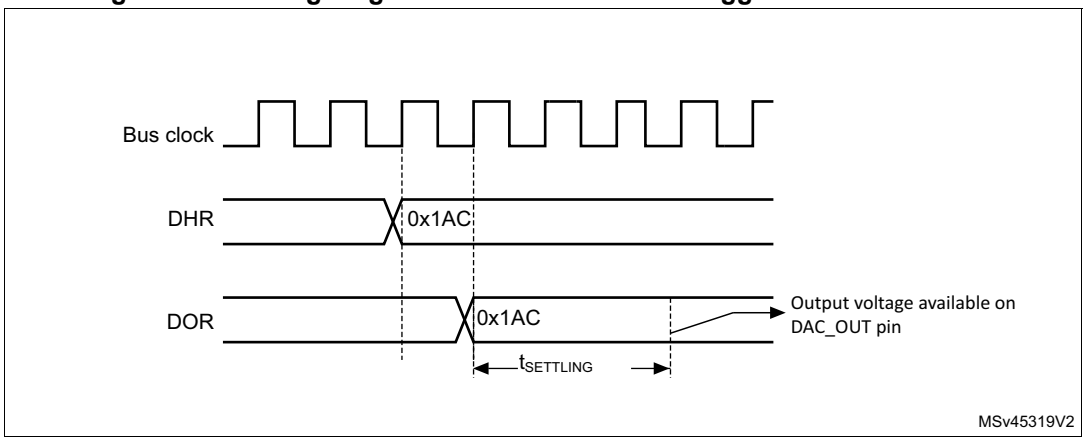
The above timing is only related to the limitation of the DAC interface. Refer also to the $t_{SETTLING}$ parameter value in the product datasheet.

Table 316. HFSEL description

HFSEL [1:0]	Clock frequency	Latency using AHB clock (dac_hclk)	Latency using dac_ker_ck clock	Function
00	< 80 MHz	3	4	DAC_DOR update rate up to 3 AHB clock cycles or 4 dac_ker_ck cycles.
01	≥ 80 MHz(1)	5	5	DAC_DOR update rate up to 5 AHB clock or dac_ker_ck cycles.
10	≥ 160 MHz	7	6	DAC_DOR update rate up to 7 AHB clock cycles or 6 dac_ker_ck cycles.
Others	Reserved	-	-	-

1. Refer to the device datasheet for the value of the maximum dac_hclk or dac_ker_ck frequency.

Figure 319. Timing diagram for conversion with trigger disabled TEN = 0



32.4.7 DAC output voltage

Digital inputs are converted to output voltages on a linear conversion between 0 and V_{REF+}.

The analog output voltage on the DAC channel pin is determined by the following equation:

$$\text{DAC output} = V_{REF} \times \frac{DOR}{4096}$$

where all voltages are expressed in Volt.

32.4.8 DAC trigger selection

If the TENx control bit is set, the conversion can then be triggered by an external event (timer counter, external interrupt line). The TSELx[3:0] control bits determine which out of 16 possible events triggers the conversion as shown in TSELx[3:0] bits of the DAC_CR register. These events can be either the software trigger or hardware triggers (see the interconnection table in *Section 32.4.2*).

Each time a DAC interface detects a rising edge on the selected trigger source (refer to the table below), the last data stored into the DAC_DHRx register are transferred into the DAC_DORx register. The DAC_DORx register is updated three dac_hclk cycles after the trigger occurs.

If the software trigger is selected, the conversion starts once the SWTRIG bit is set. SWTRIG is reset by hardware once the DAC_DORx register has been loaded with the DAC_DHRx register contents.

Note: TSELx[3:0] bit cannot be changed when the ENx bit is set.

When software trigger is selected, the transfer from the DAC_DHRx register to the DAC_DORx register takes only one dac_hclk clock cycle.

32.4.9 DMA requests

Each DAC channel has a DMA capability. Two DMA channels are used to service DAC channel DMA requests.

When an external trigger (but not a software trigger) occurs while the DMAENx bit is set, the value of the DAC_DHRx register is transferred into the DAC_DORx register when the transfer is complete, and a DMA request is generated.

In dual mode, if both DMAENx bits are set, two DMA requests are generated. If only one DMA request is needed, only the corresponding DMAENx bit must be set. In this way, the application can manage both DAC channels in dual mode by using one DMA request and a unique DMA channel.

As DAC_DHRx to DAC_DORx data transfer occurred before the DMA request, the very first data has to be written to the DAC_DHRx before the first trigger event occurs.

DMA underrun

The DAC DMA request is not queued so that if a second external trigger arrives before the acknowledgment for the first external trigger is received (first request), then no new request is issued and the DMA channelx underrun flag DMAUDRx in the DAC_SR register is set, reporting the error condition. The DAC channelx continues to convert old data.

The software must clear the DMAUDRx flag by writing 1, clear the DMAEN bit of the used DMA stream and re-initialize both DMA and DAC channelx to restart the transfer correctly.

The software must modify the DAC trigger conversion frequency or lighten the DMA workload to avoid a new DMA underrun. Finally, the DAC conversion can be resumed by enabling both DMA data transfer and conversion trigger.

For each DAC channelx, an interrupt is also generated if its corresponding DMAUDRIEx bit in the DAC_CR register is enabled.

DMA double data mode

When the DMA controller is used in normal mode, only 12-bit (or 8-bit) data are transferred by a DMA request. As the AHB width is 32 bits, two 12-bit data may be transferred simultaneously. To use this mode, set the DMADOUBLEx bit of DAC_MCR register.

A DAC DMA request is generated every two external triggers (except for software triggers) when the DMAENx bit is set:

1. When the first trigger is detected, the value of the DAC_DHRx and DAC_DHRBx registers are transferred into the DAC_DORx and DAC_DORBx registers. The actual DAC data is loaded into the DAC_DORx register. A DMA request is then generated. The DMA writes the new data to the DAC_DHRx and DAC_DHRBx data registers.
2. When the next trigger is detected, the actual DAC data is loaded into the DAC_DHRBx register. This second trigger does not generate any DMA request. The DORSTATx bit indicates which DOR data is actually loaded into the analog DAC input.

DMA underrun function is also supported in DMA double data mode.

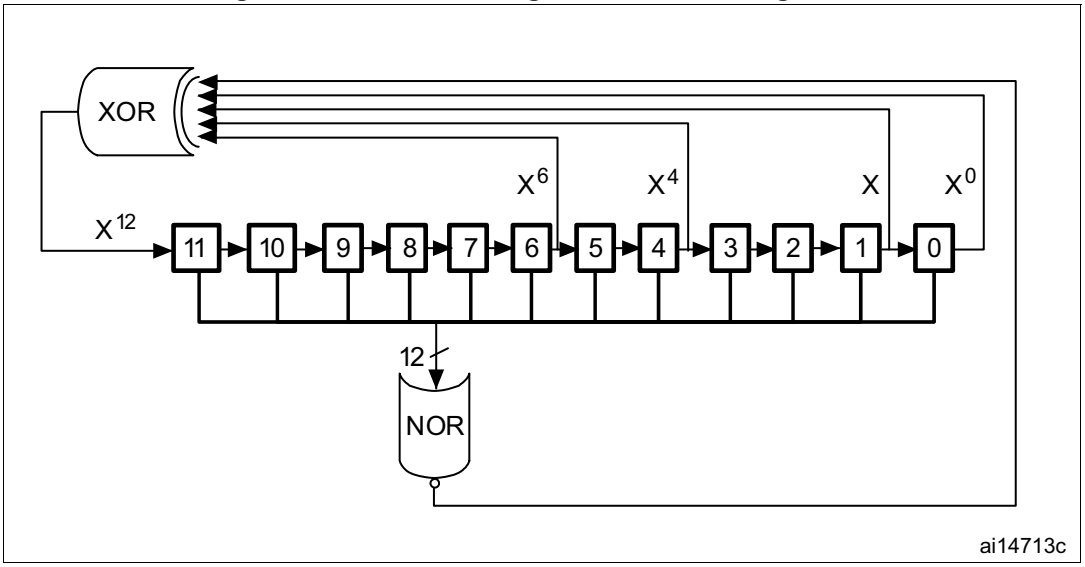
The following conditions must be met to change from double data to single data mode or vice versa:

- The DAC must be disabled.
- DMAEN bit must be cleared (ENx = 0 and DMAEN = 0).

32.4.10 Noise generation

In order to generate a variable-amplitude pseudonoise, an LFSR (linear feedback shift register) is available. DAC noise generation is selected by setting WAVEx[1:0] to 01. The preloaded value in LFSR is 0xAAA. This register is updated three dac_hclk clock cycles after each trigger event, following a specific calculation algorithm.

Figure 320. DAC LFSR register calculation algorithm

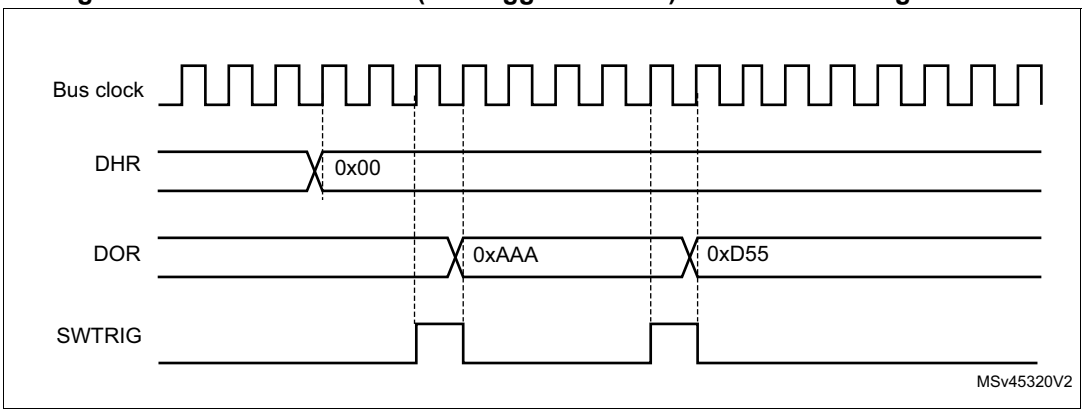


The LFSR value, that may be masked partially or totally by means of the MAMPx[3:0] bits in the DAC_CR register, is added up to the DAC_DHRx contents without overflow and this value is then transferred into the DAC_DORx register.

If LFSR is 0x0000, a 1 is injected into it (antilock-up mechanism).

It is possible to reset LFSR wave generation by resetting the WAVEx[1:0] bits.

Figure 321. DAC conversion (SW trigger enabled) with LFSR wave generation



Note: The DAC trigger must be enabled for noise generation by setting the TENx bit in the DAC_CR register.

32.4.11 Triangle-wave generation

It is possible to add a small-amplitude triangular waveform on a DC or slowly varying signal. DAC triangle-wave generation is selected by setting WAVEx[1:0] to 10. The amplitude is configured through the MAMPx[3:0] bits in the DAC_CR register. An internal triangle counter is incremented three dac_hclk clock cycles after each trigger event. The value of this counter is then added to the DAC_DHRx register without overflow and the sum is transferred into the DAC_DORx register. The triangle counter is incremented as long as it is less than the maximum amplitude defined by the MAMPx[3:0] bits. Once the configured amplitude is reached, the counter is decremented down to 0, then incremented again and so on.

It is possible to reset triangle wave generation by resetting the WAVEx[1:0] bits.

Figure 322. DAC triangle wave generation

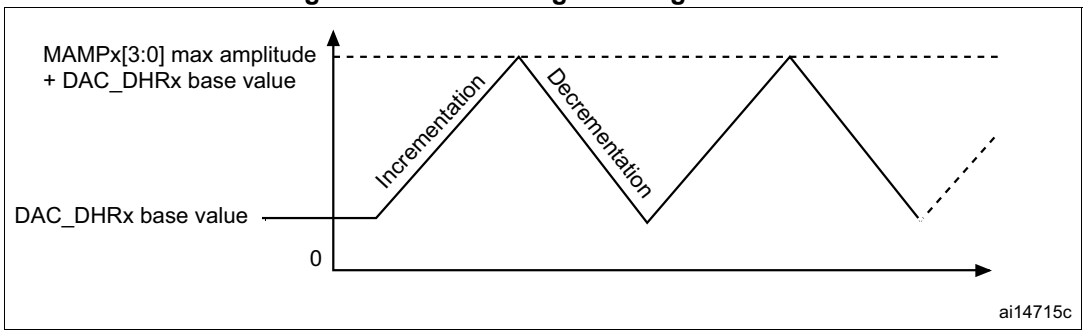
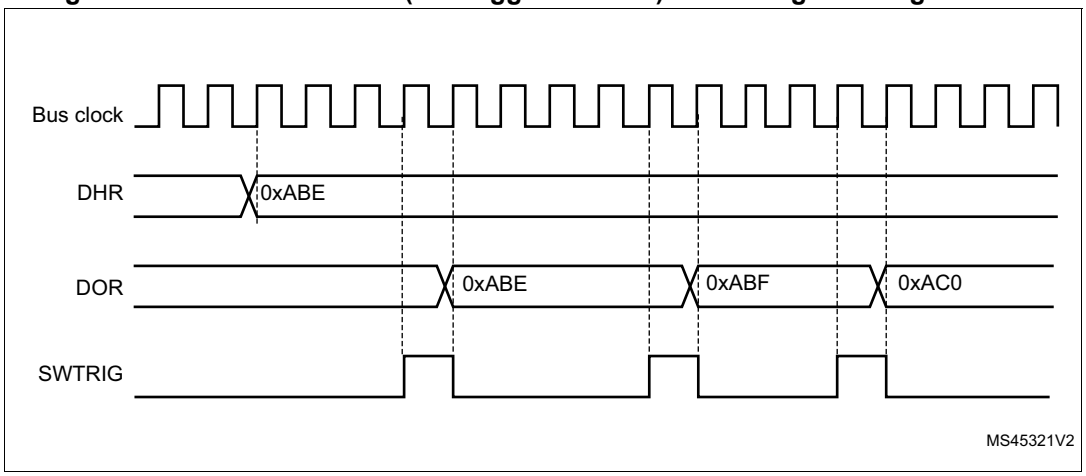


Figure 323. DAC conversion (SW trigger enabled) with triangle wave generation



Note: The DAC trigger must be enabled for triangle wave generation by setting the TENx bit in the DAC_CR register.

The MAMPx[3:0] bits must be configured before enabling the DAC, otherwise they cannot be changed.

32.4.12 DAC channel modes

Each DAC channel can be configured in normal mode or sample and hold mode. The output buffer can be enabled to obtain a high drive capability. Before enabling output buffer, the voltage offset needs to be calibrated. This calibration is performed at the factory (loaded after reset) and can be adjusted by software during application operation.

Normal mode

In normal mode, there are four combinations, by changing the buffer state and by changing the DACx_OUTy pin interconnections.

To enable the output buffer, the MODEx[2:0] bits in DAC_MCR register must be:

- 000: DAC is connected to the external pin
- 001: DAC is connected to external pin and to on-chip peripherals

To disable the output buffer, the MODEx[2:0] bits in DAC_MCR register must be:

- 010: DAC is connected to the external pin
- 011: DAC is connected to on-chip peripherals

Sample and hold mode

In sample and hold mode, the DAC core converts data on a triggered conversion, and then holds the converted voltage on a capacitor. When not converting, the DAC cores and buffer are completely turned off between samples and the DAC output is tri-stated, therefore reducing the overall power consumption. A stabilization period, which value depends on the buffer state, is required before each new conversion.

In this mode, the DAC core and all corresponding logic and registers are driven by the LSI/LSE low-speed clock (dac_hold_ck) in addition to the dac_hclk clock, allowing using the DAC channels in deep low power modes such as Stop mode.

The LSI/LSE low-speed clock (dac_hold_ck) must not be stopped when the sample and hold mode is enabled.

The sample/hold mode operations can be divided into three phases:

1. Sample phase: the sample/hold element is charged to the desired voltage. The charging time depends on capacitor value (internal or external, selected by the user). The sampling time is configured with the TSAMPLEx[9:0] bits in DAC_SHSRx register. During the write of the TSAMPLEx[9:0] bits, the BWSTx bit in DAC_SR register is set to 1 to synchronize between both clocks domains (AHB and low speed clock) and allowing the software to change the value of sample phase during the DAC channel operation
2. Hold phase: the DAC output channel is tri-stated, the DAC core and the buffer are turned off, to reduce the current consumption. The hold time is configured with the THOLDx[9:0] bits in DAC_SHHR register
3. Refresh phase: the refresh time is configured with the TREFRESHx[7:0] bits in DAC_SHRR register

The timings for the three phases above are in units of LSI/LSE clock periods. As an example, to configure a sample time of 350 µs, a hold time of 2 ms and a refresh time of 100 µs assuming LSI/LSE ~32 KHz is selected:

- 12 cycles are required for sample phase: TSAMPLEx[9:0] = 11.
- 62 cycles are required for hold phase: THOLDx[9:0] = 62.
- and 4 cycles are required for refresh period: TREFRESHx[7:0] = 4.

In this example, the power consumption is reduced by almost a factor of 15 versus normal modes.

The formulas to compute the right sample and refresh timings are described in the table below, the Hold time depends on the leakage current.

Table 317. Sample and refresh timings

Buffer State	t_{SAMP} (1)(2)	$t_{REFRESH}$ (2)(3)
Enable	7 µs + (10*R_{BON}*C_{SH})	7 µs + (R_{BON}*C_{SH})*ln(2*N_{LSB})
Disable	3 µs + (10*R_{BOFF}*C_{SH})	3 µs + (R_{BOFF}*C_{SH})*ln(2*N_{LSB})

1. In the above formula, the settling to the desired code value with ½ LSB or accuracy requires 10 constant time for 12 bits resolution. For 8-bit resolution, the settling time is 7 constant time.
2. C_{SH} is the capacitor in sample and hold mode.
3. The tolerated voltage drop during the hold phase “Vd” is represented by the number of LSBs after the capacitor discharging with the output leakage current. The settling back to the desired value with ½ LSB error accuracy requires ln(2*Nlsb) constant time of the DAC.

Example of the sample and refresh time calculation with output buffer on

The values used in the example below are provided as indication only (refer to the datasheet for product data):

C_{SH} = 100 nF

V_{REF+} = 3.0 V

Sampling phase:

t_{SAMP} = 7 µs + (10 * 2000 * 100 * 10^{-9}) = 2.007 ms

(where R_{BON} = 2 kΩ)

Refresh phase:

$t_{REFRESH}$ = 7 µs + (2000 * 100 * 10^{-9}) * ln(2*10) = 606.1 µs

(where N_{LSB} = 10 (10 LSB drop during the hold phase)

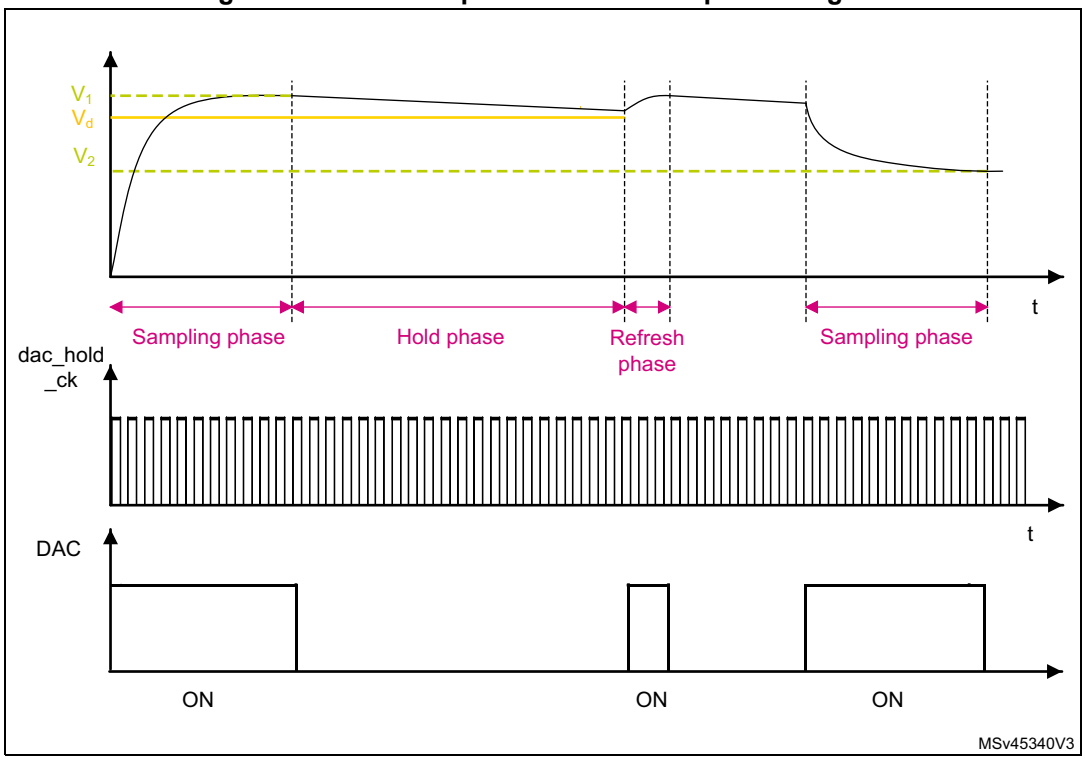
Hold phase:

D_v = i_{leak} * t_{hold} / C_{SH} = 0.0073 V (10 LSB of 12bit at 3 V)

i_{leak} = 150 nA (worst case on the IO leakage on all the temperature range)

t_{hold} = 0.0073 * 100 * 10^{-9} / (150 * 10^{-9}) = 4.867 ms

Figure 324. DAC sample and hold mode phase diagram



Like in normal mode, the sample and hold mode has different configurations.

To enable the output buffer, MODEx[2:0] bits in DAC_MCR register must be set to:

- 100: DAC is connected to the external pin
- 101: DAC is connected to external pin and to on chip peripherals

To disabled the output buffer, MODEx[2:0] bits in DAC_MCR register must be set to:

- 110: DAC is connected to external pin and to on chip peripherals
- 111: DAC is connected to on chip peripherals

  When MODEx[2:0] bits are equal to 111, an internal capacitor, C_{Lint}, holds the voltage output of the DAC core and then drive it to on-chip peripherals.

All sample and hold phases are interruptible, and any change in DAC_DHRx immediately triggers a new sample phase.

Table 318. Channel output modes summary

MODEx[2:0]			Mode	Buffer	Output connections
0	0	0	Normal mode	Enabled	Connected to external pin
0	0	1			Connected to external pin and to on chip-peripherals (such as comparators)
0	1	0		Disabled	Connected to external pin
0	1	1			Connected to on chip peripherals (such as comparators)

Table 318. Channel output modes summary (continued)

MODEx[2:0]			Mode	Buffer	Output connections
1	0	0	Sample and hold mode	Enabled	Connected to external pin
1	0	1			Connected to external pin and to on chip peripherals (such as comparators)
1	1	0		Disabled	Connected to external pin and to on chip peripherals (such as comparators)
1	1	1			Connected to on chip peripherals (such as comparators)

Note: Some packages do not feature any DACx_OUTy pin. In this case, the application must not use a channel output mode where the buffer is connected to an external pin that does not exist on the package. For more detail, refer to the product datasheet.

32.4.13 DAC channel buffer calibration

The transfer function for an N-bit digital-to-analog converter (DAC) is:

$$V_{out} = \left((D / 2^N) \times G \times V_{REF}\right) + V_{OS}$$

Where V_{OUT} is the analog output, D is the digital input, G is the gain, V_{REF} is the nominal full-scale voltage, and V_{OS} is the offset voltage. For an ideal DAC channel, G = 1 and V_{OS} = 0.

Due to output buffer characteristics, the voltage offset may differ from part-to-part and introduce an absolute offset error on the analog output. To compensate the V_{OS}, a calibration is required by a trimming technique.

The calibration is only valid when the DAC channelx is operating with buffer enabled (MODEx[2:0] = 0b000 or 0b001 or 0b100 or 0b101). if applied in other modes when the buffer is off, it has no effect. During the calibration:

- The buffer output is disconnected from the pin internal/external connections and put in tristate mode (HiZ).
- The buffer acts as a comparator to sense the middle-code value 0x800 and compare it to V_{REF+}/2 signal through an internal bridge, then toggle its output signal to 0 or 1 depending on the comparison result (CAL_FLAGx bit).

Two calibration techniques are provided:

- Factory trimming (default setting)

  The DAC buffer offset is factory trimmed. The default value of OTRIMx[4:0] bits in DAC_CCR register is the factory trimming value and it is loaded once DAC digital interface is reset.
- User trimming

  The user trimming can be done when the operating conditions differs from nominal factory trimming conditions and in particular when V_{DDA} voltage, temperature, V_{REF+} values change and can be done at any point during application by software.

Note: Refer to the datasheet for more details of the nominal factory trimming conditions.

In addition, when V_{DD} is removed (example the device enters in Standby or VBAT modes) the calibration is required.

The steps to perform a user trimming calibration are as below:

1. If the DAC channel is active, write 0 to ENx bit in DAC_CR to disable the channel.
2. Select a mode where the buffer is enabled, by writing to DAC_MCR register, MODEx[2:0] = 0b000 or 0b001 or 0b100 or 0b101.
3. Start the DAC channelx calibration, by setting the CENx bit in DAC_CR register to 1.
4. Apply a trimming algorithm:
   a) Write a code into OTRIMx[4:0] bits, starting by 0b00000.
   b) Wait for t_{TRIM} delay.
   c) Check if CAL_FLAGx bit in DAC_SR is set to 1.
   d) Until the CAL_FLAGx is read as 1 or the maximum trimming code is reached, increment OTRIMx[4:0] and repeat substeps from (b) to (d).

The software algorithm may use either a successive approximation or dichotomy techniques to compute and set the content of OTRIMx[4:0] bits in a faster way.

Note: A t_{TRIM} delay must be respected between the write to the OTRIMx[4:0] bits and the read of the CAL_FLAGx bit in DAC_SR register in order to get a correct value.This parameter is specified into datasheet electrical characteristics section.

If V_{DDA}, V_{REF+} and temperature conditions do not change during device operation while it enters more often in Standby and VBAT modes, the software may store the OTRIMx[4:0] bits found in the first user calibration in the flash or in back-up registers. then to load/write them directly when the device power is back again thus avoiding to wait for a new calibration time.

When CENx bit is set, it is not allowed to set ENx bit.

32.4.14 DAC channel conversion modes

Four conversion modes are possible.

Independent trigger without wave generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the DAC channel trigger enable bit, TENx.
2. Configure the trigger sources by setting different values in the TSELx[3:0] bits.
3. Load the DAC channel data into the desired DHR registers (DAC_DHR12R1, DAC_DHR12L1 or DAC_DHR8R1).

When a DAC channel trigger arrives, the DHRx register is transferred into DAC_DORx (three dac_hclk clock cycles later).

Independent trigger with single LFSR generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the DAC channel trigger enable bit, TENx.
2. Configure the trigger sources by setting different values in the TSELx[3:0] bits.
3. Configure the DAC channel WAVEx[1:0] bits as 01 and the same LFSR mask value in the MAMPx[3:0] bits.
4. Load the DAC channel data into the desired DHR register (DAC_DHR12R1, DAC_DHR12L1 or DAC_DHR8R1).

When a DAC channel trigger arrives, the LFSR1 counter, with the same mask, is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_hclk clock cycles later). Then the LFSR1 counter is updated.

Independent trigger with single triangle generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the DAC channel trigger enable bits, TENx.
2. Configure the trigger sources by setting different values in the TSELx[3:0] bits.
3. Configure the DAC channel WAVEx[1:0] bits as 1x and the same maximum amplitude value in the MAMPx[3:0] bits.
4. Load the DAC channel data into the desired DHR register (DAC_DHR12R1, DAC_DHR12L1 or DAC_DHR8R1).

When a DAC channel trigger arrives, the DAC channel triangle counter, with the same triangle amplitude, is added to the DHRx register and the sum is transferred into DAC_DOR1 (three dac_hclk clock cycles later). The DAC channel triangle counter is then updated.

32.4.15 Dual DAC channel conversion modes (if dual channels are available)

To efficiently use the bus bandwidth in applications that require the two DAC channels at the same time, three dual registers are implemented: DHR8RD, DHR12RD and DHR12LD. A unique register access is then required to drive both DAC channels at the same time. For the wave generation, no accesses to DHRxxxD registers are required. As a result, two output channels can be used either independently or simultaneously.

15 conversion modes are possible using the two DAC channels and these dual registers. All the conversion modes can nevertheless be obtained using separate DAC_DHRx registers if needed.

All modes are described in the paragraphs below.

Independent trigger without wave generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2.
2. Configure different trigger sources by setting different values in the TSEL1 and TSEL2 bitfields.
3. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a DAC channel1 trigger arrives, the DHR1 register is transferred into DAC_DOR1 (three dac_hclk clock cycles later).

When a DAC channel2 trigger arrives, the DHR2 register is transferred into DAC_DOR2 (three dac_hclk clock cycles later).

Independent trigger with single LFSR generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2.

2. Configure different trigger sources by setting different values in the TSEL1 and TSEL2 bitfields.
3. Configure the two DAC channel WAVEx[1:0] bits as 01 and the same LFSR mask value in the MAMPx[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a DAC channel1 trigger arrives, the LFSR1 counter, with the same mask, is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_hclk clock cycles later). Then the LFSR1 counter is updated.

When a DAC channel2 trigger arrives, the LFSR2 counter, with the same mask, is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_hclk clock cycles later). Then the LFSR2 counter is updated.

Independent trigger with different LFSR generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2.
2. Configure different trigger sources by setting different values in the TSEL1 and TSEL2 bitfields.
3. Configure the two DAC channel WAVEx[1:0] bits as 01 and set different LFSR masks values in the MAMP1[3:0] and MAMP2[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a DAC channel1 trigger arrives, the LFSR1 counter, with the mask configured by MAMP1[3:0], is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_hclk clock cycles later). Then the LFSR1 counter is updated.

When a DAC channel2 trigger arrives, the LFSR2 counter, with the mask configured by MAMP2[3:0], is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_hclk clock cycles later). Then the LFSR2 counter is updated.

Independent trigger with single triangle generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2.
2. Configure different trigger sources by setting different values in the TSEL1 and TSEL2 bitfields.
3. Configure the two DAC channel WAVEx[1:0] bits as 1x and the same maximum amplitude value in the MAMPx[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a DAC channel1 trigger arrives, the DAC channel1 triangle counter, with the same triangle amplitude, is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_hclk clock cycles later). The DAC channel1 triangle counter is then updated.

When a DAC channel2 trigger arrives, the DAC channel2 triangle counter, with the same triangle amplitude, is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_hclk clock cycles later). The DAC channel2 triangle counter is then updated.

Independent trigger with different triangle generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2.
2. Configure different trigger sources by setting different values in the TSEL1 and TSEL2 bits.
3. Configure the two DAC channel WAVEx[1:0] bits as 1x and set different maximum amplitude values in the MAMP1[3:0] and MAMP2[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a DAC channel1 trigger arrives, the DAC channel1 triangle counter, with a triangle amplitude configured by MAMP1[3:0], is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_hclk clock cycles later). The DAC channel1 triangle counter is then updated.

When a DAC channel2 trigger arrives, the DAC channel2 triangle counter, with a triangle amplitude configured by MAMP2[3:0], is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_hclk clock cycles later). The DAC channel2 triangle counter is then updated.

Simultaneous software start

To configure the DAC in this conversion mode, the following sequence is required:

- Load the dual DAC channel data to the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

In this configuration, one dac_hclk clock cycle later, the DHR1 and DHR2 registers are transferred into DAC_DOR1 and DAC_DOR2, respectively.

Simultaneous trigger without wave generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2.
2. Configure the same trigger source for both DAC channels by setting the same value in the TSEL1 and TSEL2 bitfields.
3. Load the dual DAC channel data to the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a trigger arrives, the DHR1 and DHR2 registers are transferred into DAC_DOR1 and DAC_DOR2, respectively (after three dac_hclk clock cycles).

Simultaneous trigger with single LFSR generation

1. To configure the DAC in this conversion mode, the following sequence is required:
2. Set the two DAC channel trigger enable bits TEN1 and TEN2.
3. Configure the same trigger source for both DAC channels by setting the same value in the TSEL1 and TSEL2 bitfields.
4. Configure the two DAC channel WAVEx[1:0] bits as 01 and the same LFSR mask value in the MAMPx[3:0] bits.
5. Load the dual DAC channel data to the desired DHR register (DHR12RD, DHR12LD or DHR8RD).

When a trigger arrives, the LFSR1 counter, with the same mask, is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_hclk clock cycles later). The LFSR1 counter is then updated. At the same time, the LFSR2 counter, with the same mask, is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_hclk clock cycles later). The LFSR2 counter is then updated.

Simultaneous trigger with different LFSR generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2
2. Configure the same trigger source for both DAC channels by setting the same value in the TSEL1 and TSEL2 bitfields.
3. Configure the two DAC channel WAVEx[1:0] bits as 01 and set different LFSR mask values using the MAMP1[3:0] and MAMP2[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a trigger arrives, the LFSR1 counter, with the mask configured by MAMP1[3:0], is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_hclk clock cycles later). The LFSR1 counter is then updated.
At the same time, the LFSR2 counter, with the mask configured by MAMP2[3:0], is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_hclk clock cycles later). The LFSR2 counter is then updated.

Simultaneous trigger with single triangle generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2
2. Configure the same trigger source for both DAC channels by setting the same value in the TSEL1 and TSEL2 bitfields.
3. Configure the two DAC channel WAVEx[1:0] bits as 1x and the same maximum amplitude value using the MAMPx[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a trigger arrives, the DAC channel1 triangle counter, with the same triangle amplitude, is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_hclk clock cycles later). The DAC channel1 triangle counter is then updated.

At the same time, the DAC channel2 triangle counter, with the same triangle amplitude, is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_hclk clock cycles later). The DAC channel2 triangle counter is then updated.

Simultaneous trigger with different triangle generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2
2. Configure the same trigger source for both DAC channels by setting the same value in the TSEL1 and TSEL2 bitfields.
3. Configure the two DAC channel WAVEx[1:0] bits as 1x and set different maximum amplitude values in the MAMP1[3:0] and MAMP2[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a trigger arrives, the DAC channel1 triangle counter, with a triangle amplitude configured by MAMP1[3:0], is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three AHB clock cycles later). Then the DAC channel1 triangle counter is updated.

At the same time, the DAC channel2 triangle counter, with a triangle amplitude configured by MAMP2[3:0], is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_hclk clock cycles later). Then the DAC channel2 triangle counter is updated.

32.5 DAC in low-power modes

Table 319. Effect of low-power modes on DAC

Mode	Description
Sleep	No effect, DAC used with DMA.
Stop(1)	The DAC remains active with a static value. The sample and hold mode can be selected using LSE/LSI clock.
Standby	The DAC peripheral is powered down and must be reinitialized after exiting Standby mode.

1. Refer to *Section 32.3: DAC implementation* for information on the Stop modes supported by the DAC peripheral.

32.6 DAC interrupts

Table 320. DAC interrupts

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit Sleep mode	Exit Stop mode	Exit Standby mode
DAC	DMA underrun	DMAUDRx	DMAUDRIEx	Write DMAUDRx = 1	Yes	No	No

32.7 DAC registers

Refer to *Section 1 on page 128* for a list of abbreviations used in register descriptions.

The peripheral registers have to be accessed by words (32-bit).

32.7.1 DAC control register (DAC_CR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	CEN2	DMAUDRIE2	DMAEN2	MAMP2[3:0]				WAVE2[1:0]		TSEL2[3]	TSEL2[2]	TSEL2[1]	TSEL2[0]	TEN2	EN2
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	CEN1	DMAUDRIE1	DMAEN1	MAMP1[3:0]				WAVE1[1:0]		TSEL1[3]	TSEL1[2]	TSEL1[1]	TSEL1[0]	TEN1	EN1
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **CEN2**: DAC channel2 calibration enable

This bit is set and cleared by software to enable/disable DAC channel2 calibration, it can be written only if EN2 bit is set to 0 into DAC_CR (the calibration mode can be entered/exit only when the DAC channel is disabled) Otherwise, the write operation is ignored.

0: DAC channel2 in normal operating mode

1: DAC channel2 in calibration mode

Note: This bit is available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bit 29 **DMAUDRIE2**: DAC channel2 DMA underrun interrupt enable

This bit is set and cleared by software.

0: DAC channel2 DMA underrun interrupt disabled

1: DAC channel2 DMA underrun interrupt enabled

Note: This bit is available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bit 28 **DMAEN2**: DAC channel2 DMA enable

This bit is set and cleared by software.

0: DAC channel2 DMA mode disabled

1: DAC channel2 DMA mode enabled

Note: This bit is available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bits 27:24 **MAMP2[3:0]**: DAC channel2 mask/amplitude selector

These bits are written by software to select mask in wave generation mode or amplitude in triangle generation mode.

0000: Unmask bit0 of LFSR/ triangle amplitude equal to 1
0001: Unmask bits[1:0] of LFSR/ triangle amplitude equal to 3
0010: Unmask bits[2:0] of LFSR/ triangle amplitude equal to 7
0011: Unmask bits[3:0] of LFSR/ triangle amplitude equal to 15
0100: Unmask bits[4:0] of LFSR/ triangle amplitude equal to 31
0101: Unmask bits[5:0] of LFSR/ triangle amplitude equal to 63
0110: Unmask bits[6:0] of LFSR/ triangle amplitude equal to 127
0111: Unmask bits[7:0] of LFSR/ triangle amplitude equal to 255
1000: Unmask bits[8:0] of LFSR/ triangle amplitude equal to 511
1001: Unmask bits[9:0] of LFSR/ triangle amplitude equal to 1023
1010: Unmask bits[10:0] of LFSR/ triangle amplitude equal to 2047
≥ 1011: Unmask bits[11:0] of LFSR/ triangle amplitude equal to 4095

Note: These bits are available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bits 23:22 **WAVE2[1:0]**: DAC channel2 noise/triangle wave generation enable

These bits are set/reset by software.

00: wave generation disabled
01: Noise wave generation enabled
10: Triangle wave generation enabled
11: Reserved

Note: Only used if bit TEN2 = 1 (DAC channel2 trigger enabled)
These bits are available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bits 21:18 **TSEL2[3:0]**: DAC channel2 trigger selection

These bits select the external event used to trigger DAC channel2

0000: SWTRIG2
0001: dac_ch2_trg1
0010: dac_ch2_trg2
...
1111: dac_ch2_trg15

For details on trigger configuration and mapping, refer to *Section 32.4.2: DAC pins and internal signals*.

Note: Only used if bit TEN2 = 1 (DAC channel2 trigger enabled).
These bits are available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bit 17 **TEN2**: DAC channel2 trigger enable

This bit is set and cleared by software to enable/disable DAC channel2 trigger

0: DAC channel2 trigger disabled and data written into the DAC_DHR2 register are transferred one dac_hclk clock cycle later to the DAC_DOR2 register
1: DAC channel2 trigger enabled and data from the DAC_DHR2 register are transferred three dac_hclk clock cycles later to the DAC_DOR2 register

Note: When software trigger is selected, the transfer from the DAC_DHR2 register to the DAC_DOR2 register takes only one dac_hclk clock cycle.
These bits are available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bit 16 **EN2**: DAC channel2 enable

This bit is set and cleared by software to enable/disable DAC channel2.

0: DAC channel2 disabled

1: DAC channel2 enabled

Note: These bits are available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **CEN1**: DAC channel1 calibration enable

This bit is set and cleared by software to enable/disable DAC channel1 calibration, it can be written only if bit EN1 = 0 into DAC_CR (the calibration mode can be entered/exit only when the DAC channel is disabled) Otherwise, the write operation is ignored.

0: DAC channel1 in normal operating mode

1: DAC channel1 in calibration mode

Bit 13 **DMAUDRIE1**: DAC channel1 DMA Underrun Interrupt enable

This bit is set and cleared by software.

0: DAC channel1 DMA Underrun Interrupt disabled

1: DAC channel1 DMA Underrun Interrupt enabled

Bit 12 **DMAEN1**: DAC channel1 DMA enable

This bit is set and cleared by software.

0: DAC channel1 DMA mode disabled

1: DAC channel1 DMA mode enabled

Bits 11:8 **MAMP1[3:0]**: DAC channel1 mask/amplitude selector

These bits are written by software to select mask in wave generation mode or amplitude in triangle generation mode.

0000: Unmask bit0 of LFSR/ triangle amplitude equal to 1

0001: Unmask bits[1:0] of LFSR/ triangle amplitude equal to 3

0010: Unmask bits[2:0] of LFSR/ triangle amplitude equal to 7

0011: Unmask bits[3:0] of LFSR/ triangle amplitude equal to 15

0100: Unmask bits[4:0] of LFSR/ triangle amplitude equal to 31

0101: Unmask bits[5:0] of LFSR/ triangle amplitude equal to 63

0110: Unmask bits[6:0] of LFSR/ triangle amplitude equal to 127

0111: Unmask bits[7:0] of LFSR/ triangle amplitude equal to 255

1000: Unmask bits[8:0] of LFSR/ triangle amplitude equal to 511

1001: Unmask bits[9:0] of LFSR/ triangle amplitude equal to 1023

1010: Unmask bits[10:0] of LFSR/ triangle amplitude equal to 2047

≥ 1011: Unmask bits[11:0] of LFSR/ triangle amplitude equal to 4095

Bits 7:6 **WAVE1[1:0]**: DAC channel1 noise/triangle wave generation enable

These bits are set and cleared by software.

00: wave generation disabled

01: Noise wave generation enabled

10: Triangle wave generation enabled

11: Reserved

Only used if bit TEN1 = 1 (DAC channel1 trigger enabled).

Bits 5:2 **TSEL1[3:0]**: DAC channel1 trigger selection
These bits select the external event used to trigger DAC channel1
0000: SWTRIG1
0001: dac_ch1_trg1
0010: dac_ch1_trg2
...
1111: dac_ch1_trg15
For details on trigger configuration and mapping, refer to *Section 32.4.2: DAC pins and internal signals*.

Note: Only used if bit TEN1 = 1 (DAC channel1 trigger enabled).

Bit 1 **TEN1**: DAC channel1 trigger enable
This bit is set and cleared by software to enable/disable DAC channel1 trigger.
0: DAC channel1 trigger disabled and data written into the DAC_DHR1 register are transferred one dac_hclk clock cycle later to the DAC_DOR1 register
1: DAC channel1 trigger enabled and data from the DAC_DHR1 register are transferred three dac_hclk clock cycles later to the DAC_DOR1 register

Note: When software trigger is selected, the transfer from the DAC_DHR1 *register to the DAC_DOR1 register takes only one dac_hclk clock cycle.*

Bit 0 **EN1**: DAC channel1 enable
This bit is set and cleared by software to enable/disable DAC channel1.
0: DAC channel1 disabled
1: DAC channel1 enabled

32.7.2 DAC software trigger register (DAC_SWTRGR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWTRIG2	SWTRIG1
														w	w

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **SWTRIG2**: DAC channel2 software trigger

This bit is set by software to trigger the DAC in software trigger mode.

0: No trigger

1: Trigger

Note: This bit is cleared by hardware (one dac_hclk clock cycle later) once the DAC_DHR2 register value has been loaded into the DAC_DOR2 register.

This bit is available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bit 0 **SWTRIG1**: DAC channel1 software trigger

This bit is set by software to trigger the DAC in software trigger mode.

0: No trigger

1: Trigger

Note: This bit is cleared by hardware (one dac_hclk clock cycle later) once the DAC_DHR1 register value has been loaded into the DAC_DOR1 register.

32.7.3 DAC channel1 12-bit right-aligned data holding register (DAC_DHR12R1)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	DACC1DHRB[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DACC1DHR[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **DACC1DHRB[11:0]**: DAC channel1 12-bit right-aligned data B

These bits are written by software. They specify 12-bit data for DAC channel1 when the DAC operates in double data mode.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **DACC1DHR[11:0]**: DAC channel1 12-bit right-aligned data

These bits are written by software. They specify 12-bit data for DAC channel1.

32.7.4 DAC channel1 12-bit left aligned data holding register (DAC_DHR12L1)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DACC1DHRB[11:0]												Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DACC1DHR[11:0]												Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				

Bits 31:20 **DACC1DHRB[11:0]**: DAC channel1 12-bit left-aligned data B
These bits are written by software. They specify 12-bit data for DAC channel1 when the DAC operates in double data mode.

Bits 19:16 Reserved, must be kept at reset value.

Bits 15:4 **DACC1DHR[11:0]**: DAC channel1 12-bit left-aligned data
These bits are written by software.
They specify 12-bit data for DAC channel1.

Bits 3:0 Reserved, must be kept at reset value.

32.7.5 DAC channel1 8-bit right aligned data holding register (DAC_DHR8R1)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DACC1DHRB[7:0]								DACC1DHR[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **DACC1DHRB[7:0]**: DAC channel1 8-bit right-aligned data
These bits are written by software. They specify 8-bit data for DAC channel1 when the DAC operates in double data mode.

Bits 7:0 **DACC1DHR[7:0]**: DAC channel1 8-bit right-aligned data
These bits are written by software. They specify 8-bit data for DAC channel1.

32.7.6 DAC channel2 12-bit right aligned data holding register (DAC_DHR12R2)

This register is available only on dual-channel DACs. Refer to *Section 32.3: DAC implementation*.

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	DACC2DHRB[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DACC2DHR[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **DACC2DHRB[11:0]**: DAC channel2 12-bit right-aligned data
These bits are written by software. They specify 12-bit data for DAC channel2 when the DAC operates in DMA double data mode.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **DACC2DHR[11:0]**: DAC channel2 12-bit right-aligned data
These bits are written by software. They specify 12-bit data for DAC channel2.

32.7.7 DAC channel2 12-bit left aligned data holding register (DAC_DHR12L2)

This register is available only on dual-channel DACs. Refer to *Section 32.3: DAC implementation*.

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DACC2DHRB[11:0]												Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DACC2DHR[11:0]												Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				

Bits 31:20 **DACC2DHRB[11:0]**: DAC channel2 12-bit left-aligned data B
These bits are written by software. They specify 12-bit data for DAC channel2 when the DAC operates in double data mode.

Bits 19:16 Reserved, must be kept at reset value.

Bits 15:4 **DACC2DHR[11:0]**: DAC channel2 12-bit left-aligned data
These bits are written by software which specify 12-bit data for DAC channel2.

Bits 3:0 Reserved, must be kept at reset value.

32.7.8 DAC channel2 8-bit right-aligned data holding register (DAC_DHR8R2)

This register is available only on dual-channel DACs. Refer to *Section 32.3: DAC implementation*.

Address offset: 0x1C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DACC2DHRB[7:0]								DACC2DHR[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **DACC2DHRB[7:0]**: DAC channel2 8-bit right-aligned data
These bits are written by software. They specify 8-bit data for DAC channel2 when the DAC operates in double data mode.

Bits 7:0 **DACC2DHR[7:0]**: DAC channel2 8-bit right-aligned data
These bits are written by software which specifies 8-bit data for DAC channel2.

32.7.9 Dual DAC 12-bit right-aligned data holding register (DAC_DHR12RD)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	DACC2DHR[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DACC1DHR[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **DACC2DHR[11:0]**: DAC channel2 12-bit right-aligned data
These bits are written by software which specifies 12-bit data for DAC channel2.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **DACC1DHR[11:0]**: DAC channel1 12-bit right-aligned data
These bits are written by software which specifies 12-bit data for DAC channel1.

32.7.10 Dual DAC 12-bit left aligned data holding register (DAC_DHR12LD)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DACC2DHR[11:0]												Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DACC1DHR[11:0]												Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				

Bits 31:20 **DACC2DHR[11:0]**: DAC channel2 12-bit left-aligned data
These bits are written by software which specifies 12-bit data for DAC channel2.

Bits 19:16 Reserved, must be kept at reset value.

Bits 15:4 **DACC1DHR[11:0]**: DAC channel1 12-bit left-aligned data
These bits are written by software which specifies 12-bit data for DAC channel1.

Bits 3:0 Reserved, must be kept at reset value.

32.7.11 Dual DAC 8-bit right aligned data holding register (DAC_DHR8RD)

Address offset: 0x28

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DACC2DHR[7:0]								DACC1DHR[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **DACC2DHR[7:0]**: DAC channel2 8-bit right-aligned data
These bits are written by software which specifies 8-bit data for DAC channel2.

Bits 7:0 **DACC1DHR[7:0]**: DAC channel1 8-bit right-aligned data
These bits are written by software which specifies 8-bit data for DAC channel1.

32.7.12 DAC channel1 data output register (DAC_DOR1)

Address offset: 0x2C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	DACC1DORB[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DACC1DOR[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **DACC1DORB[11:0]**: DAC channel1 data output
These bits are read-only. They contain data output for DAC channel1 B.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **DACC1DOR[11:0]**: DAC channel1 data output
These bits are read-only, they contain data output for DAC channel1.

32.7.13 DAC channel2 data output register (DAC_DOR2)

This register is available only on dual-channel DACs. Refer to *Section 32.3: DAC implementation*.

Address offset: 0x30

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	DACC2DORB[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DACC2DOR[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **DACC2DORB[11:0]**: DAC channel2 data output
These bits are read-only. They contain data output for DAC channel2 B.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **DACC2DOR[11:0]**: DAC channel2 data output
These bits are read-only, they contain data output for DAC channel2.

32.7.14 DAC status register (DAC_SR)

Address offset: 0x34

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BWST2	CAL_FLAG2	DMAUDR2	DORSTAT2	DAC2RDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	rc_w1	r	r											
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BWST1	CAL_FLAG1	DMAUDR1	DORSTAT1	DAC1RDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	rc_w1	r	r											

Bit 31 **BWST2**: DAC channel2 busy writing sample time flag

This bit is systematically set just after sample and hold mode enable. It is set each time the software writes the register DAC_SHSR2, It is cleared by hardware when the write operation of DAC_SHSR2 is complete. (It takes about 3 LSI/LSE periods of synchronization).

0:There is no write operation of DAC_SHSR2 ongoing: DAC_SHSR2 can be written

1:There is a write operation of DAC_SHSR2 ongoing: DAC_SHSR2 cannot be written

Note: This bit is available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bit 30 **CAL_FLAG2**: DAC channel2 calibration offset status

This bit is set and cleared by hardware

0: calibration trimming value is lower than the offset correction value

1: calibration trimming value is equal or greater than the offset correction value

Note: This bit is available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bit 29 **DMAUDR2**: DAC channel2 DMA underrun flag

This bit is set by hardware and cleared by software (by writing it to 1).

0: No DMA underrun error condition occurred for DAC channel2

1: DMA underrun error condition occurred for DAC channel2 (the currently selected trigger is driving DAC channel2 conversion at a frequency higher than the DMA service capability rate).

Note: This bit is available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bit 28 **DORSTAT2**: DAC channel2 output register status bit

This bit is set and cleared by hardware. It is applicable only when the DAC operates in double data mode.

0: DOR[11:0] is used actual DAC output

1: DORB[11:0] is used actual DAC output

Note: This bit is available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bit 27 **DAC2RDY**: DAC channel2 ready status bit

This bit is set and cleared by hardware.

0: DAC channel2 is not yet ready to accept the trigger nor output data

1: DAC channel2 is ready to accept the trigger or output data

Note: This bit is available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bits 26:16 Reserved, must be kept at reset value.

Bit 15 **BWST1**: DAC channel1 busy writing sample time flag

This bit is systematically set just after sample and hold mode enable and is set each time the software writes the register DAC_SHSR1, It is cleared by hardware when the write operation of DAC_SHSR1 is complete. (It takes about 3 LSI/LSE periods of synchronization).

0:There is no write operation of DAC_SHSR1 ongoing: DAC_SHSR1 can be written

1:There is a write operation of DAC_SHSR1 ongoing: DAC_SHSR1 cannot be written

Bit 14 **CAL_FLAG1**: DAC channel1 calibration offset status

This bit is set and cleared by hardware

0: calibration trimming value is lower than the offset correction value

1: calibration trimming value is equal or greater than the offset correction value

Bit 13 **DMAUDR1**: DAC channel1 DMA underrun flag

This bit is set by hardware and cleared by software (by writing it to 1).

0: No DMA underrun error condition occurred for DAC channel1

1: DMA underrun error condition occurred for DAC channel1 (the currently selected trigger is driving DAC channel1 conversion at a frequency higher than the DMA service capability rate)

Bit 12 **DORSTAT1**: DAC channel1 output register status bit

This bit is set and cleared by hardware. It is applicable only when the DAC operates in double data mode.

0: DOR[11:0] is used actual DAC output

1: DORB[11:0] is used actual DAC output

Bit 11 **DAC1RDY**: DAC channel1 ready status bit

This bit is set and cleared by hardware.

0: DAC channel1 is not yet ready to accept the trigger nor output data

1: DAC channel1 is ready to accept the trigger or output data

Bits 10:0 Reserved, must be kept at reset value.

32.7.15 DAC calibration control register (DAC_CCR)

Address offset: 0x38

Reset value: 0x00XX 00XX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTRIM2[4:0]				
											rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTRIM1[4:0]				
											rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:16 **OTRIM2[4:0]**: DAC channel2 offset trimming value

These bits are available only on dual-channel DACs. Refer to *Section 32.3: DAC implementation*.

Bits 15:5 Reserved, must be kept at reset value.

Bits 4:0 **OTRIM1[4:0]**: DAC channel1 offset trimming value

32.7.16 DAC mode control register (DAC_MCR)

Address offset: 0x3C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	SINFORMAT2	DMADOUBLE2	Res.	Res.	Res.	Res.	Res.	MODE2[2:0]		
						rw	rw						rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HFSEL[1:0]		Res.	Res.	Res.	Res.	SINFORMAT1	DMADOUBLE1	Res.	Res.	Res.	Res.	Res.	MODE1[2:0]		
rw	rw					rw	rw						rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **SINFORMAT2**: Enable signed format for DAC channel2

This bit is set and cleared by software.

0: Input data is in unsigned format

1: Input data is in signed format (2's complement). The MSB bit represents the sign.

Note: This bit is available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bit 24 **DMADOUBLE2**: DAC channel2 DMA double data mode

This bit is set and cleared by software.

0: DMA normal mode selected

1: DMA double data mode selected

Note: This bit is available only on dual-channel DACs. Refer to Section 32.3: DAC implementation.

Bits 23:19 Reserved, must be kept at reset value.

Bits 18:16 **MODE2[2:0]:** DAC channel2 mode

These bits can be written only when the DAC is disabled and not in the calibration mode (when bit EN2 = 0 and bit CEN2 = 0 in the DAC_CR register). If EN2 = 1 or CEN2 = 1 the write operation is ignored.

They can be set and cleared by software to select the DAC channel2 mode:

– DAC channel2 in normal mode

000: DAC channel2 is connected to external pin with Buffer enabled

001: DAC channel2 is connected to external pin and to on chip peripherals with buffer enabled

010: DAC channel2 is connected to external pin with buffer disabled

011: DAC channel2 is connected to on chip peripherals with Buffer disabled

– DAC channel2 in sample and hold mode

100: DAC channel2 is connected to external pin with Buffer enabled

101: DAC channel2 is connected to external pin and to on chip peripherals with Buffer enabled

110: DAC channel2 is connected to external pin and to on chip peripherals with Buffer disabled

111: DAC channel2 is connected to on chip peripherals with Buffer disabled

Note: This register can be modified only when EN2 = 0.

Refer to Section 32.3: DAC implementation for the availability of DAC channel2.

Bits 15:14 **HFSEL[1:0]**: High frequency interface mode selection
00: High frequency interface mode disabled
01: High frequency interface mode enabled for AHB clock frequency > 80 MHz
10: High frequency interface mode enabled for AHB clock frequency >160 MHz
11: Reserved

Bits 13:10 Reserved, must be kept at reset value.

Bit 9 **SINFORMAT1**: Enable signed format for DAC channel1
This bit is set and cleared by software.
0: Input data is in unsigned format
1: Input data is in signed format (2's complement). The MSB bit represents the sign.

Bit 8 **DMADOUBLE1**: DAC channel1 DMA double data mode
This bit is set and cleared by software.
0: DMA normal mode selected
1: DMA double data mode selected

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **MODE1[2:0]:** DAC channel1 mode
These bits can be written only when the DAC is disabled and not in the calibration mode (when bit EN1 = 0 and bit CEN1 = 0 in the DAC_CR register). If EN1 = 1 or CEN1 = 1 the write operation is ignored.
They can be set and cleared by software to select the DAC channel1 mode:
– DAC channel1 in normal mode
000: DAC channel1 is connected to external pin with Buffer enabled
001: DAC channel1 is connected to external pin and to on chip peripherals with Buffer enabled
010: DAC channel1 is connected to external pin with Buffer disabled
011: DAC channel1 is connected to on chip peripherals with Buffer disabled
– DAC channel1 in sample & hold mode
100: DAC channel1 is connected to external pin with Buffer enabled
101: DAC channel1 is connected to external pin and to on chip peripherals with Buffer enabled
110: DAC channel1 is connected to external pin and to on chip peripherals with Buffer disabled
111: DAC channel1 is connected to on chip peripherals with Buffer disabled
Note: This register can be modified only when EN1 = 0.

32.7.17 DAC channel1 sample and hold sample time register (DAC_SHSR1)

Address offset: 0x40

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	TSAMPLE1[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:0 **TSAMPLE1[9:0]:** DAC channel1 sample time (only valid in sample and hold mode)

These bits can be written when the DAC channel1 is disabled or also during normal operation. in the latter case, the write can be done only when BWST1 of DAC_SR register is low, If BWST1 = 1, the write operation is ignored.

*Note: It represents the number of LSI/LSE clocks to perform a sample phase. Sampling time = (*TSAMPLE1[9:0] + 1) x *LSI/LSE clock period.*

32.7.18 DAC channel2 sample and hold sample time register (DAC_SHSR2)

This register is available only on dual-channel DACs. Refer to *Section 32.3: DAC implementation*.

Address offset: 0x44

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	TSAMPLE2[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:0 **TSAMPLE2[9:0]:** DAC channel2 sample time (only valid in sample and hold mode)
These bits can be written when the DAC channel2 is disabled or also during normal operation. in the latter case, the write can be done only when BWST2 of DAC_SR register is low, if BWST2 = 1, the write operation is ignored.

*Note: It represents the number of LSI/LSE clocks to perform a sample phase. Sampling time = (*TSAMPLE1[9:0] + 1) x *LSI/LSE clock period.*

32.7.19 DAC sample and hold time register (DAC_SHHR)

Address offset: 0x48

Reset value: 0x0001 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	THOLD2[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	THOLD1[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:16 **THOLD2[9:0]:** DAC channel2 hold time (only valid in sample and hold mode).
Hold time = (THOLD[9:0]) x LSI/LSE clock period
These bits are available only on dual-channel DACs. Refer to *Section 32.3: DAC implementation*.
Note: This register can be modified only when EN2 = 0.

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:0 **THOLD1[9:0]:** DAC channel1 hold time (only valid in sample and hold mode)
Hold time = (THOLD[9:0]) x LSI/LSE clock period
Note: This register can be modified only when EN1 = 0.

Note: These bits can be written only when the DAC channel is disabled and in normal operating mode (when bit ENx = 0 and bit CENx = 0 in the DAC_CR register). If ENx = 1 or CENx = 1 the write operation is ignored.

32.7.20 DAC sample and hold refresh time register (DAC_SHRR)

Address offset: 0x4C

Reset value: 0x0001 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TREFRESH2[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TREFRESH1[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **TREFRESH2[7:0]:** DAC channel2 refresh time (only valid in sample and hold mode)
Refresh time = (TREFRESH[7:0]) x LSI/LSE clock period
These bits are available only on dual-channel DACs. Refer to *Section 32.3: DAC implementation*.
Note: This register can be modified only when EN2 = 0.

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **TREFRESH1[7:0]:** DAC channel1 refresh time (only valid in sample and hold mode)
Refresh time = (TREFRESH[7:0]) x LSI/LSE clock period
Note: This register can be modified only when EN1 = 0.

Note: These bits can be written only when the DAC channel is disabled and in normal operating mode (when bit ENx = 0 and bit CENx = 0 in the DAC_CR register). If ENx = 1 or CENx = 1 the write operation is ignored.

32.7.21 DAC register map

Table 321 summarizes the DAC registers.

Table 321. DAC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	DAC_CR	Res.	CEN2	DMAUDRIE2	DMAEN2	MAMP2[3:0]				WAVE2[2:0]		TSEL2[3:1]			TSEL2[0]	TEN2	EN2	Res.	CEN1	DMAUDRIE1	DMAEN1	MAMP1[3:0]				WAVE1[1:0]		TSEL1[3:1]			TSEL1[0]	TEN1	EN1
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	DAC_SWTRGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWTRIG2	SWTRIG1
	Reset value																															0	0
0x08	DAC_DHR12R1	Res.	Res.	Res.	Res.	DACC1DHRB[11:0]												Res.	Res.	Res.	Res.	DACC1DHR[11:0]											
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x0C	DAC_DHR12L1	DACC1DHRB[11:0]												Res.	Res.	Res.	Res.	DACC1DHR[11:0]												Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0				
0x10	DAC_DHR8R1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC1DHRB[7:0]								DACC1DHR[7:0]							
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	DAC_DHR12R2	Res.	Res.	Res.	Res.	DACC2DHRB[11:0]												Res.	Res.	Res.	Res.	DACC2DHR[11:0]											
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x18	DAC_DHR12L2	DACC2DHRB[11:0]												Res.	Res.	Res.	Res.	DACC2DHR[11:0]												Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0				
0x1C	DAC_DHR8R2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC2DHRB[7:0]								DACC2DHR[7:0]							
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	DAC_DHR12RD	Res.	Res.	Res.	Res.	DACC2DHR[11:0]												Res.	Res.	Res.	Res.	DACC1DHR[11:0]											
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x24	DAC_DHR12LD	DACC2DHR[11:0]												Res.	Res.	Res.	Res.	DACC1DHR[11:0]												Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0				
0x28	DAC_DHR8RD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC2DHR[7:0]								DACC1DHR[7:0]							
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	DAC_DOR1	Res.	Res.	Res.	Res.	DACC1DORB[11:0]												Res.	Res.	Res.	Res.	DACC1DOR[11:0]											
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x30	DAC_DOR2	Res.	Res.	Res.	Res.	DACC2DORB[11:0]												Res.	Res.	Res.	Res.	DACC2DOR[11:0]											
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0

Table 321. DAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x34	DAC_SR	BWST2	CAL_FLAG2	DMAUDR2	DORSTAT2	DAC2RDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BWST1	CAL_FLAG1	DMAUDR1	DORSTAT1	DAC1RDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0												0	0	0	0	0											
0x38	DAC_CCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTRIM2[4]	OTRIM2[3]	OTRIM2[2]	OTRIM2[1]	OTRIM2[0]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTRIM1[4]	OTRIM1[3]	OTRIM1[2]	OTRIM1[1]	OTRIM1[0]
	Reset value												X	X	X	X	X												X	X	X	X	X
0x3C	DAC_MCR	Res.	Res.	Res.	Res.	Res.	Res.	SINFORMAT2	DMADOUBLE2	Res.	Res.	Res.	Res.	Res.	MODE2 [2:0]			HFSEL[1]	HFSEL[0]	Res.	Res.	Res.	Res.	SINFORMAT1	DMADOUBLE1	Res.	Res.	Res.	Res.	Res.	MODE1 [2:0]		
	Reset value							0	0						0	0	0	0	0					0	0						0	0	0
0x40	DAC_ SHSR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSAMPLE1[9:0]									
	Reset value																							0	0	0	0	0	0	0	0	0	0
0x44	DAC_ SHSR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSAMPLE2[9:0]									
	Reset value																							0	0	0	0	0	0	0	0	0	0
0x48	DAC_ SHHR	Res.	Res.	Res.	Res.	Res.	Res.	THOLD2[9:0]										Res.	Res.	Res.	Res.	Res.	Res.	THOLD1[9:0]									
	Reset value							0	0	0	0	0	0	0	0	0	1							0	0	0	0	0	0	0	0	0	1
0x4C	DAC_ SHRR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TREFRESH2[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TREFRESH1[7:0]							
	Reset value									0	0	0	0	0	0	0	1									0	0	0	0	0	0	0	1
0x50-0x54	Reserved																																
0x58-0x60	Reserved																																
0x64-0x68	Reserved																																

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

33 Voltage reference buffer (VREFBUF)

33.1 VREFBUF introduction

The devices embed a voltage reference buffer which can be used as voltage reference for the on-chip ADCs, and also as voltage reference for external components through the VREF+ pin.

33.2 VREFBUF implementation

The table below describes the VREFBUF voltages typical values:

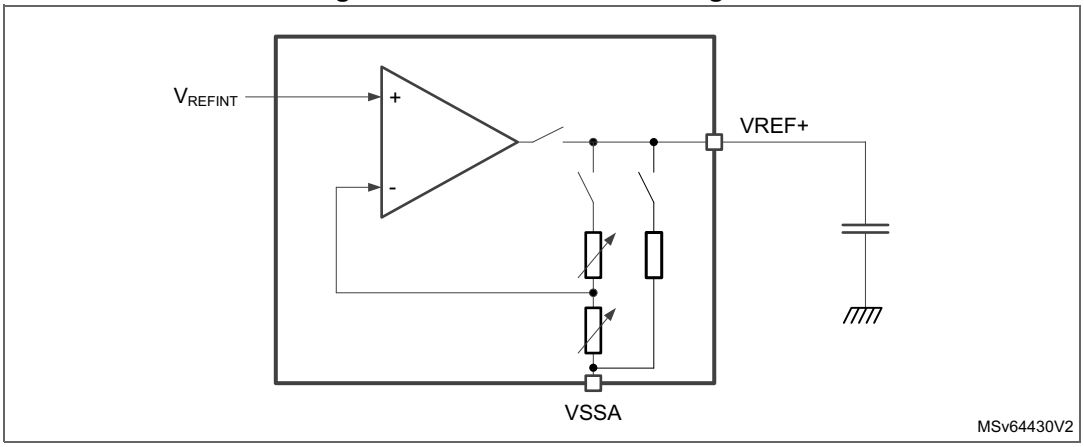
Table 322. VREFBUF typical values

Symbol	Value
VREFBUF0	2.5 V
VREFBUF1	2.048 V
VREFBUF2	1.8 V

Note: Refer to the product datasheet for more details.

33.3 VREFBUF functional description

Figure 325. VREFBUF block diagram



The internal voltage reference buffer is an operational amplifier, with programmable gain. The amplifier input is connected to the internal voltage reference V_{REFINT}. The VREFBUF supports three voltages, which are configured with VRS bits in the VREFBUF_CSR register:

- VRS = 000: VREFBUF0 voltage selected
- VRS = 001: VREFBUF1 voltage selected
- VRS = 010: VREFBUF2 voltage selected

The internal voltage reference can be configured in four different modes depending on ENVR and HIZ bits configuration. These modes are provided in the table below:

Table 323. VREF buffer modes

ENVR	HIZ	VREF buffer configuration
0	0	VREFBUF buffer off mode: – V_{REF+} pin pulled-down to V_{SSA}
0	1	External voltage reference mode (default value): – VREFBUF buffer off – V_{REF+} pin input mode
1	0	Internal voltage reference mode: – VREFBUF buffer on – V_{REF+} pin connected to VREFBUF buffer output
1	1	Hold mode: – VREF is enable without output buffer, VREF+ pin voltage is hold with the external capacitor – VRR detection disabled and VRR bit keeps last state

After enabling the VREFBUF by setting ENVR bit and clearing HIZ bit in the VREFBUF_CSR register, the user must wait until VRR bit is set, meaning that the voltage reference output has reached its expected value.

33.4 VREFBUF trimming

The VREFBUF output voltage is factory-calibrated by ST. At reset, and each time the VRS setting is changed, the calibration data is automatically loaded to the TRIM register.

Optionally user can trim the output voltage by changing the TRIM register bits directly. In this case, the VRS setting has no more effect on the TRIM register until the device is reset.

33.5 VREFBUF registers

33.5.1 VREFBUF control and status register (VREFBUF_CSR)

Address offset: 0x00

Reset value: 0x0000 0002

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VRS[2:0]			VRR	Res.	HIZ	ENVR
									rw	rw	rw	r		rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bits 6:4 **VRS[2:0]**: Voltage reference scale

These bits select the value generated by the voltage reference buffer.

VRS = 000: VREFBUF0 voltage selected.

VRS = 001: VREFBUF1 voltage selected.

VRS = 010: VREFBUF2 voltage selected.

Others: Reserved

Note: Refer to the product datasheet for each VREFBUFx voltage setting value.
The software can program this bitfield only when the VREFBUF is disabled (ENVR=0).

Bit 3 **VRR:** Voltage reference buffer ready

0: the voltage reference buffer output is not ready.

1: the voltage reference buffer output reached the requested level.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **HIZ:** High impedance mode

This bit controls the analog switch to connect or not the V_{REF+} pin.

0: V_{REF+} pin is internally connected to the voltage reference buffer output.

1: V_{REF+} pin is high impedance.

Refer to *Table 323: VREF buffer modes* for the mode descriptions depending on ENVR bit configuration.

Bit 0 **ENVR:** Voltage reference buffer mode enable

This bit is used to enable the voltage reference buffer mode.

0: Internal voltage reference mode disable (external voltage reference mode).

1: Internal voltage reference mode (reference buffer enable or hold mode) enable.

33.5.2 VREFBUF calibration control register (VREFBUF_CCR)

Address offset: 0x04

Reset value: 0x0000 00XX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIM[5:0]					
										rw	rw	rw	rw	rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:0 **TRIM[5:0]**: Trimming code

The TRIM code is a 6-bit unsigned data (minimum 000000, maximum 111111) that is set and updated according the mechanism described below.

Reset:

TRIM[5:0] is automatically initialized with the VRS = 0 trimming value stored in the flash memory during the production test.

VRS change:

TRIM[5:0] is automatically initialized with the trimming value (corresponding to VRS setting) stored in the flash memory during the production test.

Write in TRIM[5:0]:

User can modify the TRIM[5:0] with an arbitrary value. This is permanently disabling the control of the trimming value with VRS (until the device is reset).

Note: If the user application performs the trimming, the trimming code must start from 000000 to 111111 in ascending order.

33.5.3 VREFBUF register map

The following table gives the VREFBUF register map and the reset values.

Table 324. VREFBUF register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	VREFBUF_CSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VRS[2:0]			VRR	Res.	HIZ	ENVR
	Reset value																										0	0	0	0		1	0
0x04	VREFBUF_CCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIM[5:0]					
	Reset value																											x	x	x	x	x	x

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

34 Operational amplifiers (OPAMP)

34.1 OPAMP introduction

The devices embed one operational amplifier with two inputs and one output. The three I/Os can be connected to the external pins, thus enabling any type of external interconnections. The operational amplifiers can be configured internally in three possible ways:

- As a follower
- As an amplifier with a noninverting gain ranging from 2 to 16
- As an amplifier with an inverting gain ranging from -1 to -15

Refer to *Section 34.3.3: Signal routing* for detailed information on OPAMP input and output connection to internal peripherals.

34.2 OPAMP main features

- Rail-to-rail input voltage range
- Low input offset voltage (1.5 mV after calibration, 10 mV with factory calibration)
- 7 MHz gain bandwidth
- High-speed mode to achieve a better slew rate

Note: Refer to the product datasheet for detailed OPAMP characteristics.

34.3 OPAMP functional description

The OPAMP has several modes.

Each OPAMP can be individually enabled, when disabled the output is high-impedance.

When enabled, it can be in calibration mode, all input and output of the OPAMP are then disconnected, or in functional mode.

There are two functional modes, the high-speed mode and the normal mode. In functional mode, the inputs and outputs of the OPAMP are connected as described in *Section 34.3.3: Signal routing*.

34.3.1 OPAMP reset and clocks

The operational amplifier clock is necessary for accessing the registers. When the application does not need to have a read or write access to those registers, the clock can be switched off using the peripheral clock enable register. See OPAMPEN bit in *Section 11.8.29: RCC APB1 peripheral clock register (RCC_APB1LENR)*.

The bit OPAEN enables and disables the OPAMP operation. The OPAMP registers configurations should be changed before enabling the OPAEN bit to avoid spurious effects on the output.

When the output of the operational amplifier is no more needed, the operational amplifier can be disabled to save power. All the configurations previously set (including the calibration) are maintained while OPAMP is disabled.

34.3.2 Initial configuration

The default configuration of the operational amplifier is a functional mode where the three input/outputs are connected to external pins. In the default mode, the operational amplifier uses the factory trimming values for its offset calibration. See the electrical characteristics section of the datasheet for factory trimming conditions, usually the temperature is 30 °C and the voltage is 3 V. The trimming values can be adjusted. See *Section 34.3.5: Calibration* for changing the trimming values. The bit OPAHSM can be set to switch the operational amplifier to high-speed mode for a better slew rate. Both normal and high-speed mode characteristics are defined in the *section: Electrical characteristics* of the datasheet

As soon as the OPAEN bit in the OPAMPx_CSR register is set, the operational amplifier is functional. The two input pins and the output pin are connected as defined in *Section 34.3.3: Signal routing* and the default connection settings can be changed.

Note: The inputs and output pins must be configured in analog mode (default state) in the corresponding GPIOx_MODER register.

34.3.3 Signal routing

The OPAMPx_CSR register determines the routing for the operational amplifier pins.

The connections of the operational amplifier (OPAMP1) are described in the table below.

Table 325. Possible connections for OPAMP

Signal	Pin	Internal	comment
OPAMP1_VINM	PE13(INM0) PA4(INM1)	ADC3_INP7 ADC1_INP18 ADC2_INP18 OPAMP1_VOUT or PGA	The bits PGA_GAIN and VM_SEL control this pin. ADC controls the ADC input.
OPAMP1_VINP	PE11(INP0) PA5(INP2) PE12(INP3)	dac1_out1 (INP1) ADC3_INP5 ADC3_INP18 ADC1_INP19 ADC1_INN18 ADC2_INP19 ADC2_INN18 DAC1_OUT2 ADC3_INP6	The bit VP_SEL controls this pin. ADC controls the ADC input.
OPAMP1_VOUT	PB1	ADC1_INP5 ADC2_INP5 ADC3_INP10	The pin is connected when the OPAMP is enabled. The ADC input is controlled by ADC.

34.3.4 OPAMP modes

The operational amplifier inputs and outputs are all accessible on terminals. The amplifiers can be used in multiple configuration environments:

- Standalone mode (external gain setting mode)
- Follower configuration mode
- PGA modes

Note: The amplifier output pin is directly connected to the output pad to minimize the output impedance. When the amplifier is enabled, it cannot be used as a general-purpose I/O, even if the amplifier is configured as a PGA and only connected to the internal channel.

The impedance of the signal must be maintained below a level that avoids the input leakage to create significant artifacts (due to a resistive drop in the source). Refer to the electrical characteristics section in the datasheet for further details.

Standalone mode (external gain setting mode)

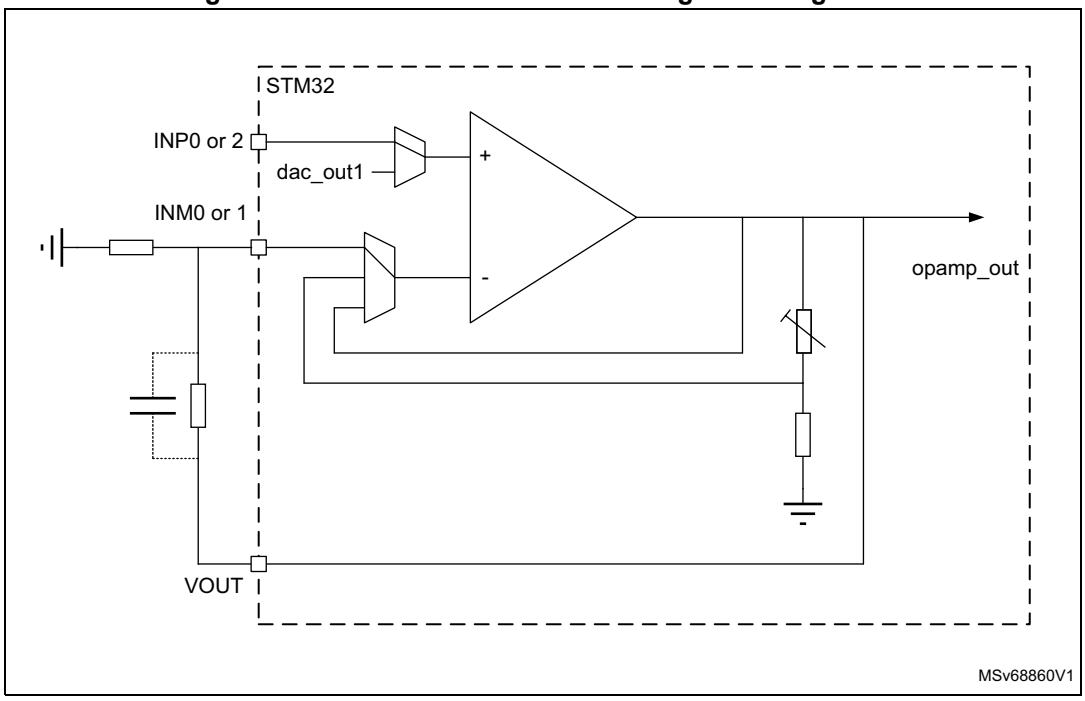
The procedure to use the OPAMP in standalone mode is presented below.

Starting from the default value of OPAMPx_CSR, and the default state of GPIOx_MODER, as soon as the OPAEN bit is set, the two input pins and the output pin are connected to the operational amplifier.

This default configuration uses the factory trimming values and operates in normal mode (highest performance). The behavior of the OPAMP can be changed as follows:

- OPAHSM can be set to “operational amplifier high speed” mode to have a high slew rate.
- USERTRIM can be set to modify the trimming values for input offsets.

Figure 326. Standalone mode: external gain setting mode



Follower configuration mode

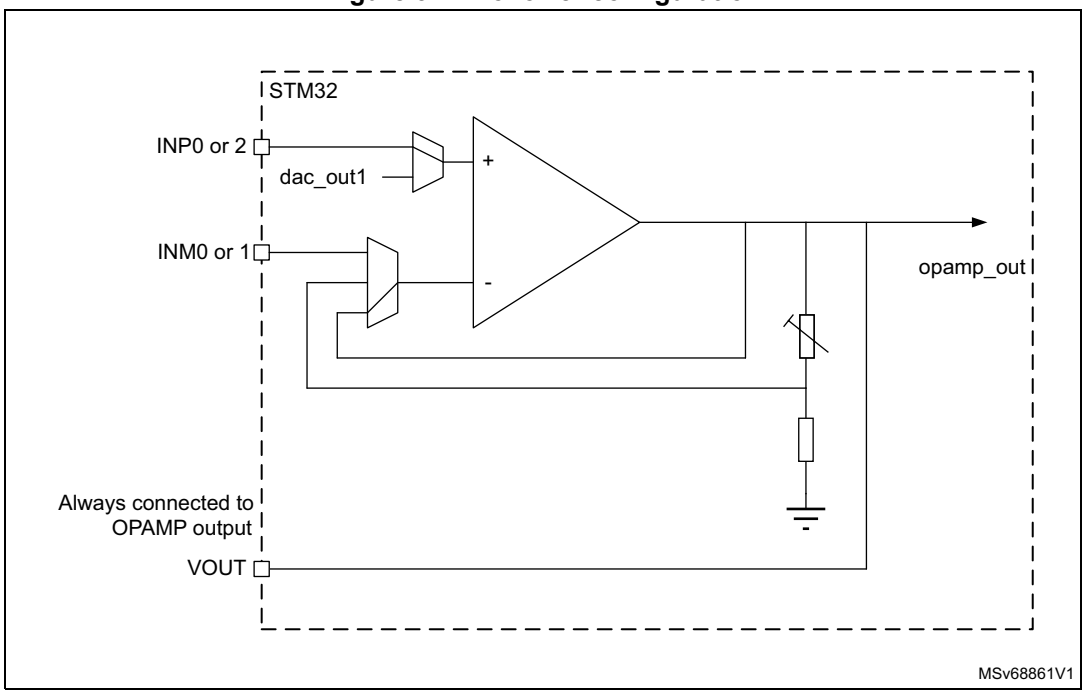
The procedure to use the OPAMP in follower mode is presented below.

- Configure VM_SEL bits as “opamp_out connected to OPAMPx_VINM input”, 11
- Configure VP_SEL bits as “GPIO connected to OPAMPx_VINP”, 00 or 10
- As soon as the OPAEN bit is set, the voltage on the none-inverting input is buffered to pin OPAMP1_VOUT.

Note: The pin corresponding to OPAMPx_VINM is free for another usage.

The signal on the OPAMP1 output is also seen as an ADC input. As a consequence, the OPAMP configured in follower mode can be used to perform impedance adaptation on input signals before feeding them to the ADC input, assuming the input signal frequency is compatible with the operational amplifier gain bandwidth specification.

Figure 327. Follower configuration



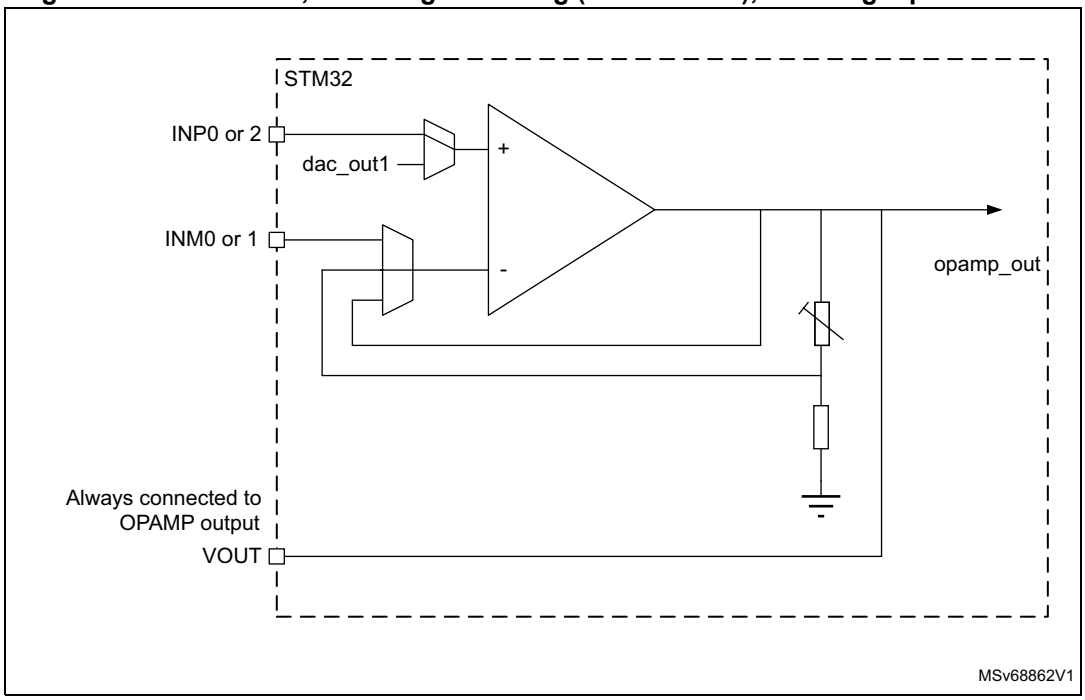
Programmable gain amplifier mode

The procedure to use the OPAMP as a programmable gain amplifier is presented below.

1. Configure VM_SEL bits as “Feedback resistor is connected to OPAMPx_VINM input”, 10
2. Configure PGA_GAIN bits as “internal gain 2, 4, 8 or 16”, 0000 to 0011
3. Configure VP_SEL bits as “GPIO connected to OPAMPx_VINP”, 00 or 10
   As soon as the OPAEN bit is set, the selected gain amplifies the none-inverting input voltage, and it is visible on pin OPAMPx_VOUT.

Note: To avoid saturation, the input voltage should stay below V_{DDA} divided by the selected gain.

Figure 328. PGA mode, internal gain setting (x2/x4/x8/x16), inverting input not used

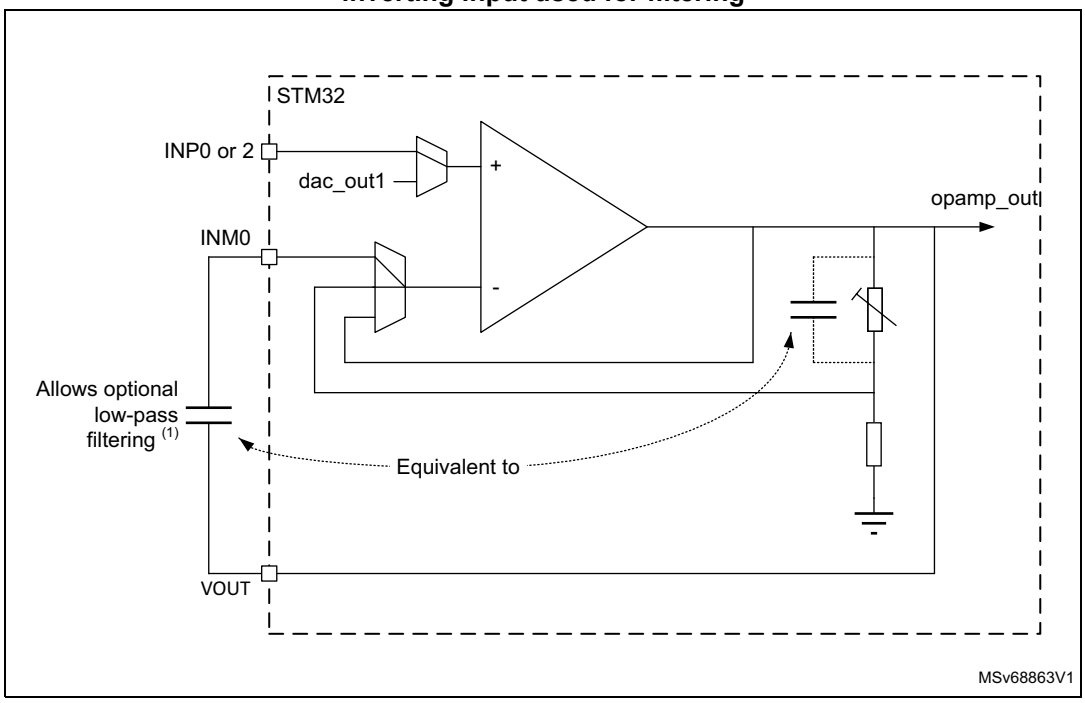


Programmable gain amplifier mode with external filtering

The procedure to use the OPAMP to amplify the amplitude of an input signal, with an external filtering, is presented below.

1. Configure VM_SEL bits as “Feedback resistor is connected to OPAMPx_VINM input”, 10
2. Configure PGA_GAIN bits as “internal gain 2, 4, 8 or 16 with filtering on INM0”, 0100 to 0111
3. Configure VP_SEL bits as “GPIO connected to OPAMPx_VINP”.
   Any external connection on INM can be used in parallel with the internal PGA. For example, a capacitor can be connected between opamp_out and INM for a filtering purpose. Refer to the datasheet for the value of resistors used in the PGA resistor network.

Figure 329. PGA mode, internal gain setting (x2/x4/x8/x16), inverting input used for filtering



1. The gain depends on the cutoff frequency.

Programmable gain amplifier, noninverting with external bias or inverting mode

The procedure to use the OPAMP to amplify the amplitude of an input signal with a bias voltage for noninverting mode or inverting mode.

1. Configure VM_SEL bits as “Feedback resistor is connected to OPAMPx_VINM input”, 10
2. Configure PGA_GAIN bits as “Inverting gain=-1,-3,-7,-15/ noninverting gain =2,4,8,16 with INM0”, 1000 to 1011
3. Configure VP_SEL bits as “GPIO connected to OPAMPx_VINP”.

Figure 330. PGA mode, noninverting gain setting (x2/x4/x8/x16) or inverting gain setting (x-1/x-3/x-7/x-15)

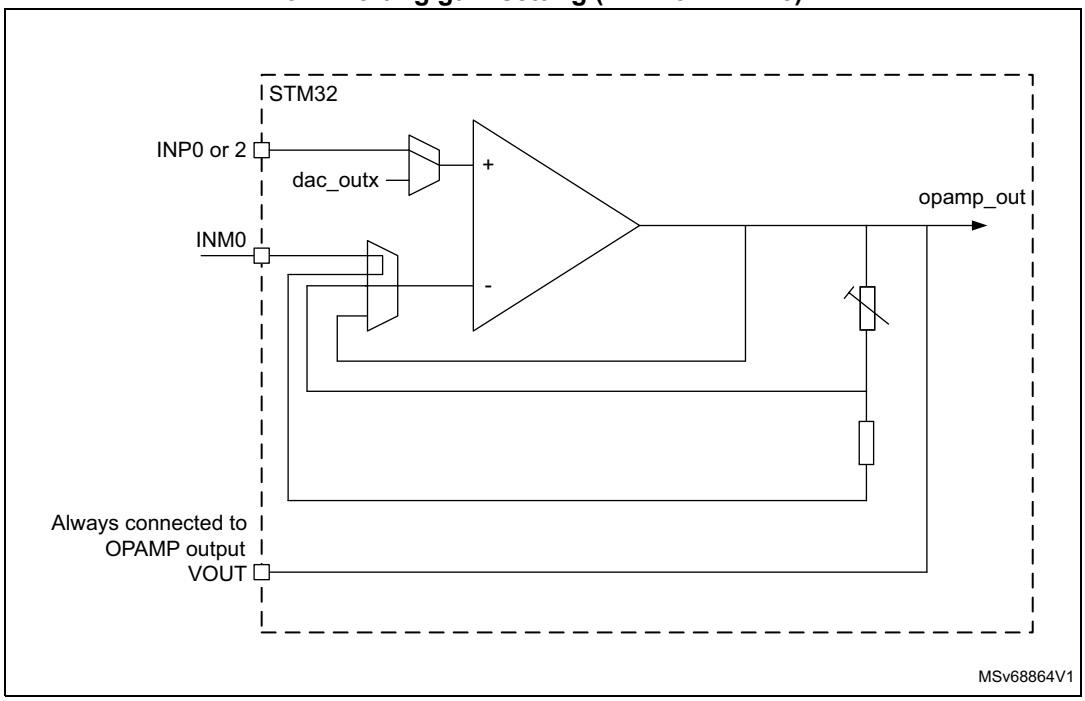
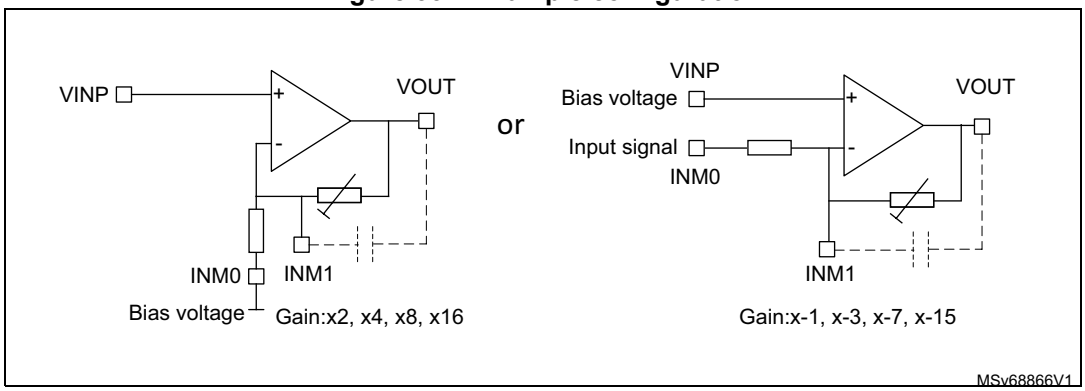


Figure 331. Example configuration



Programmable gain amplifier, noninverting with external bias or inverting mode with filtering

The procedure to use the OPAMP to amplify the amplitude of an input signal with bias voltage for noninverting mode or inverting mode with filtering

1. Configure VM_SEL bits as “Feedback resistor is connected to OPAMPx_VINM input”, 10
2. Configure PGA_GAIN bits as “Inverting gain=-1,-3,-7,-15/ noninverting gain =2,4,8,16 with INM0, INM1 node for filtering”, 1100 to 1111
3. Configure VP_SEL bits as “GPIO connected to OPAMPx_VINP”.
   Any external connection on VM1 can be used in parallel with the internal PGA. For example, a capacitor can be connected between opamp_out and VM1 for filtering purposes. See the datasheet for the value of resistors used in the PGA resistor network.

Figure 332. PGA mode, noninverting gain setting (x2/x4/x8/x16) or inverting gain setting (x-1/x-3/x-7/x-15) with filtering

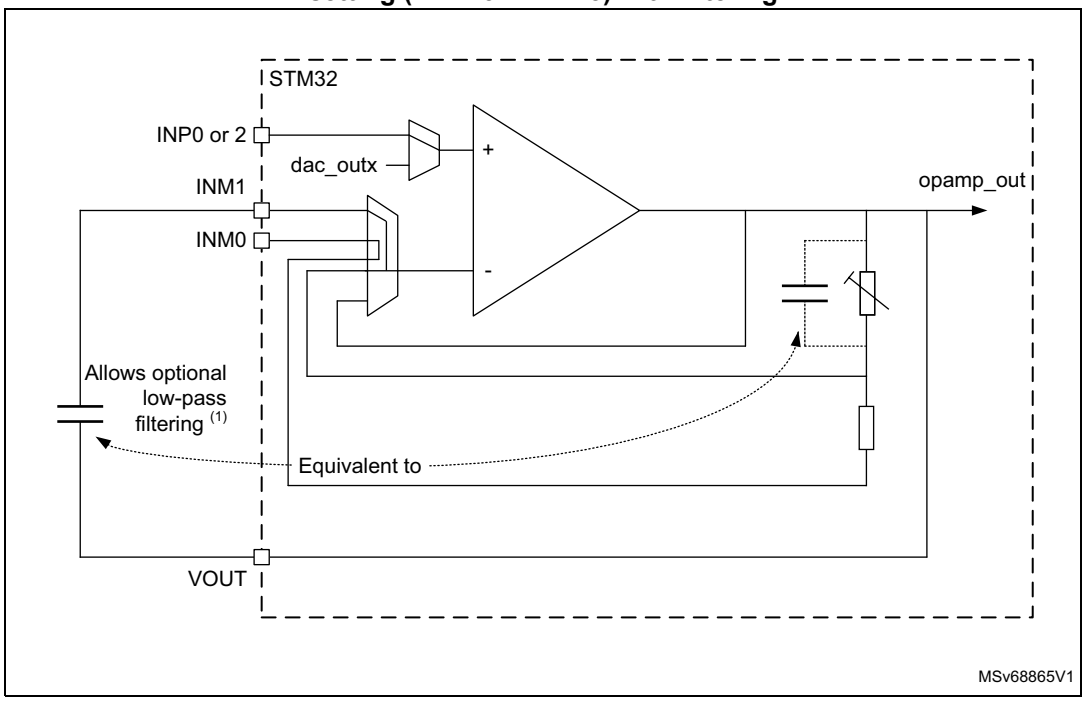
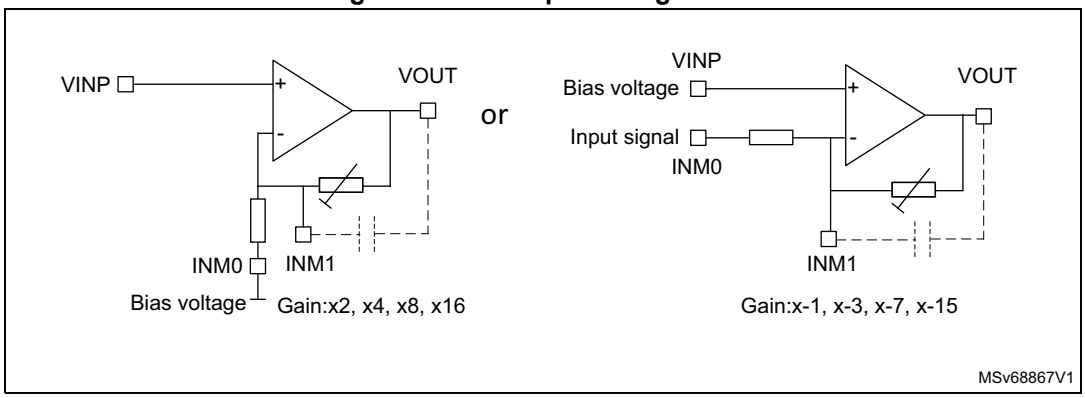


Figure 333. Example configuration



34.3.5 Calibration

The OPAMP interface continuously sends trimmed offset values to the operational amplifiers. At startup, the trimming values are initialized with the preset ‘factory’ trimming value.

The user can trim each operational amplifier. Specific registers allow the user to have different trimming values for normal mode and for high-speed mode.

The aim of the calibration is to cancel as much as possible the OPAMP inputs offset voltage. The calibration circuitry allows the user to reduce the input-offset voltage to less than ±1.5 mV within stable voltage and temperature conditions.

For each operational amplifier and each mode two trimming values need to be trimmed, one for N differential pair and one for P differential pair.

There are two registers for trimming the offsets for each operational amplifier, one for normal mode (OPAMPx_OTR) and one high-speed mode (OPAMPx_HSOTR). Each register is composed of five bits for P differential pair trimming and five bits for N differential pair trimming. These are the ‘user’ values.

The user is able to switch from ‘factory’ values to ‘user’ trimmed values using the USERTRIM bit in the OPAMPx_CSR register. This bit is reset at startup and so the ‘factory’ value is applied by default to the OPAMP option registers.

The user is liable to change the trimming values in calibration or in functional mode.

The offset trimming registers are typically configured after the calibration operation. It is initialized by setting the CALON bit to 1. When CALON = 1 the inputs of the operational amplifier are disconnected from the functional environment.

- Setting CALSEL to 01 initializes the offset calibration for the P differential pair (low voltage reference used).
- Resetting CALSEL to 11 initializes the offset calibration for the N differential pair (high-voltage reference used).

When CALON = 1, the bit CALOUT reflects the influence of the trimming value selected by CALSEL and OPAHSM. The software should increment the TRIMOFFSETN bits in the OPAMP control register from 0x00 to the first value that causes the CALOUT bit to change from 1 to 0 in the OPAMP register. If the CALOUT bit is reset, the offset is calibrated correctly and the corresponding trimming value must be stored. The CALOUT flag needs up to 1 ms after the trimming value is changed to become steady (see $t_{OFFTRIM}$max delay specification in the electrical characteristics section of the datasheet).

Note: The closer the trimming value is to the optimum trimming value, the longer it takes to stabilize. The maximum stabilization time remains below 1 ms in any case.

Table 326. Operating modes and calibration

Mode	Control bits				Output	
	OPAEN	OPAHSM	CALON	CALSEL	V_{OUT}	CALOUT flag
Normal operating mode	1	0	0	X	analog	0
High-speed mode	1	1	0	X	analog	0
Power down	0	X	X	X	Z	0
Offset calibration N difference for normal mode	1	0	1	11	analog	X
Offset calibration P difference for normal mode	1	0	1	01	analog	X
Offset calibration N difference for high-speed mode	1	1	1	11	analog	X
Offset calibration P difference for high-speed mode	1	1	1	01	analog	X

Calibration procedure

Here are the steps to perform a full calibration of either one of the operational amplifiers:

1. Set the OPAEN bit in OPAMPx_CSR to 1 to enable the operational amplifier.
2. Set the USERTRIM bit in the OPAMPx_CSR register to 1.
3. Choose a calibration mode (refer to *Table 326: Operating modes and calibration*). The steps 3 to 4 must be repeated four times. For the first iteration, select the following:
   – Normal mode and N differential pair

   The above calibration mode corresponds to OPAHSM=0 and CALSEL=11 in the OPAMPx_CSR register.
4. Increment TRIMOFFSETN[4:0] in OPAMPx_OTR starting from 00000b until CALOUT changes to 0 in OPAMPx_CSR.

Note: Between the write to the OPAMPx_OTR register and the read of the CALOUT value, make sure to wait for the $t_{OFFTRIM}$max delay specified in the electrical characteristics section of the datasheet, to get the correct CALOUT value.

Repeat steps 3 to 4 for:

- Normal_mode and P differential pair, CALSEL=01
- High-speed mode and N differential pair
- High-speed mode and P differential pair

If a mode is not used, it is not necessary to perform the corresponding calibration.

Note: During the whole calibration phase the external connection of the operational amplifier output must not pull up or down currents higher than 500 µA.

34.4 OPAMP low-power modes

Table 327. Effect of low-power modes on the OPAMP

Mode	Description
Sleep	No effect.
Stop	No effect, OPAMP registers content is kept.
Standby	The OPAMP registers are powered down and must be reinitialized after exiting Standby.

34.5 OPAMP PGA gain

When OPAMP is configured as PGA mode, it can select the gain of x2, x4, x8, x16 for noninverting mode and x-1, x-3, x-7, x-15 for inverting mode.

When OPAMP is configured as noninverting mode, the gain error is specified in the product datasheet. When it is configured as inverting mode, the gain factor is defined not only on the on-chip feedback resistor but also on the signal source output impedance. If the signal source output impedance is not negligible compare to the input feedback resistance of PGA, it creates the gain error. Refer to the PGA resistance value in the product datasheet.

34.6 OPAMP registers

The registers of this peripheral can only be accessed by-word (32-bit).

34.6.1 OPAMP1 control/status register (OPAMP1_CSR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	CAL OUT	TST REF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	USER TRIM	PGA_GAIN[3:2]	
	r	rw											rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PGA_GAIN[1:0]		CALSEL[1:0]		CALON	Res.	Res.	OPA HSM	Res.	VM_SEL[1:0]		Res.	VP_SEL[1:0]		FORCE _VP	OPAEN
rw	rw	rw	rw	rw			rw		rw	rw		rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **CALOUT:** Operational amplifier calibration output
OPAMP output status flag. During the calibration mode, OPAMP is used as comparator.
0: Noninverting < inverting
1: Noninverting > inverting

Bit 29 **TSTREF:** OPAMP calibration reference voltage output control (reserved for test)
0: INTVREF of OPAMP is not output
1: INTVREF of OPAMP is output

Bits 28:19 Reserved, must be kept at reset value.

Bit 18 **USERTRIM:** User trimming enable
This bit allows to switch from ‘factory’ AOP offset trimmed values to ‘user’ AOP offset trimmed values
This bit is active for both mode normal and high-power.
0: ‘factory’ trim code used
1: ‘user’ trim code used

Bits 17:14 **PGA_GAIN[3:0]:** Programmable gain amplifier gain setting
0000: Noninverting internal gain 2, VREF-referenced
0001: Noninverting internal gain 4, VREF-referenced
0010: Noninverting internal gain 8, VREF-referenced
0011: Noninverting internal gain 16, VREF-referenced
0100: Noninverting internal gain 2 with filtering on INM0, VREF-referenced
0101: Noninverting internal gain 4 with filtering on INM0, VREF-referenced
0110: Noninverting internal gain 8 with filtering on INM0, VREF-referenced
0111: Noninverting internal gain 16 with filtering on INM0, VREF-referenced
1000: Inverting gain = -1/ Noninverting gain =2 with INM0 node for input or bias
1001: Inverting gain = -3/ Noninverting gain =4 with INM0 node for input or bias
1010: Inverting gain = -7/ Noninverting gain =8 with INM0 node for input or bias
1011: Inverting gain = -15/ Noninverting gain =16 with INM0 node for input or bias
1100: Inverting gain = -1/ Noninverting gain =2 with INM0 node for input or bias, INM1 node for filtering
1101: Inverting gain = -3/ Noninverting gain =4 with INM0 node for input or bias, INM1 node for filtering
1110: Inverting gain = -7/ Noninverting gain =8 with INM0 node for input or bias, INM1 node for filtering
1111: Inverting gain = -15/ Noninverting gain =16 with INM0 node for input or bias, INM1 node for filtering

Bits 13:12 **CALSEL[1:0]:** Calibration selection
It is used to select the offset calibration bus used to generate the internal reference voltage when CALON = 1 or FORCE_VP = 1.
00: 0.033 * VDDA applied on OPAMP inputs
01: 0.1 * VDDA applied on OPAMP inputs (for PMOS calibration)
10: 0.5 * VDDA applied on OPAMP inputs
11: 0.9 * VDDA applied on OPAMP inputs (for NMOS calibration)

Bit 11 **CALON:** Calibration mode enabled
0: Normal mode
1: Calibration mode (all switches opened by HW)

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **OPAHSM:** Operational amplifier high-speed mode
The operational amplifier must be disable to change this configuration.
0: operational amplifier in normal mode
1: operational amplifier in high-speed mode

Bit 7 Reserved, must be kept at reset value.

Bits 6:5 **VM_SEL[1:0]:** Inverting input selection
00:INM0 connected to OPAMP_VINM input
01: INM1 connected to OPAMP_VINM input
10:Feedback resistor is connected to the OPAMP_VINM input (PGA mode), Inverting input selection depends on the PGA_GAIN setting
11:opamp_out connected to OPAMP_VINM input (Follower mode)

Bit 4 Reserved, must be kept at reset value.

Bits 3:2 **VP_SEL[1:0]:** Non inverted input selection
00: GPIO INP0 connected to OPAMP_VINP
01: dac_out1 connected to OPAMP_VINP
10: GPIO INP2 is connected to OPAMP_VINP
11: Reserved

Bit 1 **FORCE_VP:** Force internal reference on VP (reserved for test)
0: Normal operating mode. Noninverting input connected to inputs.
1: Calibration verification mode: Noninverting input connected to calibration reference voltage.

Bit 0 **OPAEN:** Operational amplifier enable
0: operational amplifier disabled
1: operational amplifier enabled
Note: If OPAMP1 is unconnected in a specific package, it must remain disabled (keep OPAMP1_CSR register default value).

34.6.2 OPAMP1 trimming register in normal mode (OPAMP1_OTR)

Address offset: 0x04

Reset value: 0x0000 XXXX (factory trimmed values)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TRIMOFFSETP[4:0]					Res.	Res.	Res.	TRIMOFFSETN[4:0]				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:8 **TRIMOFFSETP[4:0]:** Trim for PMOS differential pairs

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **TRIMOFFSETN[4:0]:** Trim for NMOS differential pairs

34.6.3 OPAMP1 trimming register in high-speed mode (OPAMP1_HSOTR)

Address offset: 0x08

Reset value: 0x0000 XXXX (factory trimmed values)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TRIMHSOFFSETP[4:0]					Res.	Res.	Res.	TRIMHSOFFSETN[4:0]				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:8 **TRIMHSOFFSETP[4:0]:** High-speed mode trim for PMOS differential pairs

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **TRIMHSOFFSETN[4:0]:** High-speed mode trim for NMOS differential pairs

34.6.4 OPAMP register map

Table 328. OPAMP register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**OPAMP1_CSR**	Res.	CALOUT	TSTREF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	USERTRIM	PGA_GAIN				CALSEL		CALON	Res.	Res.	OPAHSM	Res.	VM_SEL		Res.	VP_SEL		FORCE_VP	OPAEN
	Reset value		0	0											0	0	0	0	0	0	0	0			0		0	0		0	0	0	0
0x04	**OPAMP1_OTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIM OFFSETP[4:0]					Res.	Res.	Res.	Res.	TRIM OFFSETN[4:0]			
	Reset value																				(1)									(1)			
0x08	**OPAMP1_ HSOTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIMHS OFFSETP[4:0]					Res.	Res.	Res.	Res.	TRIMHS OFFSETN[4:0]			
	Reset value																				(1)									(1)			

1. Factory trimmed values.

Refer to *Section 2.3* for the register boundary addresses.

35 Comparator (COMP)

35.1 Introduction

The device embeds two ultra-low-power comparators, COMP1 and COMP2. It can be used for a variety of functions including:

- Wake-up from low-power mode triggered by an analog signal
- Analog signal conditioning
- Cycle-by-cycle current control loop when combined with a PWM output from a timer

35.2 COMP main features

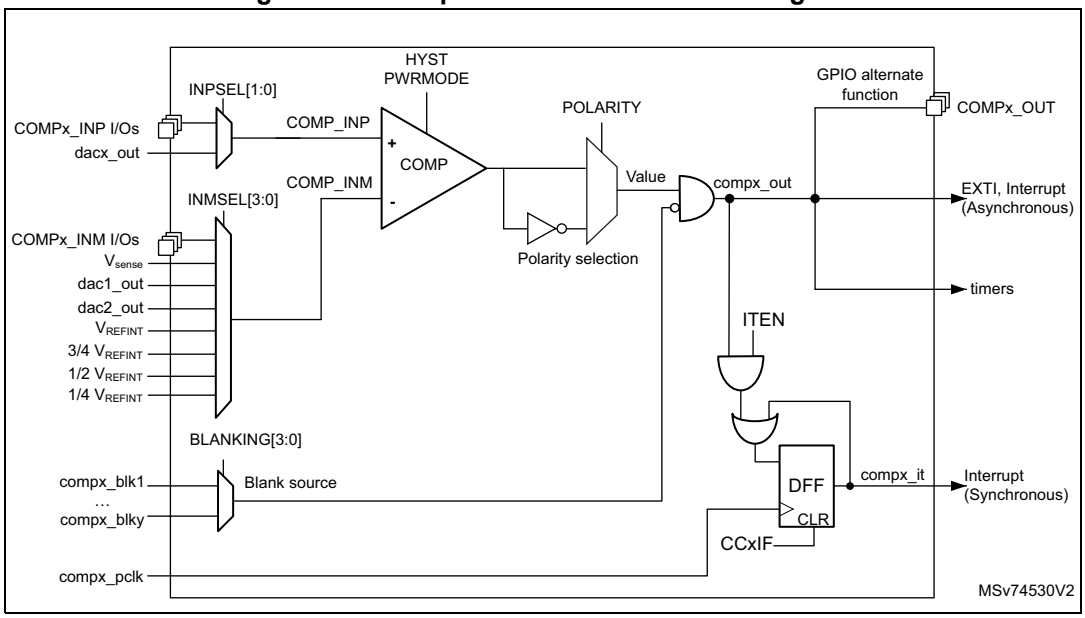
- Selectable inverting analog inputs:
  - I/O pins
  - DAC Channel outputs
  - Internal reference voltage and three sub-multiple values (1/4, 1/2, 3/4) provided by the scaler (buffered voltage divider)
- I/O pins selectable as noninverting analog inputs
- Programmable hysteresis
- Programmable speed/consumption
- Mapping of outputs to I/Os
- Redirection of outputs to timer inputs for triggering:
  - Capture events
  - OCREF_CLR events (for cycle-by-cycle current control)
  - Break events for fast PWM shutdowns
- Blanking of comparator outputs
- Interrupt generation capability with wake up from Sleep and Stop modes (through the EXTI controller)
- Interrupt output through the EXTI controller
- Direct interrupt output to the CPU

35.3 COMP functional description

35.3.1 COMP block diagram

The block diagram of the comparators is shown in the figure below.

Figure 334. Comparator functional block diagram



Note: The V_{sense} buffer is controlled by ADC bloc, to activate it set the TSEN bit in the ADC_CCR register.

35.3.2 COMP pins and internal signals

The I/Os used as comparator inputs must be configured in analog mode in the GPIO registers.

The comparator outputs can be connected to the I/Os through their alternate functions. Refer to the product datasheet for more information.

The outputs can also be internally redirected to a variety of timer inputs for the following purposes:

- Emergency shut-down of PWM signals, using BKIN and BKIN2 inputs
- Cycle-by-cycle current control, using ETR inputs of timers
- Input capture for timing measurements

The comparator output can be simultaneously addressed internally and to the I/O pins.

Table 329. COMP1/2 input/output internal signals

Signal name	Signal type	Description
dacx_out	Analog input	Analog signal from DAC peripheral
compx_blky	Digital input	See *Table 334: COMP1 blanking source assignment* and *Table 335: COMP2 blanking source assignment*

Table 329. COMP1/2 input/output internal signals (continued)

Signal name	Signal type	Description
compx_out	Digital output	COMPx output
compx_it	Digital output	COMPx interrupt out

Table 330. COMP1 non-inverting input assignment

COMP1_INP		COMP1_INPSEL[1:0]
INP0	GPIO	00
INP1	GPIO	01
INP2	dac1_out1	10

Note: Other combinations are reserved.

Table 331. COMP1 inverting input assignment

COMP1_INM		COMP1_INMSEL[3:0]
INM0	¼ V_{REFINT}	0000
INM1	½ V_{REFINT}	0001
INM2	¾ V_{REFINT}	0010
INM3	V_{REFINT}	0011
INM4	dac1_out2	0100
INM5	dac1_out1	0101
INM6	GPIO	0110
INM7	GPIO	0111
INM8	V_{SENSE}	1000
INM9	V_{BAT}/4	1001

Note: Other combinations are reserved.

Table 332. COMP2 non-inverting input assignment

COMP2_INP		COMP2_INPSEL[1:0]
INP0	GPIO	00
INP1	GPIO	01
INP2	dac1_out2	10

Note: Other combinations are reserved.

Table 333. COMP2 inverting input assignment

COMP2_INM		COMP2_INMSEL[3:0]
INM0	¼ V_{REFINT}	0000
INM1	½ V_{REFINT}	0001
INM2	¾ V_{REFINT}	0010
INM3	V_{REFINT}	0011
INM4	dac1_out2	0100

Table 333. COMP2 inverting input assignment (continued)

COMP2_INM		COMP2_INMSEL[3:0]
INM5	dac1_out1	0101
INM6	VDDCORE	0110
INM7	COMP2_INM1 GPIO	0111
INM8	COMP2_INM2 GPIO	1000
INM9	COMP2_INM3 GPIO	1001

Note: Other combinations are reserved.

Table 334. COMP1 blanking source assignment

Banking source	COMP1_BLANKING[3:0]
No blanking	0000
tim1_oc5	0001
tim2_oc3	0010
tim3_oc3	0011
tim3_oc4	0100
lptim1_ch2	0101
lptim2_ch2	0110

Note: Other combinations are reserved.

Table 335. COMP2 blanking source assignment

Banking source	COMP2_BLANKING[3:0]
No blanking	0000
tim1_oc6	0001
tim2_oc3	0010
tim3_oc3	0011
tim3_oc4	0100
tim8_oc5	0101
tim15_oc2	0110

Note: Other combinations are reserved.

35.3.3 COMP reset and clocks

The clock comp_pclk is provided by the clock controller is synchronous with the APB clock.

Note: ***Important:*** *The polarity selection logic and the output redirection to the port work independently from the APB clock. This allows the comparator to work even in Stop mode. The interrupt line, connected to the NVIC of the CPU, requires the APB clock (comp_pclk) to work. In the absence of the APB clock, the interrupt signal comp_it cannot be generated.*

35.3.4 Comparator LOCK mechanism

The comparators can be used for safety purposes, such as overcurrent or thermal protection. For applications with specific functional safety requirements, the comparator configuration can be protected against undesired alteration that could happen, for example, at program counter corruption.

For this purpose, the comparator configuration registers can be write-protected (read-only).

Upon configuring a comparator channel, its LOCK bit is set to 1. This causes the whole register set of the comparator channel to become read-only, the LOCK bit inclusive.

The write protection can only be removed through the MCU reset.

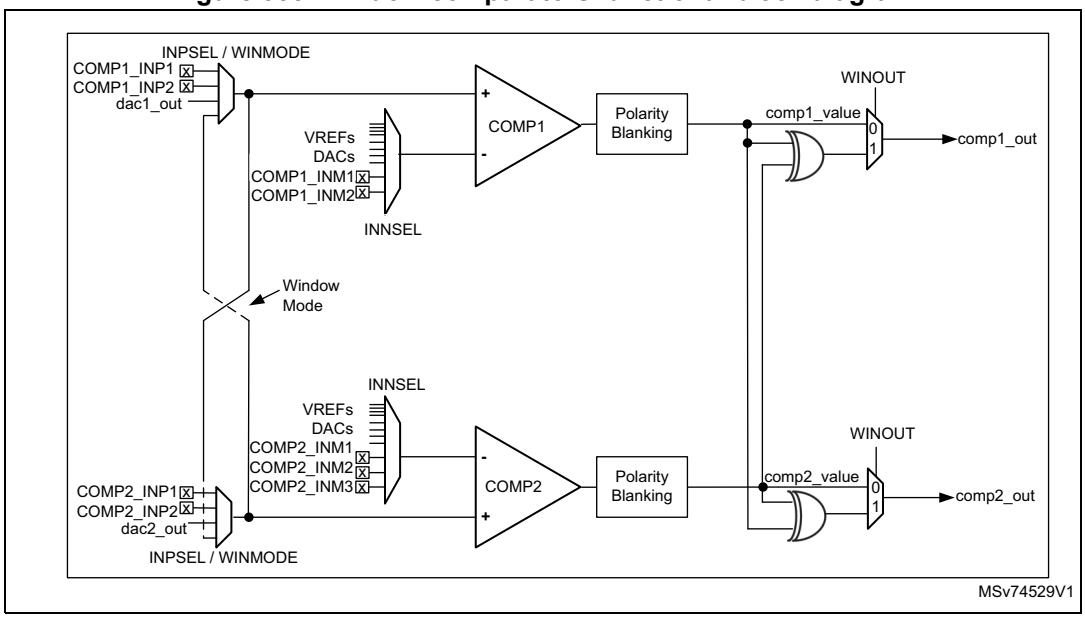
35.3.5 Window comparator

The purpose of the window comparator is to monitor the analog voltage if it is within the voltage range defined by the lower and upper threshold.

The two embedded comparators COMP1 and COMP2 can be used to create a window comparator. The monitored analog voltage is connected to the noninverting (plus) inputs of comparators connected together (COMP1 or COMP2). The upper and lower threshold voltages are connected to the inverting (minus) inputs of the comparators.

The output of the window comparator (COMP1 or COMP2) is selected with the control bit WINOUT.

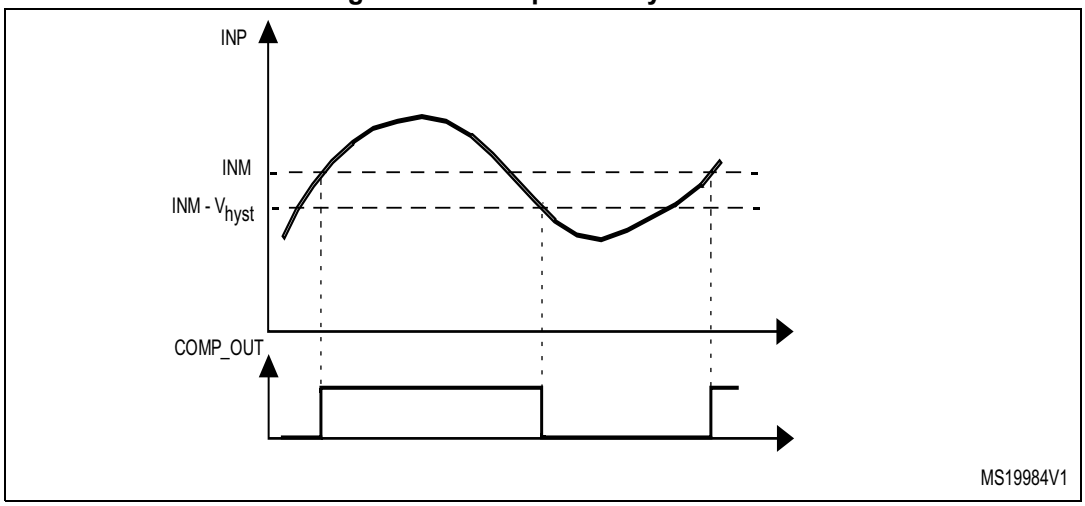
Figure 335. Window comparators functional block diagram



35.3.6 Hysteresis

The comparator includes a programmable hysteresis to avoid spurious output transitions in the case of noisy signals. The hysteresis can be disabled if it is not needed (for instance when exiting from low-power mode) to be able to force the hysteresis value using external components.

Figure 336. Comparator hysteresis

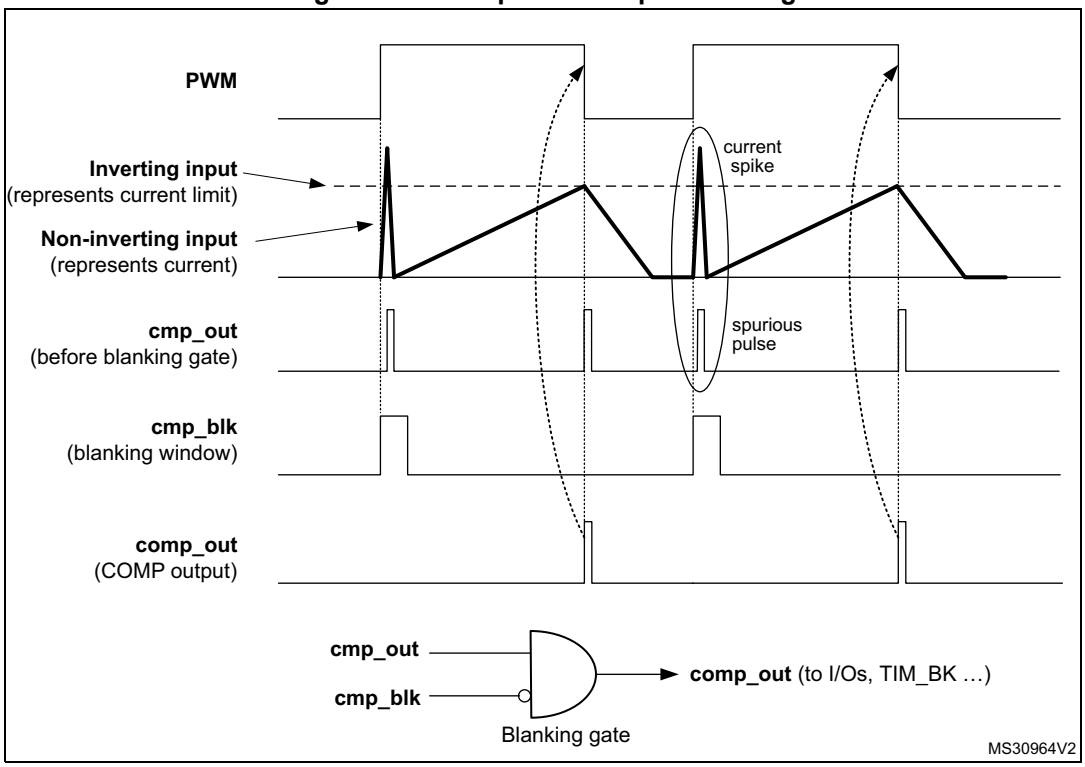


35.3.7 Comparator output blanking function

The purpose of the blanking function is to prevent the current regulation to trip upon short current spikes at the beginning of the PWM period (typically the recovery current in power switches antiparallel diodes). It uses a blanking window defined with a timer output compare signal. Refer to the register description for selectable blanking signals.

The blanking signal gates the internal comparator output such as to clean the comp_out from spurious pulses due to current spikes, as depicted in the following figure (the COMP channel number is not represented).

Figure 337. Comparator output blanking



35.3.8 COMP startup stabilization time

The comparator parameters and its output is undefined after the COMP enable (power-on) for a period defined as startup stabilization time, see the product datasheet for more details. If the comparator output is driving any critical stage of the design, it is recommended to redirect the comparator output to the device I/O through the GPIO alternate function or through IP configuration (such as timers) after the stabilization time elapses.

35.3.9 COMP power and speed modes

The power consumption of the COMP channels versus propagation delay can be adjusted to have the optimum trade-off for a given application.

The bits PWRMODE[1:0] in COMP_CFGRx registers can be programmed as follows:

- 00: High speed/full power
- 01: Medium speed/medium power
- 10: Medium speed/medium power
- 11: Very-low speed/ultra-low-power

35.4 COMP low-power modes

Table 336. Comparator behavior in low-power modes

Mode	Description
Sleep	No effect on the comparators. Comparator interrupts cause the device to exit the Sleep mode.
Stop	No effect on the comparators. Comparator interrupts cause the device to exit the Stop mode.

Note: The comparators cannot be used to exit the device from Sleep or Stop mode when the internal reference voltage is switched off.

35.5 COMP interrupts

There are two ways to use the comparator as an interrupt source.

The comparator outputs are internally connected to the extended interrupt and event controller (EXTI). Each comparator has its own EXTI line and can generate either interrupts or events to make the device exit low-power modes.

The comparator also provides an interrupt line to the NVIC of the CPU. This functionality is used when the CPU is active to handle low latency interrupt. It requires the APB clock running.

35.5.1 Wake-up interrupt through EXTI

Refer to the interrupt and events section for more details.

Sequence to enable the COMPx interrupt through the EXTI block:

1. Enable the COMPx and wait for stabilization.
2. Configure the EXTI line, receiving the compx_wkup signal, in interrupt mode, select the rising, falling, or either-edge sensitivity and enable the EXTI line.
3. Configure and enable the NVIC IRQ channel mapped to the corresponding EXTI lines.

Table 337. Interrupt through EXTI control bits

Interrupt event	Event flag	Enable control bit	Exit Sleep mode	Exit Stop modes	Exit Standby mode
compx_wkup	Through EXTI	Through EXTI	Yes	Yes	N/A

35.5.2 Interrupt through EXTI

Sequence to enable the COMPx interrupt through the EXTI block:

1. Enable the COMP and wait for stabilization.
2. Configure the EXTI line, receiving the comp_it signal, in interrupt mode, select the rising, falling, or either-edge sensitivity and enable the EXTI line.
3. Configure and enable the ITEN in COMP_CFGRx.

Table 338. Interrupt through NVIC control bits

Interrupt event	Interrupt flag	Enable control bit	Interrupt clear bit	Exit Sleep mode	Exit Stop modes
compx_it	CxIF in COMP_SR	ITEN in COMP_CFGRx	CC1xF	Yes (With APB clock)	No

Note: It is mandatory to enable the APB clock to use this interrupt. If the clock is not enabled, an interrupt is not generated.

35.5.3 Interrupt through the NVIC of the CPU

Sequence to enable the COMP interrupt through the NVIC of the CPU:

1. Enable the COMP and wait for stabilization.
2. Configure and enable the NVIC IRQ channel mapped to the comp_it line.
3. Configure and enable the ITEN in COMP_CFGRx.

Table 339. Interrupt through NVIC control bits

Interrupt event	Interrupt flag	Enable control bit	Interrupt clear bit	Exit Sleep mode	Exit Stop modes
comp_it	C1IF in	ITEN in COMP_CFGR1	CC1IF	Yes (with APB clock)	No
comp_it	C2IF in	ITEN in COMP_CFGR2	CC2IF	Yes (with APB clock)	No

Note: It is mandatory to enable the APB clock to use this interrupt. If the clock is not enabled, an interrupt is not generated.
The interrupt is active on level and not automatically clear by hardware. It must be cleared in the comparator interrupt handler by firmware with ITEN=0 (COMP_CFGR1 register).

The interrupt signal comp_it is generated on comparator level, for this reason: upon interruption occurrence, the comp_it signal must be set to low as soon as possible to avoid comparator interrupt handler reentrance. This can be done by setting ITEN=0 or changing the comparator POLARITY bit.

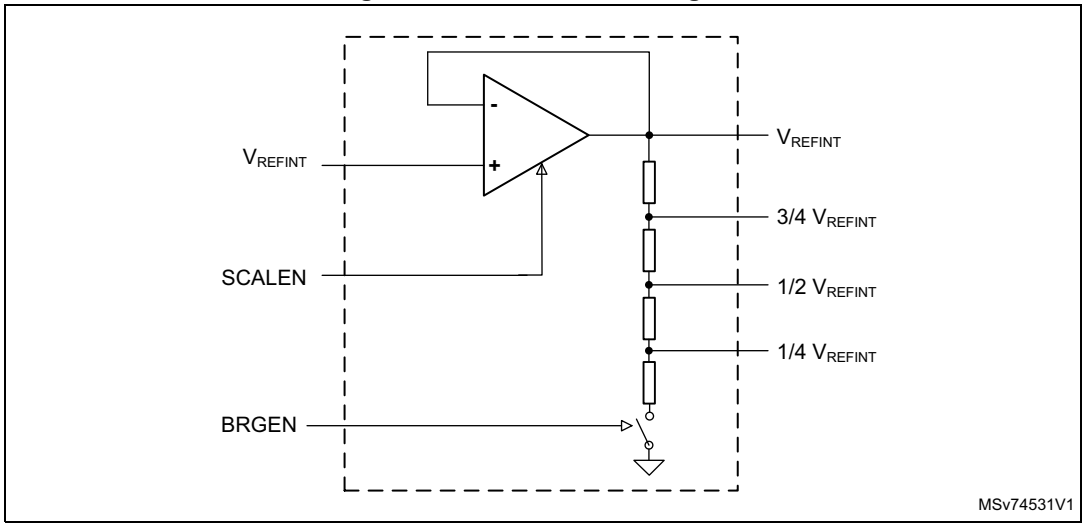
35.6 SCALER function

The scaler block is available to provide the different voltage reference levels to the comparator inputs. It is based on an amplifier driving a resistor bridge. The amplifier input is connected to the internal voltage reference.

The amplifier and the resistor bridge can be enabled separately. The amplifier is enabled by the SCALEN bits of the COMP_CFGRx registers. The resistor bridge is enabled by the BRGEN bits of the COMP_CFGRx registers.

When the resistor-divided voltage is not used, the resistor bridge can be disconnected to reduce the consumption.

Figure 338. Scaler block diagram



35.7 COMP registers

35.7.1 Comparator status register (COMP_SR)

The COMP_SR is the comparator status register.

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	C2IF	C1IF
														r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	C2VAL	C1VAL
														r	r

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **C2IF**: COMP2 Channel interrupt flag
This bit is set by hardware when the COMP2 Channel output is set
This bit is cleared by software writing 1 the CC2IF bit in the COMP_ICFR register.

Bit 16 **C1IF**: COMP1 Channel interrupt flag
This bit is set by hardware when the COMP1 Channel output is set
This bit is cleared by software writing 1 the CC1IF bit in the COMP_ICFR register.

Bits 15:2 Reserved, must be kept at reset value.

Bit 1 **C2VAL:** COMP2 Channel output status bit
This bit is read-only. It reflects the current COMP2 Channel output taking into account POLARITY and BLANKING bits effect.

Bit 0 **C1VAL:** COMP1 Channel output status bit
This bit is read-only. It reflects the current COMP1 Channel output taking into account POLARITY and BLANKING bits effect.

35.7.2 Comparator interrupt clear flag register (COMP_ICFR)

The COMP_ICFR is the comparator interrupt clear flag register.

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2IF	CC1IF
														rc_w1	rc_w1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **CC2IF**: Clear COMP2 Channel interrupt flag
Writing 1 clears the C2IF flag in the COMP_SR register.

Bit 16 **CC1IF**: Clear COMP1 Channel interrupt flag
Writing 1 clears the C1IF flag in the COMP_SR register.

Bits 15:0 Reserved, must be kept at reset value.

35.7.3 Comparator configuration register 1 (COMP_CFGR1)

The COMP_CFGR1 is the COMP1 configuration register.

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LOCK	Res.	Res.	Res.	BLANKING[3:0]				Res.	INP SEL1	Res.	INP SEL0	INMSEL[3:0]			
rw				rw	rw	rw	rw		rw		rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	WIN OUT	PWRMODE[1:0]		Res.	Res.	HYST[1:0]		Res.	ITEN	Res.	WIN MODE	POLARITY	SCALEN	BRGEN	EN
	rw	rw	rw			rw	rw		rw		rw	rw	rw	rw	rw

Bit 31 **LOCK:** Lock
This bit is set by software and cleared by a hardware system reset. It locks the whole content of the COMP Channel configuration register COMP_CFGR1[31:0].
0: COMP_CFGR1[31:0] register is read/write
1: COMP_CFGR1[31:0] register is read-only

Bits 30:28 Reserved, must be kept at reset value.

Bits 27:24 **BLANKING[3:0]:** COMP1 Channel blanking source selection
Bits of this field are set and cleared by software (only if LOCK not set).
The field selects the input source for COMP1 Channel output blanking.
See *Table 334: COMP1 blanking source assignment* for more details.

Bit 23 Reserved, must be kept at reset value.

Bit 22 **INPSEL1**: COMP1 non-inverting input selection
This bit is set and cleared by software (only if LOCK not set). It select which input is connected to the non-inverting input of COMP1 Channel.
See *Table 330: COMP1 non-inverting input assignment* for more details.

Bit 21 Reserved, must be kept at reset value.

Bit 20 **INPSEL0**: COMP1 non-inverting input selection
This bit is set and cleared by software (only if LOCK not set). It select which input is connected to the non-inverting input of COMP1 Channel.
See *Table 330: COMP1 non-inverting input assignment* for more details.

Bits 19:16 **INMSEL[3:0]**: COMP1 Channel inverting input selection
These bits are set and cleared by software (only if LOCK not set). They select which input is connected to the inverting input of COMP1 Channel.
Note: See Table 331: COMP1 inverting input assignment for more details.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **WINOUT:** COMP1 output selector
This bit is controlled by software (if not locked). It selects the COMP1 output.
0: COMP1_VALUE
1: COMP1_VALUE XOR COMP2_VALUE (required for window mode, see *Figure 335: Window comparators functional block diagram*)

Bits 13:12 **PWRMODE[1:0]:** Power mode of the COMP Channel
These bits are set and cleared by software (only if LOCK not set). They control the power/speed of the COMP Channel.
00: High speed/full power
01: Medium speed/medium power
10: Medium speed/medium power
11: Ultra-low speed/ultra-low power

Bits 11:10 Reserved, must be kept at reset value.

Bits 9:8 **HYST[1:0]:** COMP Channel hysteresis selection
These bits are set and cleared by software (only if LOCK not set). They select the Hysteresis voltage of the COMP Channel.
00: No hysteresis
01: Low hysteresis
10: Medium hysteresis
11: High hysteresis

Bit 7 Reserved, must be kept at reset value.

Bit 6 **ITEN:** COMP Channel interrupt enable
This bit is set and cleared by software (only if LOCK not set). This bit enable the interrupt generation of the COMP Channel.
0: Interrupt generation disabled for COMP Channel
1: Interrupt generation enabled for COMP Channel

Bit 5 Reserved, must be kept at reset value.

Bit 4 **WINMODE**: COMP1 non-inverting input selector for window mode

This bit is controlled by software (if not locked). It selects the signal for COMP1_INP input of the COMP1.

0: Signal selected with INPSEL[1:0]

1: COMP2_INP signal of COMP2 (required for window mode, see *Figure 335: Window comparators functional block diagram*)

Bit 3 **POLARITY:** COMP Channel polarity selection

This bit is set and cleared by software (only if LOCK not set). It inverts COMP Channel polarity.

0: COMP Channel output is not inverted

1: COMP Channel output is inverted

Bit 2 **SCALEN**: Voltage scaler enable

This bit is set and cleared by software (only if LOCK not set). This bit enables the V_{REFINT} scaler for the COMP channels.

0: V_{REFINT} scaler disabled

1: V_{REFINT} scaler enabled

Bit 1 **BRGEN:** Scaler bridge enable

This bit is set and cleared by software (only if LOCK not set). This bit enables the bridge of the scaler.

0: Scaler resistor bridge disabled

1: Scaler resistor bridge enabled

Bit 0 **EN:** COMP Channel enable

This bit is set and cleared by software (only if LOCK not set). It enables the COMP Channel.

0: Disable

1: Enable

35.7.4 Comparator configuration register 2 (COMP_CFGR2)

The COMP_CFGR2 is the COMP2 configuration register.

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LOCK	Res.	Res.	Res.	BLANKING[3:0]				Res.	INPSEL1	Res.	INPSEL0	INMSEL[3:0]			
rw				rw	rw	rw	rw		rw		rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	WINOUT	PWRMODE[1:0]		Res.	Res.	HYST[1:0]		Res.	ITEN	Res.	WINMODE	POLARITY	SCALEN	BRGEN	EN
	rw	rw	rw			rw	rw		rw		rw	rw	rw	rw	rw

Bit 31 **LOCK:** Lock

This bit is set by software and cleared by a hardware system reset. It locks the whole content of the COMP Channel configuration register COMP_CFGR2[31:0].

0: COMP_CFGR2[31:0] register is read/write

1: COMP_CFGR2[31:0] register is read-only

Bits 30:28 Reserved, must be kept at reset value.

Bits 27:24 **BLANKING[3:0]:** COMP2 Channel blanking source selection
Bits of this field are set and cleared by software (only if LOCK not set).
The field selects the input source for COMP2 Channel output blanking.
See *Table 335: COMP2 blanking source assignment* for more details.

Bit 23 Reserved, must be kept at reset value.

Bit 22 **INPSEL1**: COMP2 non-inverting input selection
This bit is set and cleared by software (only if LOCK not set). It select which input is connected to the non-inverting input of COMP2 Channel.
See *Table 332: COMP2 non-inverting input assignment* for more details.

Bit 21 Reserved, must be kept at reset value.

Bit 20 **INPSEL0**: COMP2 non-inverting input selection
This bit is set and cleared by software (only if LOCK not set). It select which input is connected to the non-inverting input of COMP2 Channel.
See *Table 332: COMP2 non-inverting input assignment* for more details.

Bits 19:16 **INMSEL[3:0]**: COMP2 Channel inverting input selection
These bits are set and cleared by software (only if LOCK not set). They select which input is connected to the inverting input of COMP2 Channel.
Note: See Table 333: COMP2 inverting input assignment for more details.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **WINOUT:** COMP2 output selector
This bit is controlled by software (if not locked). It selects the COMP2 output.
0: COMP2_VALUE
1: COMP1_VALUE XOR COMP2_VALUE (required for window mode, see *Figure 335: Window comparators functional block diagram*)

Bits 13:12 **PWRMODE[1:0]:** Power mode of the COMP Channel
These bits are set and cleared by software (only if LOCK not set). They control the power/speed of the COMP Channel.
00: High speed/full power
01: Medium speed/medium power
10: Medium speed/medium power
11: Ultra-low speed/ultra-low power

Bits 11:10 Reserved, must be kept at reset value.

Bits 9:8 **HYST[1:0]:** COMP Channel hysteresis selection
These bits are set and cleared by software (only if LOCK not set). They select the Hysteresis voltage of the COMP Channel.
00: No hysteresis
01: Low hysteresis
10: Medium hysteresis
11: High hysteresis

Bit 7 Reserved, must be kept at reset value.

Bit 6 **ITEN:** COMP Channel interrupt enable
This bit is set and cleared by software (only if LOCK not set). This bit enable the interrupt generation of the COMP Channel.
0: Interrupt generation disabled for COMP Channel
1: Interrupt generation enabled for COMP Channel

Bit 5 Reserved, must be kept at reset value.

Bit 4 **WINMODE**: COMP2 non-inverting input selector for window mode

This bit is controlled by software (if not locked). It selects the signal for COMP2_INP input of the COMP2.

0: Signal selected with INPSEL[1:0]

1: COMP1_INP signal of COMP1 (required for window mode, see *Figure 335: Window comparators functional block diagram*)

Bit 3 **POLARITY:** COMP Channel polarity selection

This bit is set and cleared by software (only if LOCK not set). It inverts COMP Channel polarity.

0: COMP Channel output is not inverted

1: COMP Channel output is inverted

Bit 2 **SCALEN**: Voltage scaler enable

This bit is set and cleared by software (only if LOCK not set). This bit enables the V_{REFINT} scaler for the COMP channels.

0: V_{REFINT} scaler disabled

1: V_{REFINT} scaler enabled

Bit 1 **BRGEN:** Scaler bridge enable

This bit is set and cleared by software (only if LOCK not set). This bit enables the bridge of the scaler.

0: Scaler resistor bridge disabled

1: Scaler resistor bridge enabled

Bit 0 **EN:** COMP Channel enable

This bit is set and cleared by software (only if LOCK not set). It enables the COMP Channel.

0: Disable

1: Enable

35.7.5 COMP register map

Table 340. COMP register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**COMP_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	C2IF	C1IF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	C2VAL	C1VAL
	Reset value															0	0															0	0
0x04	**COMP_ICFR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2IF	CC1IF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value															0	0																
0x0C	**COMP_ CFGR1**	LOCK	Res.	Res.	Res.	BLANKING [3:0]				Res.	.INPSEL1	Res.	INPSEL0	INMSEL [3:0]				Res.	WINOUT	PWRMODE [1:0]		WINMODE	Res.	HYST[1:0]		Res.	ITEN	Res.	Res.	POLARITY	SCALEN	BRGEN	EN
	Reset value	0				0	0	0	0		0		0	0	0	0	0		0	0	0	0		0	0		0			0	0	0	0
0x10	**COMP_ CFGR2**	LOCK	Res.	Res.	Res.	BLANKING [3:0]				Res.	.INPSEL1	Res.	INPSEL0	INMSEL [3:0]				Res.	WINOUT	PWRMODE [1:0]		WINMODE	Res.	HYST[1:0]		Res.	ITEN	Res.	Res.	POLARITY	SCALEN	BRGEN	EN
	Reset value	0				0	0	0	0		0		0	0	0	0	0		0	0	0	0		0	0		0			0	0	0	0

Refer to *Section 2.3* for the register boundary addresses.

36 Multi-function digital filter (MDF)

36.1 MDF introduction

The multi-function digital filter (MDF) is a high-performance module dedicated to the connection of external sigma-delta (ΣΔ) modulators. It is mainly targeted for the following applications:

- audio capture signals
- motor control
- metering

The MDF features 6 digital serial interfaces (SITFx) and digital filters (DFLTx) with flexible digital processing options to offer up to 24-bit final resolution.

The DFLTx of the MDF also include the filters of the audio digital filter (ADF).

The MDF can receive, via its serial interfaces, streams coming from various digital sensors.

The MDF supports the following standards allowing the connection of various ΣΔ modulator sensors:

- SPI interface
- Manchester coded 1-wire interface
- PDM interface

A flexible bitstream matrix (BSMX) allows the connection of any incoming bitstream to any filter.

The MDF converts an input data stream into clean decimated digital data words. This conversion is done thanks to low-pass digital filters and decimation blocks. In addition it is possible to insert a high-pass filter or a DC offset correction block.

The conversion speed and resolution are adjustable according to configurable parameters for digital processing: filter type, filter order, decimation ratio, integrator length. The maximum output data resolution is up to 24 bits. There are two conversion modes: single conversion and continuous modes. The data can be automatically stored in a system RAM buffer through DMA, thus reducing the software overhead.

A flexible trigger interface can be used to control the conversion start. This timing control can trigger simultaneous conversions or insert a programmable delay between conversions.

The MDF features an out-off limit detectors (OLD) function. There is one OLD for each digital filter chain. Independent programmable thresholds are available for each OLD, making it very suitable for over-current detection.

A short circuit detector (SCD) is also available for every selected bitstream. The SCD is able to detect a short-circuit condition with a very short latency. Independent programmable thresholds are offered in order to define the short circuit condition.

The digital processing is performed using only the kernel clock. The MDF requests the bus interface clock (AHB clock) only when data must be transfered or when a specific event requests the attention of the system processor.

36.2 MDF main features

- AHB interface
- 6 serial digital inputs:
  - configurable SPI interface to connect various digital sensors
  - configurable Manchester coded interface support
  - compatible with PDM interface to support digital microphones
- 2 common clocks input/output for ΣΔ modulators
- Flexible matrix (BSMX) for connection between filters and digital inputs
- 2 inputs to connect the internal ADCs
- 6 flexible digital filter paths, including:
  - A configurable CIC filter:
    - Can be split into 2 CIC filters: high-resolution filter and out-off limit detector
    - Can be configured in $Sinc^4$ filter
    - Can be configured in $Sinc^5$ filter
    - Adjustable decimation ratio
  - A reshape filter to improve the out-off band rejection and in-band ripple
  - A high-pass filter to cancel the DC offset
  - An offset error cancellation
  - Gain control
  - Saturation blocks
  - An out-off limit detector
- Short-circuit detector
- Clock absence detector
- 16- or 24-bit signed output data resolution
- Continuous or single conversion
- Possibility to delay independently each bitstream
- Various trigger possibilities
- Break generation on out-of limit or short-circuit detector events
- DMA can be used to read the conversion data
- Interrupts services

36.3 MDF implementation

Table 341. MDF features(1)

Modes or features	MDF1
Number of filters (DFLT) and serial interfaces (SITF)	6
MDF_CKI[x] connected to pads	X
Sound Activity Detection (SAD)	-
RXFIFO depth (number of 24-bit words)	4
Number of trigger inputs	14

Table 341. MDF features(1) (continued)

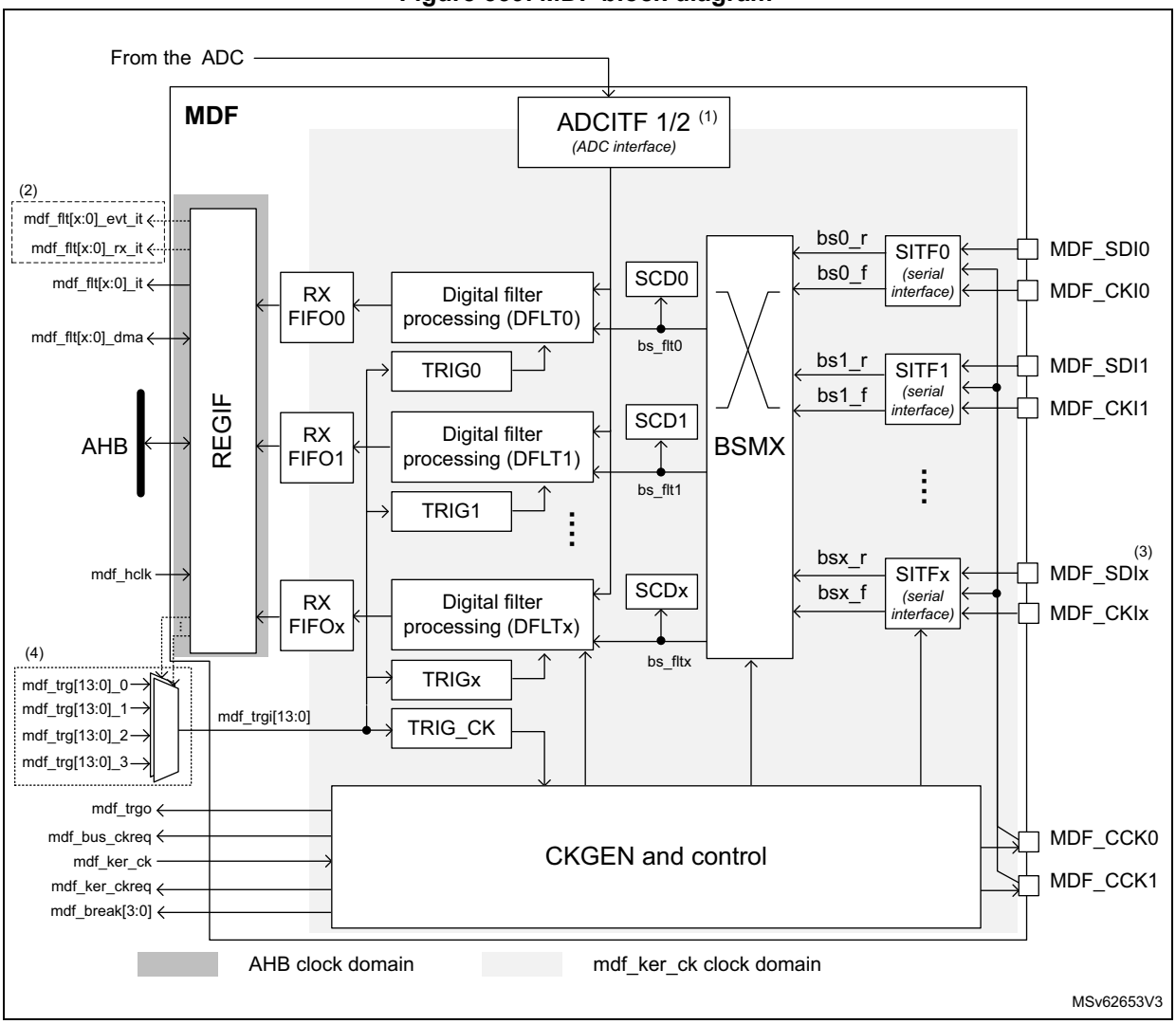
Modes or features	MDF1
ADC connected to ADCITF1	ADC1
ADC connected to ADCITF2	ADC2
Motor dedicated features (SCD, OLD, OEC, INT, snapshot, break)	X
Main path with CIC4, CIC5	X
Main path with CIC1,2, 3 or FastSinc	X
RSFLT, HPF, SAT, SCALE, DLY, Discard functions	X
Global Interrupts MDF_FLT[0:0] (mdf_it[0:0])	X
Receive interrupts MDF_RX[0:0] (mdf_rx_it[0:0])	-
Event interrupts MDF_EVT[0:0] (mdf_evt_it[0:0])	-
Autonomous in Stop mode	-
Only DMA of filter 0 connected	-
All DMA channels connected	X

1. ‘X’ = supported, ‘-’ = not supported.

36.4 MDF functional description

36.4.1 MDF block diagram

Figure 339. MDF block diagram



1. Refer to *Section 36.3: MDF implementation* to check if the ADCITF is available, and which ADCs are connected.
2. Not always implemented, refer to the vector table of the product for details.
3. Refer to *Section 36.3: MDF implementation* to check the number of filter instances available.
4. The number of trigger inputs depends on the product. Refer to *Section 36.3: MDF implementation* for details.

36.4.2 MDF pins and internal signals

Table 342. MDF external pins

Name	Signal type	Comment
MDF_CKIy (y = 0 to 5)(1)	Input	Dedicated clock signals from external sensors
MDF_SDIy (y = 0 to 5)(1)	Input	Data signal from external sensors
MDF_CCKy (y = 0, 1)	Input/output	Clock outputs for external sensor, or common clock input from external sensors

1. The number of inputs available depends on the number of filters. Refer to *Section 36.3* for details.

Table 343. MDF internal signals

Name	Signal type	Comment
mdf_trgi[13:0]	Input	Trigger inputs in order to control the acquisition (see *Table 344: MDF trigger connections* for details)
mdf_trgo	Output	Trigger output for synchronizing several MDFs
mdf_break[3:0]	Output	Break signals event generation from over-current detector or short-circuit detector (see the next table for details)
mdf_flt[5:0]_dma(1)	Input/output	DMA request/acknowledge signals for each filter processing chain
mdf_flt[5:0]_it(1)	Output	Global interrupt signals, for each MDF filter
mdf_flt[5:0]_rx_it(1)(2)	Output	Receive interrupt signals, for each MDF filter.
mdf_flt[5:0]_evt_it(1)(2)	Output	Event interrupt signals, for each MDF filter.
mdf_bus_ckreq	Output	Bus interface clock request output
mdf_ker_ckreq	Output	Kernel clock request output
mdf_ker_ck	Input	Kernel clock input
mdf_hclk	Input	AHB bus interface clock input
mdf_adcitf1_dat[15:0]	Input	ADCITF1 data input
mdf_adcitf2_dat[15:0]	Input	ADCITF2 data input

1. The number of signals available depends on the number of filters. Refer to *Section 36.3* for details.
2. Not always connected. See the interrupt vector table for details.

The table below shows the way the trigger inputs of the MDF are connected.

Table 344. MDF trigger connections

Trigger name	Trigger source
mdf_trgi0	tim1_trgo
mdf_trgi1	tim1_trgo2
mdf_trgi2	tim8_trgo
mdf_trgi3	tim8_trgo2
mdf_trgi4	tim3_trgo

Table 344. MDF trigger connections (continued)

Trigger name	Trigger source
mdf_trgi5	tim4_trgo
mdf_trgi6	tim16_oc1
mdf_trgi7	tim6_trgo
mdf_trgi8	tim7_trgo
mdf_trgi9	adf1_sad_det (sound activity detection signal from ADF1)
mdf_trgi10	exti11
mdf_trgi11	exti15
mdf_trgi12	lptim1_ch1
mdf_trgi13	adf1_trgo signal from ADF1

The table below shows the way the break outputs of the MDF are connected.

Table 345. MDF break connections

Trigger name	Trigger source
mdf_break0	tim1_brk_cmp[8], tim15_brk_cmp[8]
mdf_break1	tim1_brk2_cmp[8], tim16_brk_cmp[8]
mdf_break2	tim8_brk_cmp[8], tim17_brk_cmp[8]
mdf_break3	tim8_brk2_cmp[8]

The table below shows the way the ADC data are connected to the MDF.

Table 346. MDF ADC data connections

ADC data bus name	ADC source
mdf_adcitf1_dat[15:0]	adc1_dat
mdf_adcitf2_dat[15:0]	adc2_dat

36.4.3 Serial input interfaces (SITF)

The SITFx input interfaces allow the connection of the external sensors to the digital filters, via the bitstream matrix (BSMX). The SITFx serial interface can be configured in the following modes:

- LF_MASTER SPI mode (low-frequency)
- normal SPI mode
- Manchester mode

The amount of SITFx instances is equal to the amount of filters.

The data from each serial interface can be routed to any filter in order to perform:

- the PDM to PCM conversion

- the out-off limit detection
- the short detection

The serial interfaces are enabled by setting the corresponding SITFEN bit to 1. Once the interface is enabled, it receives serial data from the external ΣΔ modulator.

Note: Before enabling the serial interface, the user must insure that the mdf_proc_ck is already enabled (see Section 36.4.5 for details).

The SITFx are controlled via the *MDF serial interface control register x (MDF_SITFxCR)*.

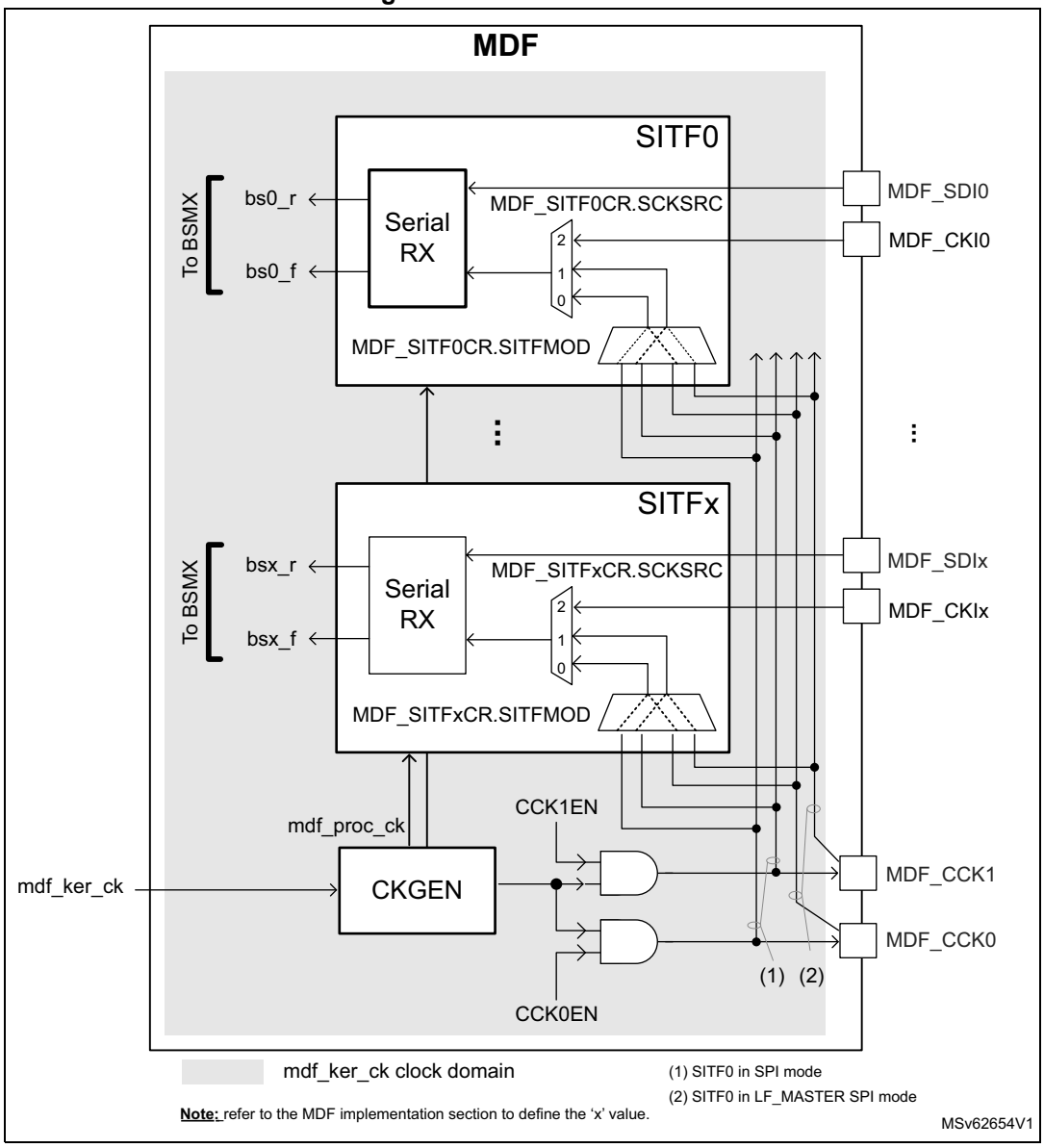
As shown in *Figure 340*, for each SITF, there is a large choice of clocking possibilities:

- If the serial interface is programmed in SPI mode, the selected clock source is a copy of the clock present on MDF_CCK0 or MDF_CCK1 or MDF_CKIx pin (see 2 in *Figure 340*).
- If the serial interface is programmed in LF_MASTER SPI mode, the selected clock source must be the clock directly provided by the CCKDIV to the MDF_CCK0 or MDF_CCK1 pin (see 1 in *Figure 340*). In this case MDF_CKIx must not be selected.

See *Table 347* for additional information.

Note: Using the common clock (MDF_CCK0 or MDF CCK1) can be helpful to share the same clock between several SITFx.

Figure 340. SITFx overview



LF_MASTER and normal SPI modes

The LF_MASTER SPI mode is a special mode allowing the usage of a mdf_proc_ck clock frequency, only two times higher than the sensor clock. This mode is dedicated to low-power use-cases, using low-speed sensors.

In LF_MASTER SPI mode, the MDF must provide the bitstream clock to the external sensors via MDF_CCK0 and MDF_CCK1 pins, and receives the bitstream data via the serial data input MDF_SDIx.

For each SITFx, the application must select the same clock than the one provided to the external sensor (MDF_CCK0 or MDF_CCK1), in order to guarantee optimal timing performances. This selection is done via SCKSRC[1:0].

Warning: The MDF_CKIx pin cannot be used in LF_MASTER SPI mode.

The normal SPI interface is a more flexible interface than the LF_MASTER SPI, but the mdf_proc_ck frequency must be at least four times higher than the sensor clock.

The application can select MDF_CCK0, MDF_CCK1 or MDF_CKIx clock for the capture of the data received via the MDF_SDIx pin.

The MDF can generate a clock to the sensors via MDF_CCK0 or MDF_CCK1 if needed.

For all SPI modes, all SITFs can share the same clock input (MDF_CCK0 or MDF_CCK1), in order to optimize the amount of requested I/Os.

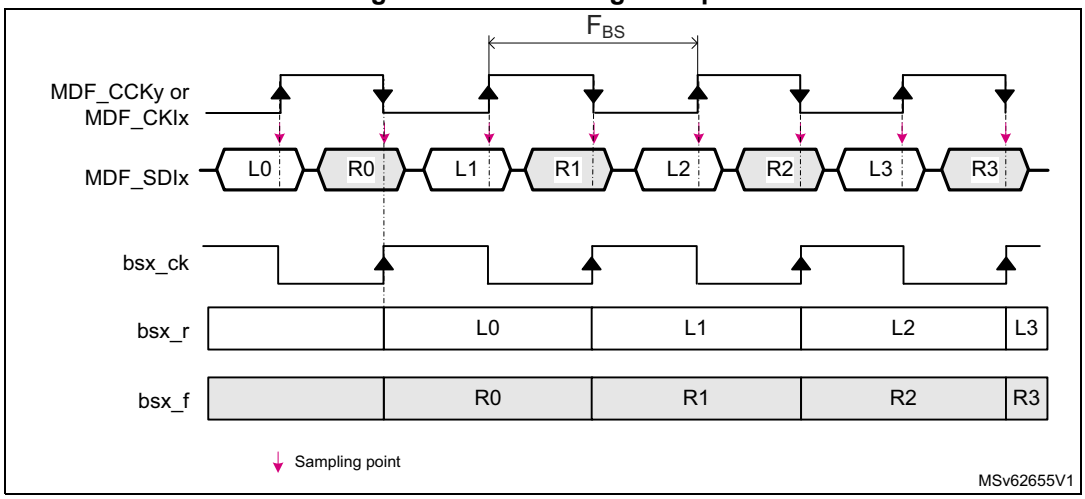
For all SPI modes, the serial data is captured using the rising and the falling edge of the selected clock. The SITFx always provides the following bitstreams:

- bitstream received using the bitstream clock falling edge (bsx_f)
- bitstream received using the bitstream clock rising edge (bsx_r)

According to the sensors connected, one of the two bitstreams may not be available.

The application can select the wanted stream via the BSMX matrix.

Figure 341. SPI timing example



To properly synchronize/receive the data stream, the frequency of the mdf_proc_ck clock must be adjusted according to the constraints listed in *Table 348*.

Clock absence detection

A no-clock-transition period may be detected when the serial interface works in normal SPI mode. This feature can be used to detect a clock failure in the SPI link.

The application can program a timeout value via the STH[4:0] bitfield of the corresponding SITFx. If the MDF does not detect clock transitions for a duration of STH[4:0] x $T_{mdf_proc_ck}$, then the CKABF flag is set.

An interrupt can be generated if CKABIE is set to 1. The STH[4:0] bitfield is in the *MDF serial interface control register x (MDF_SITFxCR)*.

When the serial interface is enabled, the CKABF flag remains to 1 until a first clock transition is detected.

To avoid spurious clock absence detection, the following sequence must be respected:

1. Configure the serial interface in normal SPI mode and enable it.
2. Clear the CKABF flag by writing CKABF bit to 1.

   If no clock transition is detected on the serial interface, the hardware immediately sets the CKABF flag to 1.
3. Read the CKABF flag:
   - If CKABF = 1, go back to step 2.
   - If CKABF i= 0, a clock has been detected. The CKABIE bit can be set to 1 if the application wants an interrupt on detection of a clock absence.

Note: The clock absence detection feature is not available in the LF_MASTER SPI mode.

Manchester mode

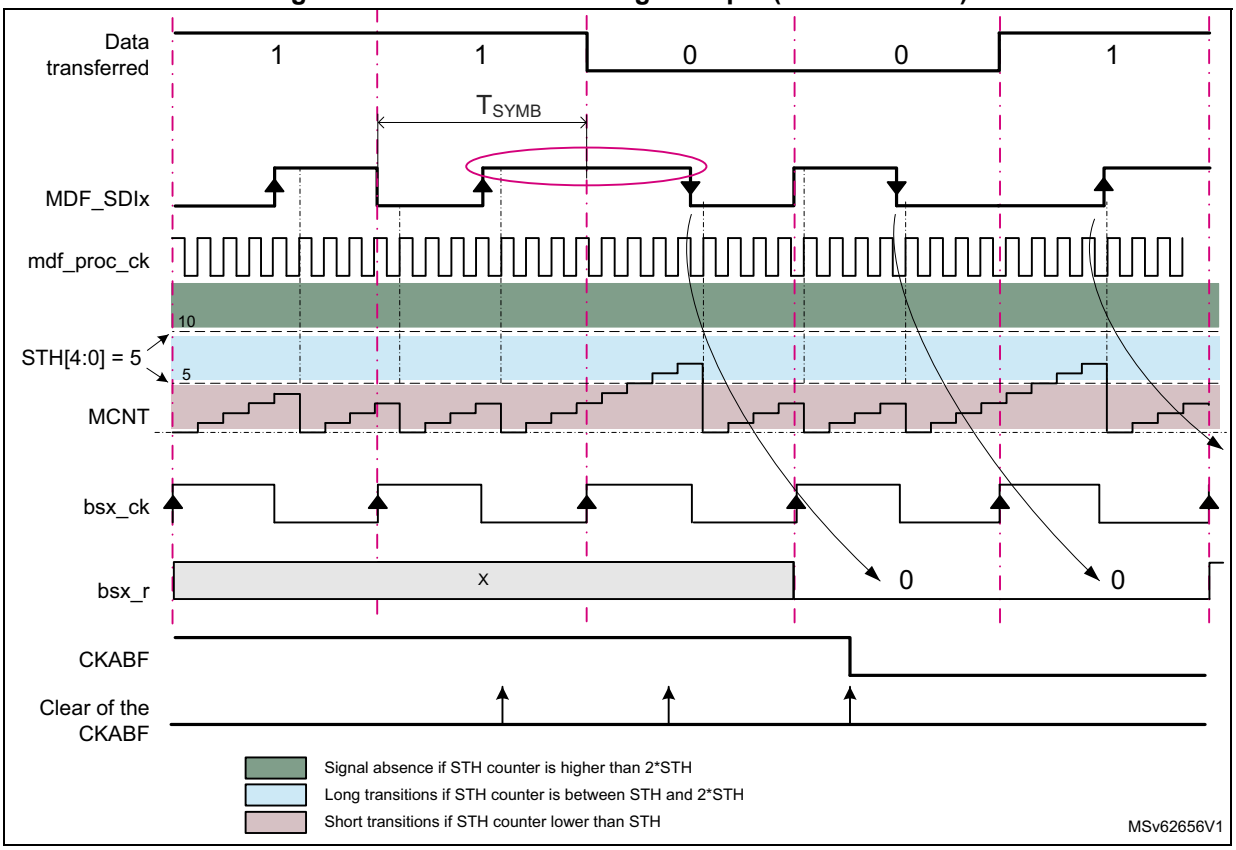
In Manchester coded format, the MDF receives data stream from the external sensor via the MDF_SDIx pin only.

The MDF_CKIx pins are not needed in this mode.

Decoded data and clock signals are recovered from serial stream after Manchester decoding. They are available on bsx_r. There are two possible settings of Manchester codings:

- signal rising edge decoded as 0 and signal falling edge decoded as 1
- signal rising edge decoded as 1 and signal falling edge decoded as 0

Figure 342. Manchester timing example (SITFMOD = 11)



To decode the incoming Manchester stream, the user must program the STH[4:0] bitfield in the *MDF serial interface control register x (MDF_SITFxCR)*. The STH[4:0] bitfield is used by the SITFx to estimate the Manchester symbol length and to detect a clock absence. An internal counter (MCNT) is restarted every time a transition is detected in the MDF_SDIx input. It is used to detect short transitions, long transitions or clock absence. A long transition indicates that the data value changed. *Figure 342* shows a case where the OVR is around height and STH[4:0] = 5.

The estimated Manchester symbol rate (T_{SYMB}) must respect the following formula:

$$(STH + 1)\times T_{mdf_proc_ck} < T_{SYMB} < (2 \times STH \times T_{mdf_proc_ck})$$

It is recommended to compute STH as follows:

$$STH[4:0] = round\left(\frac{(2 \times OVR) - 1}{3}\right)$$

where OVR represents the ratio between the mdf_proc_ck frequency and the expected Manchester symbol frequency. OVR must be higher than five, and the mdf_proc_ck clock must be adjusted according to the constraints listed in *Table 348*.

The clock absence flag CKABF is set to 1 when no transition is detected during more than 2 x STH[4:0] x $T_{mdf_proc_ck}$, or when the SITFx is not yet synchronized to the incoming Manchester stream. In addition, an interrupt can be generated if the bit CKABIE is set to 1.

When the serial interface is enabled, the MDF must first be synchronized to the incoming Manchester stream. The synchronization ends when a data transition from 0 to 1 or from 1 to 0 (pink circle in the *Figure 342*) is detected.

The end of the synchronization phase can be checked by following the software sequence:

1. Clear the CKABF flag in the *MDF DFLTx interrupt status register x (MDF_DFLTxISR)* by writing CKABF bit to 1. If the serial interface is not yet synchronized, the hardware immediately sets the CKABF flag to 1.
2. Read the CKABF flag.
   – If CKABF = 1, go back to step 1.
   – If CKABF = 0, the Manchester interface is synchronized and provides valid data.

Programming example

In the following example, the MDF kernel clock frequency ($F_{mdf_ker_ck}$) is 100 MHz and the received Manchester stream is at about 6 MHz (F_{SYMB}).

1. Provide a valid mdf_proc_ck to the SITFx.

   The mdf_proc_ck frequency must be at least six times higher than the Manchester symbol frequency (means at least 36 MHz).

   PROCDIV is programmed to 1 to perform a division by two of the kernel clock. In that case, $F_{mdf_proc_ck}$ = 50 MHz (8.33 times higher than the Manchester symbol frequency).
2. Compute STH.

   OVR is given by: OVR = $F_{mdf_proc_ck}$ / F_{SYMB} = 50 MHz / 6 MHz = 8.33.

   Then STH[4:0] = $\text{round}\left(\frac{(2 \times 8.33) - 1}{3}\right) = 5$

   The minimum allowed frequency for the Manchester stream is then:

   1 / (2 × STH × $T_{mdf_proc_ck}$) = 1 / (10 x 20 ns) = 5 MHz

   The maximum allowed frequency for the Manchester stream is then:

   1 / ((STH+1) × $T_{mdf_proc_ck}$) = 1 / (6 x 20 ns) = 8.33 MHz

36.4.4 ADC slave interface (ADCITF)

The ADCs are not always connected to the MDF. Refer to *Section 36.3* to check the situation for this product.

The MDF allows the connection of up to two ADCs to the filter path. For each filter, the DATSRC[1:0] bitfield in the *MDF digital filter configuration register x (MDF_DFLTxCICR)* allows the application to select either data from the ADCs.

Warning: The MDF does not support receiving interleaved data from one of the ADCITF input.

36.4.5 Clock generator (CKGEN)

The RCC (reset and clock controller) provides the following clocks to the MDF:

- AHB clock (mdf_hclk) used for the register interface
- kernel clock (mdf_ker_ck) mainly used by all other parts of the circuit via the CKGEN

Those clocks are not supposed to be phase locked, so all signals crossing those clock domains are resynchronized.

The clock generator (CKGEN) is responsible of the generation of the processing clock, and the clock provided to the MDF_CCK0 and MDF_CCK1 pins. All those clocks are generated from the mdf_ker_ck.

The processing clock (mdf_proc_ck) is used to run all the signals processing and to re-sample the incoming serial or parallel stream.

Note: The reshape filter (RSFLT) needs up to 24 cycles of mdf_proc_ck clock to process a sample.

To adapt the kernel clock frequency provided by the RCC, the following dividers are available:

- PROCDIV[6:0] used to adapt the kernel clock frequency to the constraints of the parallel and serial interfaces, and to the processing blocks
- CCKDIV[3:0] used to adapt the frequency of the MDF_CCK0 and MDF_CCK1 clocks

PROCDIV[6:0] and CCKDIV[3:0] must be programmed when no clock is provided to the dividers (CKGDEN = 0).

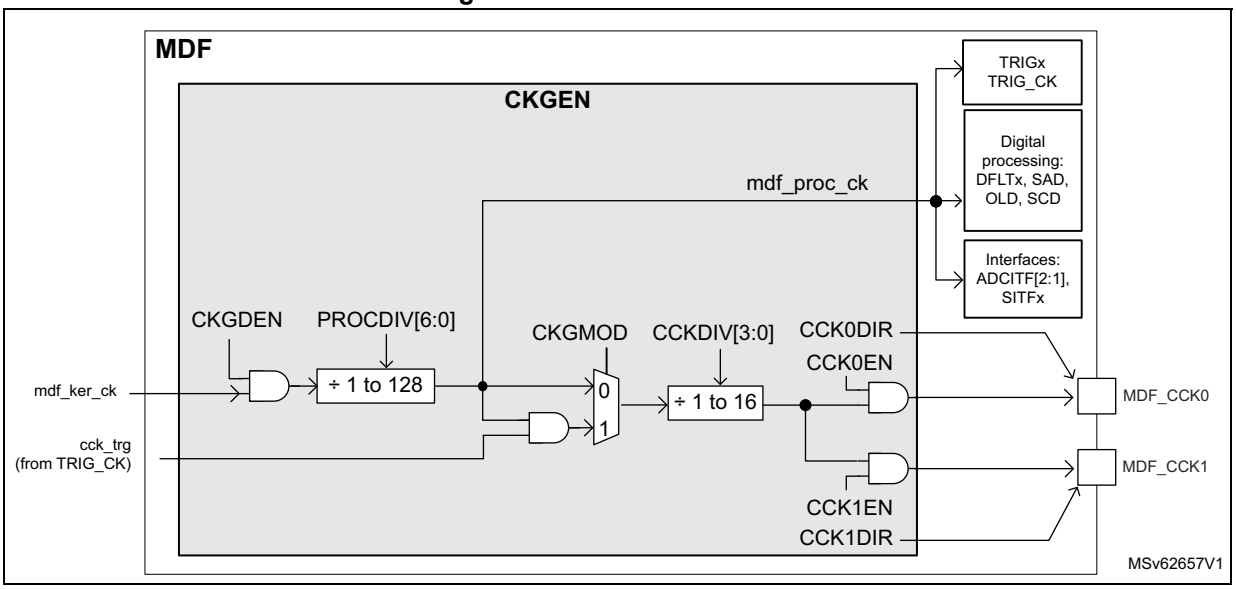
The mdf_proc_ck generation is controlled by CKGDEN.

In addition, the CKGMOD bit allows the application to define the way to trigger the CCKDIV divider:

- When CKGMOD = 0, the CCKDIV divider is started as soon as CKGDEN is set to 1.
- When CKGMOD = 1, the CCKDIV divider is started when CKGDEN is set to 1 and the programmed trigger condition occurred.

All bits and fields controlling the CKGEN are in MDF_CKGCR.

Figure 343. CKGEN overview



The trigger logic for CKGEN is handled by the TRG_CK block. As shown in *Figure 352*, the CCKDIV divider can be triggered on the rising or falling edge of one of the 16 trigger sources. When the proper trigger condition occurs, the cck_trg signal goes to high, allowing the CCKDIV divider to start. The TRG_CK logic is reset when CKGDEN is set to 0.

This feature can be helpful to synchronize the MDF_CCKy (y = 0,1) clock of several MDF instances, or to synchronize the clock generation to a timer event.

The application can control the activation of the MDF_CCK0 or MDF_CCK1 pin CCK0EN/CCK1EN and CCK0DIR/CCK1DIR bits:

- CCKyEN is used to enable the CCKDIV, and thus generates a clock for the external sensors.
- CCKyDIR is used to control the direction of the ADF_CCKy pin (input or output)

Table 347. Control of the common clock generation(1)

CCKyEN	CCKyDIR	Description
0	0	The MDF_CCKy pin is in input. An external clock can be connected to the MDF_CCKy pin and used by the SITFx in order to decode the serial stream
0	1	The MDF_CCKy pin is in output. No clock is generated, thus the MDF_CCKy pin is driven low.
1	1	The MDF_CCKy pin is in output. A clock is generated on the MDF_CCKy pin. The SITFx can use this pin as clock source in order to decode the serial stream

1. The configuration with CCKyEN = 1 and CCKyDIR = 0 must be avoided (no interest).

When CCKyDIR = 1, as soon as the CCKyEN bit is set to 1, a clock is generated to the corresponding output without any spurs.

Note: The mdf_proc_ck must be enabled (by CKGDEN = 1) before enabling other blocks (such as SITFx or DFLTx).

CKGEN activation sequence example

1. Set CKGDEN to 0.
2. Wait for CKGACTIVE = 0. If CKGDEN was previously enabled, this phase can take two periods of mdf_hclk and two periods of mdf_proc_ck.
3. Program PROCDIV[6:0], CKGMOD, CCKDIV[3:0], TRGSRC[3:0] and TRGSENS.
4. Set CKGDEN to 1.
5. Set CCKxDIR to 1 (optional).
6. Set CCKxEN to 1 (optional).

When needed, at any moment, the CCK0EN or CCK1EN value can be changed without disabling the clock generator.

Clock frequency constraints

The table below shows the frequency constraints to receive and process properly the samples.

Table 348. Clock constraints with respect to the incoming stream(1)

SITFx mode	MDF clock constraints	
	With RSFLT disabled	With RSFLT enabled
LF_MASTER SPI	F_{MDF_CCKy} max frequency limited to 5 MHz	
	$F_{mdf_proc_ck} > 2 * F_{MDF_CCKy}$ and $F_{mdf_hclk} \geq F_{mdf_proc_ck}$	$F_{mdf_proc_ck} > 24 * F_{MDF_CCKy} / (MCICD+1)$ and $F_{mdf_proc_ck} > 2 * F_{MDF_CCKy}$ and $F_{mdf_hclk} \geq F_{mdf_proc_ck}$
MASTER SPI SLAVE SPI	F_{MDF_CKx} max frequency limited to 25 MHz	
	$F_{mdf_proc_ck} > 4 * F_{MDF_CKKy}$ and F_{mdf_hclk} higher or equal to $F_{mdf_proc_ck}$	$F_{mdf_proc_ck} > 24 * F_{MDF_CKKy} / (MCICD+1)$ and $F_{mdf_proc_ck}$ higher than 4 x F_{MDF_CKKy} and F_{mdf_hclk} higher or equal to $F_{mdf_proc_ck}$
Manchester	F_{SYMB} max frequency limited to 20 MHz	
	$F_{mdf_proc_ck}$ higher than 6 * F_{SYMB} and $F_{mdf_hclk} \geq F_{mdf_proc_ck}$	$F_{mdf_proc_ck}$ higher than 24 * $F_{MDF_CKKy} / (MCICD+1)$ and $F_{mdf_proc_ck} > 6 * F_{SYMB}$ and $F_{mdf_hclk} \geq F_{mdf_proc_ck}$

1. F_{MDF_CKKy} represents the frequency of the clock received via MDF_CKIx and MDF_CCKy, or generated via MDF_CCKy.F_{SYMB} represents the frequency of the received symbol rate for Manchester mode.

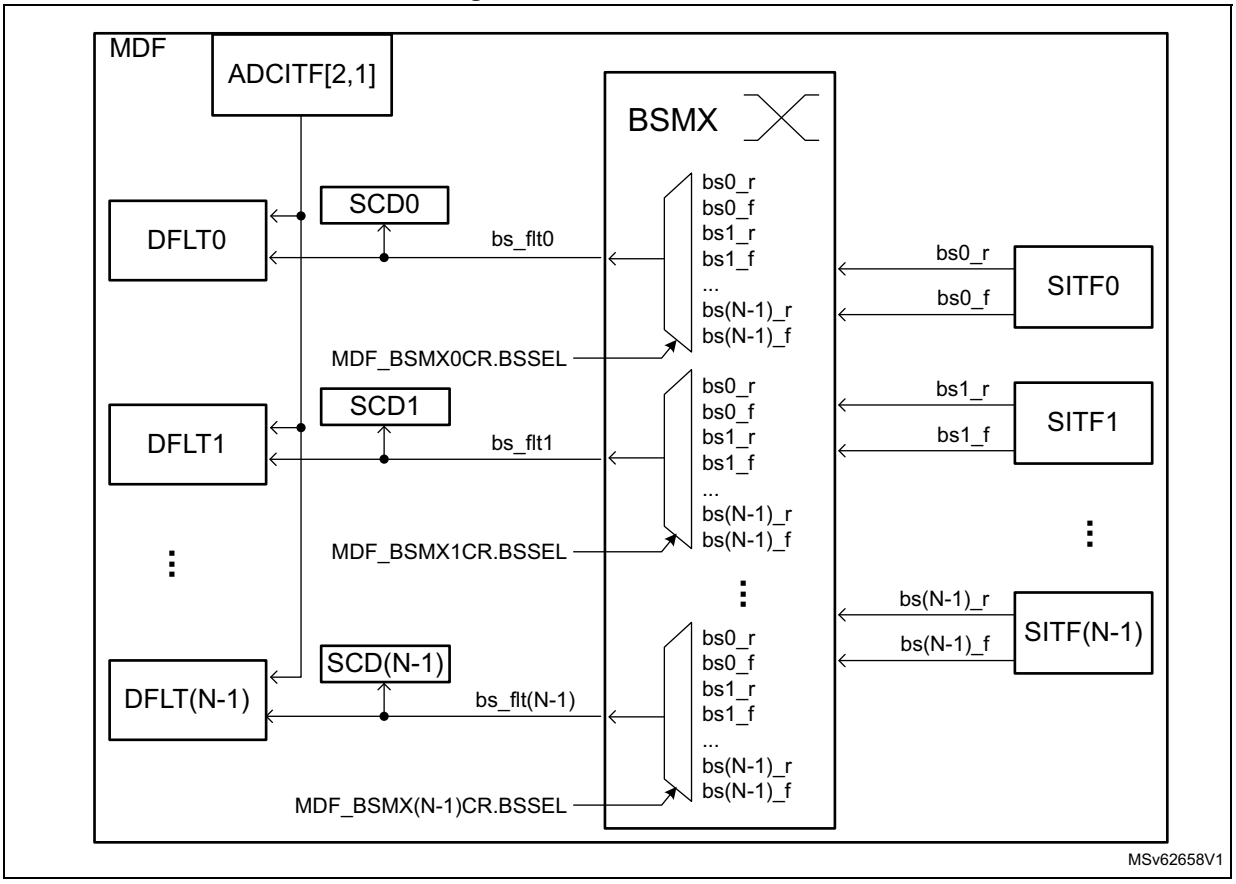
36.4.6 Bitstream matrix (BSMX)

The BSMX receives the bitstreams from all serial interfaces (SITFx) and provides the selected input to the digital filters (DFLTx) and to the short-circuit detectors (SCDx). For each filter path, any of the bitstream input can be selected.

As shown in the *Figure 340*, each SITFx block provides two bitstreams (bsx_r and bsx_f) to the BSMX.

The application to select the wanted stream via the *MDF bitstream matrix control register x (MDF_BSMXxCR)*. This selection is intended to be static.

Figure 344. BSMX overview



BSMX programming sequence example

The BSSEL[4:0] bitfield cannot be changed if the corresponding SCDx, OLDx or DFLTx is enabled. The following steps are needed to change the value of BSMX, for filter path x:

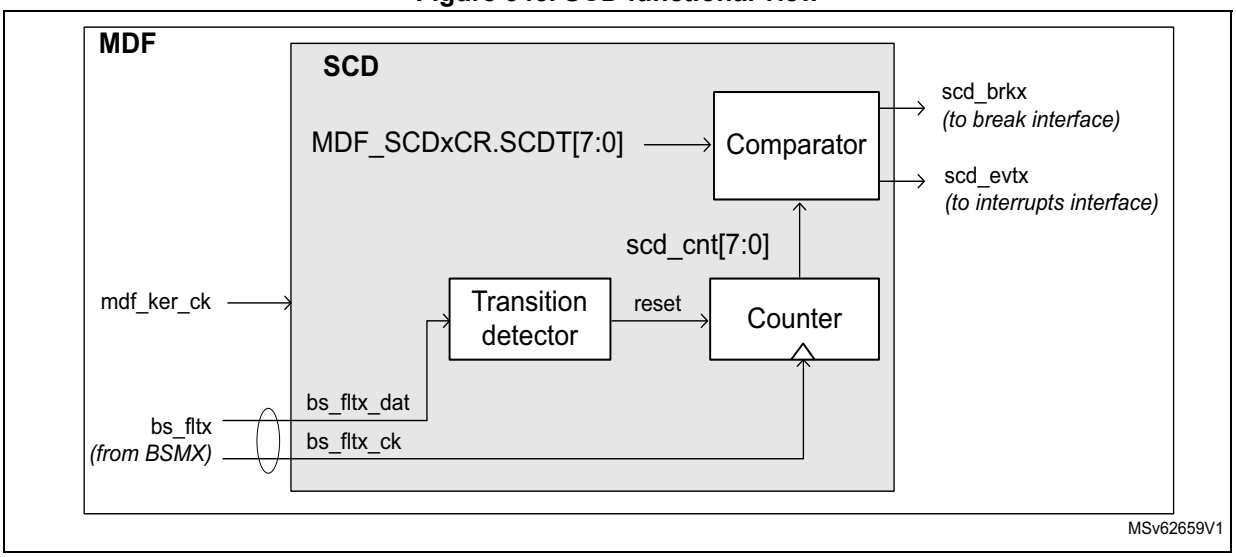
1. Set SCDEN of SCDx to 0.
2. Set DFLTEN of DFLTx to 0.
3. Set OLDEN of OLDx to 0.
4. Wait for BSMXACTIVE = 0.
5. Program BSSEL[4:0] of filter path x.
6. Set SCDEN of SCDx to 1 (optional).
7. Set DFLTEN of DFLTx to 1 (optional).
8. Set OLDEN of OLDx block to 1 (optional).

36.4.7 Short-circuit detectors (SCD)

The SCDx detects, with a very fast response time, if an analog signal reached saturated values (out-of-full scale ranges) and remained on this value for a given time.

This behavior can detect short-circuit or open-circuit errors (such as over current or over voltage). An interrupt event or/and a break signal can be generated.

Figure 345. SCD functional view

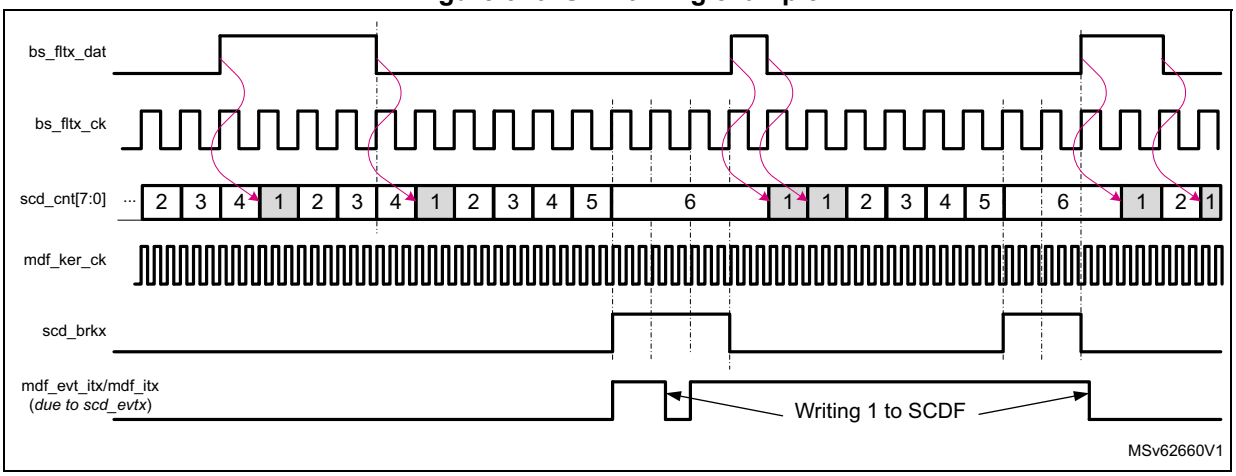


The SCDx is counting consecutive zeros or consecutive ones received from the serial interface (SITFx). A counter is restarted if there is a change in the data stream received. If this counter reaches a short-circuit threshold value (SCDT[7:0] in the *MDF short circuit detector control register x (MDF_SCDxCR)*), then a short-circuit event is invoked. Each BSMX output has its own short-circuit detector. Any BSMX output can be continuously monitored by setting the corresponding SCDEN bit to 1 in MDF_SCDxCR. Each SCD has its own threshold settings (SCDT) and its own status bit (SCDF).

The figure below shows an example where SCDT[7:0] is set to six. The break signal remains high as long as the short circuit condition is present.

No overrun event is generated when the interrupt event is pending while a new short-circuit condition is detected.

Figure 346. SCD timing example



The SCDx event generated by the SCDx block can be assigned to break output signals mdf_break[3:0]. The break signal assignment to a given short-circuit detector event is done by BKSCD[3:0] in MDF_SCDxCR. The break outputs are shared with the over-current function.

Note: SCDs cannot be used to monitor the ADC data interface (ADCITF).

SCD activation sequence example

1. Enable and configure CKGEN to generate the mdf_proc_ck.
2. Set SCDEN to 0.
3. Wait for SCDACTIVE = 0. If SCDEN was previously enabled, this phase can take two periods of mdf_hclk, and two periods of mdf_proc_ck.
4. Program BKSCD[3:0] and SCDT[7:0].
5. Set SCDEN to 1.

Note: BKSCD[3:0] and SCDT[7:0] must not be changed when SCDACTIVE = 1.

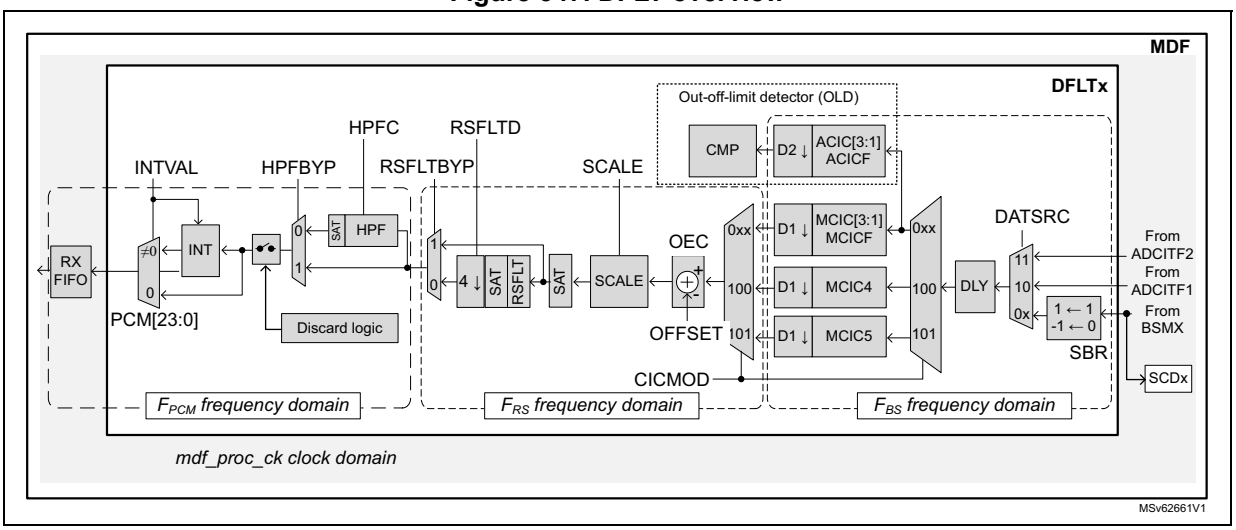
36.4.8 Digital filter processing (DFLT)

The digital filter processing includes the following sub-blocks:

- symbol remap (SBR)
- source selector
- clock skipper delay (DLY)
- CIC decimation filter that can be configured:
  - in single $Sinc^4$ or $Sinc^5$ order CIC (MCIC)
  - in two CIC filters:
    - a main filter (MCIC), high resolution
    - an auxiliary filter (ACIC), low-latency, for the out-off-limit detector (OLD)
    - both MCIC and ACIC can be configured as $Sinc^1$, $Sinc^2$, $Sinc^3$ or FastSinc
- gain control (SCALE)
- signal saturation (SAT)
- reshape filter (RSFLT)
- high-pass filter (HPF)
- integrator (INT)
- receive RXFIFO

Figure 347 shows the filter-path configuration according to CICMOD[2:0]. Several configuration bits are available to configure the digital filter to the application needs.

Figure 347. DFLT overview



Symbol remap and source selection

The symbol remap (SBR) converts the bitstream selected by the BSMX into data usable by the filter path. More especially:

- The high levels are converted into a 16-bit signed number + 1.
- The low levels are converted into a 16-bit signed number - 1.

The signal source of the digital filter can be selected via DATSRC[1:0] between the two following:

- data coming from the BSMX
- data coming from one of the ADC interfaces (ADCITF2 or 1)

Programmable micro-delay control (DLY)

The digital filter has a delay line that allows the timing adjustment of each stream with the resolution of the bitstream clock.

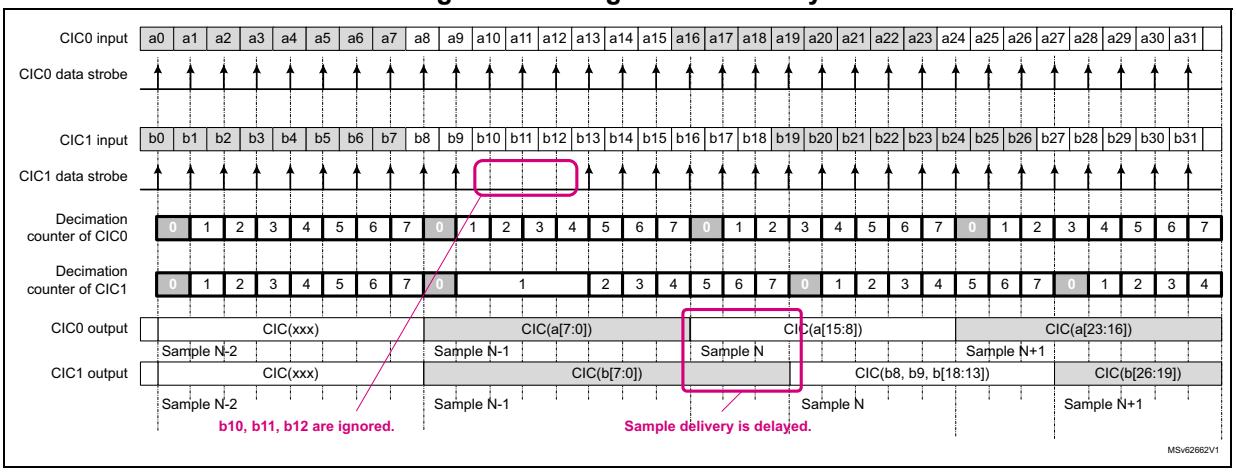
This feature is particularly helpful in the case of microphone beam forming applications where delays smaller than the final sampling rate, must be applied to the incoming stream.This feature is helpful when the MDF is synchronized with other ADF or MDF blocks for a beam forming application for example.

The delay is performed by discarding a given number of samples from the selected input stream, before samples enter into the CIC filter. This data discarding is performed by skipping a given number of data strobe, preventing the CIC filter to take into account those data.

When the wanted amount of data strobe has been skipped, the next incoming samples are strobed normally.

Figure 348 shows an example of how to apply dynamically small delay to an incoming stream. For simplification, the CIC filter performs a decimation by height in this example. CIC1 represents the CIC included in the ADF and CIC0 represents a filter from another ADF or MDF instance.

Figure 348. Programmable delay



The CIC of filter 1 (CIC1) receives a command in order to skip three incoming samples. So the input samples named b10, b11 and b12 are not processed by CIC1. As a consequence, the output sample N+1 generated by CIC0 is build from input samples a[23:16] while the sample N+1 of CIC1 is build from input samples b[26:19].

Finally, the non-skipped data stream looks delayed by three bitstream periods.

Note: When the input data strobes are skipped, the decimation counter remains frozen. As a consequence, the samples delivered by the CIC1 are a bit delayed.

Warning: It is not recommended to apply a delay bigger than the programmed decimation ratio (CIC + RSFLT decimation), especially if the MDF is programmed in interleaved acquisition mode. There is a strong risk of data misalignment inside the FIFOs.

The following steps are needed to program the amount of bitstream clock periods to be skipped:

1. Wait for SKPBF equal to 0.
2. Write SKPDLY[6:0] to the wanted number of bitstream clock periods to be skipped. The SKPBF flag goes immediately to 1, indicating that the delay value entered into SKPDLY[6:0] is under process.
   - If the corresponding DFLTx is not yet enabled (DFLTEN = 0), then the DLY logic waits for DFLTEN = 1. When the application sets DFLTEN to 1, the DLY logic starts to skip the amount of wanted data strobes.
   - If the corresponding digital filter is already enabled (DFLTEN = 1), then the DLY logic immediately starts to skip the amount of wanted data strobes.

   When the MDF skipped the amount of wanted data strobes, then SKPBF goes back to 0.
3. If the application needs to skip more data strobes, then the operation must be restarted from step 1.

The effect of the delay performed with this mechanism is cumulative as long as the MDF is enabled. In a given filter, if the application performs a D1 delay, followed by a D2 delay, then all other active filters are delayed by D1 + D2.

Data coming from ADCs can also benefit of this feature.

In interleaved acquisition mode, it is up to the application to insure that the delay applied on the different microphones is in line with the depth of the RXFIFO buffers. If the relative delay between each activated filter is less than the decimation ratio, then it costs one FIFO location.

If the interleaved acquisition mode is not used, then the delay value has no impact on the RXFIFO buffering.

Note: If SKPDLY[6:0] is written when SKPBF = 1, the write operation is ignored.

Cascaded-integrator-comb (CIC) filter

The CIC digital filters are an efficient implementation of low-pass filters, often used for decimation and interpolation. The CIC frequency response is equal to a $Sinc^N$ function, this is why they are often called Sinc filters.

The $Sinc^N$ digital filter embedded into the MDF is configurable according to the application targeted.

- For audio applications, such as speech capture from digital microphones, the application can select a high-resolution low-pass decimation filter by setting CICMOD to 100 or 101.
- If the targeted application is motor control or any other sensor capture, then the application can configure the CIC in order to offer a main filter path for acquisition (MCIC) and an auxiliary filter for fast-event generation (ACIC). This auxiliary filter can be used for example, to detect over-current conditions. This mode is selected by setting CICMOD[2:0] = 0xx.

When CICMOD[2:0] = 0xx, the following CIC filters are available:

- main filter (MCIC)
- auxiliary CIC filter (ACIC)

Both of them are configurable in FastSinc, $Sinc^1$ to $Sinc^3$.

When CICMOD[2:0] = 100, the CIC is configured into a single $Sinc^4$ and when CICMOD[2:0] = 101, the CIC is configured into a single $Sinc^5$ filter.

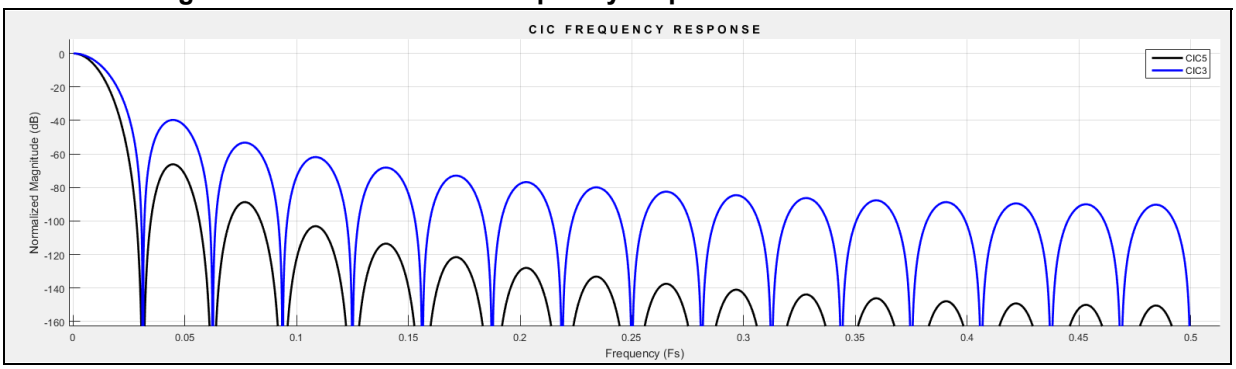
The filters have the following transfer function (impulse response in z domain):

- $Sinc^N$ filter type: $$H(z) = \left(\frac{1 - z^{-D}}{1 - z^{-1}}\right)^N$$
- FastSinc filter type: $$H(z) = \left(\frac{1 - z^{-D}}{1 - z^{-1}}\right)^2 \cdot (1 + z^{-(2 \cdot D)})$$

where N can be 1, 2, 3, 4 or 5, and D is the decimation ratio.

D is equal to MCICD+1 or ACICD+1.

Figure 349. CIC3 and CIC5 frequency response with decimation ratio = 32



CIC output data size

The size of samples delivered by the CIC (DS_{CIC}) depends on the following parameters:

- CIC order (N)
- CIC decimation ratio (D)
- data size of the input stream (DSIN)

The CIC order and decimation ratio must be programmed in order to insure that the data size does not exceed the 26-bit CIC capability.

The following formula gives the output data size (DS_{CIC}) according to the parameters above.

$$DS_{CIC} = \left(\frac{N \times Ln(D)}{Ln(2)}\right) + DS_{IN}$$

and the CIC gain is given by this formula:

$$G_{CIC} = (D)^{N}$$

The decimation ratio can be adjusted from 2 to 512 for the main CIC filter and from 1 to 32 for the auxiliary CIC filter.

The table below gives some data output size in bits for some decimation values, when the data source is a full-scale signal coming from the serial interface or from a 12-bit ADC.

Note: DS_{IN} = 1 bit for a serial bitstream but can be up to 16 bits when coming from the ADCITF.

Table 349. Data size according to CIC order and CIC decimation values

Decimation	Data size (bits) when DS_{IN} = 1 bit (data from SITFx)						Data size (bits) when DS_{IN} = 12 bits (data from ADCITF)					
	$Sinc^1$	$Sinc^2$	FastSinc	$Sinc^3$	$Sinc^4$	$Sinc^5$	$Sinc^1$	$Sinc^2$	FastSinc	$Sinc^3$	$Sinc^4$	$Sinc^5$
4	3	5	6	7	9	11	14	16	17	18	20	22
8	4	7	8	10	13	16	15	18	19	21	24	-
12	5	9	9	12	16	19	16	20	21	23	-	-
16	5	9	10	13	17	21	16	20	21	24	-	-
24	6	11	12	15	20	24	17	22	23	-	-	-
32	6	11	12	16	21	26	17	22	23	-	-	-

Table 349. Data size according to CIC order and CIC decimation values

Decimation	Data size (bits) when DS_{IN} = 1 bit (data from SITFx)						Data size (bits) when DS_{IN} = 12 bits (data from ADCITF)					
	Sinc^1	Sinc^2	FastSinc	Sinc^3	Sinc^4	Sinc^5	Sinc^1	Sinc^2	FastSinc	Sinc^3	Sinc^4	Sinc^5
64	7	13	14	19	25	-	18	24	25	-	-	-
128	8	15	16	22	-	-	19	26	-	-	-	-
256	9	17	18	25	-	-	20	-	-	-	-	-
512	10	19	20	-	-	-	21	-	-	-	-	-

The LSB part of the data provided by the CIC is not necessarily significant: it depends on the sensor performances and the ability of the CIC to reject the out-off-band noise.

The sample size at CIC output can be adjusted thanks to the SCALE block.

The table below shows the maximum allowed decimation ratio for the CIC filter, depending on the input data size. Bigger decimation ratio causes a wrap-around of the signal at CIC output, for strong input signals.

Note: The MDF cannot detect or prevent a CIC wrap-around.

Table 350. Maximum decimation ratio versus order and input data size

Filter order	Max. decimation ratio when DS_{IN} = 1 bit (SITFx)	Max. decimation ratio when DS_{IN} = 12 bits (ADCITF)	Max. decimation ratio when DS_{IN} = 16 bits (ADCITF)
Sinc^1	512	512	512
Sinc^2	512	128	32
FastSinc	512	90	22
Sinc^3	322	25	10
Sinc^4	76	11	5
Sinc^5	32	6	4

Scaling (SCALE) and saturation (SAT)

The SCALE block allows the application to adjust the amplitude of the signal provided by the CIC, by steps of 3 dB (± 0.5 dB).

The signal amplitude can be decreased by up to 8 bits (- 48.2 dB) and can be increased by up to 12 bits (+ 72.2 dB).

The gain is adjusted by the SCALE[5:0] bitfield in the *MDF digital filter configuration register x (MDF_DFLTxCICR)*.

SCALE[5:0] can be changed even if the corresponding DLFTx is enabled. During the gain transition, the signal provided by the filter is disturbed.

Due to internal resynchronization, there is a delay of some cycles of mdf_proc_ck clock between the moment where the application writes the new gain, and the moment where the gain is effectively applied to the samples. If the application attempts to write a new gain value while the previous one is not yet applied, this new gain value is ignored. Reading back SCALE[5:0] informs the application on the current gain value.

The table below shows the possible gain values.

Table 351. Possible gain values

SCALE[5:0]	Gain (dB)	SCALE[5:0]	Gain (dB)	SCALE[5:0]	Gain (dB)	SCALE[5:0]	Gain (dB)
0x20	- 48.2	0x2B	- 14.5	0x06	+ 18.1	0x11	+ 51.7
0x21	- 44.6	0x2C	- 12.0	0x07	+ 21.6	0x12	+ 54.2
0x22	- 42.1	0x2D	- 8.5	0x08	+ 24.1	0x13	+ 57.7
0x23	- 38.6	0x2E	- 6.0	0x09	+ 27.6	0x14	+ 60.2
0x24	- 36.1	0x2F	- 2.5	0x0A	+ 30.1	0x15	+ 63.7
0x25	- 32.6	0x00	0.0	0x0B	+ 33.6	0x16	+ 66.2
0x26	- 30.1	0x01	+ 3.5	0x0C	+ 36.1	0x17	+ 69.7
0x27	- 26.6	0x02	+ 6.0	0x0D	+ 39.6	0x18	+ 72.2
0x28	- 24.1	0x03	+ 9.5	0x0E	+ 42.1	-	-
0x29	- 20.6	0x04	+ 12.0	0x0F	+ 45.7	-	-
0x2A	- 18.1	0x05	+ 15.6	0x10	+ 48.2	-	-

The SAT blocks avoid having a wrap-around of the binary code when the code exceeds its maximal or minimal value.

The MDF performs saturation operations at the following levels:

- after the SCALE block (performed by the SAT block). The signal is saturated at 24 bits.
- inside the RSFLT, to insure a good filter behavior
- at the output of the HPF, to insure that the output signal does not exceed 24 bits

The SATF bit informs the application that a saturation occurred either after the SCALE, inside the RSFLT or after the HPF. In addition, an interrupt can be generated if SATIE is set to 1. As soon as a saturation is detected, the SATF flag is set to 1. It is up to the application to clear this flag in order to be able to detect a new saturation.

Those bits are in the *MDF DFLTx interrupt enable register x (MDF_DFLTxIER)* and *MDF DFLTx interrupt status register x (MDF_DFLTxISR)*.

Gain adjustment policy

To get the best MDF performances, it is important to properly adjust the gain value via SCALE[5:0].

A usual way to adjust the gain is to select the SCALE[5:0] value that gives a final signal amplitude as close as possible to the 24-bit full scale, for the maximum input signal.

A way to select the optimal gain is detailed below:

1. Check that, for the expected input signal, the data size into the CIC filter does not exceed 26 bits. This can be checked using this formula:

$$\frac{LN(SIN_{pp} \cdot D^N)}{LN(2)} < 26$$

where N represents the CIC order, D the decimation ratio and SIN_{pp} the maximum peak-to-peak amplitude of the input signal.

SIN_{pp}can take:

– a maximum peak-to-peak amplitude of 2 (± 1), for samples coming from SITF

– a maximum peak-to-peak amplitude of 4095 (+ 2047, - 2048) for samples coming from a 12-bit ADC

Example: a $Sinc^4$ can be used with a decimation ratio of 96, if the maximum input signal does not exceed ± 0.35. Indeed:

$$\frac{LN(0.7 \cdot 96^4)}{LN(2)} \sim 25.82 \text{ bits} < 26 \text{ bits}$$

2. Adjust the SCALE value.

To select the most appropriate SCALE value, the user must check if the RSFLT is used or not. If the RSFLT is used, the data size at SCALE output must not exceed 22 bits, otherwise the data size can be up to 24 bits.

The SCALE value in dB is selected using this formula:

$$SCALE_{dB} < 20 \cdot \log 10\left(\frac{2^{NB}}{SIN_{pp} \cdot D^N}\right)$$

where NB is equal to 22 if RSFLT is enabled, or 24 if RSFLT is bypassed. $SCALE_{dB}$ represents the gain value selected by SCALE[5:0].

Example: for a $Sinc^4$ with a decimation ratio of 96 and a SIN_{pp} of 0.7:

– If the RSFLT is bypassed:

$$20 \cdot \log 10\left(\frac{2^{24}}{0.7 \cdot 96^4}\right) \sim 11 \text{ dB}$$

$SCALE_{dB}$ value must be lower than - 11 dB. The closest lower value is - 12dB (SCALE[5:0] = 0x2C).

– If the RSFLT is enabled:

$$20 \cdot \log 10\left(\frac{2^{22}}{0.7 \cdot 96^4}\right) \sim 23 \text{ dB}$$

$SCALE_{dB}$ value must be lower than - 23 dB, the closest lower value is - 24.1 dB (SCALE[5:0] = 0x28).

If SCALE[5:0] is set to a higher value, then a saturation may occur. An event flag informs the user if a saturation occurred.

The table below proposes gain values for different filter configurations, when the data comes from the SITFx, according to the CIC order, and the CIC decimation ratio. This table is not exhaustive, and considers a full-scale input signal (see *Section 36.7.5* for details).

Table 352. Recommended maximum gain values versus CIC decimation ratios

CIC decimation ratio	Gain settings (dB) for configuration SITF + CICx + RSFLT (+ HPF)					Gain settings (dB) for configuration SITF + CICx (+ HPF)				
	CIC5	CIC4	CIC3	CIC2	CIC1	CIC5	CIC4	CIC3	CIC2	CIC1
8	33.6	51.7	69.7	72.2	72.2	45.7	63.7	72.2	72.2	72.2
12	18.1	39.6	60.2			30.1	51.7			
16	3.5	27.6	51.7			15.6	39.6	63.7		
20	- 6.0	21.6	48.2			6.0	33.6	60.2		
24	- 12.0	15.6	42.1	69.7		0	27.6	54.2		
28	- 20.6	9.5	36.1	66.2		- 8.5	21.6	48.2		
32	-26.6	3.5	33.6	63.7		- 14.5	15.6	45.7		
48	-	- 8.5	24.1	57.7		-	3.5	31.6	69.7	
64	-	- 20.6	15.6	51.7		-	-8.5	27.6	63.7	
128	-	-	- 2.5	39.6		-	-	9.5	51.7	
256	-	-	- 20.6	27.6		-	-	-8.5	39.6	

Reshaping filter (RSFLT)

In addition to the CIC, the MDF offers a reshaping IIR filter mainly dedicated to the audio application but also usable in other applications.

When the RSFLT is used, the sample size at its input must not exceed 22 bits.

The samples at the RSFLT output can be decimated by four or not according to the RSFLTD bit in the *MDF reshape filter configuration register x (MDF_DFLTxRSFR)*.

The RSFLT can be bypassed by setting RSFBYP to 1 in MDF_DFLTxRSFR.

The table below shows which sampling rate must be provided to the RSFLT in order to process the most common audio streams.

The RSFLT cutoff frequency (F_C) depends on the sample rates at its input (F_{RS}), and is given by the following formula:

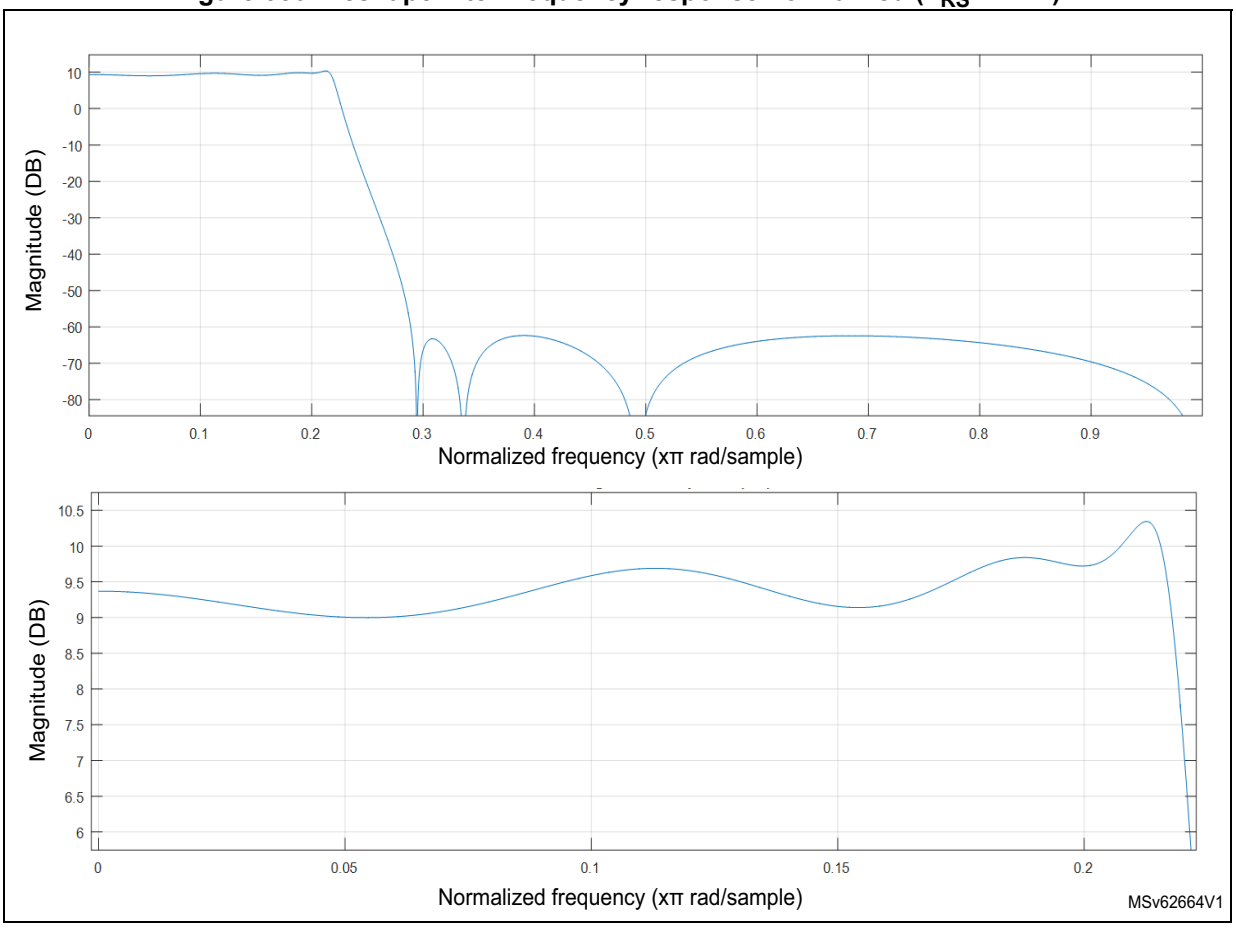
$$F_C = 0.111 \times F_{RS}$$

Table 353. Most common microphone settings

Sample rate (kHz) at RSFLT (F_{RS})	Pass band (kHz)	D2	PCM sampling rate (kHz)
32	3.55	4	8
64	7.1	4	16
128	14.2	4	32
192	21.3	4	48

The figure below shows the frequency response of the reshape filter.

Figure 350. Reshape filter frequency response normalized (F_{RS} / 2 = 1)



The RSFLT gain is about 9.3 dB, so the output data size is a little bit lower than 24 bits for a 22-bit wide input signal.

The RSFLT takes 24 clock cycles of mdf_proc_ck clock to process one sample at F_{RS}. When the RSFLT is enabled, the application must insure that the mdf_proc_ck is at least 24 times faster F_{RS}.

The RSFLT generates an event (rfovr_evt) and sets the RFOVRF flag, if the RSFLT receives a new sample while the previous one is still under processing.

When RFOVRF is set, the samples provided by the RSFLT are invalid. The application must then stop the data acquisition and provide x a faster mdf_proc_ck clock to the RSFLT.

High-pass filter (HPF)

The high-pass filter suppresses the low-frequency content from the final output data stream in case of continuous conversion mode. The high-pass filter can be enabled or disabled via HPFBYP in the *MDF reshape filter configuration register x (MDF_DFLTxRSFR)*.

The HPF is useful when there is parasitic low-frequency noise (or DC signal) in the input data source and it must be removed from the final data.

The HPF is a first order IIR filter and the cut-off frequency can be selected via HPFC[1:0] in the *MDF reshape filter configuration register x (MDF_DFLTxRSFR)*, among the following values:

- 0.000625 x F_{PCM}
- 0.00125 x F_{PCM}
- 0.00250 x F_{PCM}
- 0.00950 x F_{PCM}

Table 354. HPF 3 dB cut-off frequencies examples

HPFC	3 dB cut-off frequency for common F_{PCM} frequencies (Hz)		
	F_{PCM} = 8 kHz	F_{PCM} = 16 kHz	F_{PCM} = 48 kHz
0	5	10	30
1	10	20	60
2	20	40	120
3	76	152	456

The HPF output is saturated at 24 bits. The SATF flag is set if a sample is saturated.

Offset error compensation (OEC)

Each digital filter has its own OEC. The offset correction is performed by subtracting to the signal provided by the CIC, the OFFSET[25:0] in the *MDF offset error compensation control register x (MDF_OECxCR)*.

Due to the internal resynchronization, there is a delay of some cycles of mdf_proc_ck clock between the moment where the application writes the new offset, and the moment where the new offset value is effectively applied to the samples. If the application attempts to write a new offset value while the previous one is not yet applied, this new offset value is ignored. Reading back OFFSET[25:0] informs the application on the current offset value.

Integrator (INT)

The INT performs additional decimation and a resolution increase of data coming from the digital filter. The INT simply performs the sum of data from a digital filter for a given number of data samples from a filter.

The INT is enabled by setting INTVAL[6:0] to a value different from 0.

The amount of integrated values can be defined by INTVAL[6:0] in the range of 2 to 128.

In order to control the data width at the integrator output, the resulting data can be divided by 1, 4, 32 or 128. This feature is controlled by INTDIV[1:0].

36.4.9 Out-of-limit detector (OLD)

The OLD triggers an event when a signal reaches or crosses given maximum and minimum threshold values. The generated event can drive an interrupt or break signals (mdf_break[3:0]) when conditions are met.

The OLD can be used only if the CIC filter is configured in motor and sensing mode (CICMOD[2:0] = 0xx).

The OLD takes the input signal selected by the main filter, process it using a $Sinc^N$ or FastSinc filter (ACIC), and compares the resulting signal to programmed thresholds.

The OLD is enabled via the OLDEN bit in MDF_OLD0CR. Once enabled, the input data are continuously monitored. There is no need to have the DFLTx enabled for using the OLD function.

The MDF offers a high- and low-threshold register that are compared with given data values.

The application can generate an event if the signal is inside or outside the boundary defined by those two thresholds. This behavior is controlled via THINB in the MDF_OLD0CR.

If the application only wants to generate an event when the input signal is higher than OLDTHH, then THINB and OLDTHL must both be cleared to 0.

If the application only wants to generate an event when the input signal is lower than OLDTHH, then THINB must be set to 1 and OLDTHL must be cleared to 0.

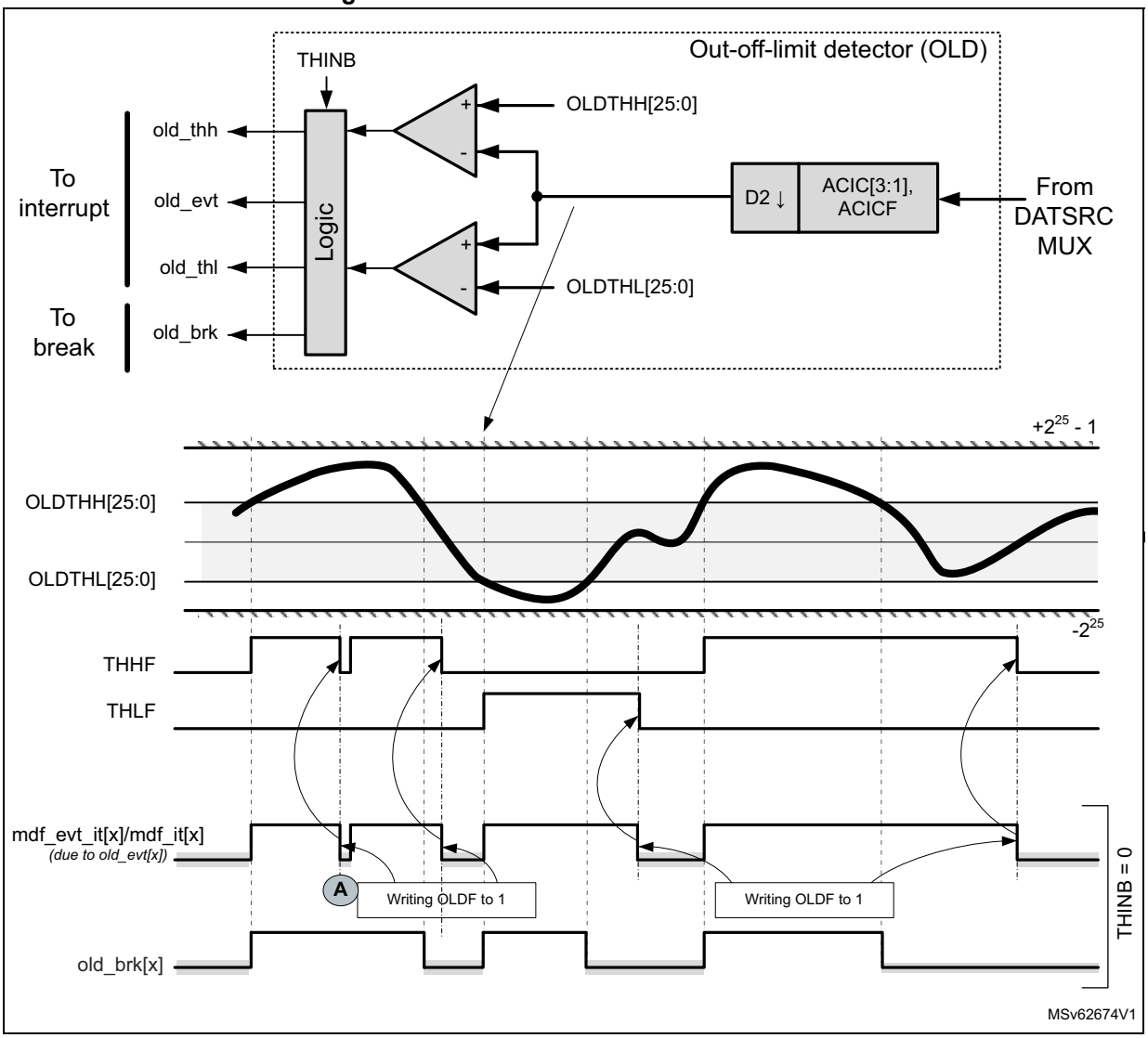
Note: It is not recommended to set a OLDTHL to a value bigger than OLDTHH.

The response time of the OLD depends on several parameters, the most important are listed hereafter:

- sampling rate frequency used by the external sensor
- ACIC decimation ratio
- ACIC order

The OLD can be used for over-current detection but also as current limiter if the PWM signal is generated by a timer receiving a old_brk signal. Generally, to get a fast response time for over-current detection, it is recommended to use the ACIC with lowest order as possible and the minimum decimation ratio. FastSinc is also a good choice for over-current detection. The application must perform a trade-off between the filter resolution and the response time.

Figure 351. Out-of-limit detector thresholds



Status flags are available in order to inform the application that an OLD event is detected. Latched events are cleared by writing 1 into the OLDF bit.

As shown in *Figure 351*, when THINB = 0, the interrupt signal remains active as long as the signal is outside the gray area. At position A, the application clears the interrupt, but the interrupt is re-asserted because the signal is still outside the gray area. When the application clears OLDF, THHF and THLF are cleared as well.

An OLD event can be assigned to one or several break output signals (mdf_break[3:0]). The break signal assignment to a given OLD event is done by BKOLD[3:0] in the *MDF out-of limit detector control register x (MDF_OLDxCR)*.

Note: The generation of break signals is independent from the interrupts generation.

OLD activation sequence example

1. Enable and configure CKGEN.
2. Set OLDEN to 0.

3. Wait for OLDACTIVE = 0. If OLDEN was previously enabled, this phase can take two periods of mdf_hclk and two periods of mdf_proc_ck.
4. Program BKOLD[3:0], ACICN[1:0], ACICD[4:0], THINB,OLDTHL[25:0] and OLDTHH[25:0].
5. Set OLDEN to 1.

36.4.10 Digital filter acquisition modes

The MDF offers the following modes to perform a data capture:

- asynchronous continuous acquisition mode
- asynchronous single-shot acquisition mode
- synchronous continuous acquisition mode
- synchronous single-shot acquisition mode
- window continuous acquisition mode
- synchronous snapshot acquisition mode

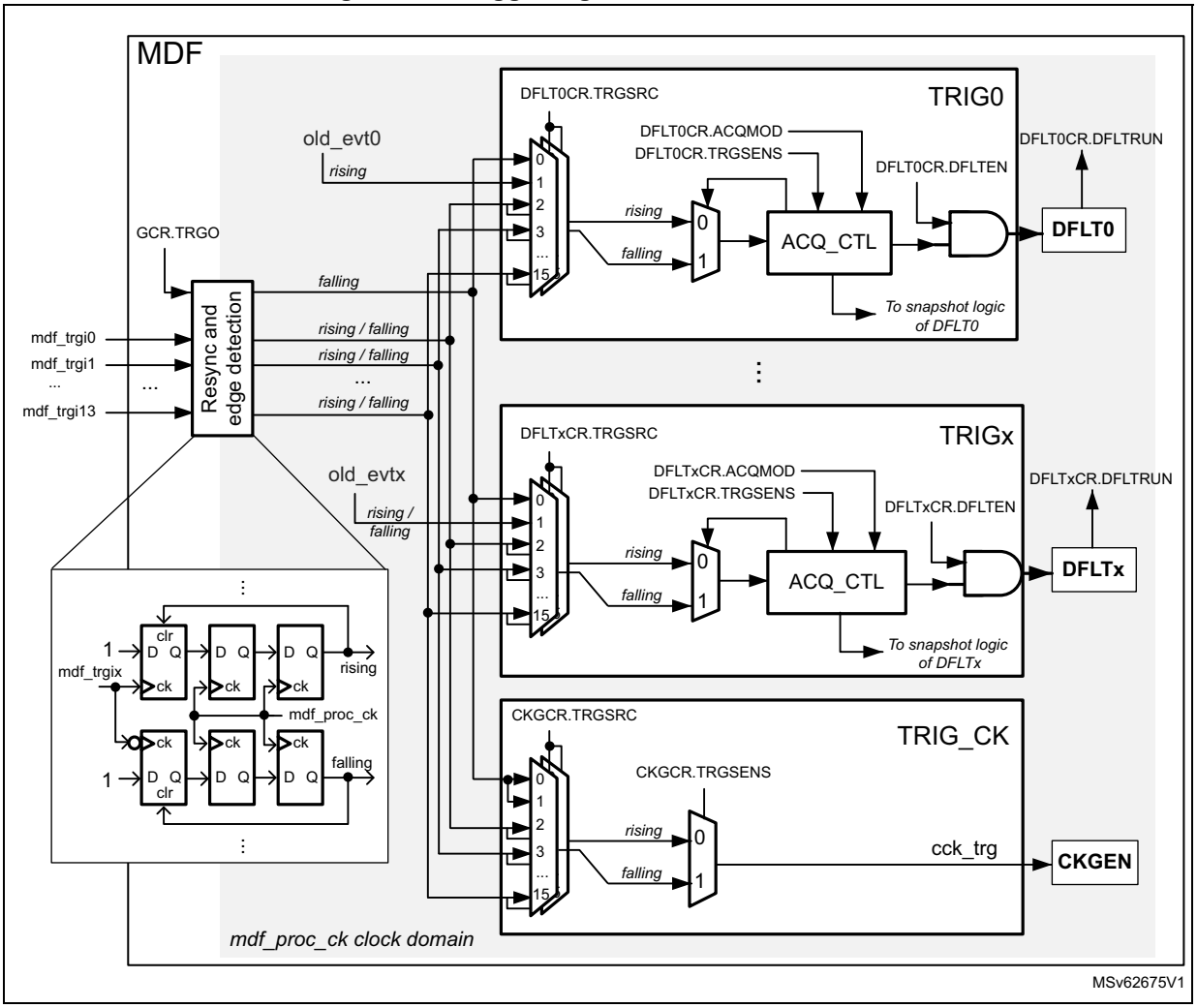
For each filter, one of these modes can be selected independently.

Note: To perform a data capture, the filters, the interfaces providing the data (SITFx or ADCITF) and the CKGEN must be enabled. If needed, MDF_CCK0 or MDF_CCK1 must be enabled as well.

The filter can be stopped immediately when DFLTEN is set to 0. This resets the filters and flushes the RXFIFO of the corresponding filter path. The DFLTACTIVE flag also goes back to 0 when the RXFIFO and the filters are reset.

The figure below shows a simplified view of the trigger logic available for each filter and for the clock generator.

Figure 352. Trigger logic for DFLT and CKGEN



A block common to all TRIG blocks performs the rising and falling edges detection and the resynchronization of the input triggers to the mdf_ker_ck clock domain. This implementation allows the application to use triggers with pulse width smaller than the mdf_ker_ck period.

In synchronous modes, the TRIG block offers the possibility to select one of the following trigger sources:

- mdf_trgi[13:0] signals (refer to *Table 344* for the trigger connections)
- TRGO bit in MDF_GCR
- OLD event of each filter path

The edge sensitivity can also be selected, except for TRGO and OLD events.

Asynchronous continuous acquisition mode

This mode allows the application to start a continuous acquisition on one or several filters by simply writing their DFLTEN bits to 1.

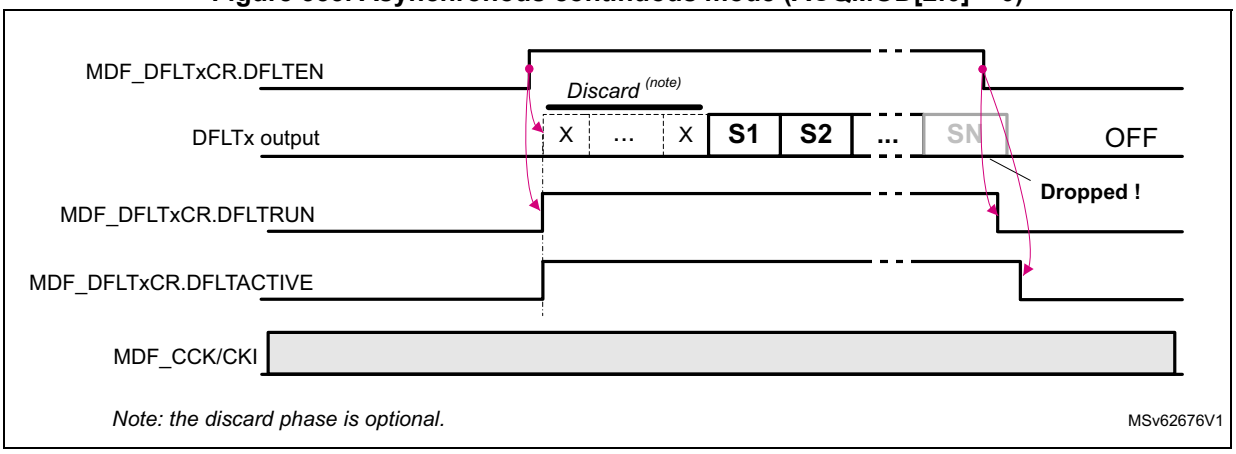
The Asynchronous continuous acquisition mode is selected when ACQMOD[2:0] = 0.

The sequence below shows the most important programming steps (assuming that DFLTEN bits of the filters are set to 0):

1. Configure and enable the clock generator (CKGEN) so that the mdf_proc_ck frequency is compatible with the targeted application (see examples in *Table 358*).
2. Enable the CKGEN (CKGDEN = 1) and, if needed, enable the MDF_CCK0 and MDF_CCK1 clocks.
3. Program the filter configuration and set the ACQMOD[2:0] to 0.
4. Set to 1 the SITFEN bit of the requested data interfaces.
5. Before setting DFLTEN to 1, wait for DFLTACTIVE = 0: it insures that the previous filter deactivation sequence terminated properly.
6. When DFLTEN is set to 1 for the filters to enable, the acquisition sequence starts immediately.

The figure below shows a simplified example of the samples generated by the DFLTx.

Figure 353. Asynchronous continuous mode (ACQMOD[2:0] = 0)



Note: The acquisition can be stopped by setting DFLTEN back to 0. This resets the filter and flushes the RXFIFO, so the samples located into the RXFIFO are lost. The ongoing DMA transfer is properly terminated. DFLTACTIVE goes back to 0 when the filter chain is reset and the RXFIFO flushed.

Asynchronous single-shot acquisition mode

This mode allows the application to start the acquisition of one sample on one or several filters by simply writing their DFLTEN bits to 1.

The Asynchronous single-shot acquisition mode is selected when ACQMOD[2:0] = 001.

The sequence below shows the most important programming steps (assuming that DFLTEN bits of the filters are cleared to 0):

1. Configure and enable the clock generator (CKGEN), so that the mdf_proc_ck frequency is compatible with the targeted application (see examples in *Table 354*).
2. Enable the CKGEN (CKGDEN = 1) and, if needed, enable the MDF_CCK0 and MDF_CCK1 clocks.
3. Program the filter configuration and set the ACQMOD[2:0] to 001.
4. Set to 1 the SITFEN bit of the requested data interfaces.

5. Before setting DFLTEN to 1, wait for DFLTACTIVE = 0: it insures that the previous filter deactivation sequence terminated properly.
6. When DFLTEN is set to 1 for the filters to enable, each selected filter provides one data to the RXFIFO and stops the acquisition.

To trigger a new acquisition, for each filter, the application must:

1. Check that the previous acquisition is completed, by waiting that DFLTRUN = 0.
2. Set again DFLTEN to 1.

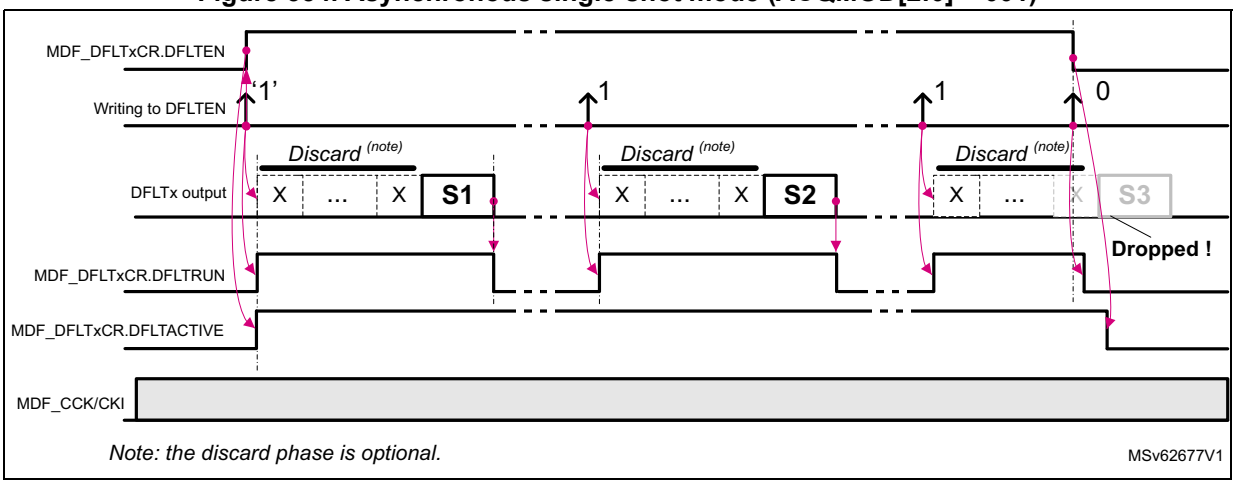
This sequence can be repeated every time a new data must be converted.

As shown in the *Figure 354*, every time DFLTEN is set to 1, an acquisition sequence is triggered. The first samples provided by the filter can be discarded if needed. At the end of each conversion, the decimation counters and filter taps are reset, and the filter is ready to start a new conversion.

If the DFLTEN is set to 0 while an acquisition is ongoing, the ongoing conversion is stopped (in the example, S3 is lost). This situation can be avoided with the following steps:

1. Wait for DFLTRUN = 0.
2. Read the sample from the RXFIFO.
3. Set DFLTEN to 0.

Figure 354. Asynchronous single-shot mode (ACQMOD[2:0] = 001)



Note: The acquisition can be stopped by setting DFLTEN back to 0. This resets the filter and flushes the RXFIFO, so the samples located into the RXFIFO are lost. The ongoing DMA transfer is properly terminated. DFLTACTIVE goes back to 0 when the filter chain is reset and the RXFIFO flushed.

Synchronous continuous acquisition mode

This mode allows the application to start a continuous acquisition on one or several filters by using the following trigger sources:

- one of the mdf_trg[13:0] signals
- OLD event of the corresponding filter
- TRGO bit

The Synchronous continuous acquisition mode is selected when ACQMOD[2:0] = 010.

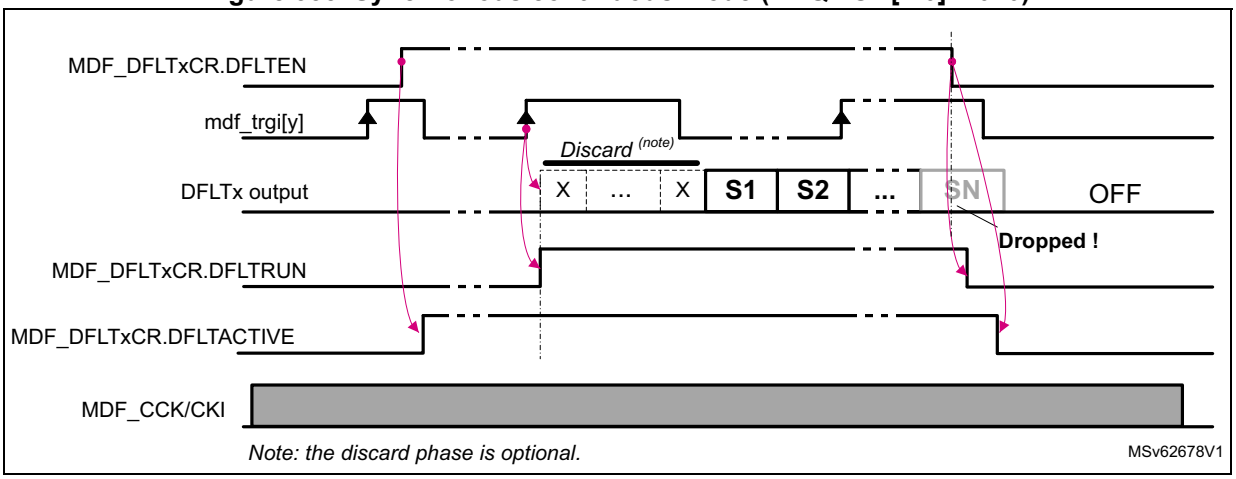
The sequence below shows the most important programming steps (assuming that DFLTEN bits of the filters are set to 0):

1. Configure and enable the clock generator (CKGEN), so that the frequency of mdf_proc_ck clock is compatible with the targeted application (see examples in *Table 354*).
2. Enable the CKGEN (CKGDEN = 1) and, if needed, enable the MDF_CCK0 and MDF_CCK1 clocks.
3. Program the filter configuration, and set the ACQMOD[2:0] to 010.
4. Set to 1 the SITFEN bit of the requested data interfaces.
5. Select the proper trigger source and sensitivity for each filter.
6. Before setting DFLTEN to 1, wait for DFLTACTIVE = 0: it insures that the previous filter deactivation sequence terminated properly.
7. Set DFLTEN to 1 for the filters to enable.
8. When the trigger condition is met, the filters start the acquisition.

The TRGSENS bit allows the selection of the trigger edge (rising or falling). The trigger is ignored if an acquisition is ongoing or if DFLTEN is set to 0.

The figure below shows a simplified example where the trigger logic is sensitive to a rising edge trigger (TRGSENS = 0). The first rising edge of the trigger signal is ignored because DFLTEN = 0. The next rising edge is taken into account and starts the acquisition. All other rising edges are ignored. The trigger logic is re-initialized when DFLTRUN goes back to 0.

Figure 355. Synchronous continuous mode (ACQMOD[2:0] = 010)



Note: The acquisition can be stopped by setting DFLTEN back to 0. This resets the filter and flushes the RXFIFO, so the samples located into the RXFIFO are lost. The ongoing DMA transfer is properly terminated. DFLTACTIVE goes back to 0 when the filter chain is reset and the RXFIFO flushed.

Synchronous single-shot acquisition mode

This mode allows the application to start a single acquisition on one or several filters by using the following trigger sources:

- one of the mdf_trg[13:0] signals
- OLD event of the corresponding filter
- TRGO bit

The Synchronous single-shot acquisition mode is selected when ACQMOD[2:0] = 011.

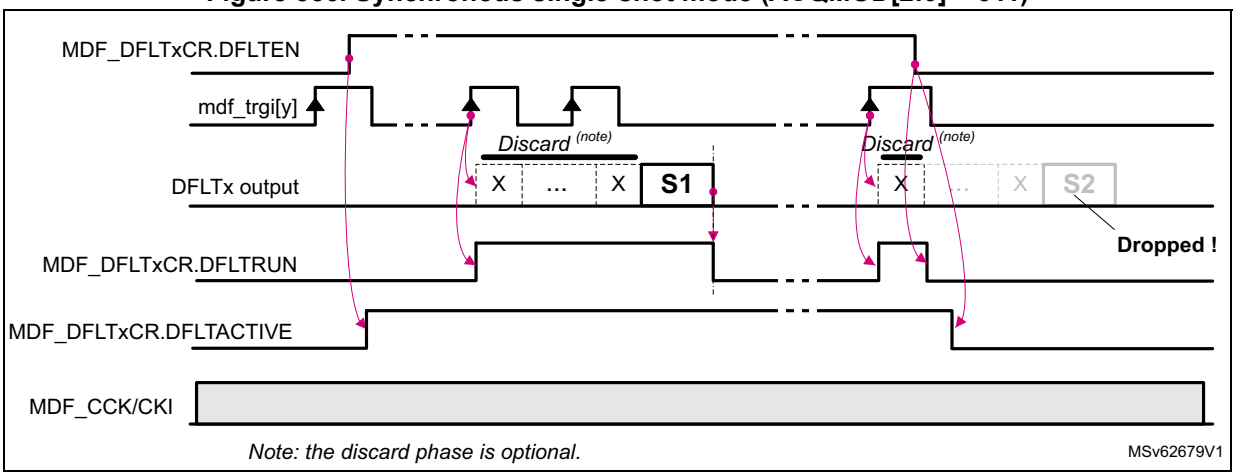
The sequence below shows the most important programming steps (assuming that DFLTEN bits of the filters are set to 0):

1. Configure and enable the clock generator (CKGEN), so that the frequency of mdf_proc_ck clock is compatible with the targeted application (see examples in *Table 354*).
2. Enable the CKGEN and, if needed, enable the MDF_CCK0 and MDF_CCK1 clocks.
3. Program the wanted filter configuration and set the ACQMOD[2:0] to 011.
4. Set to 1 the SITFEN bit of the requested data interfaces.
5. Select the proper trigger source and sensitivity for each filter.
6. Before setting DFLTEN to 1, wait for DFLTACTIVE = 0: it insures that the previous filter deactivation sequence has been properly terminated.
7. Set DFLTEN to 1 for the filters to enable.
8. Then when the trigger condition is met, the filters start the acquisition and provide one data to the RXFIFO, then the filters are ready to accept a new trigger.

TRGSENS allows the selection of the trigger edge (rising or falling). The trigger is ignored if an acquisition is ongoing or if DFLTEN is set to 0.

The figure below shows a simplified example where the trigger logic is sensitive to a rising edge trigger (TRGSENS = 0). Every time a trigger rising edge is detected with DFLTEN = 1, an acquisition sequence is triggered. The first samples provided by the filter can be discarded if needed. At the end of each conversion, the decimation counters and filter taps are reset. DFLTRUN is set to 0 and the filter is ready to start a new conversion.

Figure 356. Synchronous single-shot mode (ACQMOD[2:0] = 011)



Note: The acquisition can be stopped by setting DFLTEN back to 0. This resets the filter and flushes the RXFIFO, so the samples located into the RXFIFO are lost. The ongoing DMA transfer is properly terminated. DFLTACTIVE goes back to 0 when the filter chain is reset and the RXFIFO flushed.

Figure 356 shows a case where DFLTEN is cleared to 0 while an acquisition is ongoing: thus the sample S2 is lost. This situation can be avoided with the following steps:

1. Wait for DFLTRUN = 0.
2. Read the sample from the RXFIFO.
3. Clear DFLTEN to 0.

Note: The ongoing DMA transfer is properly terminated.

Window continuous acquisition mode

This mode allows the application to start or stop a continuous acquisition on one or several filters controlled by consecutive edges of one of the following trigger sources:

- one of the mdf_trg[13:0] signals
- TRGO bit

The window continuous acquisition mode is selected when ACQMOD[2:0] = 100.

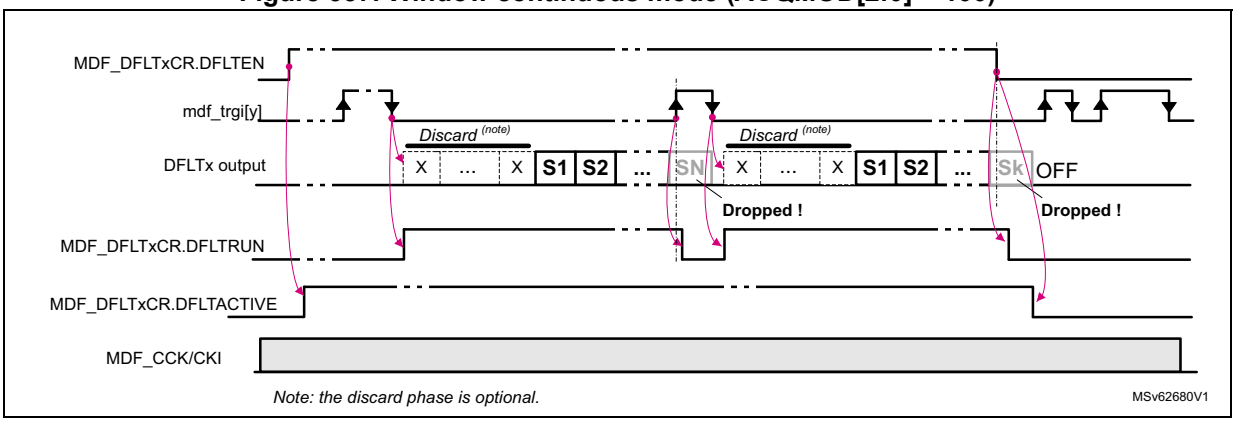
The sequence below shows the most important programming steps (assuming that DFLTEN bits of the filters are set to 0):

1. Configure and enable the clock generator (CKGEN), so that the frequency of mdf_proc_ck clock is compatible with the targeted application (see examples in *Table 354*).
2. Enable the CKGEN and, if needed, enable the MDF_CCK0 and MDF_CCK1 clocks.
3. Program the wanted filter settings and set the ACQMOD[2:0] to 100.
4. Set to 1 the SITFEN bit of the requested data interfaces.
5. Select the proper trigger source and sensitivity for each filter.
6. Before setting DFLTEN to 1, wait for DFLTACTIVE = 0: it insures that the previous filter deactivation sequence has been properly terminated.
7. Set DFLTEN to 1 for the filters to enable.
8. If TRGSENS = 0, the acquisition starts on trigger rising edge and stops on trigger falling edge. If TRGSENS = 1, the acquisition starts on trigger falling edge and stops on trigger rising edge.

Note: The acquisition may restart if the trigger condition becomes again active.

Figure 357 shows a simplified example of window continuous acquisition mode, with TRGSENS = 1. Once DFLTEN is set to 1, the MDF waits for a falling edge on the selected trigger input. When the trigger condition is met, DFLTRUN goes to 1 and the acquisition starts. The acquisition stops if the MDF detects a rising edge on the selected trigger input. If DFLTEN is still set to 1, the MDF waits again for a falling edge on the selected trigger input.

Figure 357. Window continuous mode (ACQMOD[2:0] = 100)



Note: The acquisition can be stopped by setting DFLTEN back to 0. This resets the filter and flushes the RXFIFO, so the samples located into the RXFIFO are lost. The ongoing DMA

transfer is properly terminated. DFLTACTIVE goes back to 0 when the filter chain is reset and the RXFIFO flushed.

Synchronous snapshot acquisition mode

In the acquisition modes described on previous sections, the application must wait for filters settlings time or the end of conversion before getting a new valid sample. For applications very critical in latency, the last valid sample can be get immediately, with an information on the age of this sample by using the snapshot acquisition mode.

In snapshot mode, the DFLTx is continuously acquiring the samples, but the processed samples are not stored into the RXFIFO. When a trigger occurs, the last valid sample, the current decimation value of MCIC and the sample counter of the INT are stored in MDF_SNPS0DR.

The possible trigger sources are the following:

- one of the mdf_trg[13:0] signals
- OLD event of the corresponding filter
- TRGO bit

The Synchronous snapshot acquisition mode is selected when ACQMOD[2:0] = 101.

The sequence below shows the most important programming steps (assuming that DFLTEN bits of the filters are set to 0):

1. Configure and enable the clock generator (CKGEN), so that the frequency of mdf_proc_ck clock is compatible with the targeted application (see examples in *Table 354*).
2. Enable the CKGEN and, if needed, enable the MDF_CCK0 and MDF_CCK1 clocks.
3. Program the wanted filter settings and set the ACQMOD[2:0] to 101. FTH is usually cleared to 0 to receive an interrupt as soon as the RXFIFO is not empty.
4. Set the SITFEN bit of the requested data interfaces to 1.
5. Select the proper trigger source and sensitivity for each filter.
6. Before setting DFLTEN to 1, wait for DFLTACTIVE = 0: it insures that the previous filter deactivation sequence has been properly terminated,
7. Set DFLTEN to 1 for the filters to enable.

When the trigger condition is met,

1. The MDF stores the last valid data provided by the corresponding filter, the value of the MCIC decimation counter, and the counter value of INT if selected by SNPSFMT into a shadow register.
2. The snps_evt is activated, indicating that a data is ready. If SSDRIE is set to 1, the MDF requests the AHB clock.
3. When the AHB clock is available the shadow register is stored in *MDF snapshot data register x (MDF_SNPSxDR)* and an interrupt is generated.
4. In the interrupt sub-routine, the application must do the following:
   a) Read the data located in MDF_SNPSxDR.
   b) Clear the SSDRF flag by writing it to 1.

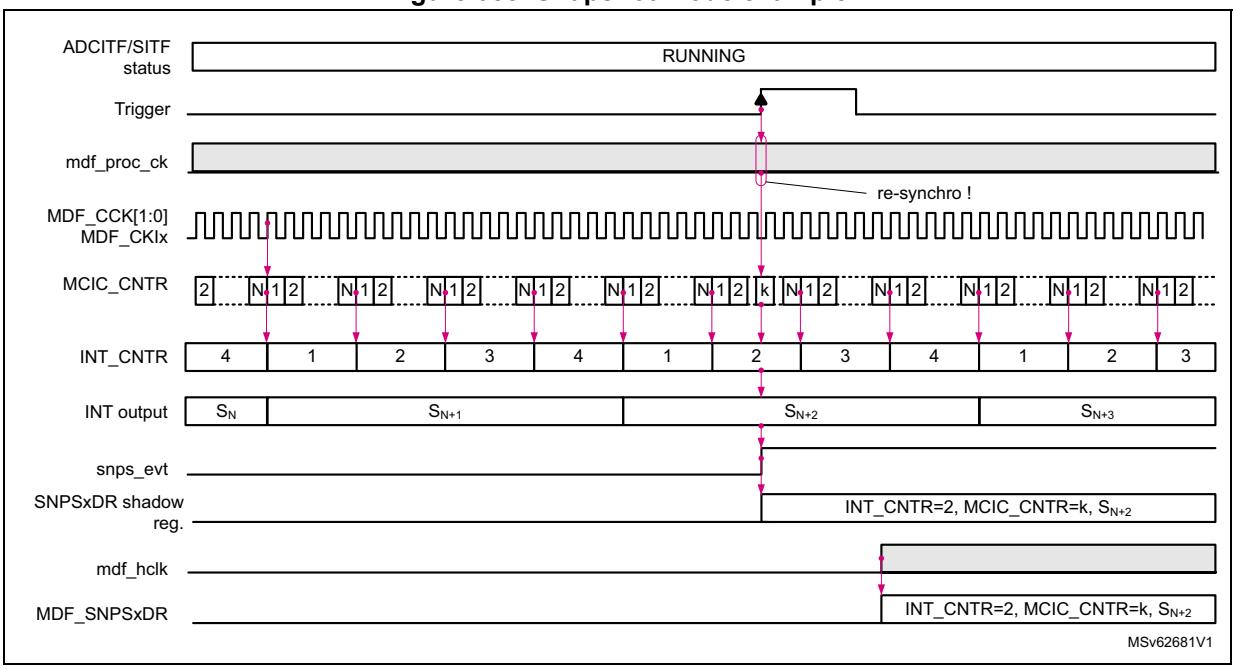
As shown in the *Figure 358*, in snapshot mode, when the trigger event occurs, it is resynchronized with the processing clock (mdf_proc_ck), the decimation counter of the MCIC (MCIC_CNTR), the integrator counter (INT_CNTR) and the last valid sample (S_{N+2}), are stored into a shadow register, and the snps_evt event is generated. When the AHB

clock is available, an interrupt is generated and the shadow register is copied in MDF_SNPSxDR. The application can read immediately the sample and the timing information.

The SSOVRF overrun flag is also available, allowing the application to check if an overrun condition occurs. A snapshot overrun condition is detected when the SSDRF flag is set to 1 while a new trigger event occurs.

In that case, the new trigger event is not taken into account. The application must clear the SSOVRF flag.

Figure 358. Snapshot mode example



Note: When an activated filter did not receive a data strobe, the filter is frozen. If the interface providing the stream is not enabled (SITF or ADCITF), the filter is frozen. Once a DFLT x is activated, CIC, HPF, IIR and INT are reinitialized. For each filter a status bit indicates if the filter is currently running or not.

Starting several filters synchronously

To start the acquisition of several filters synchronously, the following sequence must be performed (assuming that DFLTEN is set to 0):

1. Enable the CKGEN and, if needed, enable the MDF_CCK0 and MDF_CCK1 clocks.
2. Set the SITFEN bit of the requested data interfaces to 1.
3. For each filter, set the acquisition mode to synchronous (ACQMOD[2:0] = 01x).
4. For each filter, set TRGSRC[3:0] to 0 (TRGO is selected).
5. For each filter, set TRGSENS to 0 (rising edge).
6. For each filter, set DFLTEN to 1.
7. Read TRGO bit until it is read to 0.
8. Set TRGO to 1. Then the acquisition sequence for all selected filters starts immediately.

To trigger a new acquisition (in case of single-shot), the application must do the following:

1. Check that the previous acquisition is completed, by waiting DFLTRUN = 0.
2. Read TRGO until it is read to 0.
3. Set again TRGO to 1.

Discarded samples

The MDF offers the possibility to program the amount of samples to be discarded after each restart:

- to avoid capturing samples affected by the impulse response of the filter
- to delay the acquisition of filters by a specific amount of samples

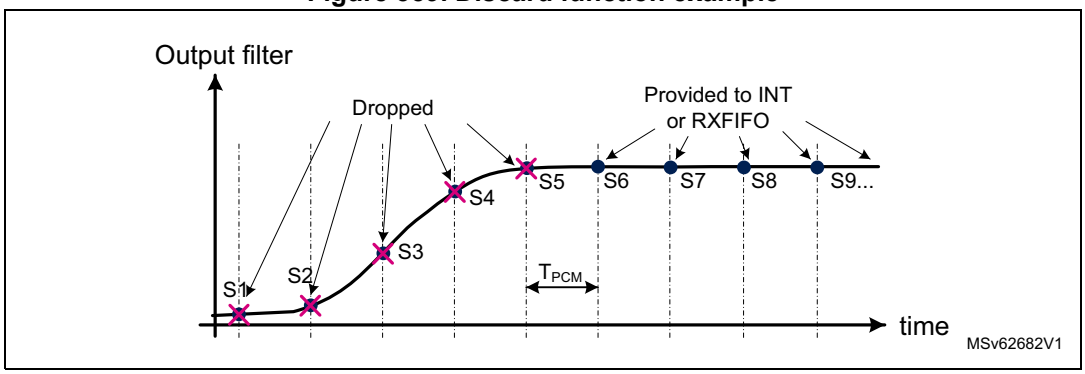
The discard function is controlled via NBDIS[7:0] as follows:

- When NBDIS[7:0] = 0, the discard function is disabled.
- When NBDIS[7:0] ≠ 0, the discard function is activated in one of the following condition:
  - when the DFLTEN bit goes to 1
  - every time an acquisition is started in (A)synchronous single-shot modes

Refer to *Figure 353* to *Figure 357*, *Figure 360* and *Figure 361*.

In the example shown in the figure below, the discard function is used to drop the first five samples provided by the digital filter (S1 to S5). The first sample transfered to the RXFIFO (or INT block if enabled) is S6.

Figure 359. Discard function example



Warning: All filters working in interleaved DMA mode must have the same NBDIS[7:0] value.

Data interface activation

The data interfaces are enabled by setting the corresponding SITFEN or ADCITFEN bit to 1. Once the digital filter is enabled, it receives the serial data from the external ΣΔ modulator or parallel internal data sources (ADC).

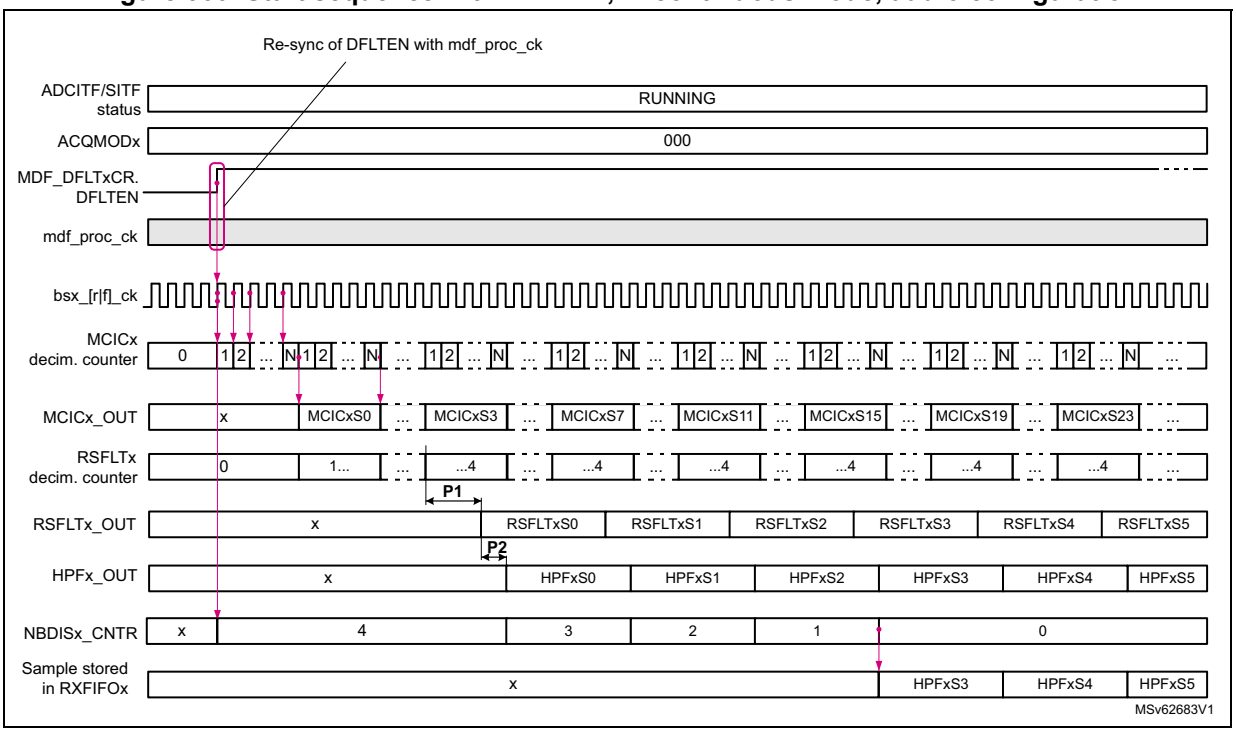
36.4.11 Start-up sequence examples

Figure 360 details an acquisition sequence start of a digital filter triggered by DFLTEN (ACQMOD[2:0] = 0), with NBDIS[7:0] = 3 (three samples to discard before acquisition).

The DFLTx is configured for audio application: MCIC, RSFLT and HPF activated.The data interface (SITFx or ADCITF) is assumed to be already activated.

Note: NBDIS[7:0] is set on purpose to a low value to simplify the drawing.

Figure 360. Start sequence with DFLTEN, in continuous mode, audio configuration



The DFLTEN bit is re-sampled into the MDF processing clock domain. When DFLTEN is detected high, the filter chain is enabled and the decimation counter of the MCIC filter is incremented at the rate of the bitstream clock.

When the MCIC decimation counter reaches its programmed value N, a sample is available for the RSFLT.

The RSFLT processes all the samples provided by the MCIC and delivers a sample to the HPF every time it processes four samples (decimation by 4) The RSFLT needs up to 24 cycles of mdf_proc_ck clock before delivering a sample (P1).

The HPF processes all the samples provided by the RSFLT, but the NBDIS function prevents the data writing in the RXFIFO as long as NBDIS_CNTR does not reach 0. This counter is decremented every time the HPF delivers a sample.

When NBDIS_CNTR reaches 0, the samples provided by the HPF are stored into the RXFIFO.

The example shown in *Figure 361* is based in a motor-control filter configuration:

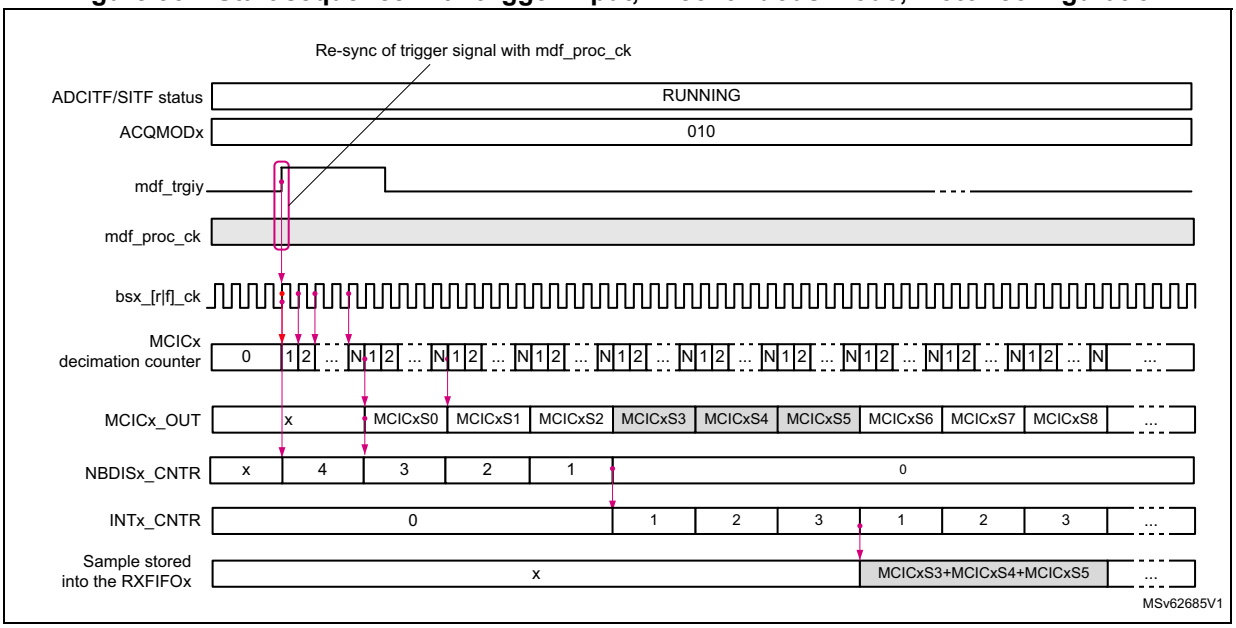
- MCIC and INT are enabled.
- SFLT and HPF are disabled.
- ACQMOD[2:0] is set to 1 and uses a mdf_trgiy input as trigger.
- NBDIS[7:0] is set to 3.
- INTVAL[6:0] is set to 2.

The mdf_trgiy input signal is re-sampled into the MDF processing clock domain to avoid any metastability issues. When the trigger condition is met (rising edge), the decimation counter of the MCIC filter is incremented at the rate of the bitstream clock.

When the MCIC decimation counter reaches its programmed value N, a sample is available. The NBDIS function prevents the samples writing in the INT as long as NBDIS_CNTR does not reach 0. This counter is decremented every time the MCIC delivers a sample.

When NBDIS_CNTR reaches 0, the new samples are provided to the INT, that performs the integration of three consecutive samples and stores them into the RXFIFO.

Figure 361. Start sequence with trigger input, in continuous mode, motor configuration

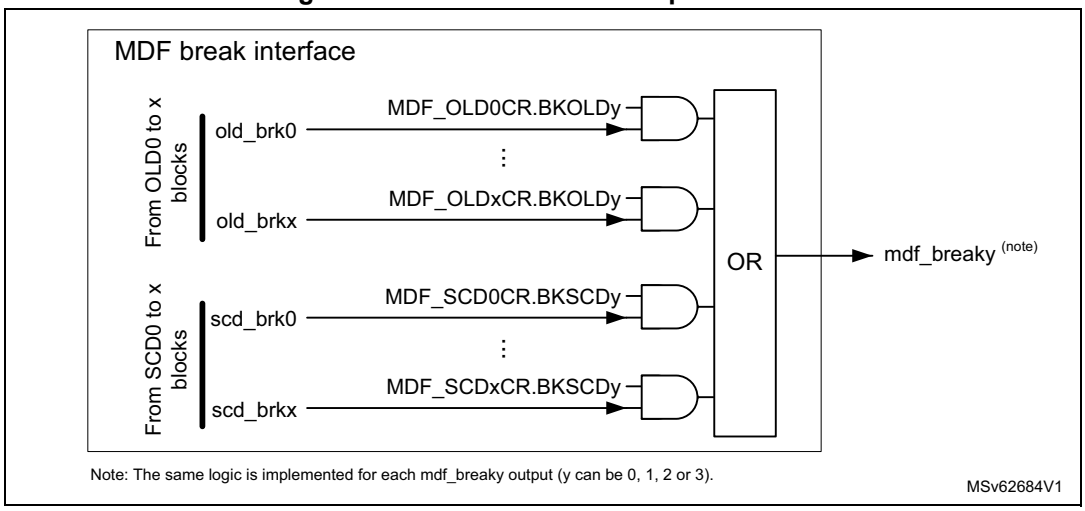


36.4.12 Break interface

The break interface merges the break events coming from the OLDx and SDCx blocks into four break signals connected to various peripherals of the product (see *Table 344* for details).

As shown in *Figure 362*, several blocks can share the same break line. A same block can also drive several break lines. The break interface is controlled via MDF_OLDxCR and MDF_SCDxCR.

Figure 362. Break interface simplified view



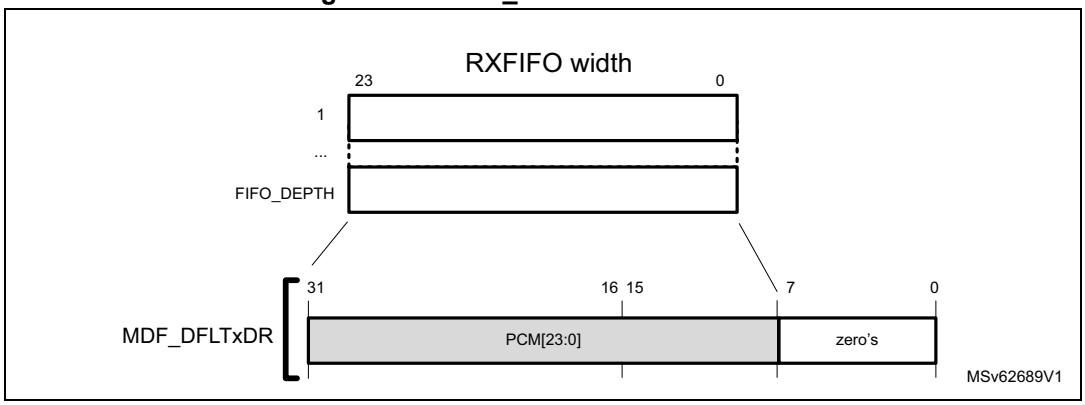
36.4.13 Data transfer to memory

Data format

The samples processed by DFLTx are stored into a RXFIFO. The application can read the samples stored into the FIFOs via the *MDF digital filter data register x (MDF_DFLTxDR)*. The samples inside this register are signed and left aligned. The bit 31 always represents the sign.

The MDF provides 24-bit left-aligned data. Performing a 16-bit access to MDF_DFLTxDR allows the application to get the 16 most significant bits. Performing a 32-bit access to MDF_DFLTxDR allows the application to get a 24-bit data size.

Figure 363. MDF_DFLTxDR data format



Data resynchronization

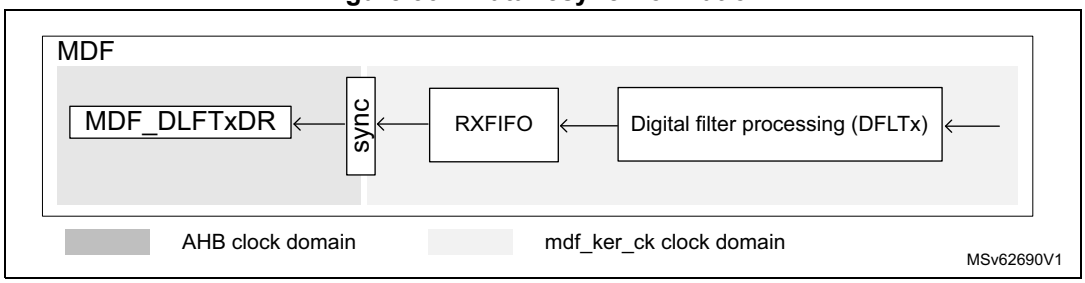
The samples stored into the RXFIFOs can be transferred into the memory by using either DMA requests or interrupt signaling.

Note: The RXFIFOs are located into the mdf_ker_ck clock domain, while MDF_DFLTxDR *are located into the mdf_hclk (AHB) clock domain.*

When the AHB clock is available, if MDF_DFLTxDR is empty and if a sample is available into the RXFIFO, this sample is transferred into MDF_DFLTxDR.

The sample transfer from the RXFIFO to MDF_DFLTxDR takes two periods of the AHB clock (mdf_hclk) and two periods of the mdf_ker_ck clock. The MDF inserts automatically wait-states if the application performs a read operation of MDF_DFLTxDR while the transfer of the new sample from the RXFIFO to MDF_DFLTxDR is not yet completed.

Figure 364. Data resynchronization



The MDF can also combine two transfer types: the independent-transfer and the interleaved-transfer modes.

Independent-transfer mode

In this mode, each RXFIFO has its own DMA channel and its own FTHF flag event.

Both single and burst DMA transfers are supported in this mode, but the application must care about the following points:

- The RXFIFO must contain at least the same amount of samples than the burst size.
- The burst mode efficiency may be reduced due to the data resynchronization explained in the previous section.

In addition, the application can select the RXFIFO threshold (FTH bit) to trigger the data transfer: a data transfer can be triggered as soon as the RXFIFO is not empty, or when the RXFIFO is half-full (containing depth / 2 samples).

For the DMA transfer, as soon as one of the RXFIFO reaches the threshold level, the corresponding DMA request is asserted in order to ask for data transfer. Successive DMA requests are performed as long as the corresponding RXFIFO is not empty.

The DMA mode of the RXFIFOx is enabled via the corresponding DMAEN bit in the *MDF digital filter control register x (MDF_DFLTxCR)*.

For the interrupt signaling, the following cases must be considered:

- If FTH = 0, as soon as a data is available in MDF_DFLTxDR, the corresponding FTHF is set, allowing the generation of an interrupt. FTHF is released as soon as MDF_DFLTxDR is read.
- If FTH = 1, as soon as one of the RXFIFO reaches the threshold level and a data is available into MDF_DFLTxDR, the corresponding FTHF is set, allowing the generation of an interrupt. The FTHF flag is released as soon as one data is read. FTHF is set again if the threshold condition is met again. In this mode, every time an interrupt occurs, the application is supposed to read FIFO_SIZE / 2 data.

The independent-transfer mode must be used when the sample rates provided by each filter paths are not perfectly synchronous, or when the streams are independent. This situation may occur for example:

- when SITF is in SLAVE mode and each external sensor provides its own sampling clock

- when the decimation ratios of the DFLTx are not the same
- when all the streams are not starting at the same time

Interleaved-transfer mode

This mode optimizes the DMA request resources by sharing a single DMA request with several RXFIFOs.

Only single DMA transfers are supported in this mode.

In interleaved-transfer mode, FTH cannot be used and only the FTHF of RXFIFO0 is available for the interrupt signaling.

For the DMA transfer, when all the RXFIFOs working in interleaved-transfer mode are not empty, some DMA requests are generated in order to read sequentially one sample of each RXFIFOs, via MDF_DFLT0DR.

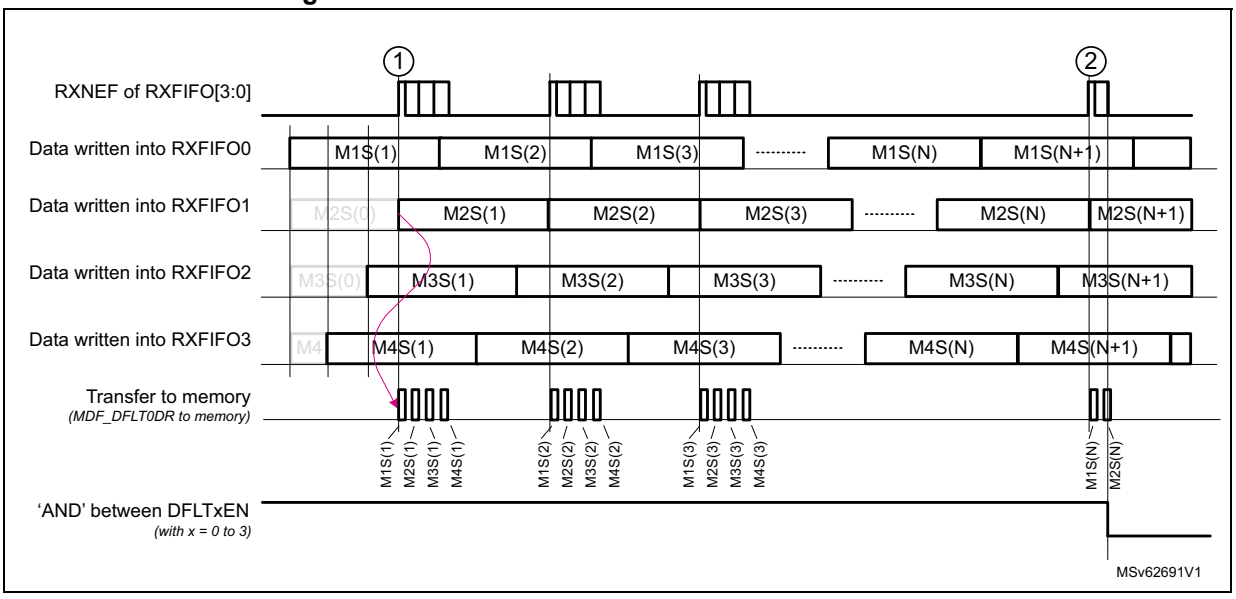
For the RXFIFOs working in interleaved-transfer mode, the DMA channel is enabled by setting to 1 DMAEN in MDF_DFLT0DR and by defining the amount of RXFIFOs working in interleaved mode via ILVNB[3:0]. DMAEN for the other RXFIFOs working in interleaved-transfer mode (RXFIFO 1 to ILVNB[3:0]) are not taken into account.

Figure 365 shows four RXFIFOs working in interleaved-transfer mode. Each RXFIFO has a delay due to the programming of the DLY block.

When all the RXFIFOs have at least one sample available (in this example the last FIFO receiving a sample is RXFIFO1), the MDF requests the data transfer to the memory (see 1 in *Figure 365*). In this figure, the DMA is assumed to be used for the data transfer to memory.

The acquisition can be simply stopped by setting DFTLEN to 0 for one of the filter configured in interleaved-transfer mode. In the example, when a DFLTEN is set to 0 (see 2 in *Figure 365*), the transfer to memory is immediately stopped. Samples M2S(N), M3S(N) and M4S(N) may be lost.

Figure 365. Data transfer in interleaved-transfer mode



In interrupt mode, when all the RXFIFOs working in interleaved-transfer mode have a data ready, the FTHF flag of RXFIFO0 is asserted to allow the interrupt generation. The application is then supposed to read sequentially one sample of each RXFIFOs, via MDF_DFLT0DR. The FTHF event is released when the first data is read.

For the RXFIFOs working in interleaved-transfer mode, the interrupt mode is enabled by setting FTHIE to 1 in MDF_DFLT0DR and by defining the amount of RXFIFOs working in interleaved-transfer mode via ILVNB[3:0]. FTHIE of the other RXFIFOs working in interleaved-transfer mode (RXFIFO1 to ILVNB[3:0]) are not taken into account.

The interleaved-transfer mode can only be applied starting at RXFIFO0 up to RXFIFOk. The number of RXFIFOs working in interleaved-transfer mode are defined by ILVNB[3:0].

When ILVNB[3:0] = 0, all RXFIFOs work in independent-transfer mode.

The interleaved-transfer mode can be used only for digital filters delivering samples perfectly synchronous each other. This is typically the case of sound capture with an array of digital microphones sharing the same bitstream clock.

Caution: To make the MDF working properly in interleaved-transfer mode, the following rules must be respected:

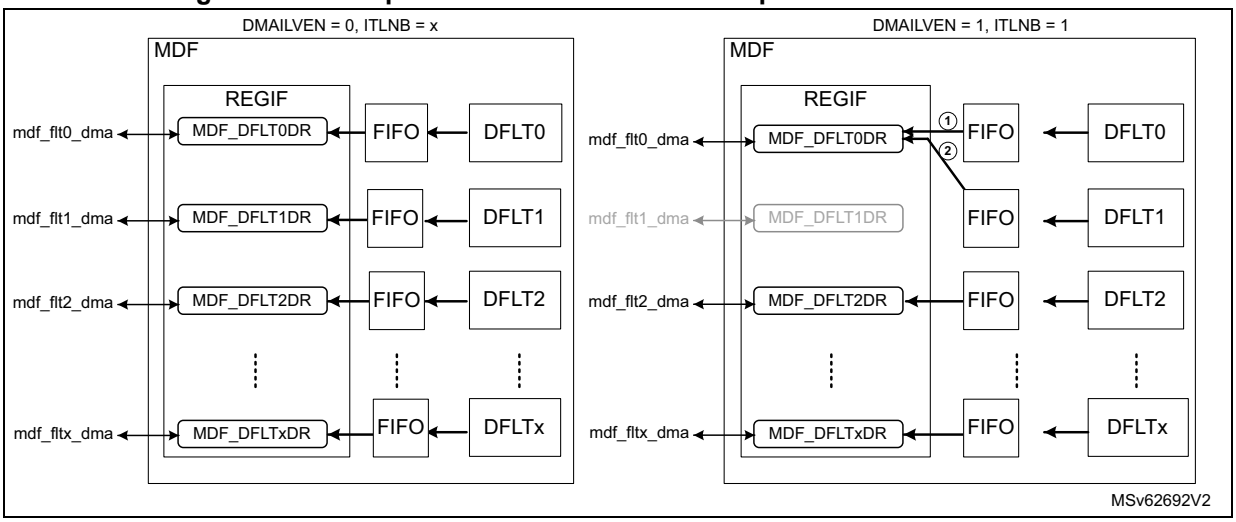
- All filters working in interleaved-transfer mode must be all synchronized together, meaning that all filters must select the same ACQMOD[2:0] (must be equal to 010 or 011), the same trigger source and the same trigger sensitivity.
- All filters working in interleaved-transfer mode must have the same configuration.
- All sensors providing the data for the filters working in interleaved-transfer mode must use the same bitstream clock frequency.
- The maximum delay difference applied with SPKDLY[6:0] for the filters working in interleaved-transfer mode must remain strictly lower than the RXFIFO depth. Normally this delay does not need to exceed one T_{PCM} period.

Note: Both independent- and interleaved-transfer modes can work in parallel: for example, the first RXFIFOs (RXFIFO0 to RXFIFOk) may work in interleaved-transfer mode when the others (RXFIFO(k+1) to RXFIFO(N)) works in independent-transfer mode.

If the AHB clock is not present when a data transfer must be performed, the MDF first requests the AHB clock (refer to Section 36.4.5: Clock generator (CKGEN) for details).

The figure below shows the data path for a configuration in independent-transfer mode (left-hand figure) and a configuration mixing both independent- and interleaved-transfer modes (right-hand figure).

Figure 366. Data path for interleaved- and independent-transfer modes



In the right-hand figure, the DFLT0 and DFLT1 filters are configured in interleaved-transfer mode. For those filters, FTH is no longer taken into account by the hardware. The samples provided by DFLT0 and DFLT1 are read from MDF_DFLT0DR. When both RXFIFOs are no longer empty, the MDF generates two DMA requests to read the sample from DFLT0 and the sample from DFLT1. If both RXFIFOs are not empty again, the same sequence is triggered.

Note: When one of the filter working in interleaved-transfer mode is disabled, the data transfer to memory of all filters in interleaved-transfer mode is stopped immediately as well.

RXFIFO overrun

A RXFIFO overrun condition is detected when the RXFIFO is full and a new sample from the DFLTx must be written.

In this case, DOVRF is set and the new sample is dropped. When the RXFIFO has at least one location available, the new incoming sample is written into the RXFIFO.

Figure 367 shows an example based on a RXFIFO depth of four words and FTH set to 1, so that FTHF goes to 1 when the RXFIFO is half-full.

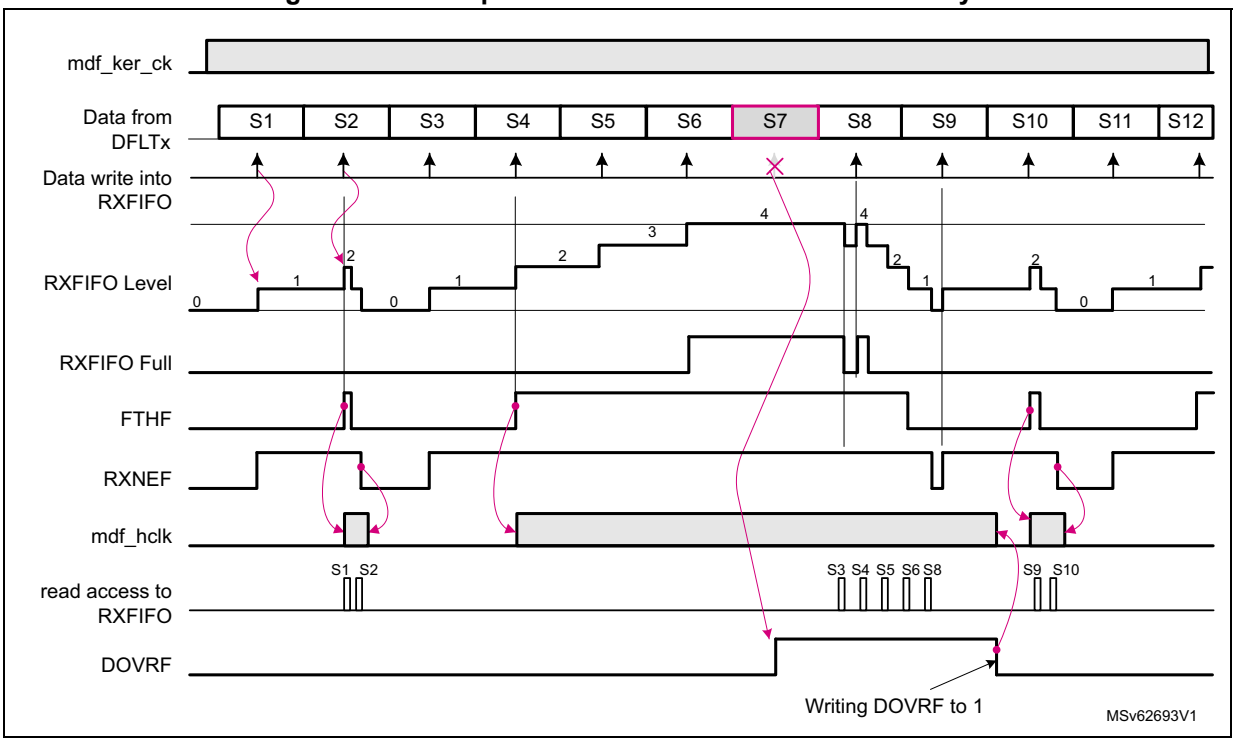
The S7 sample is lost due to an overrun: the RXFIFO is full while S7 must be written into the RXFIFO. The S7 write operation is not performed. DOVRF is set to 1 at the moment where the write operation was expected. The overflow event remains to 1 as long as it is not cleared by the application.

In this example, DOVRIE is set to 1 to have an interrupt if an overrun condition is detected.

After the S7 sample, the application manages to read data from the RXFIFO and the MDF can write the S8 sample and consecutive. Later, the application clears DOVR, allowing the detection of a new overrun situation.

In the mdf_hclk line, the gray boxes indicate that the MDF requested the AHB clock. The figure below shows the AHB clock available only when the MDF requests it. In real applications, the AHB clock may also be present if the MDF does not request it.

Figure 367. Example of overflow and transfer to memory



Note: If the MDF works in interleaved-transfer mode, the application must check the overrun status of all RXFIFOs that works in interleaved-transfer mode.

36.4.14 Register protection

The MDF embeds some hardware protection to prevent invalid situations. The table below shows the list of write-protected and unprotected fields.

Table 355. Register protection summary

Registers	Unprotected fields	Write-protected fields	Write-protection condition
MDF global control register (MDF_GCR)	TRGO	ILVNB[3:0]	DFLTACTIVE0 = 1
MDF clock generator control register (MDF_CKGCR)	CKGDEN CCK0EN CCK1EN	PROCDIV[6:0], CCKDIV[3:0], CKGMOD, TRGSRC[3:0], TRGSENS, CCK[1:0]DIR	CKGACTIVE = 1
MDF serial interface control register x (MDF_SITFxCR)	SITFEN	STH[4:0], SITFMOD[1:0], SCKSRC[1:0]	SITFACTIVEx = 1

Table 355. Register protection summary (continued)

Registers	Unprotected fields	Write-protected fields	Write-protection condition
MDF bitstream matrix control register x (MDF_BSMXxCR)	-	BSSEL[4:0]	DFLTACTIVEx = 1 or SCDACTIVEx = 1 or OLDACTIVEx = 1
MDF digital filter control register x (MDF_DFLTxCR)	DFLTEN	NBDIS[7:0], TRGSRC[3:0], TRGSENS, FTH, DMAEN, SNPSFMT, ACQMOD[2:0]	DFLTACTIVEx = 1
MDF digital filter configuration register x (MDF_DFLTxCICR)	SCALE[5:0]	MCICD[8:0], CICMOD[2:0], DATSRC[1:0]	
MDF reshape filter configuration register x (MDF_DFLTxRSFR)	-	All fields	
MDF integrator configuration register x (MDF_DFLTxINTR)	-	All fields	
MDF out-of limit detector control register x (MDF_OLDxCR)	OLDEN	ACICD[4:0], ACICN[1:0],THINB BKOLD[3:0]	OLDACTIVEx = 1
MDF OLDx low threshold register x (MDF_OLDxTHLR)	-	All fields	
MDF OLDx high threshold register x (MDF_OLDxTHHR)	-	All fields	
MDF delay control register x (MDF_DLYxCR)	-	SKPDLY[6:0]	SKPBF = 1
MDF short circuit detector control register x (MDF_SCDxCR)	SCDEN	BKSCD[3:0], SCDT[7:0]	SCDACTIVEx = 1
MDF DFLTx interrupt enable register x (MDF_DFLTxIER)	All fields	-	-
MDF DFLTx interrupt status register x (MDF_DFLTxISR)	All fields	-	-
MDF offset error compensation control register x (MDF_OECxCR)	OFFSET[25:0]	-	-

All the MDF processing is performed in the mdf_proc_ck clock domain. For that reason, enabling or disabling a MDF sub-block may take some time due to the resynchronization between the AHB clock domain and the mdf_proc_ck clock domain. XXXACTIVE flags are available to allow the application to check that the synchronization between the two clock domains is completed.

To change a write-protected bitfield, the application must follow this sequence:

1. Set the enable bit of the sub-block to 0.
2. Wait for corresponding flag XXXACTIVE = 0.
3. Modify the wanted fields.
4. Set the enable bit of the sub-block to 1.

Refer to the description of each sub-block for more details.

36.5 MDF low-power modes

Table 356. Effect of low-power modes on MDF

Mode	Description
Sleep	No effect. MDF interrupts cause the device to exit Sleep mode.
Stop(1)	The MDF registers content is kept. If the MDF is clocked by an internal oscillator available in Stop mode, the MDF remains active. The interrupts cause the device to exit Stop mode.
Standby	The MDF is powered down and must be reinitialized after exiting Standby mode.

1. Refer to *Section 36.3: MDF implementation* for details about Stop modes supported by the MDF.

36.6 MDF interrupts

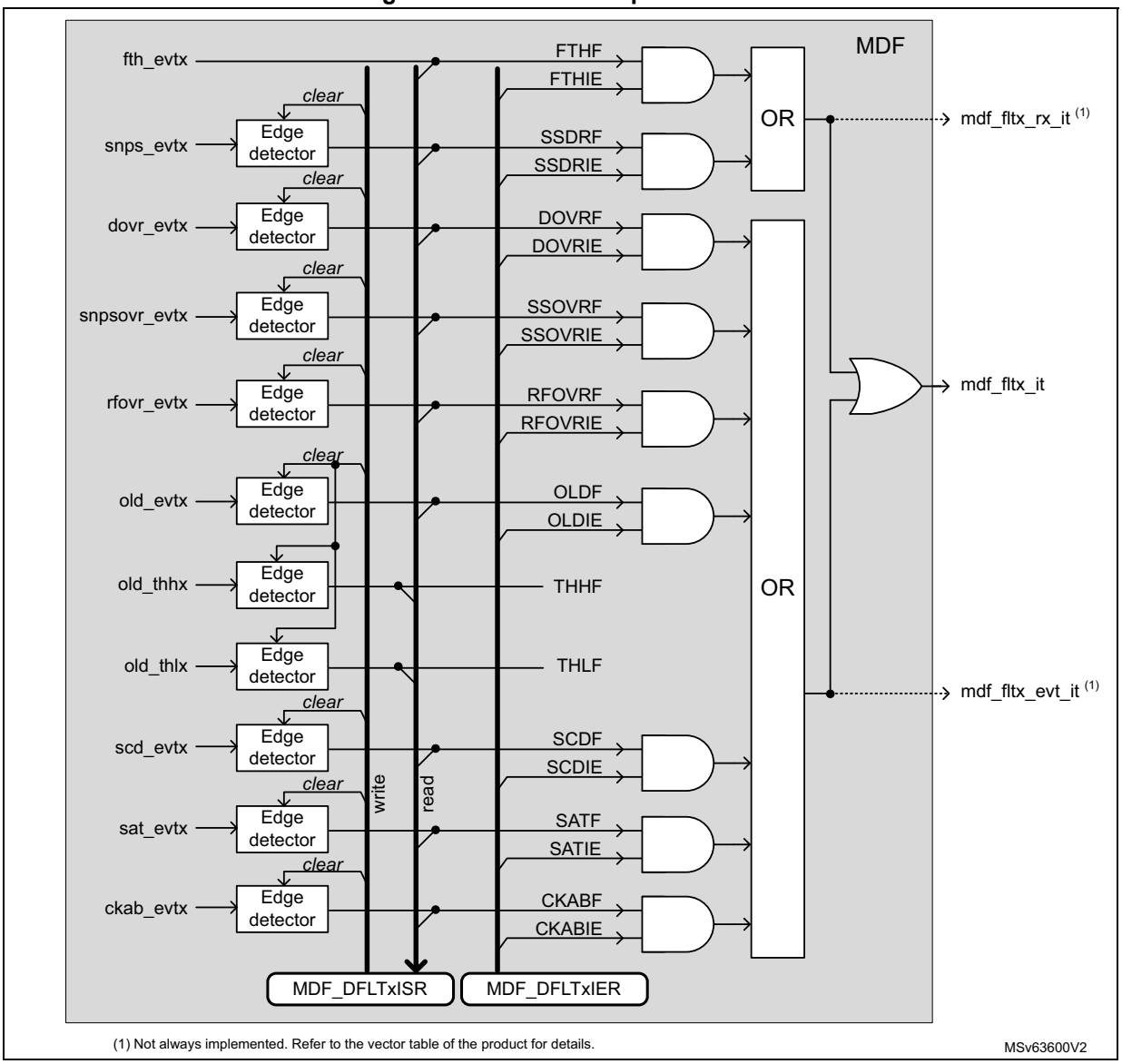
To increase the CPU performance, the MDF offers the following interrupt lines per digital filter:

- receive interrupt MDF_FLTx_RX (mdf_fltx_rx_it)
- event interrupt MDF_FLTx_EVT (mdf_fltx_evt_it)
- a combination of both interrupts MDF_FLTx (mdf_fltx_it)

Note: Interrupts are not always connected to the device (see Section 36.3: MDF implementation for more details).
The status flags are available even if the corresponding interrupt enable flag is not enabled.

The interrupt interface is controlled via the *MDF DFLTx interrupt enable register x (MDF_DFLTxIER)* and the *MDF DFLTx interrupt status register x (MDF_DFLTxISR)*.

Figure 368. MDF interrupt interface



(1) Not always implemented. Refer to the vector table of the product for details.

MSv63600V2

The table below shows which interrupt line is affected by which event, and how to clear and activate each interrupt/event.

Table 357. MDF interrupt requests

Interrupt vectors		Interrupt event	Event flag	Event/interrupt clearing method	Exit Sleep mode	Exit Stop modes[1]	Exit Standby mode
MDF_FLTx[2]	MDF_FLTx_RX[3]	RXFIFO threshold reached	FTHF	Read MDF_DFLTxDR until RXFIFO level is lower than the threshold.	Yes	Yes	No
		Snapshot data ready	SSDRF	Write SSDRF to 1.			
	MDF_FLTx_EVT[4]	Snapshot data overrun	SSOVRF	Write SSOVRF to 1.			
		RXFIFO overrun	DOVRF	Write DOVRF to 1.			
		RSFLT overrun	RFOVRF	Write RFOVRF to 1.			
		Short-circuit detector	SCDF	Write SCDF to 1.			
		Saturation detection	SATF	Write SATF to 1.			
		Channel clock absence detection	CKABF	Write CKABF to 1.			
		Out-of-limit detector	OLDF	Write OLDF to 1.			
-	-		THHF	Write OLDF to 1.	-	-	-
-	-		THLF	Write OLDF to 1.	-	-	-

1. Refer to *Section 36.3: MDF implementation* for details.
2. MDF_FLTx vector corresponds to the assertion of mdf_fltx_it signal
3. MDF_FLTx_RX vector corresponds to the assertion of mdf_fltx_rx signal.
4. MDF_FLTx_EVT vector corresponds to the assertion of mdf_fltx_evt signal.

36.7 MDF application informations

36.7.1 MDF configuration examples for audio capture

Table 358 gives some examples of the MDF settings for the digital microphones, focusing on 16 and 48 kHz output data rate. In these examples, the following is expected:

- The INT block is bypassed (INTVAL = 0).
- The offset error compensation is disabled (OFFSET = 0).

Configurations #1 and #2 are for very low-power use-cases and have a reduced signal-to-noise ratio. The user must also insure that the selected digital microphone can work properly at 512 kHz. These configurations can be used for sound detection. The RSFLT is not used to reduce as much as possible the frequency of the kernel clock (mdf_ker_ck).

Configurations #3, #4, #9, #10, #11 give signal-to-noise ratios around 115 dB, with an ideal microphone model, with a sinus signal of 997 Hz. Using the RSFLT allows a good control on the in-band ripple and a good image rejection.

Configurations #7, #8, #10 give signal-to-noise ratio around 120 dB, with an ideal microphone model, using a sinus signal of 997 Hz.

Table 358. Examples of MDF settings for microphone capture

Configuration	mdf_ker_ck (MHz)	PROCDIV + 1	CCKDIV + 1	CIC order (1)	MCICD + 1	SCALE	RSFLTBYP	RSFLTD	HPFBYP	-	mdf_proc_ck (MHz)	Total dec. ratio	F_{RS} (kHz)	F_{MDF_CCKx} (MHz)	F_{PCM} (kHz)
#1	1.024	1	2	4	64	0x2D (- 8.5 dB)	1	x	x	=>	1.024	64	-	0.512	8
#2		1	2	5	32	0x2B (- 14.5 dB)						32	-		16
#3		1	2	5	16	0x01 (+ 3.5 dB)	0	0				64	32		8
#4	2.048	1	2	5	16	0x01 (+ 3.5 dB)	0	0			2.048	64	64	1.024	16
#5	3.072	1	6	5	8	0x0B (+ 33.6 dB)	0	0			3.072	32	32	0.512	8
#6		2	2	5	12	0x06 (+ 18.1 dB)						48	64	0.768	16
#7		1	2	5	24	0x2C (- 12 dB)						96		1.536	
#8	4.096	1	2	5	32	0x27 (- 26.6 dB)	0	0			4.096	128	64	2.048	16
#9	6.144	3	2	5	16	0x02 (+ 6.0 dB)	0	0			2.048	64	64	1.024	16
#10		2	2	5	24	0x2C (- 12 dB)					3.072	96		1.536	
#11		1	2	5	16	0x01 (+ 3.5 dB)					6.144	64	192	3.072	48
#12	7.680	1	2	5	20	0x2E (- 6.0 dB)	0	0			7.680	80	192	3.840	48

1. CICMOD = 100 for CIC order equal to 4. CICMOD = 101 for CIC order equal to 5.

36.7.2 Programming examples

This example describes how to capture sound from four microphones, assuming that each microphone pair shares the same data line. The MDF_SD0 and MDF_SD2 data lines are used. The microphone clock is provided by the MDF via MDF_CCK0 pin.

Table 359. Programming sequence

Operations	Comments
Adjust the proper kernel clock frequency via the RCC block	Assuming that the RCC is programmed to provide a kernel clock (mdf_ker_ck) of 12.288 MHz
Select the proper MDF kernel clock source via the RCC block	Refer to the RCC of the product.
Enable the MDF clocks via the RCC block	Refer to the RCC of the product.
Reset the MDF via the RCC block	Refer to the RCC of the product.
AFMUX programming	Program the AFMUX to select MDF_SD0, MDF_SD2 and MDF_CCK0 function.

Table 359. Programming sequence (continued)

Operations	Comments
Enable MDF processing clock: MDF_CKGCR = 0x0103 0023	PROCDIV = 1 (division by 2): mdf_proc_ck frequency is 6.144 MHz. CCKDIV = 3 (division by 4): MDF_CCK0 clock frequency is 1.536 MHz. The MDF_CCK0 pad is set in output and generates a clock so that the microphones can exit from low-power mode.
Serial interfaces configuration: MDF_SITF0CR = 0x0000 1F01 MDF_SITF2CR = 0x0000 1F01	SCKSRC = 0 to select MDF_CCK0 as serial clock. SIFTMOD = 0 to select LF_MASTER mode. Clock absence feature is not working in this mode. The serial interfaces are enabled.
Bitstream matrix configuration: MDF_BSMX0CR = 0x0000 0000 MDF_BSMX1CR = 0x0000 0001 MDF_BSMX2CR = 0x0000 0004 MDF_BSMX3CR = 0x0000 0005	DFLT0 filter takes the bitstream of SITF0, sampled on rising edge. DFLT1 filter takes the bitstream of SITF0, sampled on falling edge. DFLT2 filter takes the bitstream of SITF2, sampled on rising edge. DFLT3 filter takes the bitstream of SITF2, sampled on falling edge.
Filters configuration (CIC): MDF_DFLT0CICR = 0x02C0 1750 MDF_DFLT1CICR = 0x02C0 1750 MDF_DFLT2CICR = 0x02C0 1750 MDF_DFLT3CICR = 0x02C0 1750	SCALE = 0x2C (- 12 dB) to avoid any saturation MCICD = 0x17 (decimation by 24) CICMOD = 5 to select a $Sinc^5$ DATSCR = 0 to select data coming from BSMX
Filters configuration (RSFLT and HPF): MDF_DFLT0RSFR = 0x0000 0100 MDF_DFLT1RSFR = 0x0000 0100 MDF_DFLT2RSFR = 0x0000 0100 MDF_DFLT3RSFR = 0x0000 0100	HPFC = 1: cut-off frequency of 16 kHz * 0.00125 = 20 Hz HPFBYP = 0: HPF not bypassed RSFLTD = 0: RSFLT decimates by 4 RSFLTBYP = 0: RSFLT is not bypassed
Filters configuration (INT): MDF_DFLT0INTR = 0x0000 0000 MDF_DFLT1INTR = 0x0000 0000 MDF_DFLT2INTR = 0x0000 0000 MDF_DFLT3INTR = 0x0000 0000	INTVAL = 0: INT filter not used Other parameter is not significant.
Micro delay adjust: MDF_DLY0CR = 0x0000 0005 MDF_DLY0CR = 0x0000 0012 MDF_DLY0CR = 0x0000 0023 MDF_DLY0CR = 0x0000 0000	Initial micro-delay for each microphone, values just given as example
Offset error correction: MDF_OEC0CR = 0x0000 0000 MDF_OEC1CR = 0x0000 0000 MDF_OEC2CR = 0x0000 0000 MDF_OEC3CR = 0x0000 0000	No correction. DC offset is removed by HPF.

Table 359. Programming sequence (continued)

Operations	Comments
Short circuit detection: MDF_SCD0CR = 0x0000 0000 MDF_SCD1CR = 0x0000 0000 MDF_SCD2CR = 0x0000 0000 MDF_SCD3CR = 0x0000 0000	SCD function for each filter is disabled.
Enable interrupt events: MDF_DFLT0IER = 0x0000 0202 MDF_DFLT1IER = 0x0000 0202 MDF_DFLT2IER = 0x0000 0202 MDF_DFLT3IER = 0x0000 0202	Enable the interrupt event the application wants to handle. In this example, the SATIE and DOVRIE bits are set to 1 to have an interrupt if a saturation or an data overflow occurs.
Digital filter control: MDF_DFLT0CR = 0x0000 0027 MDF_DFLT1CR = 0x0000 0027 MDF_DFLT2CR = 0x0000 0027 MDF_DFLT3CR = 0x0000 0027 Wait for DFLTACTIVE = 0 for the filters	NBDIS = 0: no samples discarded TRGSRC = 0: TRGO selected as trigger source TRGSENS = 0: Trigger on rising edge ACQMOD = 2: Synchronous continuous acquisition mode DMAEN = 1: DMA interface enabled DFLTEN = 1: digital filter enabled
Clear status flags: MDF_DFLT0ISR = 0x0000 0FFF MDF_DFLT1ISR = 0x0000 0FFF MDF_DFLT2ISR = 0x0000 0FFF MDF_DFLT3ISR = 0x0000 0FFF	Clear all the status flags before running the filters.
Program the DMA Enable the DMA	The DMA must be programmed in order to read the data inside MDF_DFLT0DR every time a DMA request is generated. Note that when the MDF is in interleaved acquisition mode, data of filters 0, 1, 2, and 3 are read via MDF_DFLT0DR register.
Start acquisition: MDF_GCR = 0x0000 0031	ILVNB = 3: interleaved mode with DFLT0,1,2, and 3 TRGO = 1 to trigger the acquisition of all filters waiting for TRGO rising edge event

36.7.3 Connection examples

Figure 369 shows simple connection examples of the MDF to external sensors:

- Picture on the left: four digital microphones connected to the MDF

  In this connection, DMIC1 is intended to be used alone. This is why it uses a dedicated clock (MDF_CCK0). DMIC1 is also connected to a dedicated data line in case the application intends to power-down DMIC2/3/4, when only DMIC1 is used. If the application keeps DMIC2/3/4 powered, DMIC2 and DMIC1 can share the same data line, reducing the connection to four I/Os.

  If the power consumption is not an issue, when a single microphone is used, all the microphones can be connected to the same common clock (MDF_CCK0) and each

microphone pair can share the same data line. In this case, only three I/Os are required.

In this example, the data transfer to memory can be performed either using the interleaved- or the independent-transfer mode.

- Picture in the center: sensor providing several data lines with a common clock

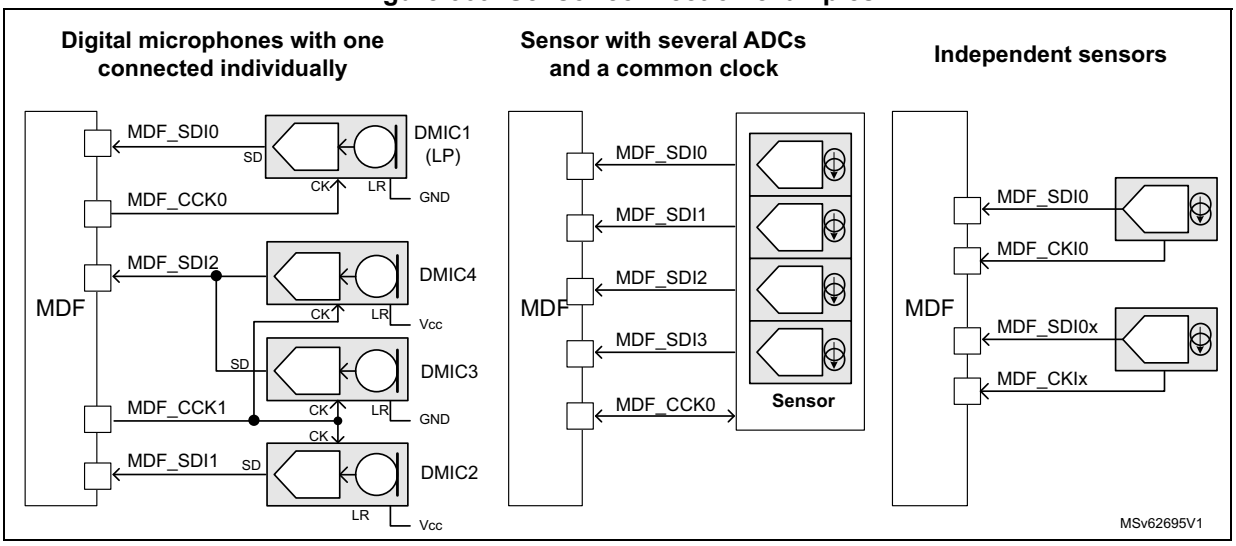
  Each data line can represent different parameters (such as current or voltage). The common clock can be provided either by the sensor or by the MDF. The data line can be shared or not by two sensors if the sensor allows it. In the figure below, the sensor does not allow the sharing of the data lines.

  In this example, the data transfer to memory can be performed either using the interleaved- or independent-transfer mode.

- Picture on the right: two independent sensors connected to the MDF

  Each of them has its dedicated clock and data lines. In this case, the data transfer to memory must use the independent-transfer mode.

Figure 369. Sensor connection examples



36.7.4 Global frequency response

Figure 370 shows the global frequency response for a 16 kHz audio signal with a digital microphone working at 1.024 MHz. The filter configuration is the following:

- CIC order 4 or 5, with a decimation ratio of 16
- RSFLT enabled, with a decimation ratio of 4
- HPF enable with a cut-off frequency of 40 Hz

The figure below shows the theoretical frequency response using a CIC4 and a CIC5.

Figure 370. Global frequency response

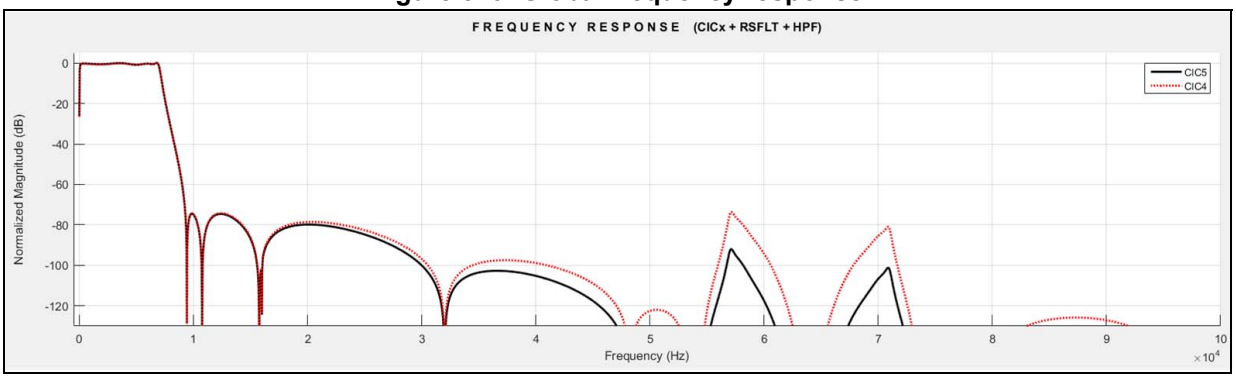


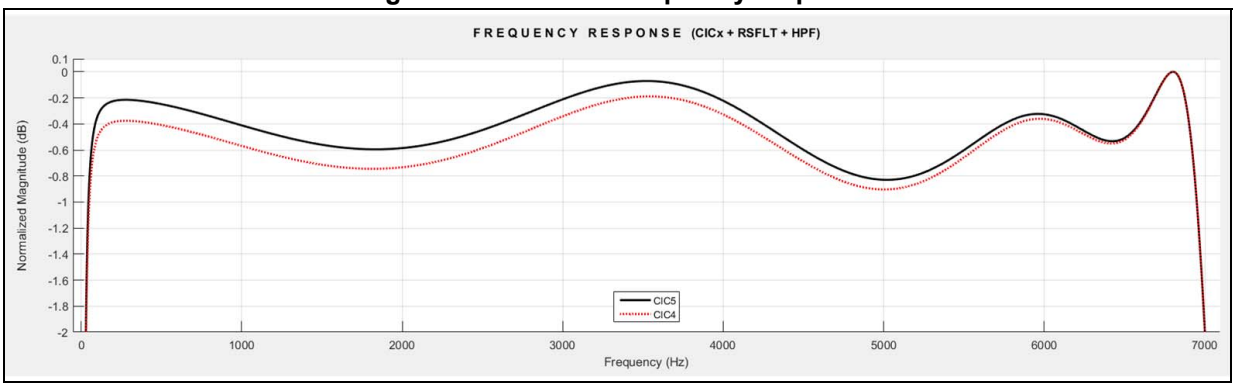
Figure 371 shows the in-band ripple for a 16 kHz audio signal with a digital microphone working at 1.024 MHz. The filter configuration is the following:

- CIC order 4 or 5, with a decimation ratio of 16
- RSFLT enabled, with a decimation ratio of 4
- HPF enable with a cut-off frequency of 20 Hz

The resulting in-band ripple is ± 0.41 dB for CIC5, and ± 0.45 for CIC4.

The -3 dB cut-off frequency is 7061 Hz.

Figure 371. Detailed frequency response



36.7.5 Total MDF gain

This section details how to compute the signal level provided by the MDF according to the filter settings. The formula does not take into account the filters transfer function.

A signal level may be expressed in dBFS (decibel full scale). A 0 dBFS level is assigned to the maximum possible digital level. For example, a signal that reaches 50 % of the maximum level, has a - 6 dBFS level (6 dB below full scale).

For example, for the MDF offering a final data width of 24 bits, a signal having an amplitude of 2 * 10^6 LSB has a level of:

$$20 \times \log_{10}\left(\frac{2 \times 10^{6}}{2^{(24-1)}}\right) = -12.45 \text{ dBFS}$$

In addition, the data size of a signal having an amplitude (Amp) expressed in LSB is given by:

$$DS = \left(\frac{\ln(Amp)}{\ln(2)} + 1\right) \text{ bits}$$

One bit need to be added for negative values.

So a signal having an amplitude of 2 * 10^6 LSB, has a data size of 21.9 bits.

CIC gain

The CIC gain (G_{CIC} and GdB_{CIC}) can be deduced from the following formula giving data size in bits (DS_{CIC}).

$$DS_{CIC} = (N \times \log_2(D1)) + DS_{IN}$$

And the bit growth is:

$$BG_{CIC} = (N \times \log_2(D1))$$

where N represents the CIC order (selected by CICMOD[2:0]), and D1 is the decimation ratio (given by MCICD).

DS_{IN} represents the data size (in bits) of the input signal.

Warning: DS_{CIC} is very important for CIC filters. In order to work fine, DS_{CIC} must not exceed 26 bits.

$$G_{CIC} = 2^{(BG_{CIC})} = (D1)^N$$

which gives, in decibels:

$$GdB_{CIC} = 20 \times \log_{10}((D1)^N)$$

Note: The same formulas are valid for the ACIC.

Data size at SCALE output

The data size at SCALE output (including the CIC gain) is a key information as the RSFLT starts to have some saturations if the peak-to-peak signal amplitude at SCALE output is higher than 22 bits.

If the RSFLT is bypassed, then a peak-to-peak signal amplitude of 24 bits is accepted. The resulting data size is given by:

$$DS_{SCALE} = N \times \log_2(D1) + \log_2\left(10^{\frac{GDB_{SCALE}}{20}}\right) + DS_{IN}$$

The data size at SCALE output (DS_{SCALE}) is expressed in bits and GdB_{SCALE} represents the gain selected by SCALE[5:0], in dB.

RSFLT gain

The RSFLT gain in the useful bandwidth is typically 9.5 dB, but due to ripple a margin of about ± 0.5 dB must be considered. Typically, the RSFLT increases the bit size by BG_{RSFLT}:

$$BG_{RSFLT} = 10^{\frac{9.5\ dB}{20}} = 2.98 = 1.6\ bits$$

INT gain

The INT block can also introduce a gain if the rescaling value is different from the integration value.

$$G_{INT} = \frac{IVAL}{IDIV}$$

and:

$$GdB_{INT} = 20 \times \log_{10}\left(\frac{IVAL}{IDIV}\right)$$

The bit growth of the INT is then given by the following formula:

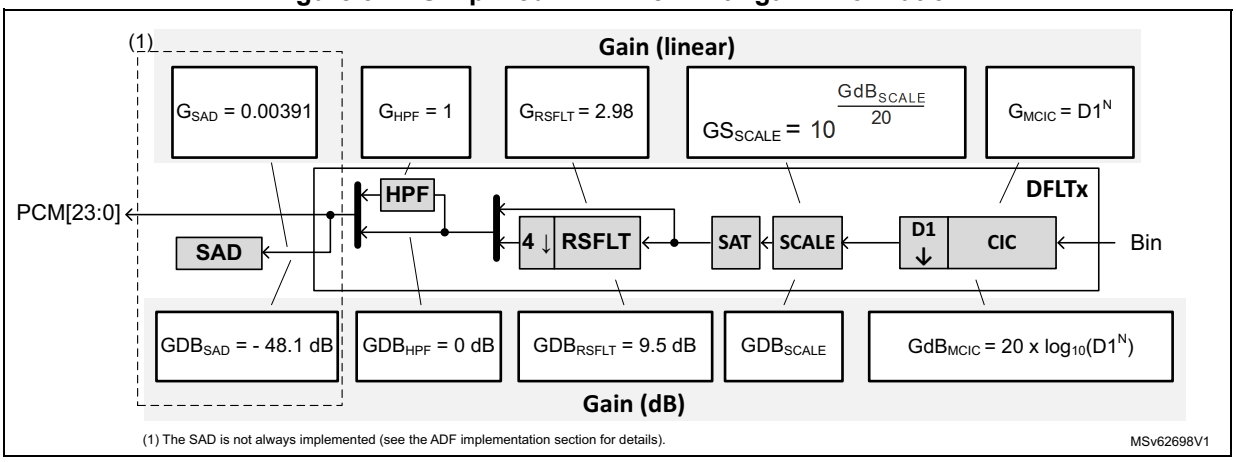
$$BG_{INT} = \log_2\left(\frac{IVAL}{IDIV}\right)$$

IVAL represents the integration value selected by INTVAL[6:0], and IDIV represents the integrator output division selected by INTDIV[1:0].

Note: The HPF filter has a gain of 0 dB.

The figure below shows a simplified view of the filter path, and gives for each significant component the expression of the bit growth and the gain.

Figure 372. Simplified DFLT view with gain information



The table below summarizes the final data size for different filter configurations.

Table 360. Output signal levels

Filter configurations	Final signal level (dBFS)	Final signal size (bits)
CIC + RSFLT (+ HPF)	$SdB_{OUT} = 20 \times \log_{10}\left(\frac{2^{DS_{OUT}}}{2^{24}}\right)$	$DS_{OUT} = DS_{SCALE} + 1.6$ bits DS_{SCALE} must be lower than 22 bits.
CIC + RSFLT (+ HPF) + INT		$DS_{OUT} = DS_{SCALE} + BG_{INT} + 1.6$ bits DS_{SCALE} must be lower than 22 bits.
CIC (+ HPF) + INT		$DS_{OUT} = DS_{SCALE} + BG_{INT}$ DS_{SCALE} must be lower than 24 bits.

Example using the main filter chain

If the MDF filter is programmed as follows:

- The input signal is coming from a serial interface (DS_{IN} = 1 bit).
- CIC order = 5 (N), with a decimation value of 24 (D1).
- SCALE[5:0] is set to -12 dB.
- RSFLT is enabled and the decimation by four is enabled.
- HPF is enabled.
- INT is disabled.

Check first the data size at CIC output:

$$DS_{CIC} = (5 \times \log_2(24)) + 1 \text{ bit} = 23.92 \text{ bits}$$

The size is lower than 26 bits, so the CIC works in good conditions.

The data size at CIC output is very close to 24 bits, so the SCALE must be adjusted in order to provide a signal 22 bits max to the RSFLT. An attenuation of 12 dB is needed.

Then the signal level provided to the RSFLT is:

$$DS_{SCALE} = DS_{CIC} + \log_2\left(10^{\frac{-12}{20}}\right) = 23.92 - 1.99 = 21.93 \text{ bits}$$

At the end, the final signal amplitude is:

$$DS_{OUT} = DS_{SCALE} + 1.6 \text{ bits} = (21.93 + 1.6) = 23.52 \text{ bits}$$

or

$$SDB_{OUT} = 20 \times \log_{10}\left(\frac{2^{23.52}}{2^{24}}\right) = -2.84 \text{ dBFS}$$

The RSFLT ripple a margin of about ± 0.41 dB (in this configuration) must be considered.

Example using the OLD filter chain

In the following example, the application wants to trigger an OLD event when the voltage coming from a shunt resistor reaches ± 200 mV.

Hypothesis:

- The ΣΔ sensor is specified to support a full-scale signal of ± 350 mV.
- The ACIC decimation ratio (D2) is fixed to 32.
- The ACIC order (N) is fixed to 3.

The ΣΔ sensor provides a full-scale digital signal (amplitude of one bit) for a signal higher or equal to ± 350 mV. If the input signal is equal 200 mV, then the digital signal amplitude provided by the sensor is 200 / 350 = 0.571.

The gain of the ACIC filter is:

$G_{CIC} = (D2)^N = 32^3 = 32768$

A signal having an amplitude of 200 mV at sensor input has then an amplitude of about 32768 * 0.571 = 18725 LSB at ACIC output.

OLDTHH must be set to 18725 and OLDTHL must be set to -18725.

36.8 MDF registers

All the MDF registers must be accessed either in word (32-bit) or half-word (16-bit) formats.

The registers are described for the MDF instance having the biggest number of filters. For registers related to filters, the number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

36.8.1 MDF global control register (MDF_GCR)

Address offset: 0x000

Reset value: 0x0000 0000

This register is used for controls common to all digital filters.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ILVNB[3:0]				Res.	Res.	Res.	TRGO
								rw	rw	rw	rw				rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **ILVNB[3:0]**: Interleaved number

This bitfield is set and reset by software. it enables or disables the interleaved-transfer mode and defines how many digital filters work in this mode.
This bitfield cannot be changed when DFLTEN = 1 in MDF_DFLT0CR.
0000: Interleaved-transfer mode disabled
0001: Data from DFLT0 and DFLT1 are interleaved.
0010: Data from DFLT0, DFLT1 and DFLT2 are interleaved.
...
1111: Data from DFLT0 to DFLT15 are interleaved.

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **TRGO**: Trigger output control

This bit is set by software and reset by hardware. It is used to start the acquisition of several filters synchronously. It is also able to synchronize several MDF together by controlling the mdf_trgo signal.

0: Write 0 has no effect. Read 0 means that the trigger can be set again to 1.

1: Write 1 generates a positive pulse on mdf_trgo signal and triggers the acquisition on the enabled filters having ACQMOD[2:0] = 0x1 and selecting TRGO as trigger. Read 1 means that the trigger pulse is still active.

36.8.2 MDF clock generator control register (MDF_CKGCR)

Address offset: 0x004

Reset value: 0x0000 0000

This register is used to control the clock generator. The mdf_proc_ck clock must be enabled before enabling other MDF parts.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CKGACTIVE	PROCDIV[6:0]							Res.	Res.	Res.	Res.	CCKDIV[3:0]			
r	rw	rw	rw	rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRGSRC[3:0]				Res.	Res.	Res.	TRGSENS	Res.	CCK1DIR	CCK0DIR	CKGMOD	Res.	CCK1EN	CCK0EN	CKGDEN
rw	rw	rw	rw				rw		rw	rw	rw		rw	rw	rw

Bit 31 **CKGACTIVE**: Clock generator active flag

This bit is set and cleared by hardware. This flag must be used by the application to check if the clock generator is effectively enabled (active) or not. The protected fields of this function can only be updated when CKGACTIVE = 0 (refer to *Section 36.4.14* for details). The delay between a transition on CKGDEN and a transition on CKGACTIVE is two periods of AHB clock and two periods of mdf_proc_ck.

0: The clock generator is not active and can be configured if needed.

1: The clock generator is active and protected fields cannot be configured.

Bits 30:24 **PROCDIV[6:0]**: Divider to control the serial interface clock

This bitfield is set and reset by software. It is used to adjust the frequency of the clock provided to the SITF.

$$F_{mdf_itf_ck} = \frac{F_{mdf_ker_ck}}{(PROCDIV + 1)}$$

This bitfield must not be changed if one of the filters is enabled (DFTEN = 1).

0: mdf_ker_ck provided to the SITF

1: mdf_ker_ck/2 provided to the SITF

2: mdf_ker_ck/3 provided to the SITF

...

127: mdf_ker_ck/128 provided to the SITF

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **CCKDIV[3:0]**: Divider to control the MDF_CCK clock

This bitfield is set and reset by software. It is used to adjust the frequency of the MDF_CCK clock. The input clock of this divider is the clock provided to the SITF. More globally, the frequency of the MDF_CCK is given by the following formula:

$$F_{MDF_CCK} = \frac{F_{mdf_ker_ck}}{(PROCDIV + 1) \times (CCKDIV + 1)}$$

This bitfield must not be changed if one of the filters is enabled (DFTEN = 1).

0000: The MDF_CCK clock is mdf_proc_ck.

0001: The MDF_CCK clock is mdf_proc_ck / 2.

0010: The MDF_CCK clock is mdf_proc_ck / 3.

...

1111: The MDF_CCK clock is mdf_proc_ck / 16.

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 15:12 **TRGSRC[3:0]**: Digital filter trigger signal selection

This bitfield is set and cleared by software.It is used to select which external signals trigger for the corresponding filter. This bitfield is not significant if CKGMOD = 0.

000x: TRGO selected

0010: mdf_trg[0] selected

0011: mdf_trg[1] selected

...

1111: mdf_trg[13] selected

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details.)

Bits 11:9 Reserved, must be kept at reset value.

Bit 8 **TRGSENS**: CKGEN trigger sensitivity selection

This bit is set and cleared by software. It is used to select the trigger sensitivity of the trigger signals. This bit is not significant if the CKGMOD = 0.

0: A rising edge event triggers the activation of CKGEN dividers.

1: A falling edge even triggers the activation of CKGEN dividers.

Note: When the trigger source is TRGO, TRGSENS value is not taken into account. When TRGO is selected, the sensitivity is forced to falling edge. This bit can be write-protected (refer to Section 36.4.14 for details).

Bit 7 Reserved, must be kept at reset value.

Bit 6 **CCK1DIR**: MDF_CCK1 direction

This bit is set and reset by software.It is used to control the direction of the MDF_CCK1 pin.

0: MDF_CCK1 pin direction is in input.

1: MDF_CCK1 pin direction is in output.

Note: This bit can be write-protected (refer to Section 36.4.14 for details).

Bit 5 **CCK0DIR**: MDF_CCK0 direction

This bit is set and reset by software.It is used to control the direction of the MDF_CCK0.

0: MDF_CCK0 pin direction is in input.

1: MDF_CCK0 pin direction is in output.

Note: This bit can be write-protected (refer to Section 36.4.14 for details).

Bit 4 **CKGMOD**: Clock generator mode

This bit is set and reset by software. It is used to define the way the clock generator is enabled. This bit must not be changed if one of the filters is enabled (DFTEN = 1).

0: The kernel clock is provided to the dividers as soon as CKGDEN is set to 1.

1: The kernel clock is provided to the dividers when CKGDEN is set to 1 and the trigger condition met.

Note: This bit can be write-protected (refer to Section 36.4.14 for details).

Bit 3 Reserved, must be kept at reset value.

Bit 2 **CCK1EN**: MDF_CCK1 clock enable

This bit is set and reset by software. It is used to control the generation of the bitstream clock on the MDF_CCK1 pin.

0: Bitstream clock not generated

1: Bitstream clock generated on the MDF_CCK1 pad

Bit 1 **CCK0EN**: MDF_CCK0 clock enable

This bit is set and reset by software.It is used to control the generation of the bitstream clock on the MDF_CCK0 pin.

0: Bitstream clock not generated

1: Bitstream clock generated on the MDF_CCK0 pad

Bit 0 **CKGDEN**: CKGEN dividers enable

This bit is set and reset by software. It is used to enable/disable the clock dividers of the CKGEN: PROCDIV and CCKDIV.

0: CKGEN dividers disabled

1: CKGEN dividers enabled

36.8.3 MDF serial interface control register x (MDF_SITFxCR)

Address offset: 0x080 + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 1F00

This register is used to control the serial interfaces (SITFx). The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SITFACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	STH[4:0]					Res.	Res.	SITFMOD[1:0]		Res.	SCKSRC[1:0]		SITFEN
			rw	rw	rw	rw	rw			rw	rw		rw	rw	rw

Bit 31 **SITFACTIVE**: Serial interface active flag

This bit is set and cleared by hardware. It is used by the application to check if the serial interface is effectively enabled (active) or not. The protected fields of this function can only be updated when the SITFACTIVE is set to 0 (refer to *Section 36.4.14* for details).

The delay between a transition on SITFEN and a transition on SITFACTIVE is two periods of AHB clock and two periods of mdf_proc_ck.

0: The serial interface is not active and can be configured if needed.

1: The serial interface is active and protected fields cannot be configured.

Bits 30:13 Reserved, must be kept at reset value.

Bits 12:8 **STH[4:0]**: Manchester symbol threshold/SPI threshold
This bitfield is set and cleared by software. It is used for Manchester mode to define the expected symbol threshold levels (refer to *Manchester mode* for details on computation).
In addition this bitfield is used to define the timeout value for the clock absence detection in Normal SPI mode. STH[4:0] values lower than four are invalid.
Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **SITFMOD[1:0]**: Serial interface type
This bitfield is set and cleared by software. it is used to define the serial interface type.
00: LF_MASTER SPI mode
01: Normal SPI mode
10: Manchester mode: rising edge = logic 0, falling edge = logic 1
11: Manchester mode: rising edge = logic 1, falling edge = logic 0
Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bit 3 Reserved, must be kept at reset value.

Bits 2:1 **SCKSRC[1:0]**: Serial clock source
This bitfield is set and cleared by software. it is used to select the clock source of the serial interface.
00: Serial clock source is MDF_CCK0.
01: Serial clock source is MDF_CCK1.
1x: Serial clock source is MDF_CKIx (not allowed in LF_MASTER SPI mode).
Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bit 0 **SITFEN**: Serial interface enable
This bit is et and cleared by software. It is used to enable/disable the serial interface.
0: Serial interface disabled
1: Serial interface enabled

36.8.4 MDF bitstream matrix control register x (MDF_BSMXxCR)

Address offset: 0x084 + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

This register is used to select the bitstream to be provided to the corresponding digital filter and to the SCD. The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BSMXACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BSSEL[4:0]				
											rw	rw	rw	rw	rw

Bit 31 **BSMXACTIVE**: BSMX active flag

This bit is set and cleared by hardware. It is used by the application to check if the BSMX is effectively enabled (active) or not. BSSEL[4:0] can only be updated when the BSMXACTIVE is set to 0. Th is BSMXACTIVE flag is a logical OR between OLDACTIVE, DFLTACTIVE, and SCDACTIVE flags. Both of them must be set to 0 in order update BSSEL[4:0] bitfield.

0: BSMX is not active and can be configured if needed.

1: BSMX is active and protected fields cannot be configured.

Bits 30:5 Reserved, must be kept at reset value.

Bits 4:0 **BSSEL[4:0]**: Bitstream Selection

This bitfield is set and cleared by software. It is used to select the bitstream to be processed for DFLTx and SCDx. The size of this bitfield depends on the number of DFLTx instantiated. If this bitfield selects a not instantiated input, the MDF selects the valid stream bsx_f having the higher index number.

00000: bs0_r provided to DFLTx and SCDx

00001: bs0_f provided to DFLTx and SCDx

00010: bs1_r provided to DFLTx and SCDx (if instantiated)

00011: bs1_f provided to DFLTx and SCDx (if instantiated)

...

11110: bs15_r provided to DFLTx and SCDx (if instantiated)

11111: bs15_f provided to DFLTx and SCDx (if instantiated)

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

36.8.5 MDF digital filter control register x (MDF_DFLTxCR)

Address offset: 0x088 + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DFLTACTIVE	DFLTRUN	Res.	Res.	NBDIS[7:0]								Res.	Res.	Res.	SNPSFMT
r	r			rw	rw	rw	rw	rw	rw	rw	rw				rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRGSRC[3:0]				Res.	Res.	Res.	TRGSENS	Res.	ACQMOD[2:0]			Res.	FTH	DMAEN	DFLTEN
rw	rw	rw	rw				rw		rw	rw	rw		rw	rw	w

Bit 31 **DFLTACTIVE**: Digital filter active flag

This bit is set and cleared by hardware. It indicates if the digital filter is active: can be running or waiting for events.

0: Digital filter not active (can be re-enabled again, via DFLTEN, if needed)

1: Digital filter active

Bit 30 **DFLTRUN**: Digital filter run status flag

This bit is set and cleared by hardware. It indicates if the digital filter is running or not.

0: Digital filter not running and ready to accept a new trigger event

1: Digital filter running

Bits 29:28 Reserved, must be kept at reset value.

Bits 27:20 **NBDIS[7:0]**: Number of samples to be discarded

This bitfield is set and cleared by software. it is used to define the number of samples to be discarded every time the DFLTx is re-started.

0: No sample discarded

1: 1 sample discarded

2: 2 samples discarded

...

255: 255 samples discarded

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 19:17 Reserved, must be kept at reset value.

Bit 16 **SNPSFMT**: Snapshot data format

This bit is set and cleared by software. It is used to select the data format for the snapshot mode.

0: Integrator counter (INT_CNT) not inserted into MDF_SNPSxDR, leaving a data resolution of 23 bits

1: Integrator counter (INT_CNT) inserted at position [15:9] of MDF_SNPSxDR, leaving a data resolution of 16 bits.

Note: This bit can be write-protected (refer to Section 36.4.14 for details).

Bits 15:12 **TRGSRC[3:0]**: Digital filter trigger signal selection

This bitfield is set and cleared by software. It is used to select which external signals trigger the corresponding filter.

0000: TRGO selected

0001: OLDx event selected

0010: mdf_trg[0] selected

...

1111: mdf_trg[13] selected

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 11:9 Reserved, must be kept at reset value.

Bit 8 **TRGSENS**: Digital filter trigger sensitivity selection

this bit is set and cleared by software. It is used to select the trigger sensitivity of the external signals

0: A rising edge event triggers the acquisition.

1: A falling edge even triggers the acquisition.

Note: When the trigger source is TRGO or OLDx event, TRGSENS value is not taken into account. When TRGO is selected, the sensitivity is forced to falling edge, when OLDx event is selected, the sensitivity is forced to rising edge.
This bit can be write-protected (refer to Section 36.4.14 for details).

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **ACQMOD[2:0]**: Digital filter trigger mode

This bitfield is set and cleared by software. It is used to select the filter trigger mode.

000: Asynchronous continuous acquisition mode

001: Asynchronous single-shot acquisition mode

010: Synchronous continuous acquisition mode

011: Synchronous, single-shot acquisition mode

100: Window continuous acquisition mode

101: Synchronous snapshot mode

Others: same a 000

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bit 3 Reserved, must be kept at reset value.

Bit 2 **FTH**: RXFIFO threshold selection

This bit is set and cleared by software. It is used to select the RXFIFO threshold. This bit is not significant for RXFIFOs working in interleaved-transfer mode (see *Interleaved-transfer mode* for details).

0: RXFIFO threshold event generated when the RXFIFO is not empty

1: RXFIFO threshold event generated when the RXFIFO is half-full

Note: This bit can be write-protected (refer to Section 36.4.14 for details).

Bit 1 **DMAEN**: DMA requests enable

This bit is set and cleared by software. It is used to control the generation of DMA request to transfer the processed samples into the memory.

0: DMA interface for the corresponding digital filter disabled

1: DMA interface for the corresponding digital filter enabled

Note: This bit can be write-protected (refer to Section 36.4.14 for details).

Bit 0 **DFLTEN**: Digital filter enable

This bit is set and cleared by software. It is used to control the start of acquisition of the corresponding digital filter path. This bit behavior depends on ACQMOD[2:0]and external events. The serial or parallel interface delivering the samples must be enabled as well.

0: Acquisition immediately stopped

1: Acquisition immediately started if ACQMOD[2:0] = 00x or 101, or acquisition started when the proper trigger event occurs if ACQMOD[2:0] = 01x or 100.

36.8.6 MDF digital filter configuration register x (MDF_DFLTxCICR)

Address offset: 0x08C + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

This register is used to control the main CIC filter.The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	SCALE[5:0]						Res.	Res.	Res.	MCICD8
						rw	rw	rw	rw	rw	rw				rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MCICD[7:0]								Res.	CICMOD[2:0]			Res.	Res.	DATSRC[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw			rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:20 **SCALE[5:0]**: Scaling factor selection
This bitfield is set and cleared by software. It is used to select the gain to be applied at CIC output (refer to *Table 351* for details). If the application attempts to write a new gain value while the previous one is not yet applied, this new gain value is ignored. Reading back this bitfield informs the application on the current gain value.
000000: 0 dB
000001: + 3.5 dB
000010: + 6 dB or shift left by 1 bit
...
011000: + 72 dB or shift left by 12 bits
100000: - 48.2 dB or shift right by 8 bits (default value)
100001: - 44.6 dB
100010: - 42.1 dB or shift right by 7 bits
100011: - 38.6 dB
...
101110: - 6 dB or shift right by 1 bit
101111: - 2.5 dB
Others: Reserved

Bits 19:17 Reserved, must be kept at reset value.

Bits 16:8 **MCICD[8:0]**: CIC decimation ratio selection
This bitfield is set and cleared by software. It is used to select the CIC decimation ratio. A decimation ratio smaller than two is not allowed. The decimation ratio is given by (CICDEC+1).
0: Decimation ratio is 2.
1: Decimation ratio is 2.
2: Decimation ratio is 3..
3: Decimation ratio is 4
...
511: Decimation ratio is 512.
Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **CICMOD[2:0]**: Select the CIC mode
This bitfield is set and cleared by software.It is used to select the configuration and the order of the MCIC. When CICMOD[2:0] = 0xx, the CIC is split into two filters: the main CIC (MCIC) and the auxiliary CIC (ACIC, used for the out-off limit detector).
000: CIC split in two filters and MCIC configured in FastSinc filter
001: CIC split in two filters and MCIC configured in $Sinc^1$ filter
010: CIC split in two filters and MCIC configured in $Sinc^2$ filter
011: CIC split in two filters and MCIC configured in $Sinc^3$ filter
100: CIC configured in single $Sinc^4$ filter
others: CIC configured in single $Sinc^5$ filter
Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **DATSRC[1:0]**: Source data for the digital filter
This bitfield is set and cleared by software.
0x: Stream coming from the BSMX selected
10: Stream coming from the ADCITF1 selected
11: Stream coming from the ADCITF2 selected
Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

36.8.7 MDF reshape filter configuration register x (MDF_DFLTxRSFR)

Address offset: 0x090 + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

This register is used to control the reshape and HPF filters. The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	HPFC[1:0]		HPFBYP	Res.	Res.	RSFLTD	Res.	Res.	Res.	RSFLTBYP
						rw	rw	rw			rw				rw

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:8 **HPFC[1:0]**: High-pass filter cut-off frequency

This bitfield is set and cleared by software. It is used to select the cut-off frequency of the high-pass filter. F_{PCM} represents the sampling frequency at HPF input.

00: Cut-off frequency = 0.000625 x F_{PCM}

01: Cut-off frequency = 0.00125 x F_{PCM}

10: Cut-off frequency = 0.00250 x F_{PCM}

11: Cut-off frequency = 0.00950 x F_{PCM}

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bit 7 **HPFBYP**: High-pass filter bypass

This bit is set and cleared by software. It is used to bypass the high-pass filter.

0: HPF not bypassed (default value)

1: HPF bypassed

Note: This bit can be write-protected (refer to Section 36.4.14 for details).

Bits 6:5 Reserved, must be kept at reset value.

Bit 4 **RSFLTD**: Reshaper filter decimation ratio

This bit is set and cleared by software. It is used to select the decimation ratio for the reshape filter.

0: Decimation ratio is 4 (default value).

1: Decimation ratio is 1.

Note: This bit can be write-protected (refer to Section 36.4.14 for details).

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **RSFLTBYP**: Reshaper filter bypass

This bit is set and cleared by software. It is used to bypass the reshape filter and its decimation block.

0: Reshape filter not bypassed (default value)

1: Reshape filter bypassed

Note: This bit can be write-protected (refer to Section 36.4.14 for details).

36.8.8 MDF integrator configuration register x (MDF_DFLTxINTR)

Address offset: 0x094 + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

This register is used to the integrator (INT) settings. The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	INTVAL[6:0]							Res.	Res.	INTDIV[1:0]	
					rw	rw	rw	rw	rw	rw	rw			rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:4 **INTVAL[6:0]**: Integration value selection

This bitfield is set and cleared by software. It is used to select the integration value.
0: The integration value is 1, meaning bypass mode (default after reset).
1: The integration value is 2.
2: The integration value is 3.
...
127: The integration value is 128.

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **INTDIV[1:0]**: Integrator output division

This bitfield is set and cleared by software. It is used to rescale the signal at the integrator output in order keep the data width lower than 24 bits.
00: The integrator data outputs are divided by 128 (default value).
01: The integrator data outputs are divided by 32.
10: The integrator data outputs are divided by 4.
11: The integrator data outputs are not divided.

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

36.8.9 MDF out-of limit detector control register x (MDF_OLDxCR)

Address offset: 0x098 + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

This register is used to configure the OLDx.The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OLDACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ACICD[4:0]					Res.
r										rw	rw	rw	rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	ACICN[1:0]		Res.	Res.	Res.	Res.	BKOLD[3:0]				Res.	Res.	THINB	OLDEN
		rw	rw					rw	rw	rw	rw			rw	rw

Bit 31 **OLDACTIVE**: OLDx active flag

This bit is set and cleared by hardware. It is used to check if the OLDx is effectively enabled (active) or not. The protected fields and registers of this function can only be updated when the OLDACTIVE is set to 0 (refer to *Section 36.4.14* for details).

The delay between a transition on OLDEN and a transition on OLDACTIVE is two periods of AHB clock and two periods of mdf_proc_ck.

0: OLDx not active and can be configured if needed

1: OLDx active and protected fields cannot be configured

Bits 30:22 Reserved, must be kept at reset value.

Bits 21:17 **ACICD[4:0]**: OLDx CIC decimation ratio selection

This bitfield is set and cleared by software. It is used to select the decimation ratio of the ACIC. It is only taken into account by the MDF when CICMOD[2:0] = 0xx. The decimation ratio is given by (ACICD + 1).

0: Decimation ratio is 1.

1: Decimation ratio is 2.

2: Decimation ratio is 3.

3: Decimation ratio is 4.

...

31: Decimation ratio is 32.

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 16:14 Reserved, must be kept at reset value.

Bits 13:12 **ACICN[1:0]**: OLDx CIC order selection

This bitfield is set and cleared by software. It is used to select the ACIC type and order. It is only taken into account by the MDF when CICMOD[2:0] = 0xx.

00: FastSinc filter type

01: $Sinc^1$ filter type

10: $Sinc^2$ filter type

11: $Sinc^3$ filter type

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 11:8 Reserved, must be kept at reset value.

Bits 7:4 **BKOLD[3:0]**: Break signal assignment for out-of limit detector

This bitfield is set and cleared by software.

BKOLD[i] = 0: Break signal (mdf_break[i]) not assigned to threshold event

BKOLD[i] = 1: Break signal (mdf_break[i]) assigned to threshold event

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **THINB**: Threshold In band

This bit is set and cleared by software.

0: The OLDx generates an event if the signal is lower than OLDTHL or higher than OLDTHH (default value).

1: The OLDx generates an event if the signal is lower than OLDTHH and higher than OLDTHL.

Note: This bit can be write-protected (refer to Section 36.4.14 for details).

Bit 0 **OLDEN**: OLDx enable

This bit is set and cleared by software.

0: OLDx disabled (default value)

1: OLDx enabled, including the ACIC filter working in continuous mode

36.8.10 MDF OLDx low threshold register x (MDF_OLDxTHLR)

Address offset: 0x09C + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

This register is used for the adjustment of the out-off-limit low threshold. The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	OLDTHL[25:16]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OLDTHL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:0 **OLDTHL[25:0]**: OLD low threshold value

This bitfield is set and cleared by software. OLDTHL represents a 26-bit signed value. The real threshold compared to the signal provided by the filter is OLDTHL.

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

36.8.11 MDF OLDx high threshold register x (MDF_OLDxTHHR)

Address offset: 0x0A0 + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

This register is used for the adjustment of the OLDx high threshold. The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	OLDTHH[25:16]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OLDTHH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:0 **OLDTHH[25:0]**: OLDx high threshold value

This bitfield is set and cleared by software. OLDTHH represents a 26-bit signed value. The real threshold compared to the signal provided by the filter is OLDTHH.

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

36.8.12 MDF delay control register x (MDF_DLYxCR)

Address offset: 0x0A4 + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

This register is used for the adjustment stream delays. The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SKPBF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SKPDLY[6:0]						
									rw	rw	rw	rw	rw	rw	rw

Bit 31 **SKPBF**: Skip busy flag

This bit is set and cleared by hardware. It is used to control if the delay sequence is completed.

0: MDF ready to accept a new value into SKPDLY[6:0]

1: Last valid SKPDLY[6:0] still under processing

Bits 30:7 Reserved, must be kept at reset value.

Bits 6:0 **SKPDLY[6:0]**: Delay to apply to a bitstream

This bitfield is set and cleared by software. It defines the number of input samples that are skipped. Skipping is applied immediately after writing to this bitfield, if SKPBF = 0 and the corresponding DFLTEN = 1. If SKPBF = 1, the value written into the register is ignored by the delay state machine.

0: No input sample skipped

1: 1 input sample skipped

...

127: 127 input samples skipped

36.8.13 MDF short circuit detector control register x (MDF_SCDxCR)

Address offset: 0x0A8 + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

This register is used for the adjustment stream delays. The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SCDACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SCDT[7:4]			
r												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SCDT[3:0]				Res.	Res.	Res.	Res.	BKSCD[3:0]				Res.	Res.	Res.	SCDEN
rw	rw	rw	rw					rw	rw	rw	rw				rw

Bit 31 **SCDACTIVE**: SCDx active flag

This bit is set and cleared by hardware. It is used to check if the SCDx is effectively enabled (active) or not. The protected fields of this function can only be updated when the SCDACTIVE is set to 0 (refer to *Section 36.4.14* for details).

The delay between a transition on SCDEN and a transition on SCDACTIVE is two periods of AHB clock and two periods of mdf_proc_ck.

0: SCDx not active and can be configured if needed

1: SCDx active and protected fields cannot be configured

Bits 30:20 Reserved, must be kept at reset value.

Bits 19:12 **SCDT[7:0]**: SCDx threshold

This bitfield is set and cleared by software. These bits are written by software to define the threshold counter for SCDx. If this value is reached, a short-circuit detector event occurs on a given input stream.

0: 2 consecutive 1's or 0's generate an event.

1: 2 consecutive 1's or 0's generate an event.

2: 3 consecutive 1's or 0's generate an event.

...

255: 256 consecutive 1's or 0's generate an event.

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 11:8 Reserved, must be kept at reset value.

Bits 7:4 **BKSCD[3:0]**: Break signal assignment for short circuit detector

This bitfield is set and cleared by software.

BKSCD[i] = 0: Break signal (mdf_break[i]) not assigned to this SCD event

BKSCD[i] = 1: Break signal (mdf_break[i]) assigned to this SCD event

Note: This bitfield can be write-protected (refer to Section 36.4.14 for details).

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **SCDEN**: SCDx enable

This bit is set and cleared by software.

0: SCDx disabled

1: SCDx enabled,

36.8.14 MDF DFLT0 interrupt enable register 0 (MDF_DFLT0IER)

Address offset: 0x0AC

Reset value: 0x0000 0000

This register is used for allowing or not the events to generate an interrupt.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	RFOVRIE	CKABIE	SATIE	SCDIE	SSOVRIE	Res.	Res.	OLDIE	Res.	SSDRIE	DOVRIE	FTHIE
				rw	rw	rw	rw	rw			rw		rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **RFOVRIE**: Reshape filter overrun interrupt enable
This bit is set and cleared by software.
0: Reshape filter overrun interrupt disabled
1: Reshape filter overrun interrupt enabled

Bit 10 **CKABIE**: Clock absence detection interrupt enable
This bit is set and cleared by software.
0: Clock absence interrupt disabled
1: Clock absence interrupt enabled

Bit 9 **SATIE**: Saturation detection interrupt enable
This bit is set and cleared by software.
0: Saturation interrupt disabled
1: Saturation interrupt enabled

Bit 8 **SCDIE**: SCD0 interrupt enable
This bit is set and cleared by software.
0: SCD0 interrupt disabled
1: SCD0 interrupt enabled

Bit 7 **SSOVRIE**: Snapshot overrun interrupt enable
This bit is set and cleared by software.
0: Snapshot overrun interrupt disabled
1: Snapshot overrun interrupt enabled

Bits 6:5 Reserved, must be kept at reset value.

Bit 4 **OLDIE**: OLD0 interrupt enable
This bit is set and cleared by software.
0: OLD0 event interrupt disabled
1: OLD0 event interrupt enabled

Bit 3 Reserved, must be kept at reset value.

Bit 2 **SSDRIE**: Snapshot data ready interrupt enable
This bit is set and cleared by software.
0: Snapshot data ready interrupt disabled
1: Snapshot data ready interrupt enabled

Bit 1 **DOVRIE**: Data overflow interrupt enable
This bit is set and cleared by software.
0: Data overflow interrupt disabled
1: Data overflow interrupt enabled

Bit 0 **FTHIE**: RXFIFO threshold interrupt enable
This bit is set and cleared by software.
0: RXFIFO threshold interrupt disabled
1: RXFIFO threshold interrupt enabled

36.8.15 MDF DFLTx interrupt enable register x (MDF_DFLTxIER)

Address offset: 0x12C + 0x80 * (x - 1), (x = 1 to 5)

Reset value: 0x0000 0000

This register is used for allowing or not, the events to generate an interrupt. The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	RFOVRIE	CKABIE	SATIE	SCDIE	SSOVRIE	Res.	Res.	OLDIE	Res.	SSDRIE	DOVRIE	FTHIE
				rw	rw	rw	rw	rw			rw		rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **RFOVRIE**: Reshape filter overrun interrupt enable
This bit is set and cleared by software.
0: Reshape filter overrun interrupt disabled
1: Reshape filter overrun interrupt enabled

Bit 10 **CKABIE**: Clock absence detection interrupt enable
This bit is set and cleared by software.
0: Clock absence interrupt disabled
1: Clock absence interrupt enabled

Bit 9 **SATIE**: Saturation detection interrupt enable
This bit is set and cleared by software.
0: Saturation interrupt disabled
1: Saturation interrupt enabled

Bit 8 **SCDIE**: SCDx interrupt enable
This bit is set and cleared by software.
0: SCDx interrupt disabled
1: SCDx interrupt enabled

Bit 7 **SSOVRIE**: Snapshot overrun interrupt enable
This bit is set and cleared by software.
0: Snapshot overrun interrupt disabled
1: Snapshot overrun interrupt enabled

Bits 6:5 Reserved, must be kept at reset value.

Bit 4 **OLDIE**: OLDx interrupt enable
This bit is set and cleared by software.
0: OLDx event interrupt disabled
1: OLDx event interrupt enabled

Bit 3 Reserved, must be kept at reset value.

Bit 2 **SSDRIE**: Snapshot data ready interrupt enable
This bit is set and cleared by software.
0: Snapshot data ready interrupt disabled
1: Snapshot data ready interrupt enabled

Bit 1 **DOVRIE**: Data overflow interrupt enable
This bit is set and cleared by software.
0: Data overflow interrupt disabled
1: Data overflow interrupt enabled

Bit 0 **FTHIE**: RXFIFO threshold interrupt enable
This bit is set and cleared by software.
0: RXFIFO threshold interrupt disabled
1: RXFIFO threshold interrupt enabled

36.8.16 MDF DFLT0 interrupt status register 0 (MDF_DFLT0ISR)

Address offset: 0x0B0

Reset value: 0x0000 0000

This register contains the status flags for each digital filter path.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	RFOVRF	CKABF	SATF	SCDF	SSOVRF	THHF	THLF	OLDF	RXNEF	SSDRF	DOVRF	FTHF
				rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	r	r	rc_w1	r	rc_w1	rc_w1	r

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **RFOVRF**: Reshape filter overrun detection flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no reshape filter overrun is detected. Write 0 has no effect.
1: Read 1 means that reshape filter overrun is detected. Write 1 clears this flag.

Bit 10 **CKABF**: Clock absence detection flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no clock absence is detected. Write 0 has no effect.
1: Read 1 means that a clock absence is detected. Write 1 clears this flag.

Bit 9 **SATF**: Saturation detection flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no saturation is detected. Write 0 has no effect.
1: Read 1 means that a saturation is detected. Write 1 clears this flag.

Bit 8 **SCDF**: Short-circuit detector flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no SCD0 event is detected. Write 0 has no effect.
1: Read 1 means that a SCD0 event is detected. Write 1 clears this flag.

Bit 7 **SSOVRF**: Snapshot overrun flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no snapshot overrun event is detected. Write 0 has no effect.
1: Read 1 means that a snapshot overrun event is detected. Write 1 clears this flag.

Bit 6 **THHF**: High-threshold status flag

This bit is set by hardware and cleared by software by writing this bit to 1. It indicates the status of the high-threshold comparator when the last OLD0 event occurred. This bit gives additional information on the conditions triggering the last OLD0 event. It can be cleared by writing OLDF flag to 1.

0: The signal was lower than OLDTHH when the last OLD0 event occurred.

1: The signal was higher than OLDTHH when the last OLD0 event occurred.

Bit 5 **THLF**: Low-threshold status flag

This bit is set by hardware and cleared by software by writing this bit to 1. It indicates the status of the low-threshold comparator when the last OLD0 event occurred. This bit gives additional information on the conditions triggering the last OLD0 event. It can be cleared by writing OLDF flag to 1.

0: The signal was higher than OLDTHL when the last OLD0 event occurred.

1: The signal was lower than OLDTHL when the last OLD0 event occurred.

Bit 4 **OLDF**: OLD0 flag

This bit is set by hardware and cleared by software by writing this bit to 1.

0: Read 0 means that no OLD0 event is detected. Write 0 has no effect.

1: Read 1 means that an OLD0 event is detected Write 1 clears THHF, THLF and OLDF.

Bit 3 **RXNEF**: RXFIFO not-empty flag

this bit is set and cleared by hardware according to the RXFIFO level.

0: RXFIFO empty

1: RXFIFO not empty

Bit 2 **SSDRF**: Snapshot data ready flag

This bit is set by hardware and cleared by software by writing this bit to 1.

0: Read 0 means that no data is available. Write 0 has no effect.

1: Read 1 means that a new data is available. Write 1 clears this flag.

Bit 1 **DOVRF**: Data overflow flag

This bit is set by hardware and cleared by software by writing this bit to 1.

0: Read 0 means that no overflow is detected. Write 0 has no effect.

1: Read 1 means that an overflow is detected; Write 1 clears this flag.

Bit 0 **FTHF**: RXFIFO threshold flag

This bit is set by hardware and cleared by hardware when the RXFIFO level is lower than the threshold.

0: RXFIFO threshold not reached

1: RXFIFO threshold reached

36.8.17 MDF DFLTx interrupt status register x (MDF_DFLTxISR)

Address offset: 0x130 + 0x80 * (x - 1), (x = 1 to 5)

Reset value: 0x0000 0000

This register contains the status flags for each digital filter path. The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	RFOVRF	CKABF	SATF	SCDF	SSOVRF	THHF	THLF	OLDF	RXNEF	SSDRF	DOVRF	FTHF
				rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	r	r	rc_w1	r	rc_w1	rc_w1	r

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **RFOVRF**: Reshape filter overrun detection flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no reshape filter overrun is detected. Write 0 has no effect.
1: Read 1 means that reshape filter overrun is detected. Write 1 clears this flag.

Bit 10 **CKABF**: Clock absence detection flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no clock absence is detected. Write 0 has no effect.
1: Read 1 means that a clock absence is detected. Write 1 clears this flag.

Bit 9 **SATF**: Saturation detection flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no saturation is detected. Write 0 has no effect.
1: Read 1 means that a saturation is detected. Write 1 clears this flag.

Bit 8 **SCDF**: Short-circuit detector flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no SCD event is detected. Write 0 has no effect.
1: Read 1 means that a SCD event is detected. Write 1 clears this flag.

Bit 7 **SSOVRF**: Snapshot overrun flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no snapshot overrun event is detected. Write 0 has no effect.
1: Read 1 means that a snapshot overrun event is detected. Write 1 clears this flag.

Bit 6 **THHF**: High-threshold status flag
This bit is set by hardware and cleared by software by writing this bit to 1. It indicates the status of the high-threshold comparator when the last OLDx event occurred. This bit gives additional information on the conditions triggering the last OLDx event. It can be cleared by writing OLDF flag to 1.
0: The signal was lower than OLDTHH when the last OLDx event occurred.
1: The signal was higher than OLDTHH when the last OLDx event occurred.

Bit 5 **THLF**: Low-threshold status flag

This bit is set by hardware and cleared by software by writing this bit to 1. It indicates the status of the low-threshold comparator when the last OLDx event occurred. This bit gives additional information on the conditions triggering the last OLDx event. It can be cleared by writing OLDF flag to 1.

0: The signal was higher than OLDTHL when the last OLDx event occurred.

1: The signal was lower than OLDTHL when the last OLDx event occurred.

Bit 4 **OLDF**: OLDx flag

This bit is set by hardware and cleared by software by writing this bit to 1.

0: Read 0 means that no OLDx event is detected. Write 0 has no effect.

1: Read 1 means that an OLDx event is detected Write 1 clears THHF, THLF and OLDF.

Bit 3 **RXNEF**: RXFIFO not-empty flag

this bit is set and cleared by hardware according to the RXFIFO level.

0: RXFIFO empty

1: RXFIFO not empty

Bit 2 **SSDRF**: Snapshot data ready flag

This bit is set by hardware and cleared by software by writing this bit to 1.

0: Read 0 means that no data is available. Write 0 has no effect.

1: Read 1 means that a new data is available. Write 1 clears this flag.

Bit 1 **DOVRF**: Data overflow flag

This bit is set by hardware and cleared by software by writing this bit to 1.

0: Read 0 means that no overflow is detected. Write 0 has no effect.

1: Read 1 means that an overflow is detected; Write 1 clears this flag.

Bit 0 **FTHF**: RXFIFO threshold flag

This bit is set by hardware and cleared by hardware when the RXFIFO level is lower than the threshold.

0: RXFIFO threshold not reached

1: RXFIFO threshold reached

36.8.18 MDF offset error compensation control register x (MDF_OECxCR)

Address offset: 0x0B4 + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

This register contains the offset compensation value. The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	OFFSET[25:16]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OFFSET[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:0 **OFFSET[25:0]**: Offset error compensation
This bitfield is set and cleared by software. If the application attempts to write a new offset value while the previous one is not yet applied, this new offset value is ignored. Reading back this bitfield informs the application on the current offset value.
This bitfield represents the value to be subtracted to the signal before going to the SCALE.

36.8.19 MDF snapshot data register x (MDF_SNPSxDR)

Address offset: 0x0EC + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

This register is used to read the data processed by each digital filter in snapshot mode. The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SDR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTSDR[6:0]							MCICDC[8:0]								
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **SDR[15:0]**: Contains the 16 MSB of the last valid data processed by the digital filter.

Bits 15:9 **EXTSDR[6:0]**: Extended data size
If SNPSFMT = 0, this bitfield contains the bits 7 to 1 of the last valid data processed by the digital filter.
If SNPSFMT = 1, this bitfield contains the INT accumulator counter value when the last trigger event occurs (INT_CNT).

Bits 8:0 **MCICDC[8:0]**: Contains the MCIC decimation counter value when the last trigger event occurs (MCIC_CNT)

36.8.20 MDF digital filter data register x (MDF_DFLTxDR)

Address offset: 0x0F0 + 0x80 * x, (x = 0 to 5)

Reset value: 0x0000 0000

This register is used to read the data processed by each digital filter. The number of registers is equal to the amount of filters. Refer to *Section 36.3* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DR[23:8]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DR[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r	r	r	r								

Bits 31:8 **DR[23:0]**: Data processed by digital filter

Bits 7:0 Reserved, must be kept at reset value.

36.8.21 MDF register map

Table 361. MDF register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	MDF_GCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ILVNB [3:0]				Res.	Res.	Res.	TRGO
	Reset value																									0	0	0	0				0
0x004	MDF_CKGCR	CKGACTIVE	PROCDIV[6:0]							Res.	Res.	Res.	Res.	CCKDIV [3:0]				TRGSRC [3:0]				Res.	Res.	Res.	TRGSENS	Res.	CCK1DIR	CCK0DIR	CKGMOD	Res.	CCK1EN	CCK0EN	CKGDEN
	Reset value	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0				0		0	0	0		0	0	0
0x008-0x07C	Reserved																																
0x080 + 0x80 * x (x = 0 to 5)	MDF_SITFxCR	SITFACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STH[4:0]				Res.	Res.	SITFMOD [1:0]		Res.	SCKSRC [1:0]		SITFEN
	Reset value	0																			1	1	1	1	1			0	0		0	0	0
0x084 + 0x80 * x (x = 0 to 5)	MDF_BSMXxCR	BSMXACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BSSEL[4:0]				
	Reset value	0																											0	0	0	0	0
0x088 + 0x80 * x (x = 0 to 5)	MDF_DFLTxCR	DFLTACTIVE	DFLTRUN	Res.	Res.	NBDIS[7:0]								Res.	Res.	Res.	SNPSFMT	TRGSRC [3:0]				Res.	Res.	Res.	TRGSENS	Res.	ACQMOD [2:0]			Res.	FTH	DMAEN	DFLTEN
	Reset value	0	0			0	0	0	0	0	0	0	0				0	0	0	0	0				0		0	0	0		0	0	0
0x08C + 0x80 * x (x = 0 to 5)	MDF_DFLTxCICR	Res.	Res.	Res.	Res.	Res.	Res.	SCALE[5:0]						Res.	Res.	Res.	MCICD[8:0]									Res.	CICMOD [2:0]			Res.	Res.	DATSRC [1:0]	
	Reset value							0	0	0	0	0	0				0	0	0	0	0	0	0	0	0		0	0	0			0	0
0x090 + 0x80 * x (x = 0 to 5)	MDF_ DFLTxRSFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HPFC[1:0]		HPFBYP	Res.	Res.	RSFLTD	Res.	Res.	Res.	RSFLTBYP
	Reset value																							0	0	0			0				0
0x094 + 0x80 * x (x = 0 to 5)	MDF_DFLTxINTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INTVAL[6:0]							Res.	Res.	INTDIV [1:0]	
	Reset value																						0	0	0	0	0	0	0			0	0
0x098 + 0x80 * x (x = 0 to 5)	MDF_OLDxCR	OLDACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ACICD[4:0]					Res.	Res.	Res.	ACICN [1:0]		Res.	Res.	Res.	Res.	BKOLD [3:0]				Res.	Res.	THINB	OLDEN
	Reset value	0										0	0	0	0	0				0	0					0	0	0	0			0	0

Table 361. MDF register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x09C + 0x80 * x (x = 0 to 5)	MDF_OLDxTHLR	Res.	Res.	Res.	Res.	Res.	Res.	OLDTHL[25:0]																									
	Reset value							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A0 + 0x80 * x (x = 0 to 5)	MDF_OLDxTHHR	Res.	Res.	Res.	Res.	Res.	Res.	OLDTHH[25:0]																									
	Reset value							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A4 + 0x80 * x (x = 0 to 5)	MDF_DLYxCR	SKPBF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SKPDLY[6:0]						
	Reset value	0																									0	0	0	0	0	0	0
0x0A8 + 0x80 * x (x = 0 to 5)	MDF_SCDxCR	SCDACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SCDT[7:0]								Res.	Res.	Res.	Res.	BKSCD [3:0]				Res.	Res.	Res.	SCDEN
	Reset value	0												0	0	0	0	0	0	0	0					0	0	0	0				0
0x0AC	MDF_DFLT0IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFOVRIE	CKABIE	SATIE	SCDIE	SSOVRIE	Res.	Res.	OLDIE	Res.	SSDRIE	DOVRIE	FTHIE
	Reset value																					0	0	0	0	0			0		0	0	0
0x0B0	MDF_DFLT0ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFOVRF	CKABF	SATF	SCDF	SSOVRF	THHF	THLF	OLDF	RXNEF	SSDRF	DOVRF	FTHF
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x0B4 + 0x80 * x (x = 0 to 5)	MDF_OECxCR	Res.	Res.	Res.	Res.	Res.	Res.	OFFSET[25:0]																									
	Reset value							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B8-0x0E8	Reserved																																
0x0EC + 0x80 * x (x = 0 to 5)	MDF_SNPSxDR	SDR[15:0]																EXTSDR[6:0]							MCICDC[8:0]								
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0F0 + 0x80 * x (x = 0 to 5)	MDF_DFLTxDR	DR[23:0]																								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								
0x12C + 0x80*(x-1) (x=1 to 5)	MDF_DFLTxIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFOVRIE	CKABIE	SATIE	SCDIE	SSOVRIE	Res.	Res.	OLDIE	Res.	SSDRIE	DOVRIE	FTHIE
	Reset value																					0	0	0	0	0			0		0	0	0
0x130 + 0x80*(x-1) (x=1 to 5)	MDF_DFLTxISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFOVRF	CKABF	SATF	SCDF	SSOVRF	THHF	THLF	OLDF	RXNEF	SSDRF	DOVRF	FTHF
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

37 Audio digital filter (ADF)

37.1 ADF introduction

The audio digital filter (ADF) is a high-performance module dedicated to the connection of external sigma-delta (∑Δ) modulators. It is mainly targeted for the following applications:

- audio capture signals
- metering

The ADF features one digital serial interface (SITF0) and one digital filter (DFLT0) with flexible digital processing options in order to offer up to 24-bit final resolution.

The ADF serial interface supports several standards allowing the connection of various ∑Δ modulator sensors:

- SPI interface
- Manchester coded 1-wire interface
- PDM interface

The ADF converts an input data stream into clean decimated digital data words. This conversion is done thanks to low-pass digital filters and decimation blocks. In addition, it is possible to insert a high-pass filter.

The conversion speed and resolution are adjustable according to configurable parameters for digital processing: filter bypass, filter order, decimation ratio. The maximum output data resolution is up to 24 bits. There are two conversion modes: single conversion and continuous modes. The data can be automatically stored in a system RAM buffer through DMA, thus reducing the software overhead.

A sound activity detector (SAD) is available for the detection of sounds or voice signals. The SAD is connected at the output of the DFLT0. Several parameters can be programmed in order to adjust properly the SAD to the sound environment. The SAD strongly reduces the power consumption by preventing the storage of samples into the system memory, as long as the observed signal does not match the programmed criteria.

The digital processing is performed using only the kernel clock. The ADF requests the bus interface clock (AHB clock) only when data must be transfered or when a specific event requests the attention of the system processor.

37.2 ADF main features

- AHB Interface
- 1 serial digital input:
  - configurable SPI interface to connect various digital sensors
  - configurable Manchester coded interface support
  - compatible with PDM interface to support digital microphones
- 2 common clocks input/output for ∑Δ modulators
- 1 flexible digital filter path including:
  - A MCIC filter configurable in $Sinc^4$ or $Sinc^5$ filter with an adjustable decimation ratio
  - A reshape filter to improve the out-off band rejection and in-band ripple

  - A high-pass filter to cancel the DC offset
  - Gain control
  - Saturation blocks
- Clock absence detector
- Sound activity detector
- 24-bit signed output data resolution
- Continuous or single conversion
- Possibility to delay the selected bitstream
- One trigger input
- DMA can be used to read the conversion data
- Interrupts services

37.3 ADF implementation

Table 362. ADF features(1)

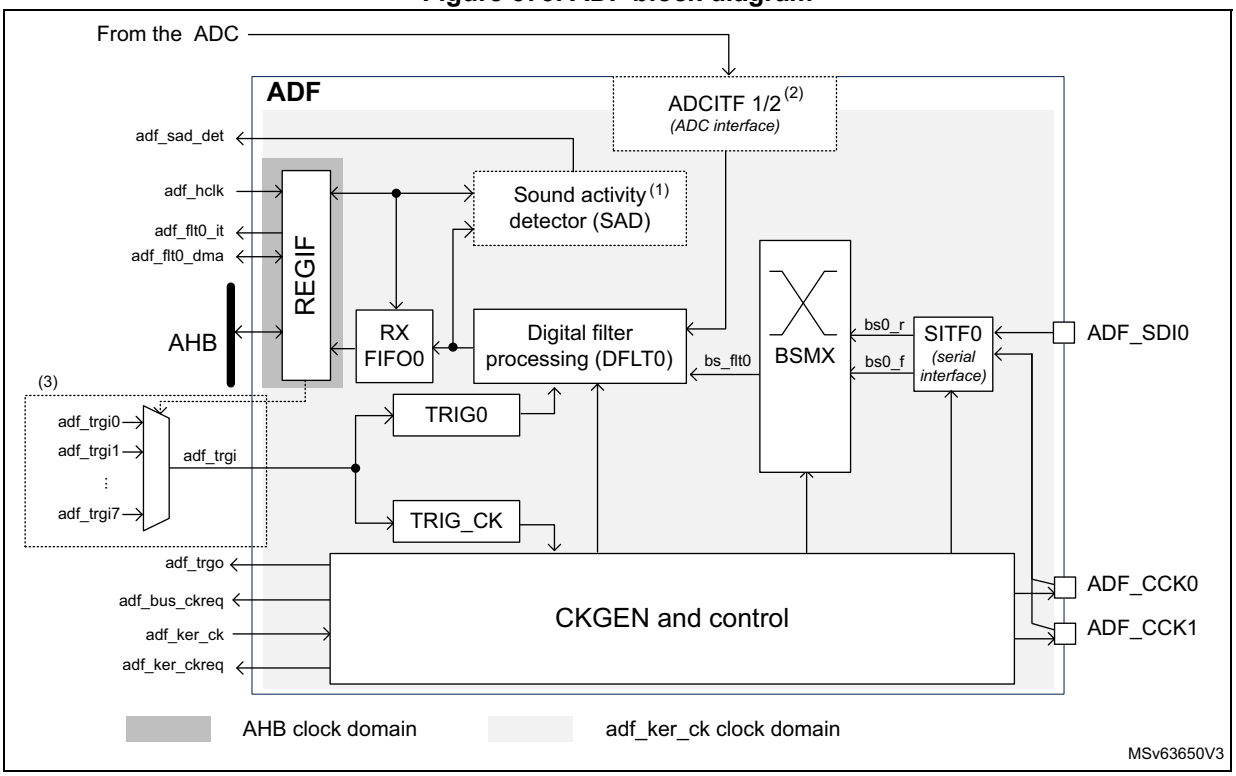
Mode or feature	ADF1
Number of filters (DFLTx) and serial interfaces (SITFx)	1
MDF_CKIy/ADF_CKI0 connected to pins	-
Sound activity detection (SAD)	X
RXFIFO depth (number of 24-bit words)	4
ADC connected to ADCITF1	ADC3
ADC connected to ADCITF2	-
Motor dedicated features (SCD, OLD, OEC, INT, snapshot, break)	-
Main path with CIC4, CIC5	X
Main path with CIC1,2, 3 or FastSinc	-
RSFLT, HPF, SAT, SCALE, DLY, Discard functions	X
Autonomous in Stop modes	-

1. ‘X’ = supported, ‘-’ = not supported.

37.4 ADF functional description

37.4.1 ADF block diagram

Figure 373. ADF block diagram



1. Refer to *Section 37.3: ADF implementation* to check if the SAD is available.
2. Refer to *Section 37.3: ADF implementation* to check if the ADCITF is available, and which ADCs are connected.
3. The number of trigger inputs depends on the product. Refer to *Table 365* for details.

37.4.2 ADF pins and internal signals

Table 363. ADF external pins

Pin name	Pin type	Remarks
ADF_SDI0	Input	Data signal from external sensors
ADF_CCKy (y = 0,1)	Input/output	Clock outputs for external sensor, or common clock input from external sensors

Table 364. ADF internal signals

Signal name	Signal type	Remarks
adf_trgi	Input	Trigger inputs to control the acquisition (see *Table 365: ADF trigger connections* for details)
adf_trgo	Output	Trigger output for synchronizing with other MDF instances

Table 364. ADF internal signals (continued)

Signal name	Signal type	Remarks
adf_flt0_dma	Input/output	DMA request/acknowledge signals for the ADF processing chain
adf_flt0_it	Output	Global interrupt signals
adf_bus_ckreq	Output	Bus interface clock request output
adf_ker_ckreq	Output	Kernel clock request output
adf_ker_ck	Input	Kernel clock input
adf_hclk	Input	AHB bus interface clock input
adf_sad_det	Output	SAD sound detection: 1 means that detecting sound
adf_adcitf1_dat[15:0]	Input	ADCITF1 data input
adf_adcitf2_dat[15:0]	Input	ADCITF2 data input

Table 365. ADF trigger connections

Trigger name	Direction	Trigger source/destination
adf_trgi	Input	From exti15
adf_trgo	Output	To mdf_trgi13

Table 366. ADF ADC data connections

ADC data bus name	ADC source
adf_adcitf1_dat[15:0]	adc3_dat

37.4.3 Serial input interface (SITF)

The SITF0 input interface allows the connection of the external sensor to the digital filter via the bitstream matrix (BSMX). The SITF0 can be configured in the following modes:

- LF_MASTER SPI mode (low-frequency)
- normal SPI mode
- Manchester mode

The data from the serial interface is routed to the filter in order to perform the PDM to PCM conversion and the sound activity detection.

The serial interface is enabled by setting the SITFEN bit to 1. Once the interface is enabled, it receives serial data from the external ∑Δ modulator.

Note: Before enabling the *serial interface, the user must insure that the adf_proc_ck is already enabled (see Section 37.4.5: Clock generator (CKGEN) for details).*

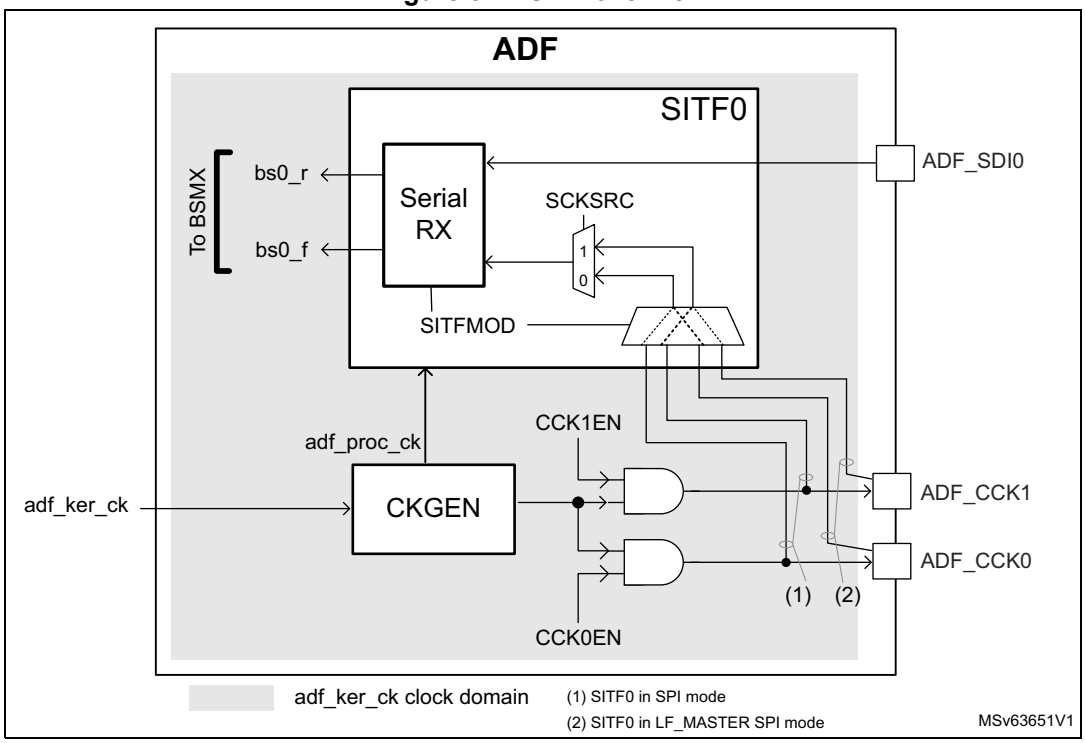
The SITF0 is controlled via the *ADF serial interface control register 0 (ADF_SITF0CR)*.

As shown in the *Figure 374*, ADF_CCK0 or ADF_CCK1 can be selected as clock source, in order to sample the incoming bitstream:

- If the serial interface is programmed in SPI mode, the selected clock source is a copy of the clock present on the ADF_CCK0 or ADF_CCK1 pin.
- If the serial interface is programmed in LF_MASTER SPI mode, the selected clock source is the clock directly provided by the CCKDIV to the ADF_CCK0 or ADF_CCK1 pin.

See *Table 367* for additional information.

Figure 374. SITF overview



LF_MASTER and normal SPI modes

The LF_MASTER SPI mode is a special mode allowing the use of an adf_proc_ck clock frequency, only two times bigger than the sensor clock. This mode is dedicated to low-power use-cases, using low-speed sensors.

In LF_MASTER SPI mode, the ADF must provide the bitstream clock to the external sensors via ADF_CCK0 and ADF_CCK1 pins. The ADF receives the bitstream data via the serial data input ADF_SDI0.

For the SITF0, the application must select the same clock than the one provided to the external sensor (ADF_CCK0 or ADF_CCK1), in order to guarantee optimal timing performances. This selection is done via SCKSRC[1:0].

The normal SPI interface is a more flexible interface than the LF_MASTER SPI, but the adf_proc_ck frequency must be at least four times higher than the sensor clock.

The application can select ADF_CCK0 or ADF_CCK1 clock for the capture of the data received via the ADF_SDI0 pin.

The ADF can generate a clock to the sensors via ADF_CCK0 or ADF_CCK1 if needed.

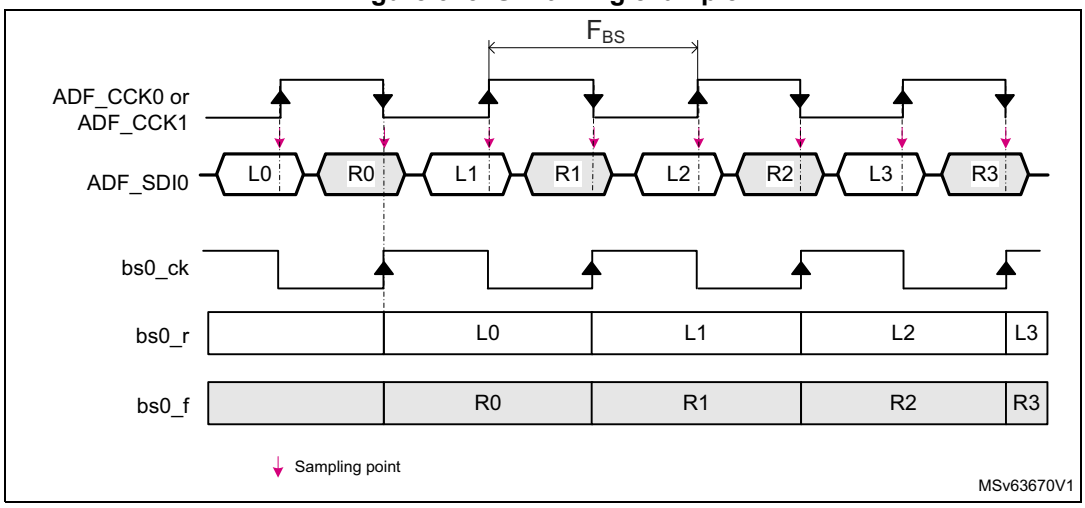
For all SPI modes, the serial data is captured using the rising and the falling edge of the selected clock. The SITF0 always provides the following bitstreams:

- bitstream received using the bitstream clock falling edge (bs0_f)
- bitstream received using the bitstream clock rising edge (bs0_r)

According to the sensors connected, one of the two bitstreams may not be available.

The application can select the wanted stream via the BSMX matrix.

Figure 375. SPI timing example



To properly synchronize/receive the data stream, the adf_proc_ck frequency must be adjusted according to the constraints listed in *Table 368*.

Clock absence detection

A no-clock-transition period may be detected when the serial interface works in normal SPI mode. This feature can be used to detect a clock failure in the SPI link.

The application can program a timeout value via the STH[4:0] bitfield of the SITF0. If the ADF does not detect clock transitions for a duration of STH[4:0] x $T_{adf_proc_ck}$, then the CKABF flag is set.

An interrupt can be generated if CKABIE is set to 1. The STH[4:0] bitfield is in the *ADF serial interface control register 0 (ADF_SITF0CR)*.

When the serial interface is enabled, the CKABF flag remains to 1 until a first clock transition is detected.

To avoid spurious clock absence detection, the following sequence must be respected:

1. Configure the serial interface in normal SPI mode and enable it.
2. Clear the CKABF flag by writing CKABF bit to 1.

   If no clock transition is detected on the serial interface, the hardware immediately sets the CKABF flag to 1.

3. Read the CKABF flag:
   – If CKABF = 1, go back to step 2.
   – If CKABF = 0, a clock has been detected. The CKABIE bit can be set to 1 if the application wants an interrupt on detection of a clock absence.

Note: The clock absence detection feature is not available in the LF_MASTER SPI mode.

Manchester mode

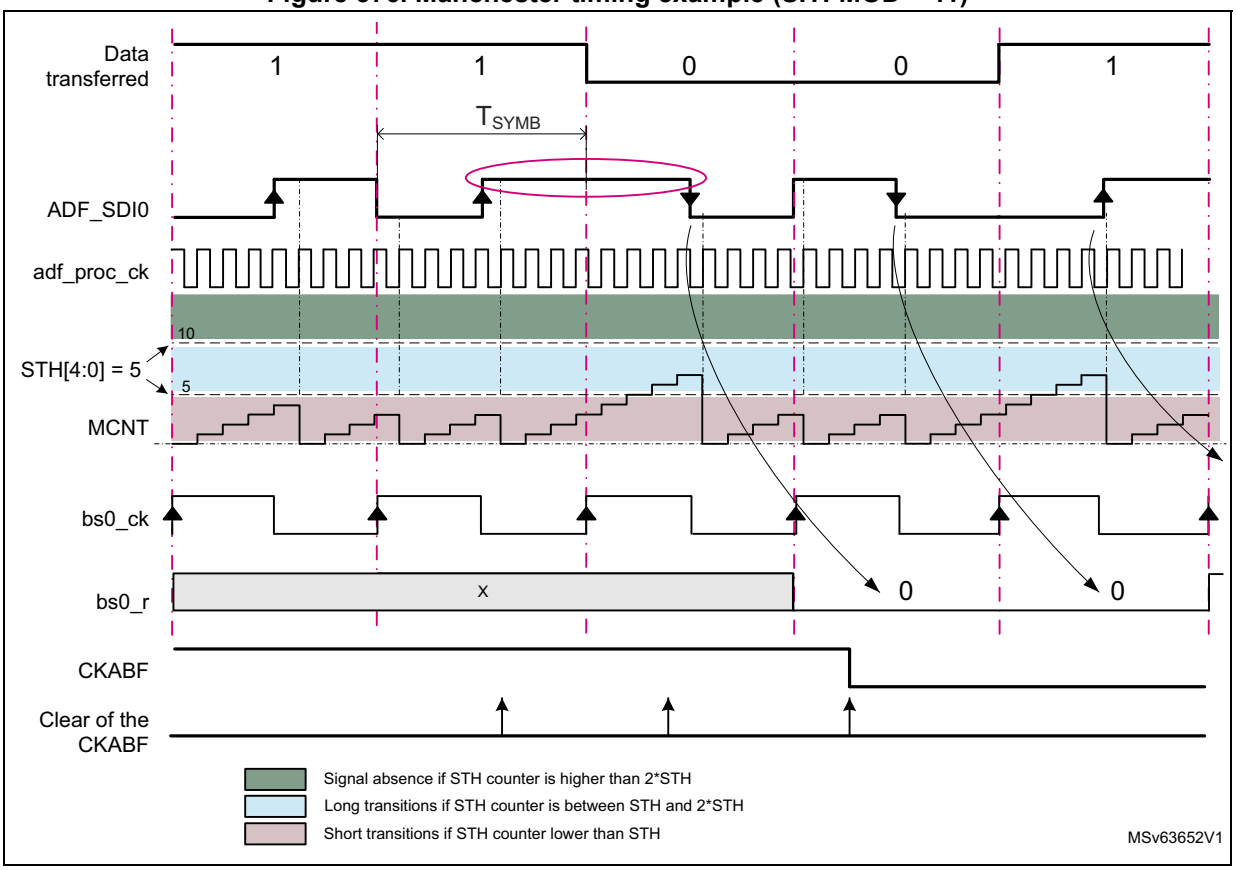
In Manchester coded format, the ADF receives data stream from the external sensor via the ADF_SDI0 pin only.

The ADF_CCK0 and ADF_CCK1 pins are not needed in this mode.

Decoded data and clock signals are recovered from serial stream after Manchester decoding. They are available on bs0_r. There are two possible settings of Manchester codings:

- signal rising edge decoded as 0 and signal falling edge decoded as 1
- signal rising edge decoded as 1 and signal falling edge decoded as 0

Figure 376. Manchester timing example (SITFMOD = 11)



To decode the incoming Manchester stream, the user must program STH[4:0] in the *ADF serial interface control register 0 (ADF_SITF0CR)*. The STH[4:0] bitfield is used by the SITF0 to estimate the Manchester symbol length and to detect a clock absence. An internal counter (MCNT) is restarted every time a transition is detected in the ADF_SDI0 input. It is used to detect short transitions, long transitions or clock absence. A long transition indicates

that the data value changed. *Figure 376* shows a case where the OVR is around height and STH[4:0] = 5.

The estimated Manchester symbol rate (T_{SYMB}) must respect the following formula:

$$(STH + 1) \times T_{adf_proc_ck} < T_{SYMB} < (2 \times STH \times T_{adf_proc_ck})$$

It is recommended to compute STH as follows:

$$STH[4:0] = round\left(\frac{(2 \times OVR) - 1}{3}\right)$$

where OVR represents the ratio between the adf_proc_ck frequency and the expected Manchester symbol frequency. OVR must be higher than five, and the adf_proc_ck clock must be adjusted according to the constraints listed in *Table 368*.

The clock absence flag CKABF is set to 1 when no transition is detected during more than 2 x STH[4:0] x $T_{adf_proc_ck}$, or when the SITF0 is not yet synchronized to the incoming Manchester stream. In addition, an interrupt can be generated if the bit CKABIE is set to 1.

When the serial interface is enabled, the ADF must first be synchronized to the incoming Manchester stream. The synchronization ends when a data transition from 0 to 1 or from 1 to 0 (pink circle in the *Figure 376*) is detected.

The end of the synchronization phase can be checked by following the software sequence:

1. Clear the CKABF flag in the *ADF DFLT0 interrupt status register 0 (ADF_DFLT0ISR)* by writing CKABF bit to 1. If the serial interface is not yet synchronized the hardware immediately set the CKABF flag to 1.
2. Read the CKABF flag:
   – If CKABF= 1, go back to step 1.
   – If CKABF = 0, the Manchester interface is synchronized and provides valid data.

Programming example

In the following example, the ADF kernel clock frequency ($F_{adf_ker_ck}$) is 100 MHz and the received Manchester stream is at about 6 MHz (F_{SYMB}):

1. Provide a valid adf_proc_ck to the SITF0.

   The adf_proc_ck frequency must be at least six times higher than the Manchester symbol frequency (means at least 36 MHz).

   PROCDIV is programmed to 1 to perform a division by two of the kernel clock. In that case, $F_{adf_proc_ck}$ = 50 MHz (8.33 times higher than the Manchester symbol frequency).
2. Compute STH.

   OVR is given by: OVR = $F_{adf_proc_ck}$ / F_{SYMB} = 50 MHz / 6 MHz = 8.33.

   Then $STH[4:0] = round\left(\frac{(2 \times 8.33) - 1}{3}\right) = 5$

   The minimum allowed frequency for the Manchester stream is then:

   1 / (2 × STH × $T_{adf_proc_ck}$) = 1 / (10 x 20 ns) = 5 MHz

   The maximum allowed frequency for the Manchester stream is then:

   1 / ((STH+1) × $T_{adf_proc_ck}$) = 1 / (6 x 20 ns) = 8.33 MHz

37.4.4 ADC slave interface (ADCITF)

The ADCs are not always connected to the ADF. Refer to *Section 37.3* to check the situation for this product.

The ADF allows the connection of up to two ADCs to the filter path. For the filter, the DATSRC[1:0] bitfield in the *ADF digital filer configuration register 0 (ADF_DFLT0CICR)* allows the application to select data from the ADCs.

Warning: The ADF does not support receiving interleaved data from one of the ADCITF input.

37.4.5 Clock generator (CKGEN)

The RCC (reset and clock controller) provides the following clocks to the ADF:

- AHB clock (adf_hclk) used for the register interface
- kernel clock (adf_ker_ck) mainly used by all other parts of the circuit via the CKGEN

These clocks are not supposed to be phase locked, so all signals crossing those clock domains are resynchronized.

The clock generator (CKGEN) is responsible of the generation of the processing clock, and the clock provided to the ADF_CCK0 and ADF_CCK1 pins. All those clocks are generated from the adf_ker_ck.

The processing clock (adf_proc_ck) is used to run all the signal processing and to re-sample the incoming serial or parallel stream.

To adapt the kernel clock frequency provided by the RCC, the following dividers are available:

- PROCDIV[6:0] used to adapt the kernel clock frequency to the constraints of the parallel and serial interfaces, and to the processing blocks
- CCKDIV[3:0] used to adapt the frequency of the ADF_CCK0 and ADF_CCK1 clocks

PROCDIV[6:0] and CCKDIV[3:0] must be programmed when no clock is provided to the dividers (CKGDEN = 0).

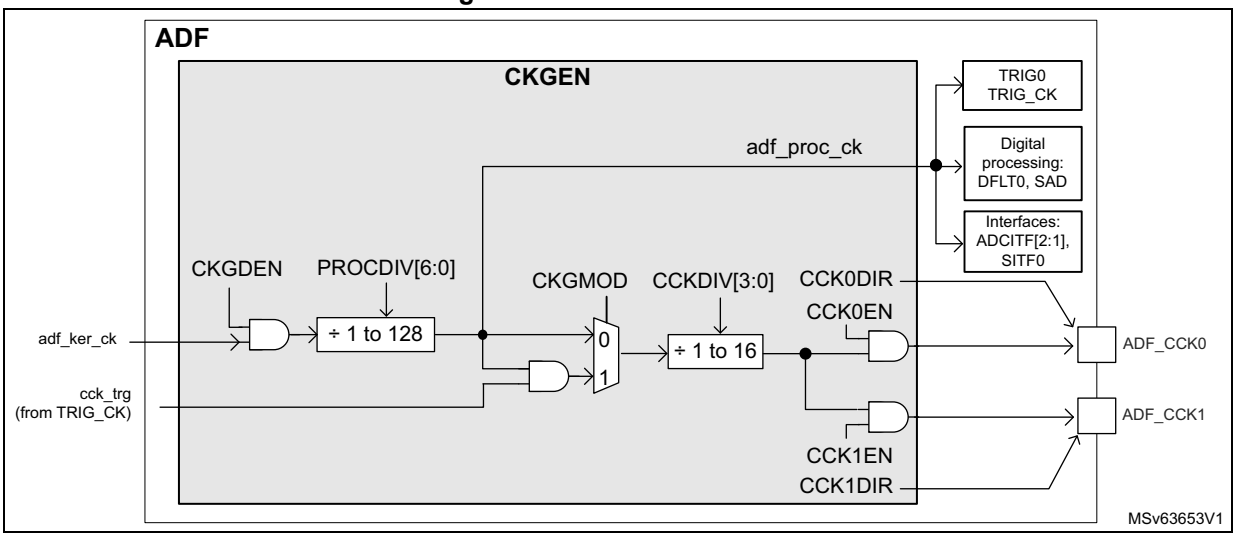
The adf_proc_ck generation is controlled by CKGDEN.

In addition, the CKGMOD bit allows the application to define the way to trigger the CCKDIV divider:

- When CKGMOD = 0, the CCKDIV divider is started as soon as CKGDEN is set to 1.
- When CKGMOD = 1, the CCKDIV divider is started when CKGDEN is set to 1 and the programmed trigger condition occurred.

All the bits and fields controlling the CKGEN are in the *ADF clock generator control register (ADF_CKGCR)*.

Figure 377. CKGEN overview



The trigger logic for CKGEN is handled by the block TRG_CK. As shown in *Figure 382*, the CCKDIV divider can be triggered on the rising or falling edge of an external trigger source. When the proper trigger condition occurs, the cck_trg signal goes to high, allowing the CCKDIV divider to start. The TRG_CK logic is reset when CKGDEN is set to 0.

This feature can be helpful to synchronize the ADF_CCKy (y = 0,1) clock of several ADF instances, or to synchronize the clock generation to a timer event.

The application can control the activation of the ADF_CCK0 or ADF_CCK1 pin thanks to CCK0EN/CCK1EN and CCK0DIR/CCK1DIR bits:

- CCKyEN is used to enable the CCKDIV, and thus generates a clock for the external sensors.
- CCKyDIR is used to control the direction of the ADF_CCKy pin (input or output)

Table 367. Control of the common clock generation(1)

CCKyEN	CCKyDIR	Description
0	0	The ADF_CCKy pin is in input. An external clock can be connected to the ADF_CCKy pin and used by the SITF0 in order to decode the serial stream
0	1	The ADF_CCKy pin is in output. No clock is generated. The ADF_CCKy pin is driven low.
1	1	The ADF_CCKy pin is in output. A clock is generated on the ADF_CCKy pin. The SITF0 can use this pin as clock source in order to decode the serial stream

1. The configuration with CCKyEN = 1 and CCyDIR = 0 is not shown must be avoided (no interest).

Note: The adf_proc_ck must be enabled (by CKGDEN = 1) before enabling other blocks (such as SITF0 or DFLT0).

CKGEN activation sequence example

1. Set CKGDEN to 0.
2. Wait for CKGACTIVE = 0. If CKGDEN was previously enabled, this phase can take two periods of adf_hclk, and two periods of adf_proc_ck.
3. Program PROCDIV[6:0], CKGMOD, CCKDIV[3:0], TRGSRC[3:0], TRGSENS, CCK1EN and CCK0EN.
4. Set CKGDEN to 1.

When needed, at any moment, CCK[1:0]EN bitfield value can be changed without disabling the clock generator.

Clock frequency constraints

Table 368 shows the frequency constraints to receive and process properly the samples.

Note: The reshape filter (RSFLT) needs up to 24 cycles of adf_proc_ck clock to process one sample.

Table 368. Clock constraints with respect to the incoming stream(1)

SITF0 mode	ADF clock constraints	
	With RSFLT disabled	With RSFLT enabled
LF_MASTER SPI	F_{ADF_CCKy} max frequency limited to 5 MHz	
	$F_{adf_proc_ck} > 2 \times F_{ADF_CCKy}$ and $F_{adf_hclk} \geq F_{adf_proc_ck}$	$F_{adf_proc_ck} > 24 \times F_{ADF_CCKy} / (MCICD+1)$ and $F_{adf_proc_ck} > 2 \times F_{ADF_CCKy}$ and $F_{adf_hclk} \geq F_{adf_proc_ck}$
MASTER SPI SLAVE SPI	F_{ADF_CKx} max frequency limited to 25 MHz	
	$F_{adf_proc_ck} > 4 \times F_{ADF_CCKy}$ and $F_{adf_hclk} \geq F_{adf_proc_ck}$	$F_{adf_proc_ck} > 24 \times F_{ADF_CCKy} / (MCICD+1)$ and $F_{adf_proc_ck} > 4 \times F_{ADF_CCKy}$ and $F_{adf_hclk} \geq F_{adf_proc_ck}$
Manchester	F_{SYMB} max frequency limited to 20 MHz	
	$F_{adf_proc_ck} > 6 \times F_{SYMB}$ and $F_{adf_hclk} \geq F_{adf_proc_ck}$	$F_{adf_proc_ck} > 24 \times F_{ADF_CCKy} / (MCICD+1)$ and $F_{adf_proc_ck} > 6 \times F_{SYMB}$ and $F_{adf_hclk} \geq F_{adf_proc_ck}$

1. F_{ADF_CCKy} represents the frequency of clock received via ADF_CCKy, or generated via ADF_CCKy. F_{SYMB} represents the frequency of the received symbol rate for Manchester mode.

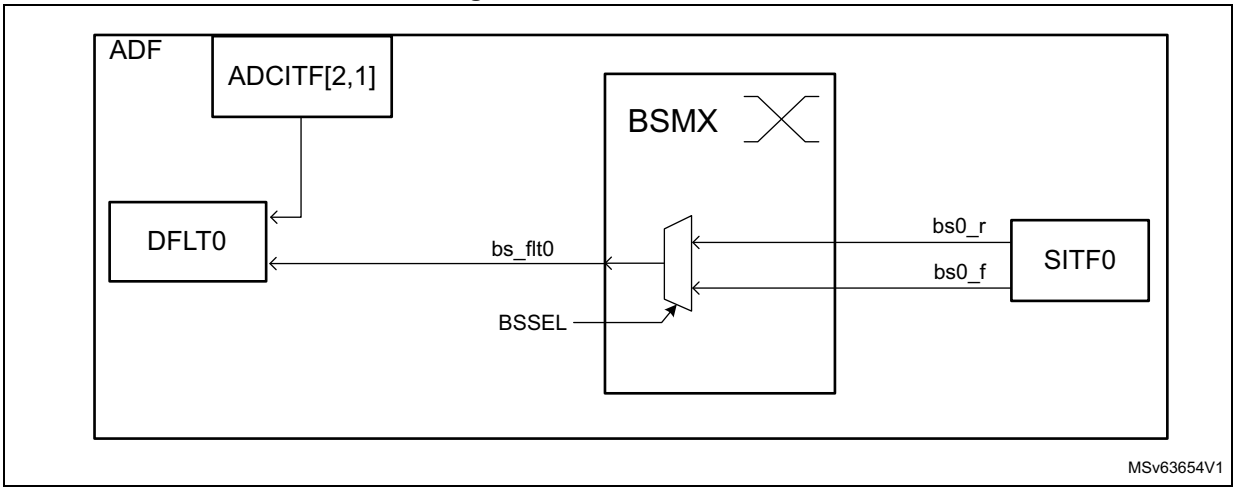
37.4.6 Bitstream matrix (BSMX)

The BSMX receives the bitstreams from the serial interface SITF0 and provides the selected stream to the digital filter DFLT0.

As shown in *Figure 373*, the SITF0 provides two bitstreams (bs0_r and bs0_f) to the BSMX.

The application to select the wanted stream via the *ADF bitstream matrix control register 0 (ADF_BSMX0CR)*. This selection is intended to be static.

Figure 378. BSMX overview



BSMX programming sequence example

The BSSEL[4:0] bitfield cannot be changed if the DFLT0 is enabled. The following steps are needed to change the value of BSMX:

1. Set DFLTEN of DFLT0 to 0.
2. Wait for BSMXACTIVE = 0.
3. Program BSSEL[4:0].
4. Set DFLTEN of DFLT0 to 1.

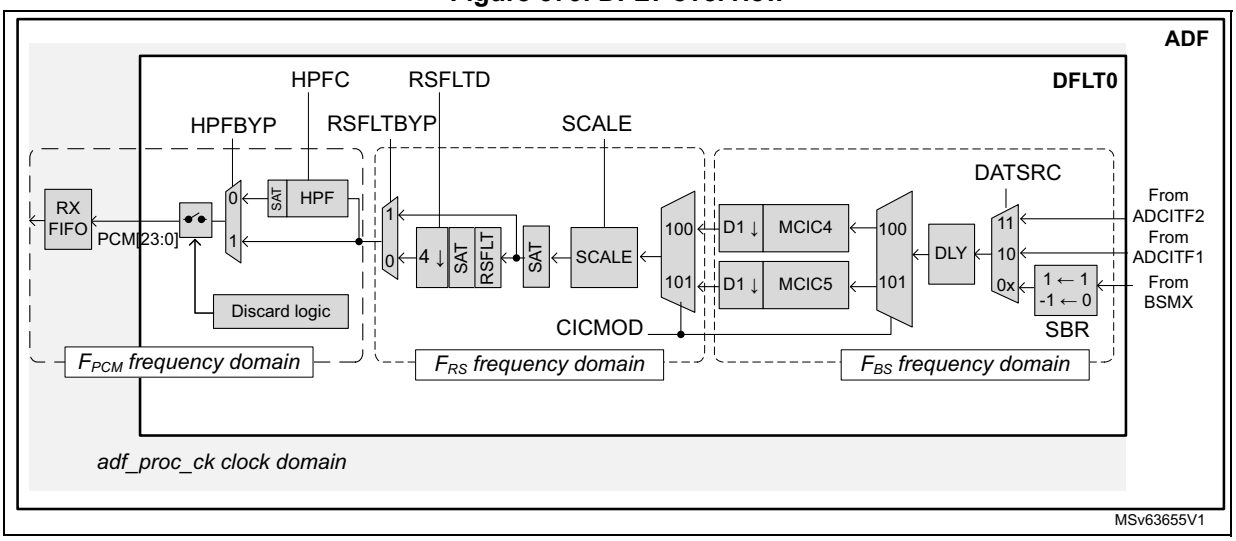
37.4.7 Digital filter processing (DFLT)

The digital filter processing includes the following sub-blocks:

- symbol remap (SBR)
- clock skipper delay (DLY)
- MCIC decimation filter that can be configured in $Sinc^4$ or $Sinc^5$
- gain control (SCALE)
- signal saturation (SAT)
- reshape filter (RSFLT)
- high-pass filter (HPF)
- receive RXFIFO

Figure 379 shows the filter path configuration according to CICMOD[2:0]. Several configuration bits are available to configure the digital filter to the application needs.

Figure 379. DFLT overview



Symbol remap and source selection

The symbol remap (SBR) converts the bitstream selected by the BSMX into data usable by the filter path. More especially:

- The high levels are converted into a 16-bit signed number + 1.
- The low levels are converted into a 16-bit signed number - 1.

The signal source of the digital filter can be selected via DATSRC[1:0] between the two following:

- data coming from the BSMX
- data coming from one of the ADC interfaces (ADCITF2 or 1)

Programmable micro-delay control (DLY)

The digital filter has a delay line that allows the timing adjustment of each stream with the resolution of the bitstream clock.

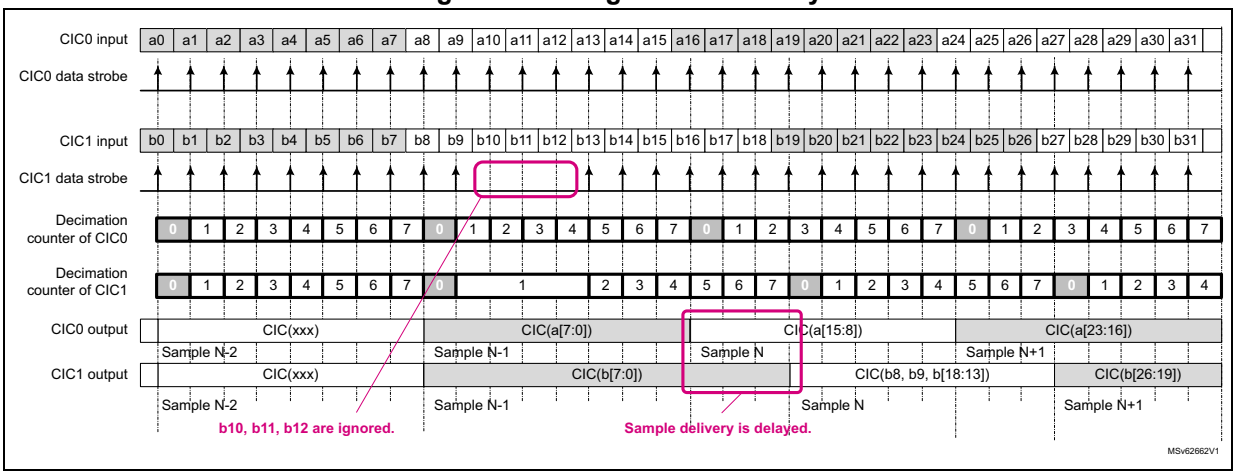
This feature is particularly helpful in the case of microphone beam forming applications where delays smaller than the final sampling rate must be applied to the incoming stream. This feature can be used when the ADF is synchronized with another MDF instance (if present in the product) for a beam forming application for example.

The delay is performed by discarding a given number of samples from the selected input stream, before samples enter into the CIC filter. This data discarding is done by skipping a given number of data strobe, preventing the CIC filter to take into account those data.

When the wanted amount of data strobe has been skipped, the next incoming samples are strobed normally.

Table 380 shows an example on how to apply dynamically small delay to an incoming stream. For simplification, the CIC filter performs a decimation by height in this example. CIC1 represents the CIC included in the ADF and CIC0 represents a filter from another MDF instance (if present in the product).

Figure 380. Programmable delay



The CIC of the ADF (CIC1) receives a command in order to skip three incoming samples. So the input samples named b10, b11 and b12 are not processed by CIC1. As a consequence, the output sample N+1 generated by CIC0 is built from input samples a[23:16] while the sample N+1 of CIC1 is built from input samples b[26:19].

Finally, the non-skipped data stream looks delayed by three bitstream periods.

Note: When the input data strobes are skipped, the decimation counter remains frozen. As a consequence, the samples delivered by the CIC1 are a bit delayed.

The following steps are needed to program the amount of bitstream clock periods to be skipped:

1. Wait for SKPBF equal to 0.
2. Write SKPDLY[6:0] to the wanted number of bitstream clock periods to be skipped. The SKPBF flag goes immediately to 1, indicating that the delay value entered into SKPDLY[6:0] is under process.
   - If the DFLT0 is not yet enabled (DFLTEN = 0), then the DLY logic waits for DFLTEN = 1. When the application sets DFLTEN to 1, the DLY logic starts to skip the amount of wanted data strobes.
   - If the DFLT0 is already enabled (DFLTEN = 1), then the DLY logic immediately starts to skip the amount of wanted data strobes.

   When the ADF skipped the amount of wanted data strobes, then SKPBF goes back to 0.
3. If the application needs to skip more data strobes, then the operation must be restarted from step 1.

The effect of the delay performed with this mechanism is cumulative as long as the ADF is enabled. If the application performs a D1 delay followed by a D2 delay, then all other active filters are delayed by D1 + D2.

Note: If SKPDLY[6:0] is written when SKPBF = 1, the write operation is ignored.

Cascaded-integrator-comb (CIC) filter

The CIC digital filters are an efficient implementation of low-pass filters, often used for decimation and interpolation. The CIC frequency response is equal to a $Sinc^N$ function, this is why they are often called Sinc filters.

The Sinc^N digital filter embedded into the ADF can be configurable in Sinc^4 or Sinc^5, according to CICMOD:

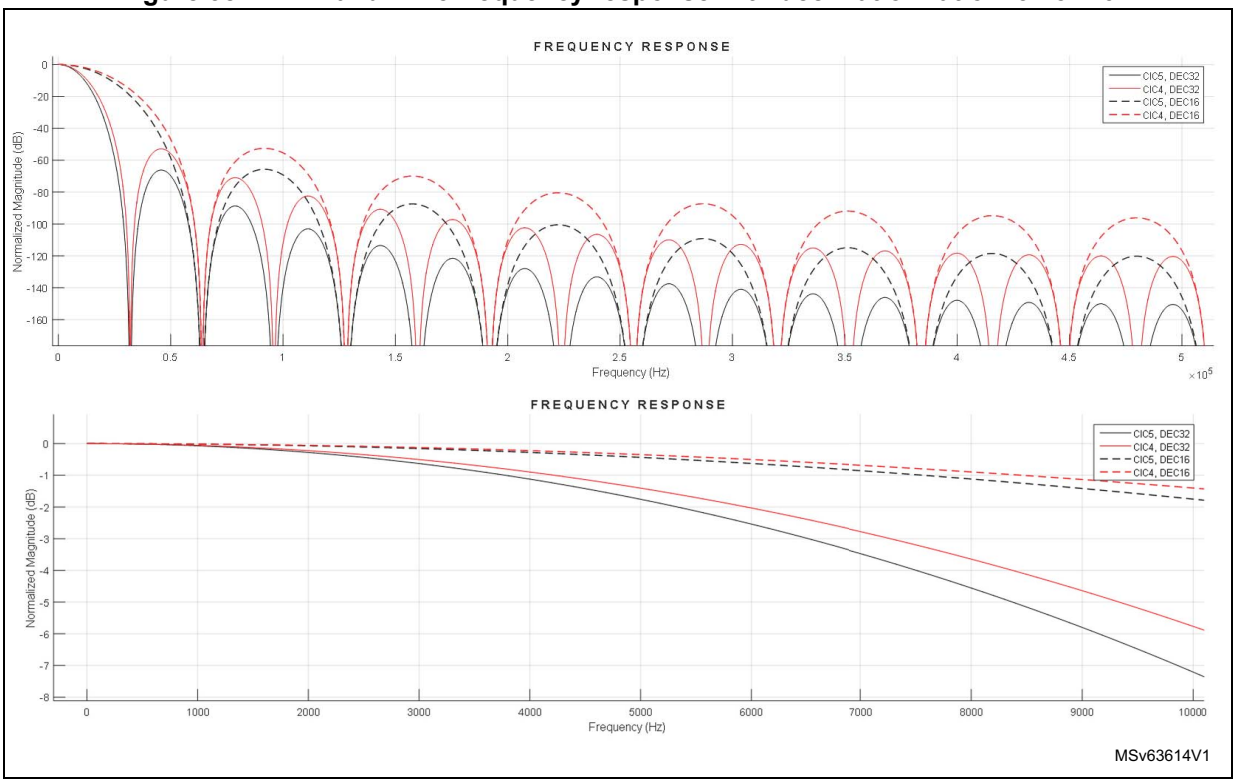
- If CICMOD[2:0] = 4, Sinc^4 is selected.
- If CICMOD[2:0] = 5, Sinc^5 is selected.

The filters have the following transfer function:

$$H(z) = \left(\frac{1 - z^{-D}}{1 - z^{-1}}\right)^N$$

where N can be 4 or 5, and D is the decimation ratio. D is equal to MCICD+1.

Figure 381. CIC4 and CIC5 frequency response with decimation ratio = 32 or 16



CIC output data size

The size of samples delivered by the CIC (DS_{CIC}), depends on the following parameters:

- CIC order (N)
- CIC decimation ratio (D)
- data size of the input stream (DSIN)

The CIC order and decimation ratio must be programmed in order to insure that the data size does not exceed the 26-bit CIC capability.

The following formula gives the output data size (DS_{CIC}) according to the parameters above.

$$DS_{CIC} = \left(\frac{N \times Ln(D)}{Ln(2)}\right) + DS_{IN}$$

and the CIC gain is given by this formula:

$$G_{CIC} = (D)^N$$

The decimation ratio can be adjusted from 2 to 512 for the CIC filter.

Table 369 gives some data output size in bits for some decimation values, when the data source is a full-scale signal coming from the serial interface or from a 12-bit ADC.

Note: DS_{IN} = 1 bit for a serial bitstream, but can be up to 16 bits when coming from the ADCITF.

Table 369. Data size according to CIC order and CIC decimation values

Decimation	Data size (bits) when DS_{IN} = 1 bit (data from SITF0)		Data size (bits) when DS_{IN} = 12 bits (data from ADCITF)	
	Sinc^4	Sinc^5	Sinc^4	Sinc^5
4	9	11	20	22
8	13	16	24	-
10	15	18	26	-
12	16	19	-	-
16	17	21	-	-
20	19	23	-	-
24	20	24	-	-
32	21	26	-	-
48	24	-	-	-
64	25	-	-	-
76	26	-	-	-

Note: For a full-scale input signal, the decimation ratio must not exceed 76 for a Sinc^4 and 32 for a Sinc^5.

The LSB parts of the data provided by the CIC is not necessarily significant: it depends on the sensor performances and the ability of the CIC to reject the out-off band noise.

The sample size at CIC output can be adjusted thanks to the SCALE block.

Scaling (SCALE) and saturation (SAT)

The SCALE block allows the application to adjust the amplitude of the signal provided by the CIC, by steps of 3 dB (± 0.5 dB).

The signal amplitude can be decreased by up to 8 bits (- 48.2 dB), and can be increased by up to 12 bits (+ 72.2 dB).

The gain is adjusted by the SCALE[5:0] bitfield in the *ADF digital filer configuration register 0 (ADF_DFLT0CICR)*.

SCALE[5:0] can be changed even if the DFLT0 is enabled. During the gain transition, the signal provided by the filter is disturbed.

Due to internal resynchronization, there is a delay of some cycles of adf_proc_ck clock between the moment where the application writes the new gain, and the moment where the gain is effectively applied to the samples. If the application attempts to write a new gain value while the previous one is not yet applied, this new gain value is ignored. Reading back SCALE[5:0] informs the application on the current gain value.

Table 370 shows the possible gain values.

Table 370. Possible gain values

SCALE[5:0]	Gain (dB)	SCALE[5:0]	Gain (dB)	SCALE[5:0]	Gain (dB)	SCALE[5:0]	Gain (dB)
0x20	- 48.2	0x2B	- 14.5	0x06	+ 18.1	0x11	+ 51.7
0x21	- 44.6	0x2C	- 12.0	0x07	+ 21.6	0x12	+ 54.2
0x22	- 42.1	0x2D	- 8.5	0x08	+ 24.1	0x13	+ 57.7
0x23	- 38.6	0x2E	- 6.0	0x09	+ 27.6	0x14	+ 60.2
0x24	- 36.1	0x2F	- 2.5	0x0A	+ 30.1	0x15	+ 63.7
0x25	- 32.6	0x00	0.0	0x0B	+ 33.6	0x16	+ 66.2
0x26	- 30.1	0x01	+ 3.5	0x0C	+ 36.1	0x17	+ 69.7
0x27	- 26.6	0x02	+ 6.0	0x0D	+ 39.6	0x18	+ 72.2
0x28	- 24.1	0x03	+ 9.5	0x0E	+ 42.1	-	-
0x29	- 20.6	0x04	+ 12.0	0x0F	+ 45.7	-	-
0x2A	- 18.1	0x05	+ 15.6	0x10	+ 48.2	-	-

The SAT blocks avoid having a wrap-around of the binary code when the code exceeds its maximal or minimal value.

The ADF performs saturation operations at the following levels:

- after the SCALE block (performed by the SAT block): The signal is saturated at 24 bits.
- inside the RSFLT, to insure a good filter behavior
- at the output of the HPF, to insure that the output signal does not exceed 24 bits

The SATF bit informs the application that a saturation occurred either after the SCALE, inside the RSFLT or after the HPF. In addition, an interrupt can be generated if SATIE is set to 1. As soon as a saturation is detected, the SATF flag is set to 1. It is up to the application to clear this flag in order to be able to detect a new saturation.

Those bits are in the *ADF DFLT0 interrupt enable register (ADF_DFLT0IER)* and *ADF DFLT0 interrupt status register 0 (ADF_DFLT0ISR)*.

Gain adjustment policy

To get the best ADF performances, it is important to properly adjust the gain value via SCALE[5:0].

A usual way to adjust the gain is to select the SCALE[5:0] value that gives a final signal amplitude as close as possible to the 24-bit full-scale, for the maximum input signal.

A way to select the optimal gain is detailed below:

1. Check that, for the expected input signal, the data size into the CIC filter does not exceed 26 bits. This can be checked using this formula:

$$\frac{LN(SIN_{pp} \cdot D^N)}{LN(2)} < 26$$

where N represents the CIC order, D the decimation ratio and SIN_{pp} the maximum peak-to-peak amplitude of the input signal.

SIN_{pp}can take:

– a maximum peak-to-peak amplitude of 2 (± 1), for samples coming from SITF0

– A maximum peak-to-peak amplitude of 4095 (+ 2047, - 2048), for samples coming from a 12-bit ADC

Example: a $Sinc^4$ can be used with a decimation ratio of 96, if the maximum input signal does not exceed ± 0.35. Indeed:

$$\frac{LN(0.7 \cdot 96^4)}{LN(2)} \sim 25.82 \text{ bits} < 26 \text{ bits}$$

2. Adjust the SCALE value.

   To select the most appropriate SCALE value, the user must check if the RSFLT is used or not. If the RSFLT is used, the data size at SCALE output must not exceed 22 bits, otherwise the data size can be up to 24 bits.

   The SCALE value in dB must be selected using this formula:

$$SCALE_{dB} < 20 \cdot \log 10\left(\frac{2^{NB}}{SIN_{pp} \cdot D^{N}}\right)$$

   where NB is equal to 22 if RSFLT is enabled, or 24 if RSFLT is bypassed. $SCALE_{dB}$ represents the gain value selected by SCALE[5:0].

   Example: For a $Sinc^4$ with a decimation ratio of 96 and a SIN_{pp} of 0.7.

   – If the RSFLT is bypassed:

$$20 \cdot \log 10\left(\frac{2^{24}}{0.7 \cdot 96^{4}}\right) \sim -11 \text{ dB}$$

     $SCALE_{dB}$ value must be lower than - 11 dB, the closest lower value is - 12dB (SCALE[5:0] = 0x2C).

   – If the RSFLT is enabled:

$$20 \cdot \log 10\left(\frac{2^{22}}{0.7 \cdot 96^{4}}\right) \sim -23 \text{ dB}$$

     $SCALE_{dB}$ value must be lower than - 23 dB, the closest lower value is - 24.1 dB (SCALE[5:0] = 0x28).

   If SCALE[5:0] is set to a higher value, then a saturation may occur. An event flag informs the user if a saturation occurred.

Table 371 proposes gain values for different filter configurations, when the data comes from the SITF0, according to the MCIC order, and the MCIC decimation ratio. This table is not exhaustive and considers a full-scale input signal (see *Section 37.7.5: Total ADF gain* for details).

Table 371. Recommended maximum gain values versus CIC decimation ratios

CIC decimation ratio	Gain settings (dB) for configuration SITF + CICx + RSFLT (+ HPF)		Gain settings (dB) for configuration SITF + CICx (+ HPF)	
	CIC5	CIC4	CIC5	CIC4
8	33.6	51.7	45.7	63.7
12	18.1	39.6	30.1	51.7
16	3.5	27.6	15.6	39.6
20	- 6.0	21.6	6.0	33.6
24	- 12.0	15.6	0	27.6
28	- 20.6	9.5	- 8.5	21.6

Table 371. Recommended maximum gain values versus CIC decimation ratios (continued)

CIC decimation ratio	Gain settings (dB) for configuration SITF + CICx + RSFLT (+ HPF)		Gain settings (dB) for configuration SITF + CICx (+ HPF)	
	CIC5	CIC4	CIC5	CIC4
32	- 26.6	3.5	- 4.5	15.6
48	-	- 8.5	-	3.5
64	-	- 20.6	-	- 8.5

Reshaping filter (RSFLT)

In addition to the CIC, the ADF offers a reshaping IIR filter mainly dedicated to the audio application, but also usable in other applications.

When the RSFLT is used, the sample size at its input must not exceed 22 bits.

The samples at the RSFLT output can be decimated by four or not according to the RSFLTD bit in the *ADF reshape filter configuration register 0 (ADF_DFLT0RSFR)*.

The RSFLT can be bypassed by setting RSFBYP to 1 in the *ADF reshape filter configuration register 0 (ADF_DFLT0RSFR)*.

Table 372 shows which sampling rate must be provided to the RSFLT in order to process the most common audio streams.

The RSFLT cutoff frequency (F_C) depends on the sample rates at its input (F_{RS}), and is given by the following formula:

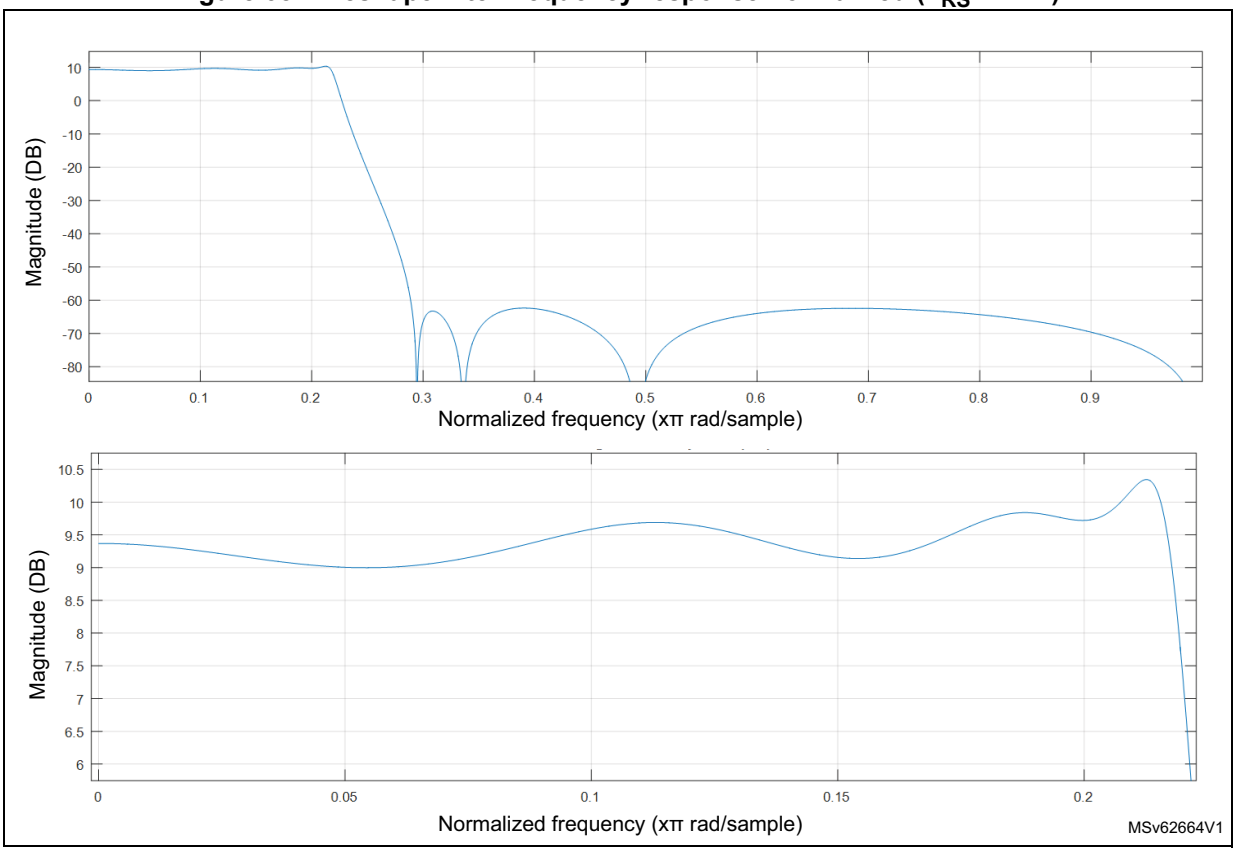
$$F_C = 0.111 \times F_{RS}$$

Table 372. Most common microphone settings

Sample rate (kHz) at RSFLT (F_{RS})	Pass band (kHz)	D2	PCM sampling rate (kHz)
32	3.55	4	8
64	7.1	4	16
128	14.2	4	32
192	21.3	4	48

Table 382 shows the frequency response of the reshape filter.

Figure 382. Reshape filter frequency response normalized (F_{RS} / 2 = 1)



The RSFLT gain is close to 9.3 dB, so the output data size is a little bit lower than 24 bits for a 22-bit wide input signal.

The RSFLT takes 24 clock cycles of adf_proc_ck clock to process one sample at F_{RS}. When the RSFLT is enabled, the application must insure that the adf_proc_ck is at least 24 times faster F_{RS}.

The RSFLT generates an event (rfovr_evt) and sets the RFOVRF flag, if the RSFLT receives a new samples while the previous one is still under processing.

When RFOVRF is set, the samples provided by the RSFLT are invalid. The application must then stop the data acquisition and provides a faster adf_proc_ck clock to the RSFLT.

High-pass filter (HPF)

The high-pass filter suppresses the low-frequency content from the final output data stream in case of continuous conversion mode. The high-pass filter can be enabled or disabled via HPFBYP in the *ADF reshape filter configuration register 0 (ADF_DFLT0RSFR)*.

The HPF is useful when there is parasitic low-frequency noise (or DC signal) in the input data source that must be removed from the final data.

The HPF is a first order IIR filter and the cut-off frequency can be selected via HPFC[1:0] in the *ADF reshape filter configuration register 0 (ADF_DFLT0RSFR)*, among the following values:

- 0.000625 x F_{PCM}
- 0.00125 x F_{PCM}
- 0.00250 x F_{PCM}
- 0.00950 x F_{PCM}

Table 373. HPF 3 dB cut-off frequency examples

HPFC	3 dB cut-off frequency for common F_{PCM} frequencies (Hz)		
	F_{PCM} = 8 kHz	F_{PCM} = 16 kHz	F_{PCM} = 48 kHz
0	5	10	30
1	10	20	60
2	20	40	120
3	76	152	456

The HPF output is saturated at 24 bits. The SATF flag is set if a sample is saturated.

37.4.8 Digital filter acquisition modes

The ADF offers the following modes to perform a data capture:

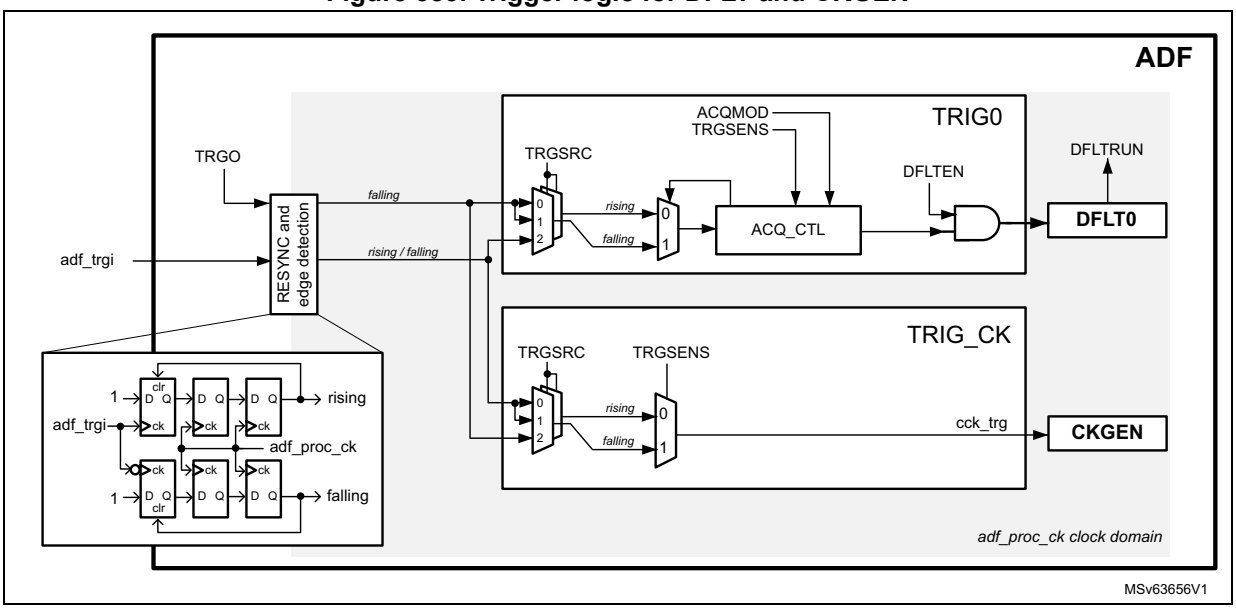
- asynchronous continuous acquisition mode
- asynchronous single-shot acquisition mode
- synchronous continuous acquisition mode
- synchronous single-shot acquisition mode
- window continuous acquisition mode

Note: To perform a data capture, the filter, the interface providing the data (SITF0 or ADCITF) and the CKGEN must be enabled. If needed, the ADF_CCK0 or ADF_CCK1 must be enabled as well.

The filter can be stopped immediately when DFLTEN is set to 0. This action resets the filter and flushes the RXFIFO. The DFLTACTIVE flag also goes back to 0 when the RXFIFO and the filter is reset.

Table 383 shows a simplified view of the trigger logic available for each filter and for the clock generator.

Figure 383. Trigger logic for DFLT and CKGEN



A block common to all TRIG blocks performs the rising and falling edges detection and the resynchronization of the input trigger to the adf_ker_ck clock domain. This implementation allows the application to use triggers with pulse width smaller than the adf_ker_ck period.

In synchronous modes, the TRIG block offers the possibility to select adf_trgi or TRGO bit as trigger sources. The TRGO bit is in the *ADF global control register (ADF_GCR)*.

The edge sensitivity can also be selected.

Asynchronous continuous acquisition mode

This mode allows the application to start a continuous acquisition by simply writing the DFLTEN bit to 1.

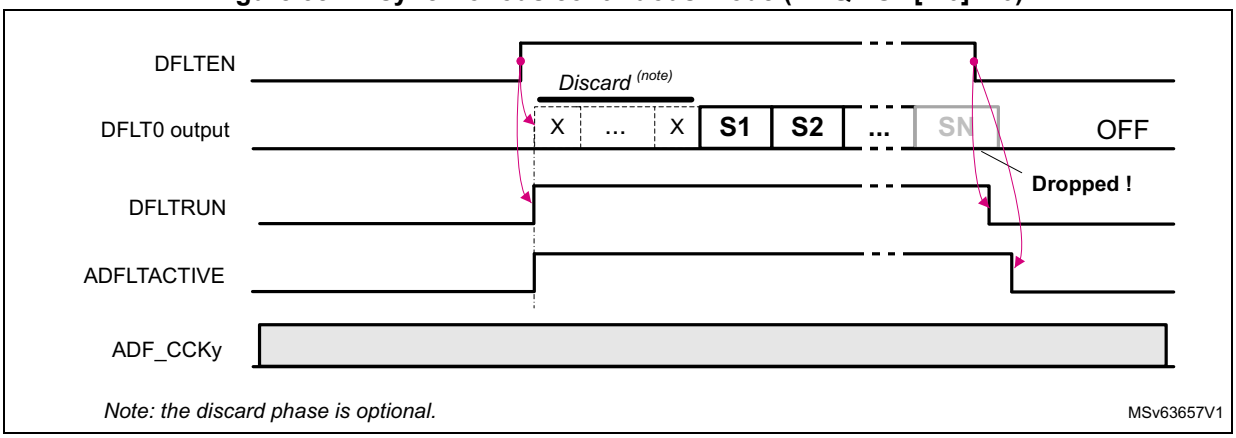
The asynchronous continuous acquisition mode is selected when ACQMOD[2:0] = 0.

The sequence below shows the most important programming steps (assuming that DFLTEN is set to 0):

1. Configure and enable the clock generator (CKGEN) so that the adf_proc_ck frequency is compatible with the targeted application (see examples in *Table 377*).
2. Enable the CKGEN (CKGDEN = 1) and, if needed, enable the ADF_CCK0 and ADF_CCK1 clocks.
3. Program the filter configuration and set the ACQMOD[2:0] to 0.
4. Set to 1 the SITFEN bit of the serial data interface.
5. Before setting DFLTEN to 1, wait for DFLTACTIVE = 0: it insures that the previous filter deactivation sequence terminated properly.
6. When DFLTEN is set to 1, the acquisition sequence starts immediately.

Figure 384 shows a simplified example of the samples generated by the DFLT0.

Figure 384. Asynchronous continuous mode (ACQMOD[2:0] = 0)



Note: The acquisition can be stopped by setting DFLTEN back to 0. This resets the filter and flushes the RXFIFO, so the samples located into the RXFIFO are lost. The ongoing DMA transfer is properly terminated. DFLTACTIVE goes back to 0 when the filter chain is reset and the RXFIFO flushed.

Asynchronous single-shot acquisition mode

This mode allows the application to start the acquisition of one sample by simply writing the DFLTEN bit to 1.

The asynchronous single-shot acquisition mode is selected when ACQMOD[2:0] = 001.

The sequence below shows the most important programming steps (assuming that DFLTEN is set to 0):

1. Configure and enable the clock generator (CKGEN), so that the adf_proc_ck frequency is compatible with the targeted application (see examples in *Table 377*).
2. Enable the CKGEN (CKGDEN = 1) and, if needed, enable the ADF_CCK0 and ADF_CCK1 clocks.
3. Program the filter configuration, and set the ACQMOD[2:0] to 001.
4. Set to 1 the SITFEN bit.
5. Before setting DFLTEN to 1, wait for DFLTACTIVE = 0: it insures that the previous filter deactivation sequence terminated properly.
6. When DFLTEN is set to 1, the filter provides one data to the RXFIFO and stops the acquisition.

To trigger a new acquisition, the application must:

1. Check that the previous acquisition is completed, by waiting that DFLTRUN = 0.
2. Set again DFLTEN to 1.

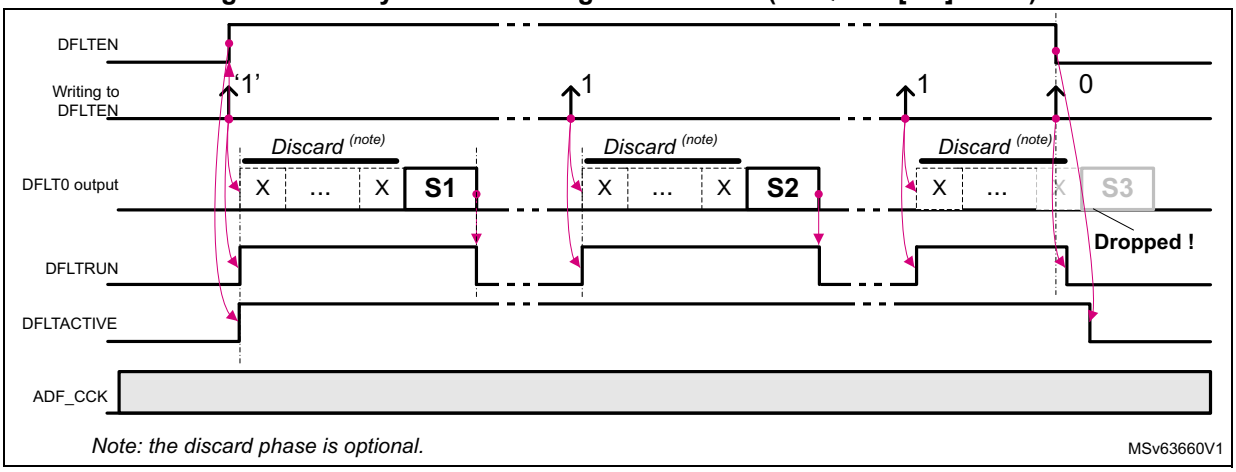
This sequence can be repeated every time a new data must be converted.

As shown in *Figure 384*, every time DFLTEN is set to 1, an acquisition sequence is triggered. The first samples provided by the filter can be discarded if needed. At the end of each conversion, the decimation counters and filter taps are reset, and the filter is ready to start a new conversion.

If DFLTEN is set to 0 while an acquisition is ongoing, the ongoing conversion is stopped (in the example, S3 is lost). This situation can be avoided with the following steps:

1. Wait for DFLTRUN = 0.
2. Read the sample from the RXFIFO.
3. Set DFLTEN to 0.

Figure 385. Asynchronous single-shot mode (ACQMOD[2:0] = 001)



Note: The acquisition can be stopped by setting DFLTEN back to 0. This resets the filter and flushes the RXFIFO, so the samples located into the RXFIFO are lost. The ongoing DMA transfer is properly terminated. DFLTACTIVE goes back to 0 when the filter chain is reset and the RXFIFO flushed.

Synchronous continuous acquisition mode

This mode allows the application to start a continuous acquisition by using one of the following trigger sources:

- adf_trgi signal
- TRGO bit

The Synchronous continuous acquisition mode is selected when ACQMOD[2:0] = 010.

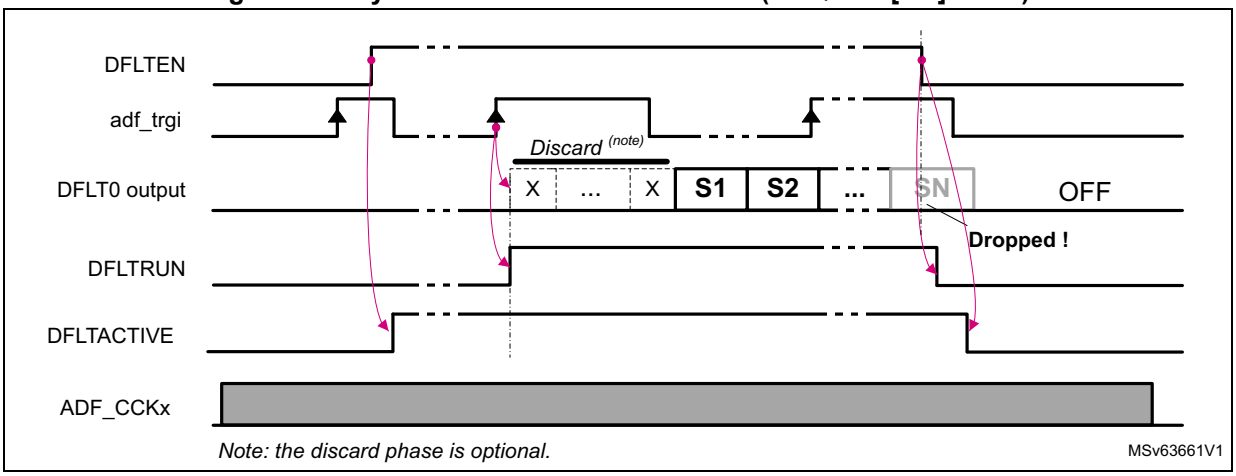
The sequence below shows the most important programming steps (assuming that DFLTEN is set to 0):

1. Configure and enable the clock generator (CKGEN), so that the frequency of adf_proc_ck clock is compatible with the targeted application (see examples in *Table 377*).
2. Enable the CKGEN (CKGDEN = 1) and, if needed, enable the ADF_CCK0 and ADF_CCK1 clocks.
3. Program the filter configuration and set the ACQMOD[2:0] to 010.
4. Set to 1 the bit SITFEN.
5. Select the proper trigger source and sensitivity.
6. Before setting DFLTEN to 1, wait for DFLTACTIVE = 0: it insures that the previous filter deactivation sequence terminated properly.
7. Set DFLTEN to 1.
8. When the trigger condition is met, the filter starts the acquisition.

The TRGSENS bit allows the selection of the trigger edge (rising or falling). The trigger is ignored if an acquisition is ongoing or if DFLTEN is set to 0.

Figure 386 shows a simplified example where the trigger logic is sensitive to a rising edge trigger (TRGSENS = 0). The first rising edge of the trigger signal is ignored because DFLTEN = 0. Then the next rising edge is taken into account and starts the acquisition. All other rising edges are ignored. The trigger logic is re-initialized when DFLTRUN goes back to 0.

Figure 386. Synchronous continuous mode (ACQMOD[2:0] = 010)



Note: The acquisition can be stopped by setting DFLTEN back to 0. This resets the filter and flushes the RXFIFO, so the samples located into the RXFIFO are lost. The ongoing DMA transfer is properly terminated. DFLTACTIVE goes back to 0 when the filter chain is reset and the RXFIFO flushed.

Synchronous single-shot acquisition mode

This mode allows the application to start a single acquisition by using one of the following trigger sources:

- adf_trgi signal
- TRGO bit

The Synchronous single-shot acquisition mode is selected when ACQMOD[2:0] = 011.

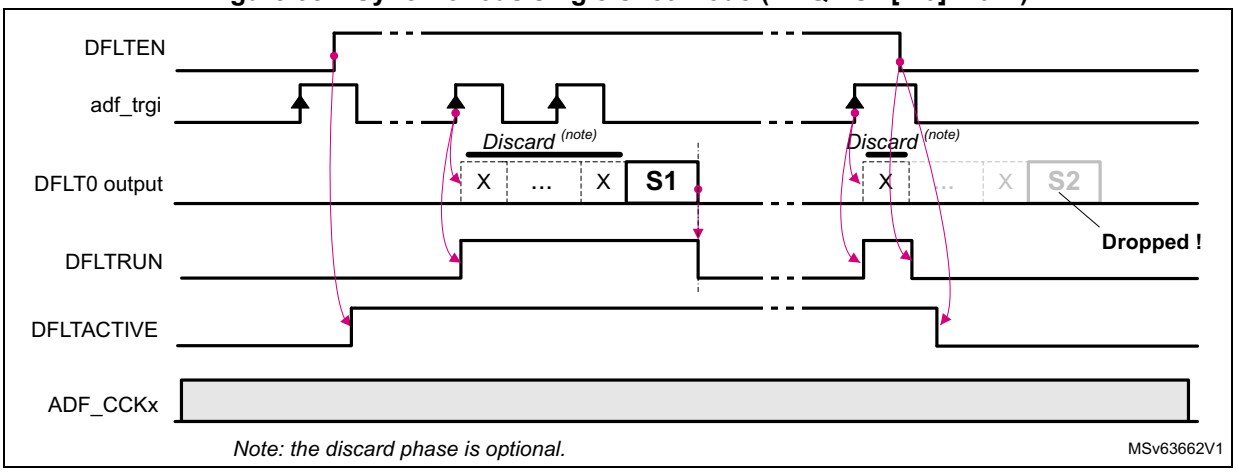
The sequence below shows the most important programming steps (assuming that DFLTEN is set to 0):

1. Configure and enable the clock generator (CKGEN), so that the frequency of adf_proc_ck clock is compatible with the targeted application (see examples in *Table 377*).
2. Enable the CKGEN and, if needed, enable the ADF_CCK0 and ADF_CCK1 clocks.
3. Program the filter configuration, and set the ACQMOD[2:0] to 011.
4. Set to 1 the SITFEN bit.
5. Select the proper trigger source and sensitivity.
6. Before setting DFLTEN to 1, wait for DFLTACTIVE = 0: it insures that the previous filter deactivation sequence terminated properly.
7. Set DFLTEN to 1.
8. When the trigger condition is met, the filter starts the acquisition and provides one data to the RXFIFO, then the filter is ready to accept a new trigger.

TRGSENS allows the selection of the trigger edge (rising or falling). The trigger is ignored if an acquisition is ongoing, or if DFLTEN is set to 0.

Figure 387 shows a simplified example where the trigger logic is sensitive to a rising edge trigger (TRGSENS = 0). Every-time a trigger rising edge is detected with DFLTEN = 1, an acquisition sequence is triggered. The first samples provided by the filter can be discarded if needed. At the end of each conversion, the decimation counters and filter taps are reset. DFLTRUN is set to 0 and the filter is ready to start a new conversion.

Figure 387. Synchronous single-shot mode (ACQMOD[2:0] = 011)



Note: The acquisition can be stopped by setting DFLTEN back to 0. This resets the filter and flushes the RXFIFO, so the samples located into the RXFIFO are lost. The ongoing DMA transfer is properly terminated. DFLTACTIVE goes back to 0 when the filter chain is reset and the RXFIFO flushed.

Figure 386 shows a case where the DFLTEN is set to 0 while an acquisition is ongoing (the sample S2 is lost). This situation can be avoided with the following steps:

1. Wait for DFLTRUN = 0.
2. Read the sample from the RXFIFO.
3. Clear DFLTEN to 0.

Window continuous acquisition mode

This mode allows the application to start or stop a continuous acquisition controlled by consecutive edges of one of the following trigger sources:

- adf_trgi signal
- TRGO bit

The window continuous acquisition mode is selected when ACQMOD[2:0] = 100.

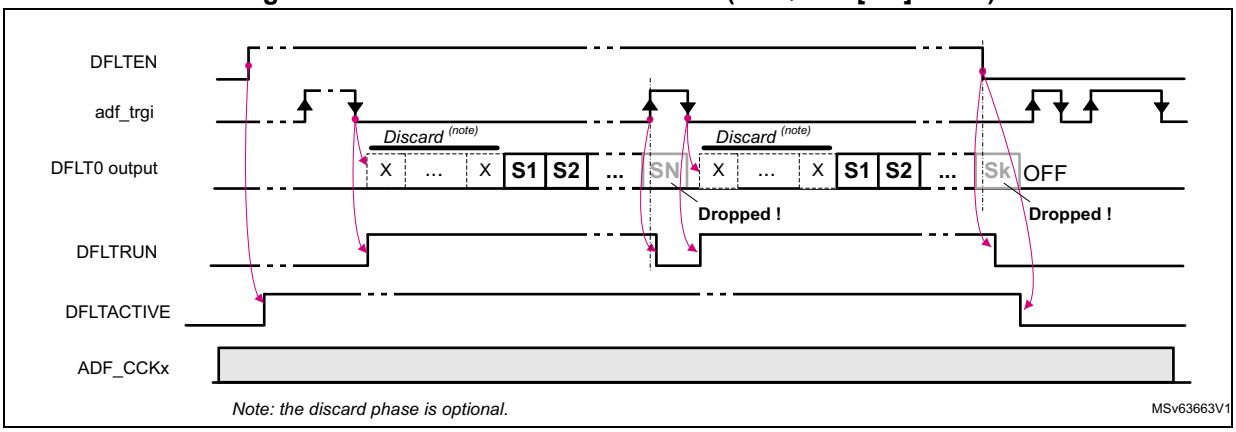
The sequence below shows the most important programming steps (assuming that DFLTEN is set to 0):

1. Configure and enable the clock generator (CKGEN), so that the frequency of adf_proc_ck clock is compatible with the targeted application (see examples in *Table 377*).
2. Enable the CKGEN and, if needed, enable the ADF_CCK0 and ADF_CCK1 clocks.
3. Program the filter settings and set the ACQMOD[2:0] to 100.
4. Set to 1 the SITFEN bit.
5. Select the proper trigger source and sensitivity.
6. Before setting DFLTEN to 1, wait for DFLTACTIVE = 0: it insures that the previous filter deactivation sequence terminated properly.
7. Set DFLTEN to 1.
8. If TRGSENS = 0, the acquisition starts on trigger rising edge and stops on trigger falling edge. If TRGSENS = 1, the acquisition starts on trigger falling edge and stops on trigger rising edge.

Note: The acquisition may restart if the trigger condition becomes again active.

Figure 388 shows a simplified example of window continuous acquisition mode, with TRGSENS = 1. Once DFLTEN is set to 1, the ADF waits for a falling edge on the selected trigger input. When the trigger condition is met, DFLTRUN goes to 1 and the acquisition starts. The acquisition stops if the ADF detects a rising edge on the selected trigger input. If DFLTEN is still set to 1, the ADF waits again for a falling edge on the selected trigger input.

Figure 388. Window continuous mode (ACQMOD[2:0] = 100)



Note: The acquisition can be stopped by setting DFLTEN back to 0. This resets the filter and flushes the RXFIFO, so the samples located into the RXFIFO are lost. The ongoing DMA transfer is properly terminated. DFLTACTIVE goes back to 0 when the filter chain is reset and the RXFIFO flushed.

Starting several filters synchronously

If the ADF is used with MDF instances (if present in the product), it is possible to start simultaneously the acquisition of all the filters. This synchronization capability depends on the way the triggers are connected in the product. Generally, an ADF is able to trigger MDF instances, if its adf_trgo signal is connected as trigger input to those blocks (see *Section 37.4.2: ADF pins and internal signals* to check trigger capabilities).

In the following programming example, one ADF has its adf_trgo signal connected to some MDFs. To start the acquisition of several filters synchronously, the following sequence must be performed (assuming that DFLTEN bits of the filters are set to 0):

On MDFs receiving the adf_trgo trigger:

1. Enable the CKGEN (CKGDEN = 1) and, if needed, enable the ADF_CCK0 and ADF_CCK1 clocks.
2. Set to 1 the SITFEN bit of the requested data interfaces.
3. For each filter, set the acquisition mode to synchronous (ACQMOD[2:0] = 01x).
4. For each filter, set TRGSRC[3:0] in order to select the adf_trgo trigger input.
5. For each filter, set TRGSENS to 0 (rising edge).
6. For each filter, set DFLTEN to 1.

On the ADF generating the adf_trgo trigger:

1. Enable the CKGEN (CKGDEN = 1) and, if needed, enable the ADF_CCK[1:0] clocks.
2. Set to 1 the SITFEN bit of the requested data interfaces.
3. Set the acquisition mode to synchronous (ACQMOD[2:0] = 01x).
4. Set TRGSRC[3:0] to 0 (TRGO selected).
5. Set TRGSENS to 0 (rising edge).
6. Set DFLTEN to 1.
7. Read TRGO bit until it is read to 0.
8. Set TRGO to 1. Then the acquisition sequence for all selected filters starts immediately.

To trigger a new acquisition (in case of single-shot) the application must do the following:

1. Check that the previous acquisition is completed, by waiting DFLTRUN = 0.
2. Read TRGO until it is read to 0.
3. Set again the bit TRGO to 1.

Discarded samples

The ADF offers the possibility to program the amount of samples to be discarded after each restart:

- to avoid capturing samples affected by the impulse response of the filter
- to delay the acquisition of filters by a specific amount of samples

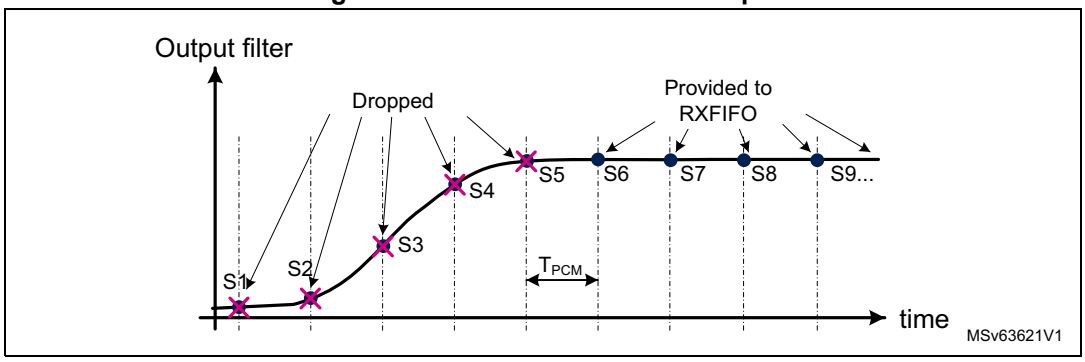
The discard function is controlled via NBDIS[7:0] as follows:

- When NBDIS[7:0] = 0, the discard function is disabled.
- When NBDIS[7:0] ≠ 0, the discard function is activated in one of the following condition:
  - when the DFLTEN bit goes to 1
  - every time an acquisition is started in (A)synchronous single-shot modes

Refer to *Figure 383* to *Figure 387*, and *Figure 389*.

In the example shown in *Figure 389*, the discard function is used to drop the first five samples provided by the digital filter (S1 to S5). The first sample transfered to the RXFIFO is S6.

Figure 389. Discard function example



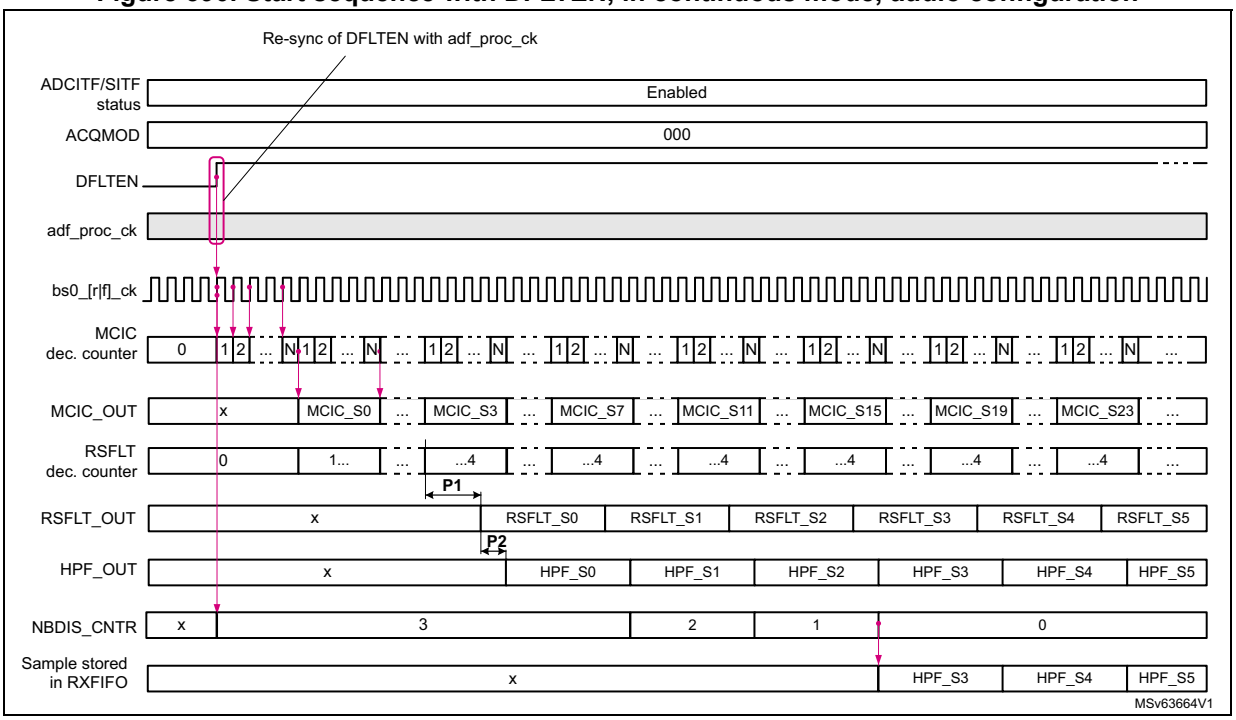
37.4.9 Start-up sequence examples

Figure 390 details a start of acquisition sequence of a digital filter triggered by DFLTEN (ACQMOD[2:0] = 0), with NBDIS[7:0] = 3 (three samples to discard before acquisition).

The DFLT0 is configured for audio application: MCIC, RSFLT and HPF activated.The data interface (SITF0 or ADCITF) is assumed to be already activated.

Note: NBDIS[7:0] is set on purpose to a small value to simplify the drawing.

Figure 390. Start sequence with DFLTEN, in continuous mode, audio configuration



The DFLTEN bit is re-sampled into the ADF processing clock domain. When DFLTEN is detected high, the filter chain is enabled, and the decimation counter of the MCIC filter is incremented at the rate of the bitstream clock.

When the MCIC decimation counter reached its programmed value N, a sample is available for the RSFLT.

The RSFLT processes all the samples provided by the MCIC, and delivers a sample to the HPF every-time it processes four samples (decimation by 4). The RSFLT needs up to 24 cycles of adf_proc_ck clock before delivering a sample (P1).

The HPF processes all the samples provided by the RSFLT, but the NBDIS function prevents the data writing in the RXFIFO as long as NBDIS_CNTR does not reach 0.

When NBDIS_CNTR reaches 0, the samples provided by the HPF are stored into the RXFIFO.

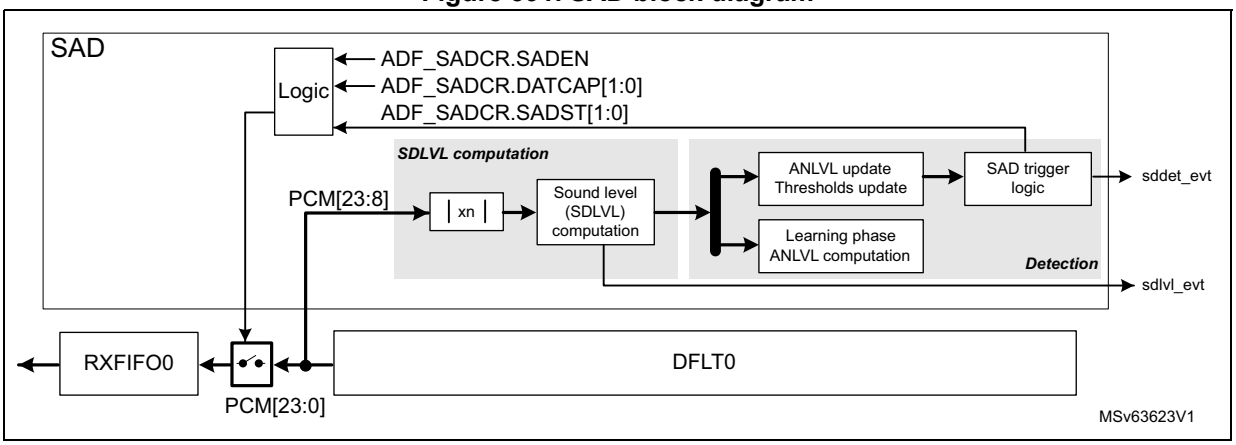
37.4.10 Sound activity detection (SAD)

The SAD is based on the computation of the ambient noise level (ANLVL) and of the short-term sound level (SDLVL). The SAD offers the following ways to detect a sound:

- when the SDLVL reaches a threshold referenced to the ambient noise level
- when the SDLVL reaches a fixed threshold
- when the ANLVL reaches a fixed threshold

As shown in *Figure 391*, the SAD takes the 16 MSB samples from the DFLT0 output.

Figure 391. SAD block diagram



The SAD is highly configurable, and the application can adjust several parameters:

- SAD detection behavior (SADMOD)
- number of samples used to compute the sound level (FRSIZE)
- number of frames used to compute the ambient noise level during the learning phase (LFRNB)
- slope of the ambient noise estimator (ANSLP)
- minimum expected ambient noise level (ANMIN)
- threshold level (SNTHR)
- threshold hysteresis (HYSTEN)
- hangover window in order to filter spurious transitions between DETECT and MONITOR states (HGOVR)
- data capture mode (DATCAP)

SAD detection behavior

The SAD can use the following ways to detect a sound, selected by SADMOD[1:0]:

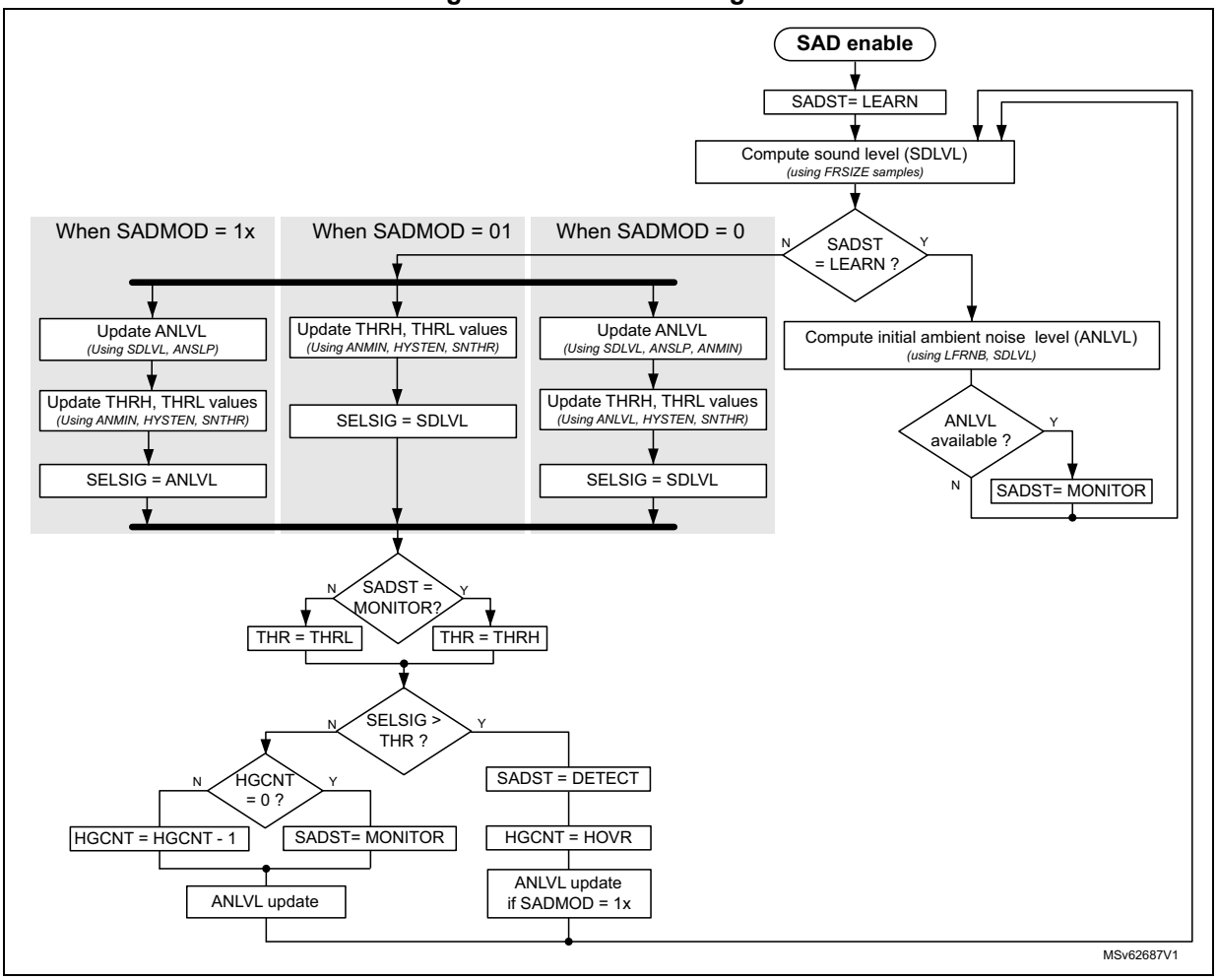
- When SADMOD[1:0] = 0, the SAD works like a voice-activity detection. In this mode, the SAD estimates the ambient noise level according to the computed sound level values. The threshold of the trigger is elaborated from the estimated ambient noise. Finally the current sound level is compared to this threshold. In a first approximation, the SAD triggers if the peak-to-average value of the input signal reaches a level defined by SNTHR[3:0].
- When SADMOD[1:0] = 01, the SAD compares the current sound level (SDLVL) to a fixed trigger value defined by the application via SNTHR[3:0] and ANMIN[12:0]. This mode allows a fast SAD reaction as the amount of samples used to compute the sound level can be configured via FRSIZE[2:0].
- When SADMOD[1:0] = 1x, the SAD compares the estimated ambient noise level (ANLVL) to a fixed trigger value defined by the application via SNTHR[3:0] and ANMIN[12:0]. This mode avoids unwanted triggers, due to peak levels, but the SAD reacts more slowly to an input signal variation. It is nevertheless possible to adjust the reaction time via FRSIZE[2:0] and ANSLP[2:0].

SAD states

As shown in *Figure 391*, the SAD works as follows:

1. When enabled (SADEN = 1), the SAD is first in LEARN state to perform a first estimation of the ambient noise level.
2. The SAD continuously computes the short-term sound level (SDLVL) using the samples provided by the DFLT0. The amount of samples used to compute the sound level is given by FRSIZE[2:0]. The samples processed by the DFLT0 can be transferred into the memory or not depending on DATCAP[1:0] value.
3. The initial ambient noise level (ANLVL) is computed using the consecutive sound level values. The application can define how much sound level values are used to perform the computation of this initial ambient noise estimation (LFRNB).
4. When the initial ambient noise level (ANLVL) is computed, the SAD switches to the MONITOR state.
5. Every time a new short-term sound level value is available, the SAD updates the ambient noise level and the thresholds according to the selected detection mode.
6. If the SAD triggers, then the following happens:
   – The SAD switches to DETECT state.
   – The sddet_evt event is asserted.
   – The adf_sad_det signal is set to high.
7. The hangover function insures that the DETECT state is maintained even if the sound level goes below the threshold level for a time given by HGOVR.

Figure 392. SAD flow diagram



Sound level computation (SDLVL)

Once enabled, the SAD computes continuously the sound level value. The sound level represents the average of the absolute value of an amount of PCM samples given by FRSIZE[2:0].

$$SDLVL = \frac{1}{N_{FRSIZE}} \times \sum_{n=1}^{N_{FRSIZE}} |PCM(n)|$$

where N_{FRSIZE} is the amount of PCM samples given by FRSIZE[2:0].

Ambient noise estimation (ANLVL)

The ambient noise level (ANLVL) is computed when SADMOD[1:0] is 00 or 10.

The ambient noise level is computed differently according to the state of the SAD as detailed below:

- ANLVL computation during the LEARN state

  Every time the SAD is enabled, a learning phase is initiated in order to estimate a first value of the ambient noise level. During this phase, the SAD cannot trigger.

  During the LEARN phase, the ambient noise level is computed as follows:

$$ANLVL = \frac{1}{N_{LFRNB}} \times \sum_{n=1}^{N_{LFRNB}} |SDLVL(n)|$$

  where N_{LFRNB} is the amount of frames given by LFRNB[2:0] bitfield.

- ANLVL computation during the MONITOR or DETECT state

  When the learning phase is completed, the SAD updates the ambient noise level in the following way:

  – The SAD computes the new possible values for the ambient noise level:

    ANLVL_UP = ANLVL * (1+2^(ANSLP-12))

    ANLVL_DN = ANLVL * (1-2^(ANSLP-10))

  – The ANLVL takes the ANLVL_DN value if the current sound level is lower than ANLVL_DN, otherwise ANLVL takes the value of ANLVL_UP.

    The ANLVL is not updated if the current sound level is higher than the threshold level, except if SADMOD[1:0] = 10.

  – When SADMOD[1:0] = 0, if the new ANLVL value is lower than ANMIN[12:0], ANLVL is replaced by ANMIN.

  The slope of the noise estimator can be adjusted to optimize the detection of the wanted signal. This slope is adjusted via ANSLP[2:0] in the *ADF SAD configuration register (ADF_SADCFGR)*.

Table 374 shows the allowed values according to the frame size and the sampling rate of the data observed by the SAD. The recommended values when the SADMOD[1:0] = 0 are the ones into the gray shaded cells.

Table 374. ANSLP values versus FRSIZE and sampling rates

FRSIZE	ANSLP values for Fs = 8 kHz			ANSLP values for Fs = 16 kHz		
	Slow(1)	typical(2)	Fast(3)	Slow(1)	typical(2)	Fast(3)
0 (8 samples)	0	1	2	-	0	1
1 (16 samples)	1	2	3	0	1	2
2 (32 samples)	2	3	4	1	2	3
3 (64 samples)	3	4	5	2	3	4
4 (128 samples)	4	5	6	3	4	5
5 (256 samples)	5	6	7	4	5	6
6 (512 samples)	6	7	-	5	6	7

1. The slow slope is equal to - 8.5 dB/s for the negative slope and + 2.1 dB/s for the positive slope.
2. The typical slope is equal to - 17.1 dB/s for the negative slope and + 4.2 dB/s for the positive slope.
3. The fast slope is equal to - 34.2 dB/s for the negative slope and + 8.5 dB/s for the positive slope.

The slopes can also be computed using the following formulas:

$$SLC_{UP} = 20 \times \frac{F_s}{F_{SIZE}} \times \log 10(1 + 2^{(ANSLP - 12)})$$

$$SLC_{DN} = 20 \times \frac{F_s}{F_{SIZE}} \times \log 10(1 - 2^{(ANSLP - 10)})$$

where F_S is the sampling rate of the stream observed by the SAD and F_{SIZE} is the frame size defined by FRSIZE[2:0].

Threshold computation

The way the threshold value is computed depends on SADMOD[1:0]:

- If SADMOD[1:0] = 0, THRH is obtained by multiplying the current ANLVL value with the gain defined in SNTHR[3:0].

  $$THR_H = ANLVL \times 10^{\frac{GdB_{SNTHR}}{20}}$$

  This threshold value is then compared to the current sound level (SDLVL).
- If SADMOD[1:0] = 01, THRH is obtained by multiplying the current ANMIN[12:0] with the gain defined by SNTHR[3:0].

  $$THR_H = ANMIN \times 10^{\frac{GdB_{SNTHR}}{20}}$$

  This threshold value is then compared to the current sound level (SDLVL).

- If SADMOD[1:0] = 1x, THRH is obtained by multiplying the current ANMIN[12:0] by 4.

$$THR_H = ANMIN \times 4$$

This threshold value is then compared to:

$$ANLVL \times 10^{\frac{GdB_{SNTHR}}{20}}$$

The hysteresis mode can be enabled to reduce the spurious transitions between MONITOR and DETECT states. In hysteresis mode (HYSTEN = 1), the following threshold values are used:

- THRH when the SAD is in MONITOR state.
- THRL when the SAD is in DETECT state.

Table 375 shows the thresholds values according to SNTHR.

Table 375. Threshold values according SNTHR(1)

SNTHR[3:0]	THR_H		THR_L		Comments
0	LVL + 3.5 dB	LVL x 1.5	LVL + 3.5 dB	LVL x 1.5	No hysteresis
1	LVL + 6.0 dB	LVL x 2	LVL + 3.5 dB	LVL x 1.5	Hysteresis of 2.5 dB
2	LVL + 9.5 dB	LVL x 3	LVL + 6.0 dB	LVL x 2	Hysteresis of 3.5 dB
3	LVL + 12.0 dB	LVL x 4	LVL + 9.5 dB	LVL x 3	Hysteresis of 2.5 dB
4	LVL + 15.6 dB	LVL x 6	LVL + 12.0 dB	LVL x 4	Hysteresis of 3.5 dB
5	LVL + 18.1 dB	LVL x 8	LVL + 15.6 dB	LVL x 6	Hysteresis of 2.5 dB
6	LVL + 21.6 dB	LVL x 12	LVL + 18.1 dB	LVL x 8	Hysteresis of 3.5 dB
7	LVL + 24.1 dB	LVL x 16	LVL + 21.6 dB	LVL x 12	Hysteresis of 2.5 dB
8	LVL + 27.6 dB	LVL x 24	LVL + 24.1dB	LVL x 16	Hysteresis of 3.5 dB
9	LVL + 30.1 dB	LVL x 32	LVL + 27.6dB	LVL x 24	Hysteresis of 2.5 dB

1. LVL must be replaced by ANLVL when SADMOD[1:0] = 0 and by ANMIN for other SADMOD[1:0] values.

When the hysteresis function is disabled, the SAD always use THRH.

Note: The hysteresis mode must not be used when SADMOD[1:0] = 1x.

Trigger logic

The signal compared to this threshold depends also on SADMOD[1:0].

The trigger condition is reached when the selected signal (SELSIG) is bigger than the threshold level.

If the trigger condition is met, the following happens:

- The SAD switches to DETECT state.
- The SAD refreshes the hangover counter with HGOVR.
- The sddet_evt event is asserted if the SAD transits from MONITOR to DETECT.
- The adf_sad_det signal is set to high.

The SAD remains in DETECT state as long as the trigger condition is met or the hangover down-counter is different from 0.

The sddet_evt event indicates when the SAD enters and/or exits the DETECT state. This event is used to generate an interrupt when a sound is detected or when a sound is no longer detected:

- When DETCFG = 0, the application receives an event only when the SAD enters the DETECT state.
- When DETCFG = 1, the application receives an event when the SAD enters or exits the DETECT state.

The adf_sad_det signal remains high as long as the SAD is in DETECT state.

The SAD also provides a flag indicating that a new sound level value is available (SDLVLF). The last computed sound level (SDLVL[14:0]) is available in the *ADF SAD sound level register (ADF_SADSDLVR)*, and the last computed ambient noise level (ANLVL[14:0]), in the *ADF SAD ambient noise level register (ADF_SADANLVR)*.

Note: The SAD can work even when the AHB clock is not present. In that case, the SAD does not update SDLVL[14:0] and ANLVL[14:0].

To get the latest valid SDLVL[14:0] and ANLVL[14:0] values, the application must read the ADF_SADSDLVR, and ADF_SADANLVR registers, when the SDLVLF flag goes high. This can be done in the following ways:

- by polling the SDLVLF flag:
  a) Clear the SDLVLF flag by writing SDLVLF to 1.
  b) Wait for SDLVLF = 1, by reading ADF_DFLTxISR.
  c) Read ADF_SADSDLVR and ADF_SADANLVR.
  d) Clear SDLVLF by writing it to 1.
  e) Go to step 2 if other values must to be read.
- by generating an interrupt:
  a) Read ADF_DFLTxISR.
  b) If SDLVLF = 1, read ADF_SADSDLVR and ADF_SADANLVR, and clear SDLVLF by writing it to 1.
  c) Handle other status flags and exit from ISR.

Sample transfer to memory

The SAD offers the following options to control the samples transfer from DFLT0 to the system memory:

- If DATCAP[1:0] = 1x, the samples are transferred into the system memory as soon as DFLT0 and SAD are enabled. The transfer does not depend on the SAD state.
- If DATCAP[1:0] = 01, the samples are transferred into the system memory when the SAD detects a sound (when the SAD is in DETECT state), assuming that DFLT0 and SAD are enabled.
- If DATCAP[1:0] = 0, the samples are not transferred into the memory. This mode can be used if the application only wants to observe but does not need samples for other processing.

Note: DATCAP[1:0] is taken into account only when the SADEN = 1. For example, if the SAD configuration is DATCAP[1:0] = 0, SADEN = DFLTEN = 1, and if the application sets now SADEN to 0, the samples provided by the DFLT0 are transferred to the RXFIFO.

Programming recommendations

To make the SAD function working properly, the ADF must be programmed as follows:

1. Provide the proper kernel clock (adf_ker_ck) to the ADF.
2. Configure the CKGEN and enable it.
3. Configure the SITF and enable it (note that microphones have a settling time of several milliseconds).
4. Configure the DFLT0. A typical setting is the following:
   – CIC5 with a decimation ratio of 12, 16 or 24
   – RSFLT with a decimation ratio of 4
   – HPF with HPFC = 2 or 3

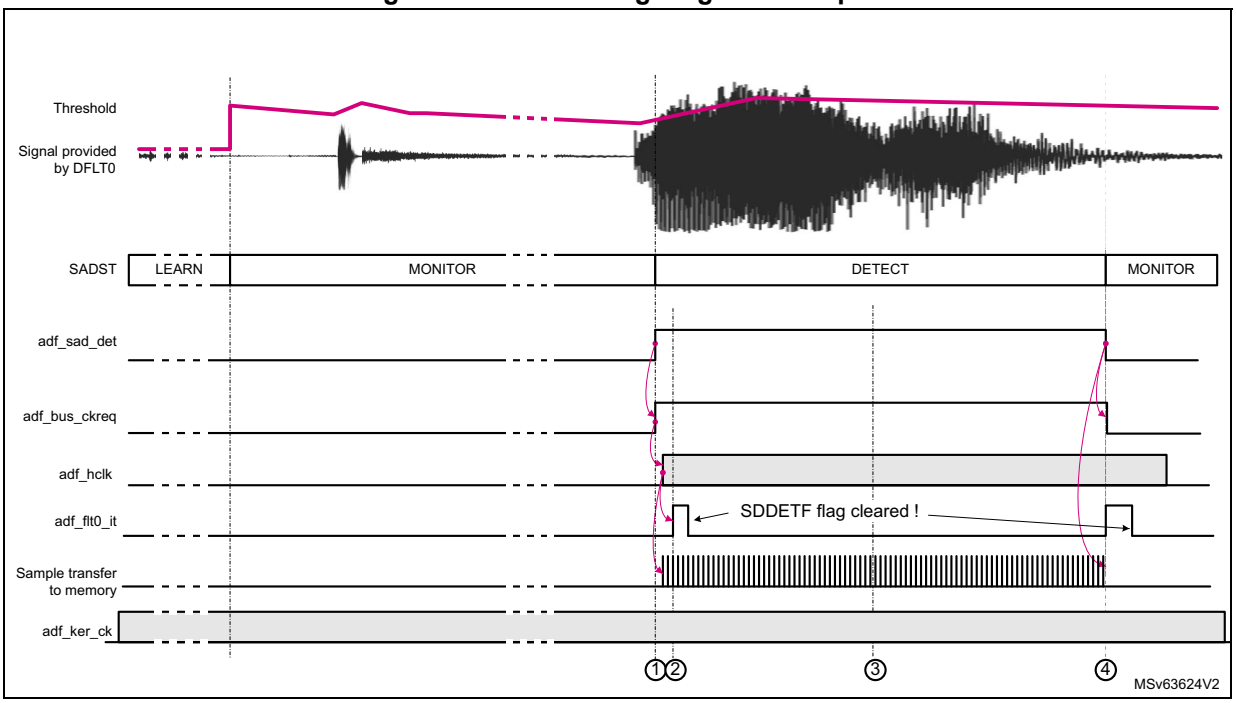
   For a very-low power implementation, the RSFLT can be bypassed.
5. Set SADEN to 0.
6. Wait for SADACTIVE = 0. If SADEN was previously enabled, this phase can take two periods of adf_hclk, and two periods of adf_proc_ck.
7. Configure the SAD as follows:
   – Set DATCAP[1:0] to 0, if the application does not want to store the samples into the system memory.
   – Set DATCAP[1:0] to 01, if the application wants to store the samples into the system memory only when the SAD detects a sound.
   – Set DATCAP[1:0] to 11, if the application wants to store the samples into the system memory continuously.
8. Configure the DMA (optional).
9. Enable the SAD.
10. Enable the DFLT0.

Figure 392 shows a simplified timing diagram when the SAD works with DATCAP[1:0] = 01.

Thanks to the kernel clock (adf_ker_ck), the SAD continuously monitors the audio signal provided by the DFLT0. The threshold is also continuously updated according to the ambient noise level estimation.

- When the SAD detects a sound higher than the programmed threshold (1), the ADF requests the bus clock (adf_bus_ckreq asserted).
- When the bus clock is available (see 2 in *Figure 392*) then:
  – The data transfer to the memory is triggered.
  – The event interrupt (adf_evt_it) can be generated.
- In this example, the event interrupt (adf_evt_it) is used to wake up the application. The interrupt line is released by clearing SDDETF by writing 1 to it.
- As long as the SAD remains in DETECT state, the application waits to get enough samples and calls, for example the keyword recognition algorithm (see 3 in *Figure 392*).
- In the case shown in *Figure 393*, the SAD state (SADST) goes back to MONITOR before the keyword is recognized. If DETCFG is set to 1, an event signals when the SAD goes back to MONITOR state. The SAD stops the transfer of samples into the memory and the application can clean up the receive buffer for the next detection (see 4 in *Figure 392*).

Figure 393. SAD timing diagram example



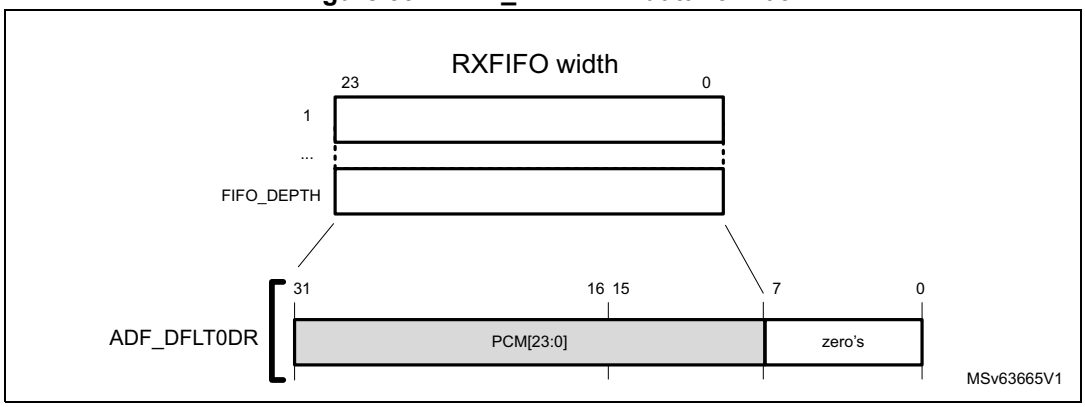
37.4.11 Data transfer to memory

Data format

The samples processed by DFLT0 are stored into a RXFIFO. The application can read the samples stored into these FIFOs via the *ADF digital filter data register 0 (ADF_DFLT0DR)*. The samples inside this register are signed and left aligned. The bit 31 always represents the sign.

The ADF provides 24-bit left-aligned data. Performing a 16-bit access to ADF_DFLT0DR allows the application to get the 16 most significant bits. Performing a 32-bit access to ADF_DFLT0DR allows the application to get a 24-bit data size.

Figure 394. ADF_DFLTxDR data format



Data resynchronization

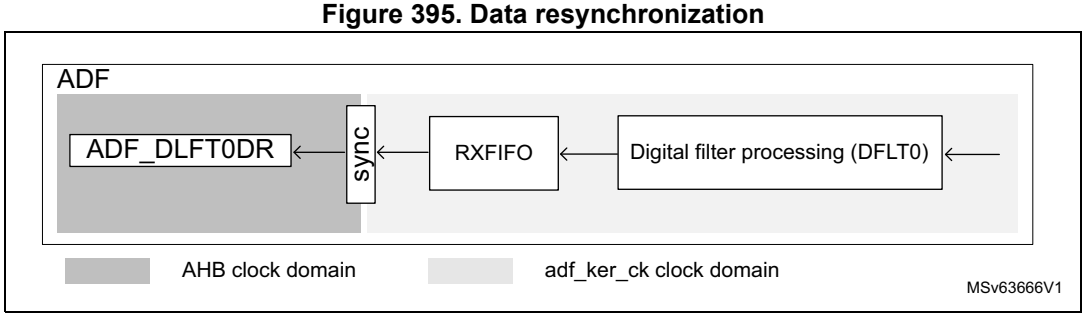
The samples stored into the RXFIFO can be transferred into the memory by using either DMA requests or interrupt signaling.

Note: The RXFIFO is located into the adf_ker_ck clock domain, while ADF_DFLT0DR *is located into the adf_hclk (AHB) clock domain.*

When the AHB clock is available, if ADF_DFLT0DR is empty and if a sample is available into the RXFIFO, this sample is transferred into ADF_DFLT0DR.

The sample transfer from the RXFIFO to ADF_DFLT0DR takes two periods of the AHB clock (adf_hclk) and two periods of the adf_ker_ck clock. The ADF inserts automatically wait-states if the application performs a read operation of ADF_DFLT0DR while the transfer of the new sample from the RXFIFO to ADF_DFLT0DR is not yet completed.

Figure 395. Data resynchronization



Data transfer

The content of the RXFIFO can be transfered to the memory either by using a DMA channel or interrupt services.

Both single and burst, DMA transfers are supported by the ADF, but the application has to care about the following points:

- The RXFIFO must contain at least the same amount of samples than the burst size.
- The burst mode efficiency may be reduced due to the data resynchronization explained in the previous section.

Note: The burst mode is not available in all products (see the DMA section to check if the product supports it).

In addition, the application can select the RXFIFO threshold (FTH bit) in order to trigger the data transfer: a data transfer can be triggered as soon as the RXFIFO is not empty, or when the RXFIFO is half-full (containing depth/2 samples).

For the DMA transfer, as soon as one of the RXFIFO reaches the threshold level, the DMA request is asserted in order to ask for data transfer. Successive DMA requests are performed as long as the RXFIFO is not empty.

The DMA mode of the RXFIFO is enabled via the DMAEN bit in ADF_DFLT0DR.

For the interrupt signaling, the following cases must be considered:

- If FTH = 0, as soon as a data is available in ADF_DFLT0DR, the FTHF is set, allowing the generation of an interrupt. FTHF is released as soon as ADF_DFLT0DR is read.
- If FTH = 1, as soon as the RXFIFO reaches the threshold level and a data is available in ADF_DFLT0DR, the FTHF is set, allowing the generation of an interrupt. FTHF is released as soon as one data is read. FTHF is set again if the threshold condition is

met again. In this mode, every time an interrupt occurs, the application is supposed to read FIFO_SIZE/2 data.

RXFIFO overrun

A RXFIFO overrun condition is detected when the RXFIFO is full, and a new sample from the DFLT0 must be written.

In this case, DOVRF is set and the new sample is dropped. When the RXFIFO has at least one location available, the new incoming sample is written into the RXFIFO.

Figure 396 shows an example based on a RXFIFO depth of four words and FTH set to 1, so that FTHF goes to 1 when the RXFIFO is half-full.

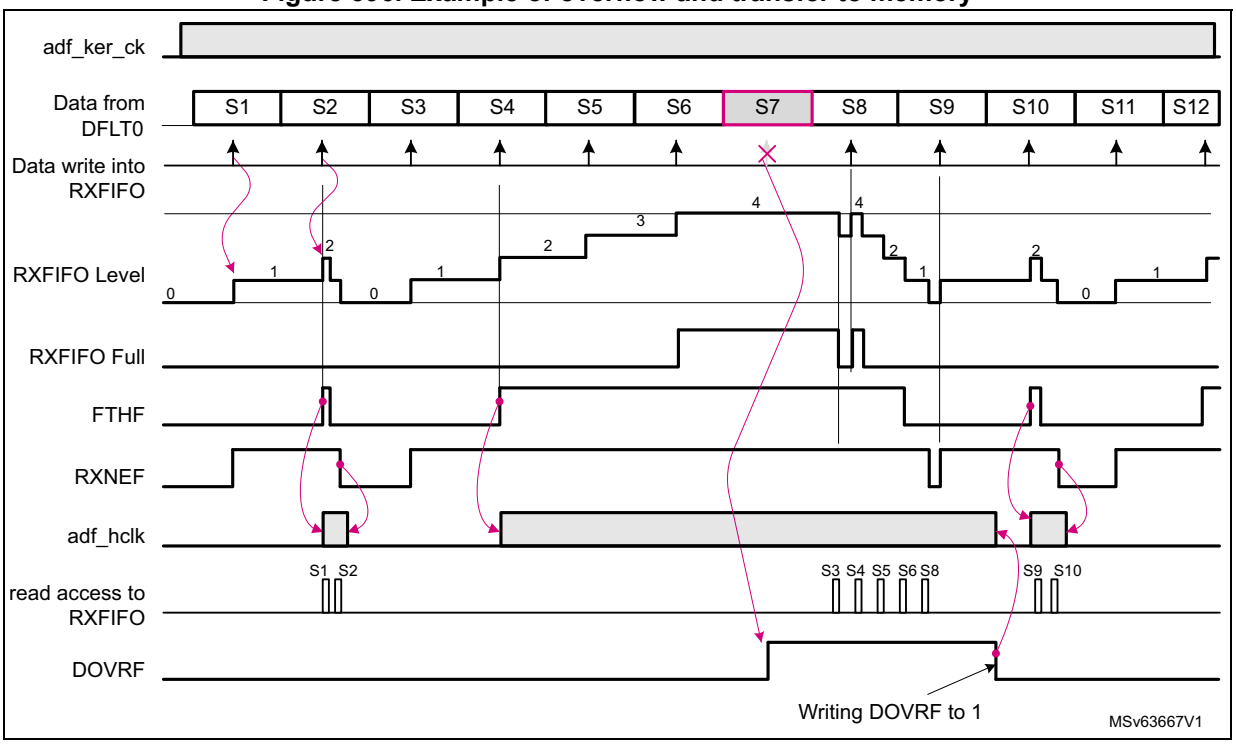
The S7 sample is lost due to an overrun: the RXFIFO is full while S7 must be written into the RXFIFO. The S7 write operation is not performed. DOVRF is set to 1 at the moment where the write operation was expected. The overflow event remains to 1 as long as it is not cleared by the application.

In this example, DOVRIE is set to 1 to have an interrupt if an overrun condition is detected.

After the S7 sample, the application manages to read data from the RXFIFO, and the ADF can write the S8 sample and consecutive. Later, the application clears DOVR, allowing the detection of a new overrun situation.

In the adf_hclk line, the gray boxes indicate that the ADF requested the AHB clock. *Figure 396* shows the AHB clock available only when the ADF requests it. In real applications, the AHB clock may also be present if the ADF does not request it.

Figure 396. Example of overflow and transfer to memory



37.4.12 Register protection

The ADF embeds some hardware protection to prevent invalid situations. *Table 376* shows the list of write-protected and unprotected fields.

Table 376. Register protection summary

Registers	Unprotected fields	Write-protected fields	Write-protection condition
ADF global control register (ADF_GCR)	TRGO	-	DFLTACTIVE0 = 1
ADF clock generator control register (ADF_CKGCR)	CKGDEN CCK0EN CCK1EN	PROCDIV[6:0], CCKDIV[3:0], CKGMOD, TRGSRC[3:0], TRGSENS, CCK[1:0]DIR	CKGACTIVE = 1
ADF serial interface control register 0 (ADF_SITF0CR)	SITFEN	STH[4:0], SITFMOD[1:0], SCKSRC[1:0]	SITFACTIVEx = 1
ADF bitstream matrix control register 0 (ADF_BSMX0CR)	-	BSSEL[4:0]	DFLTACTIVEx = 1
ADF digital filter control register 0 (ADF_DFLT0CR)	DFLTEN	NBDIS[7:0], TRGSRC[3:0], TRGSENS, FTH, DMAEN, SNPSFMT, ACQMOD[2:0]	DFLTACTIVEx = 1
ADF digital filer configuration register 0 (ADF_DFLT0CICR)	SCALE[5:0]	MCICD[8:0], CICMOD[2:0], DATSRC[1:0]	
ADF reshape filter configuration register 0 (ADF_DFLT0RSFR)	-	All fields	
ADF delay control register 0 (ADF_DLY0CR)	-	SKPDLY[6:0]	SKPBF = 1
ADF DFLT0 interrupt enable register (ADF_DFLT0IER)	All fields	-	-
ADF DFLT0 interrupt status register 0 (ADF_DFLT0ISR)	All fields	-	-
ADF SAD control register (ADF_SADCR)	SADEN	FRSIZE[2:0], DETCFG, SADMOD[1:0], HYSTEN, DATCAP[1:0]	SADACTIVE = 1
ADF SAD configuration register (ADF_SADCFGR)	-	ANMIN[12:0], SNTHR[3:0], HGOVR[3:0], LFRNB[2:0], ANSLP[2:0]	SADACTIVE = 1

All the ADF processing is performed in the adf_proc_ck clock domain. For that reason, enabling or disabling an ADF sub-block may take some time due to the resynchronization between the AHB clock domain and the adf_proc_ck clock domain. XXXACTIVE flags are available to allow the application to check that the synchronization between the two clock domains is completed.

To change a write-protected bitfield, the application must follow this sequence:

1. Set the enable bit of the sub-block to 0.
2. Wait for corresponding flag XXXACTIVE = 0.
3. Modify the wanted fields.
4. Set the enable bit of the sub-block to 1.

Refer to the description of each sub-block for details.

37.5 ADF low-power modes

Table 377. Effect of low-power modes on ADF

Mode	Description
Sleep	No effect. ADF interrupts cause the device to exit the Sleep mode.
Stop(1)	The ADF registers content is kept. Thanks to the kernel clock request feature, if the ADF is clocked by an internal oscillator available in Stop mode, the ADF remains active. The interrupts cause the device to exit Stop mode.
Standby	The ADF is powered down and must be reinitialized after exiting Standby mode.

1. Refer to *Section 37.3: ADF implementation* for details about Stop modes supported by the ADF.

37.6 ADF interrupts

To increase the CPU performance, the ADF offers an interrupt line (adf_flt0_it), sensitive to several events.

Note: The status flags are available even if the corresponding interrupt enable flag is not enabled.

The interrupt interface is controlled via the *ADF DFLT0 interrupt enable register (ADF_DFLT0IER)* and the *ADF DFLT0 interrupt status register 0 (ADF_DFLT0ISR)*.

Figure 397. ADF interrupt interface

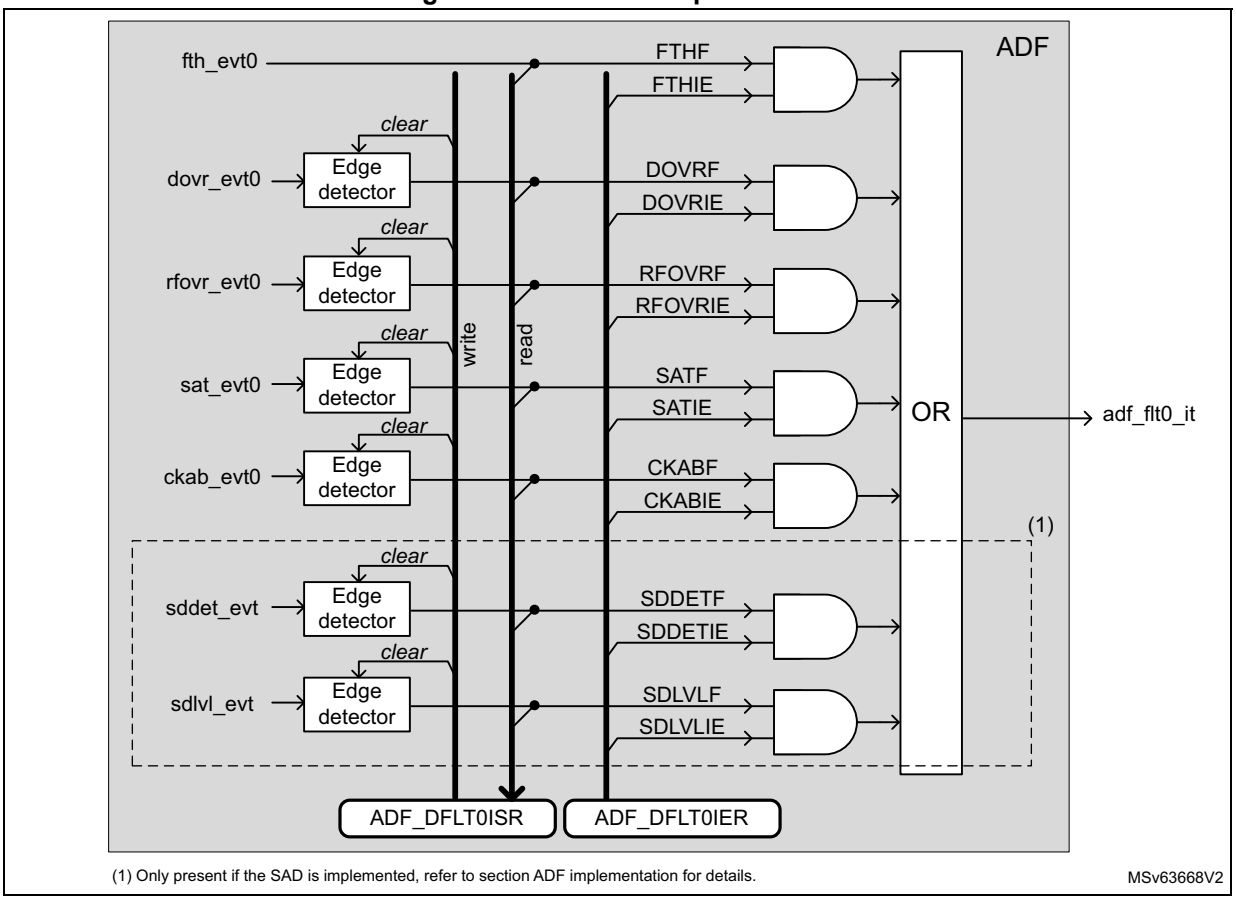


Table 378 shows which interrupt line is affected by which event, and how to clear and activate each interrupt/event.

Table 378. ADF interrupt requests

Interrupt vector	Interrupt event	Event flag	Event/interrupt clearing method	Exit Sleep mode	Exit Stop modes(1)	Exit Standby mode
ADF_FLT0(2)	RXFIFO threshold reached	FTHF	Read ADF_DFLT0DR until RXFIFO level is lower than the threshold.	Yes	Yes	No
	RXFIFO overrun	DOVRF	Write DOVRF to 1.			
	RSFLT overrun	RFOVRF	Write RFOVRF to 1.			
	Saturation detection	SATF	Write SATF to 1.			
	Channel clock absence detection	CKABF	Write CKABF to 1.			
	SAD: sound detected	SDDETF	Write SDDETF to 1.			
	SAD: sound level value available	SDLVLF	Write SDLVLF to 1.			

1. Refer to *Section 37.3: ADF implementation* for details.
2. ADF_FLT0 vector corresponds to the assertion of adf_flt0_it signal.

37.7 ADF application information

37.7.1 ADF configuration examples for audio capture

Table 379 gives some examples of the ADF settings for the digital microphones, focusing on 16 and 48 kHz output data rate.

Configurations #1 and #2 are for very low-power use-cases and have a reduced signal-to-noise ratio. The user must also insure that the selected digital microphone can work properly at 512 kHz. These configurations can be used for sound detection. The RSFLT is not used to reduce as much as possible the frequency of the kernel clock (adf_ker_ck).

Configurations #3, #4, #9, #10, #11 give signal-to-noise ratios around 115 dB, with an ideal microphone model, with a sinus signal of 997 Hz. Using the RSFLT allows a good control on the in-band ripple, and a good image rejection.

Configurations #7, #8, #10 give signal-to-noise ratio around 120 dB, with an ideal microphone model, using a sinus signal of 997 Hz.

Table 379. Examples of ADF settings for microphone capture

Configuration	adf_ker_ck (MHz)	PROCDIV + 1	CCKDIV + 1	CIC order (1)	MCICD + 1	SCALE	RSFLTBYP	RSFLTD	HPFBYP	-	adf_proc_ck (MHz)	Total dec. ratio	F_{RS} (kHz)	F_{ADF_CCKx} (MHz)	F_{PCM} (kHz)
#1	1.024	1	2	4	64	0x2D (- 8.5 dB)	1	x	x	=>	1.024	64	-	0.512	8
#2		1	2	5	32	0x2B (- 14.5 dB)						32	-		16
#3		1	2	5	16	0x01 (+ 3.5 dB)	0	0				64	32		8
#4	2.048	1	2	5	16	0x01 (+ 3.5 dB)	0	0			2.048	64	64	1.024	16
#5	3.072	1	6	5	8	0x0B (+ 33.6 dB)	0	0			3.072	32	32	0.512	8
#6		2	2	5	12	0x06 (+ 18.1 dB)						48	64	0.768	16
#7		1	2	5	24	0x2C (- 12 dB)						96		1.536	
#8	4.096	1	2	5	32	0x27 (- 26.6 dB)	0	0			4.096	128	64	2.048	16
#9	6.144	3	2	5	16	0x02 (+ 6.0 dB)	0	0			2.048	64	64	1.024	16
#10		2	2	5	24	0x2C (- 12 dB)					3.072	96		1.536	
#11		1	2	5	16	0x01 (+ 3.5 dB)					6.144	64	192	3.072	48
#12	7.680	1	2	5	20	0x2E (- 6.0 dB)	0	0			7.680	80	192	3.840	48

1. CICMOD = 100 for CIC order equal to 4. CICMOD = 101 for CIC order equal to 5.

37.7.2 Programming examples

Example 1

This example describes the programming of ADF for the capture of a signal coming from a digital microphone, using only the CIC4, with a decimation of 48, assuming that the kernel clock is 1.536 MHz. Typically, this configuration can be used to detect sound using the SAD.

Table 380. Programming sequence (CIC4)

Operations	Comments
Adjust the proper kernel clock frequency via the RCC	Assuming that the RCC is programmed to provide a kernel clock (adf_ker_ck) of 1.536 MHz coming from a RC oscillator.
Select the proper ADF kernel clock source via the RCC	Refer to the RCC of the product.
Enable the ADF clocks via the RCC	Refer to the RCC of the product.
Reset the ADF via the RCC	Refer to the RCC of the product.
AFMUX programming	Program the AFMUX to select ADF_SD0 and ADF_CCK0 functions.
Enable ADF processing clock: ADF_CKGCR = 0x0001 0023	PROCDIV = 0 (bypass): adf_proc_ck frequency is 1.536 MHz. CCKDIV = 1 (division by 2): ADF_CCK0 clock frequency is 768 kHz. The ADF_CCK0 pin is set in output and generates a clock so that the microphone can exit from low-power mode.
Serial interfaces configuration: ADF_SITF0CR = 0x0000 1F01	SCKSRC = 0 to select ADF_CCK0 as serial clock. SIFTMOD = 0 to select LF_MASTER SPI mode. Clock absence feature is not working in this mode. The serial interface is enabled.
Bitstream matrix configuration: ADF_BSMX0CR = 0x0000 0000	DFLT0 filter takes the bitstream of SITF0, sampled on rising edge
Filters configuration (CIC): ADF_DFLT0CICR = 0x0040 2F40	SCALE = 0x04 (12 dB): RSFLT is not enabled. Note that the gain is 8.5 dB, higher than recommended in order to improve signal accuracy for the SAD. Saturation is not an issue in this case, as only the detection of a signal much lower than the full scale is needed. MCICD = 0x2F (decimation by 48) CICMOD = 4 to select a $Sinc^4$ DATSCR = 0 to select data coming from BSMX
Filters configuration (RSFLT and HPF): ADF_DFLT0RSFR = 0x0000 0301	HPFC = 3: cut-off frequency of 16kHz * 0.0095 = 152 Hz HPFBYP = 0: HPF not bypassed RSFLTBYP = 1: RSFLT bypassed
Micro delay adjust: ADF_DLY0CR = 0x0000 0000	Not used in this example
Enable interrupt events: ADF_DFLT0IER = 0x0000 1000	Enable the interrupt events the application wants to handle. In this example, SDDETIE is set to 1 to have an interrupt if a sound is detected.

Table 380. Programming sequence (CIC4) (continued)

Operations	Comments
SAD setting: ADF_SADCR = 0x0000 1400	SADMOD = 1: Trigger based on sound level values FRSIZE = 4: Sound level computed on 128 samples HYSTEN = 0: No hysteresis DETCFG = 0: interrupt generated when the SAD enters in DETECT state DATCAP = 0: samples not transferred to memory SADEN = 0: SAD not yet enabled
SAD setting: ADF_SADCFGR = 0x0025 0001	ANMIN = 0x25: Sound threshold of 37 * 10^SNTHR/20 = 74 LSB(1) HGOVR = 0: four frames (4 x 128 = 512 samples) LFRNB = 0: Learning phase set to two frames. Not useful in this mode. ANSLP = 0: Not used in this mode SNTHR = 1: Threshold set to 6 dB (see ANMIN)
Clear status flags: ADF_DFLT0ISR = 0x0000 0FFF	Clear all the status flags before running the ADF
Enable the SAD: ADF_SADCR = 0x0000 1401 Wait for SADACTIVE flag = 1	Enable first the SAD, in order to be sure that data transfer to memory are blocked by the SAD.
Enable the filter: ADF_DFLT0CR = 0x0000 0001	NBDIS = 0: no samples discarded ACQMOD = 0: Asynchronous continuous acquisition mode DMAEN = 0: DMA interface not used DFLTEN = 1: Filter enabled

1. SNTHR and ANMIN values are computed using the same approach than in *Threshold programming with SADMOD = 01* (detection of a sound higher than 63 dBSPL).

Example 2

This example describes the programming of ADF for the capture of a signal coming from a digital microphone, using the CIC5, and the RSFLT, with a total decimation of 64.

Table 381. Programming sequence (CIC5)

Operations	Comments
Adjust the proper kernel clock frequency via the RCC	Assuming that the RCC is programmed to provide a kernel clock (adf_ker_ck) of 6.144 MHz
Select the proper ADF kernel clock source via the RCC	Refer to the RCC of the product.
Enable the ADF clocks via the RCC	Refer to the RCC of the product.
Reset the ADF via the RCC	Refer to the RCC of the product.
AFMUX programming	Program the AFMUX to select ADF_SD0 and ADF_CCK0 functions.
Enable ADF processing clock: ADF_CKGCR = 0x0201 0023	PROCDIV = 2 (division by 3): adf_proc_ck frequency is 6.144 MHz. CCKDIV = 1 (division by 2): ADF_CCK0 clock frequency is 1.024 MHz. The ADF_CCK0 pin is set in output and generates a clock so that the microphone can exit from low-power mode.

Table 381. Programming sequence (CIC5) (continued)

Operations	Comments
Serial interfaces configuration: ADF_SITF0CR = 0x0000 1F01	SCKSRC = 0 to select ADF_CCK0 as serial clock. SIFTMOD = 0 to select LF_MASTER SIPI mode. Clock absence feature is not working in this mode. The serial interface is enabled.
Bitstream matrix configuration: ADF_BSMX0CR = 0x0000 0000	DFLT0 filter takes the bitstream of SITF0, sampled on rising edge
Digital filter control: ADF_DFLT0CR = 0x0000 0006	NBDIS = 0: no samples discarded ACQMOD = 0: Asynchronous continuous acquisition mode DMAEN = 1: DMA interface not used DFLTEN = 0: Filter disabled FTH = 1: RXFIFO half-full
Filters configuration (CIC): ADF_DFLT0CICR = 0x0010 0F50	SCALE = 0x01(+3.5 dB): Output limited to 22 bits due to RSFLT. MCICD = 0xF (decimation by 16) CICMOD = 5 to select a $Sinc^5$ DATSCR = 0 to select data coming from BSMX
Filters configuration (RSFLT and HPF): ADF_DFLT0RSFR = 0x0000 0200	HPFC = 2: cut-off frequency of 16 kHz * 0.0025 = 40 Hz HPFBYP = 0: HPF not bypassed RSFLTBYP = 0: RSFLT not bypassed RSFLTD = 0: Decimation by 4
Micro delay adjust: ADF_DLY0CR = 0x0000 0000	Not used in this example
Enable interrupt events: ADF_DFLT0IER = x	Enable the interrupt events the application wants to handle.
Clear status flags: ADF_DFLT0ISR = 0x0000 0FFF	Clear all the status flags before running the ADF
Program the DMA Enable the DMA	The DMA must be programmed in order to read the data inside the ADF_DLT0DR register every time a DMA request is generated.
Start acquisition: ADF_DFLT0CR = 0x0000 0007	The ADF starts to filter data.

37.7.3 Connection examples

Figure 397 shows simple connection examples of the ADF to external sensors.

- Picture on the left: two digital microphones connected to the ADF

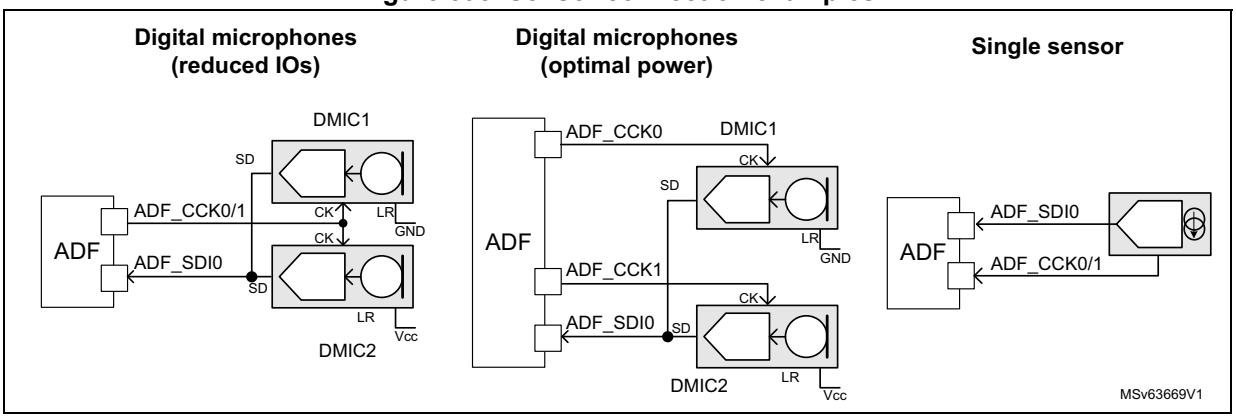
  In this connection, the amount of connections is optimized; DMIC1 and DMIC2 are sharing the same data line, and the same clock line. BSMX allows the application to connect the digital filter either to DMIC1 or to DMIC2. In this configuration when one of the microphone is used, the other is activated as well, as they share the same clock.
- Picture in the center: two digital microphones connected to the ADF

  In this connection, DMIC1 and DMIC2 are sharing the same data line, but have a dedicated clock line. BSMX allows the application to connect the filter either to DMIC1 or to DMIC2. When the application wants to use a microphone, it is possible to keep the other in low-power mode by forcing its clock line to 0 (CCKyEN = 0, CCKyDIR = 1).

- Picture on the right: single sensor connected to the ADF

  It is also possible to configure the CCK0 and CCK1 pins to input in order to connect sensors providing the clock.

Figure 398. Sensor connection examples



37.7.4 Global frequency response

Figure 398 shows the global frequency response for a 16 kHz audio signal with a digital microphone working at 1.024 MHz. The filter configuration is the following:

- CIC order 4 or 5, with a decimation ratio of 16
- RSFLT enabled, with a decimation ratio of 4
- HPF enabled with a cut-off frequency of 40 Hz

Figure 399 shows the theoretical frequency response using a CIC4 and a CIC5.

Figure 399. Global frequency response

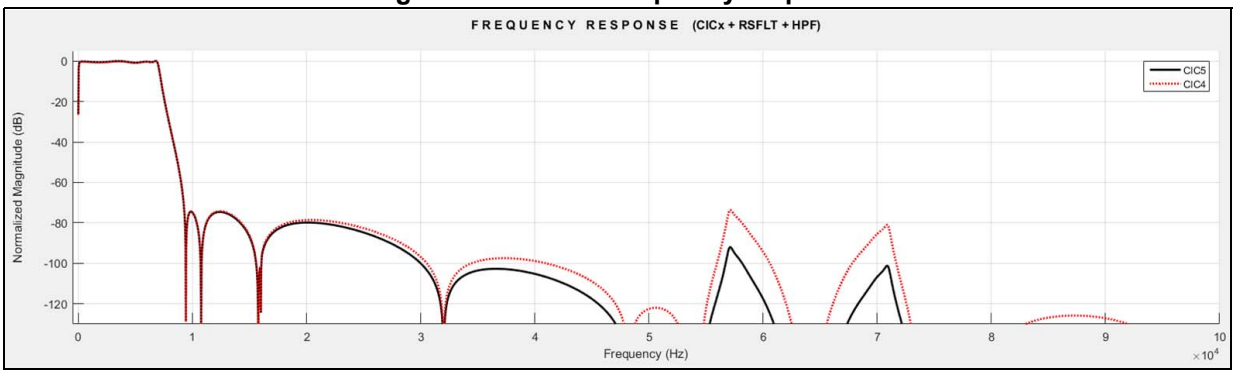


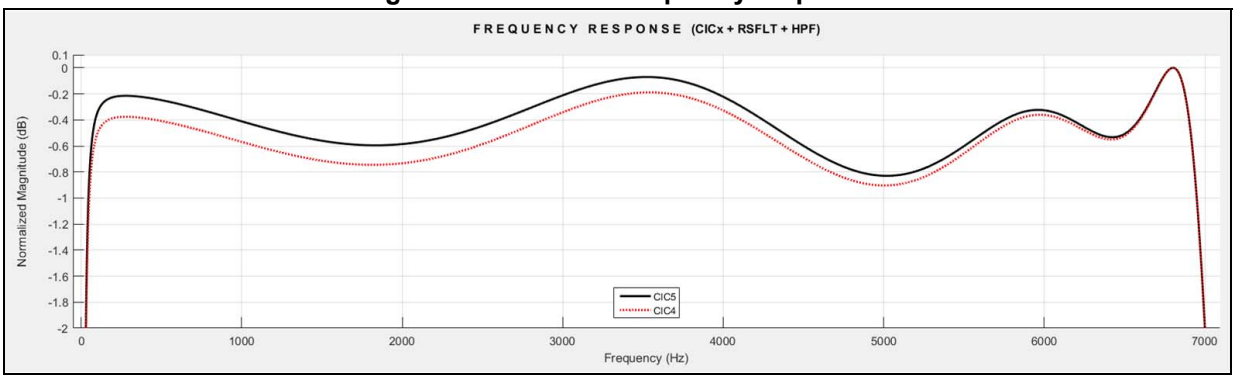
Figure 400 shows the in-band ripple for a 16 kHz audio signal with a digital microphone working at 1.024 MHz. The filter configuration is the following:

- CIC order 4 or 5, with a decimation ratio of 16
- RSFLT enabled, with a decimation ratio of 4
- HPF enabled with a cut-off frequency of 20 Hz

The resulting in-band ripple is ± 0.41 dB for CIC5, and ± 0.45 dB for CIC4.

The - 3 dB cut-off frequency is 7061 Hz.

Figure 400. Detailed frequency response



37.7.5 Total ADF gain

This section details how to compute the signal level provided by the ADF according to the filter settings.

A signal level may be expressed in dBFS (decibel full scale). A 0 dBFS level is assigned to the maximum possible digital level. For example, a signal that reaches 50 % of the maximum level, has a – 6 dBFS level (6 dB below full scale).

For example, for the ADF offering a final data width of 24 bits, a signal having an amplitude of 2 * 10^6 LSB has a level of:

$$20 \times \log_{10}\left(\frac{2 \times 10^6}{2^{(24-1)}}\right) = -12.45 \text{ dBFS}$$

In addition, the data size of a signal having an amplitude (Amp) expressed in LSB is given by:

$$DS = \left(\frac{\ln(Amp)}{\ln(2)} + 1\right) \text{ bits}$$

One bit need to be added for negative values.

So a signal having an amplitude of 2 * 10^6 LSB, has a data size of 21.9 bits.

CIC gain

The CIC gain (G_{CIC} and GdB_{CIC}) can be deduced from the following formula giving data size in bits (DS_{CIC}).

$$DS_{CIC} = (N \times \log_2(D1)) + DSin$$

where N represents the CIC order (selected by CICMOD[2:0]), and D1 is the decimation ratio (given by MCICD[8:0]).

DSin represents the data size (in bits) of the signal at CIC input.

Warning: DS_{CIC} is very important for CIC filter. In order to work fine, DS_{CIC} must not exceed 26 bits.

The CIC gain G_{CIC} is given by:

$$G_{CIC} = (D1)^N$$

which gives in decibels:

$$GdB_{CIC} = 20 \times \log_{10}((D1)^N)$$

Data size at SCALE output

The data size at SCALE output (including the CIC gain), is a key information as the RSFLT starts to have some saturations, if the peak-to-peak signal amplitude at SCALE output is higher than 22 bits.

If the RSFLT is bypassed, then a peak-to-peak signal amplitude of 24 bits is accepted.

The signal amplitude at SCALE output is:

$$Asout_{SCALE} = D1^N \times 10^{\frac{GdB_{SCALE}}{20}} \times Asin_{DFLT}$$

GdB_{SCALE} represents the gain selected by SCALE[5:0], in dB.

$Asout_{SCALE}$ is the signal amplitude at SCALE output (in LSB), and $Asin_{DFLT}$ is the signal amplitude at CIC input (LSB).

$$DS_{SCALE} = \frac{\ln(Asout_{SCALE})}{\ln(2)} + 1$$

The data size at SCALE output (DS_{SCALE}) is expressed in bits.

RSFLT gain

The RSFLT gain in the useful bandwidth is typically 9.5 dB, but due to ripple a margin of about ± 0.41 dB must be considered.

$$G_{RSFLT} = 10^{\frac{9.5\ dB}{20}} = 2.98 \text{ typical}$$

Note: The HPF filter has a gain of 0 dB.

SAD gain

The SAD is using only the 16 MSB on the signal, as a consequence, from the SAD point of view, the truncation from 24 to 16 bits can be seen as an attenuation.

$$GdB_{SAD} = -48.1dB$$

and

$$G_{SAD} = 0.003906$$

The *Figure 401* shows a simplified view of the filter path and gives, for each significant component, the expression of the bit growth and the gain.

Figure 401. Simplified DFLT view with gain information

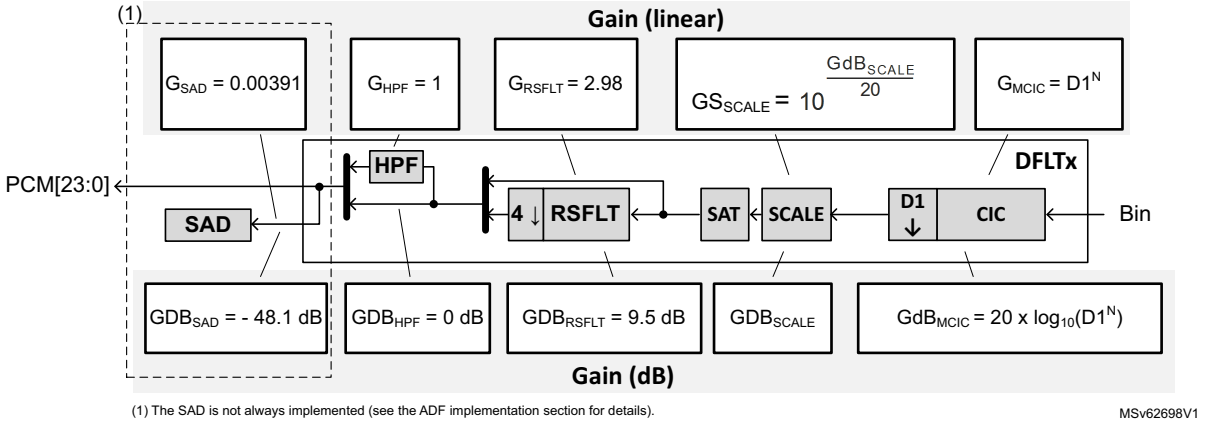


Table 382 summarizes of the final data size for different filter configurations.

Table 382. Output signal levels

Filter configurations	Final signal amplitude (LSB)
CIC + RSFLT + HPF + SAD	Samples provided to the RXFIFO: $Asout_{RXFIFO} = D1^N \times 10^{\frac{GdB_{SCALE}}{20}} \times 10^{\frac{9.5}{20}} \times Asin_{DFLT}$ Samples provided to the SAD: $Asout_{SAD} = D1^N \times 10^{\frac{GdB_{SCALE}}{20}} \times 10^{\frac{9.5}{20}} \times 0.003906 \times Asin_{DFLT}$ DS_{SCALE} must be lower than 22 bits.
CIC + RSFLT (+ HPF)	$ASout_{HPF} = D1^N \times 10^{\frac{GdB_{SCALE}}{20}} \times 10^{\frac{9.5}{20}} \times Asin_{DFLT}$ DS_{SCALE} must be lower than 22 bits.
CIC (+ HPF)	$ASout_{HPF} = D1^N \times 10^{\frac{GdB_{SCALE}}{20}} \times Asin_{DFLT}$ DS_{SCALE} must be lower than 24 bits.

Example using the main filter chain

If the ADF filter is programmed as follows:

- The input signal is coming from a serial interface ($Dsin_{RSFLT}$ = 1 bit).
- CIC order = 5 (N), with a decimation value of 24 (D1).
- SCALE[5:0] is set to - 12 dB.

- RSFLT enabled, and the decimation by four is enabled.
- HPF is enabled.

Check first the data size at CIC output:

$$DS_{CIC} = (5 \times \log_2(24)) + 1 \text{ bit} = 23.92 \text{ bits}$$

The size is lower than 26 bits, so the CIC works in good conditions.

The data size at CIC output is very close to 24 bits, so the SCALE must be adjusted in order to provide a 22-bit max signal to the RSFLT. An attenuation of 12 dB is needed.

Then the signal level provided to the RSFLT is:

$$Asout_{SCALE} = 24^5 \times 10^{\frac{-12}{20}} \times 1 = 2.10^6$$

$$DS_{SCALE} = \frac{\ln(2.10^6)}{\ln(2)} + 1 = 21.93 \text{ bits}$$

If a higher gain is used, the RSFLT may saturate the output signal for strong input signals.

At the end, the final signal amplitude is:

$$Asout_{HPF} = 24^5 \times 10^{\frac{-12}{20}} \times 10^{\frac{9.5}{20}} \times 1 = 5.9711 \times 10^6$$

$$Dsout_{HPF} = \left(\frac{\ln(5.9711 \times 10^6)}{\ln(2)} + 1\right) = 23.51 \text{ bits}$$

or:

$$SDB_{OUT} = 20 \times \log_{10}\left(\frac{2^{23.51}}{2^{24}}\right) = -2.84 \text{ dBFS}$$

37.7.6 How to compute SAD thresholds

The SAD does not compute the RMS value of the converted signal, but the average of the absolute values. As a consequence, the estimated level differs from the RMS value of the signal:

- For a sine signal having an RMS value of 1, the SAD computes a level of 0.9.
- For a white or pink noise signal having an RMS value of 1, the SAD computes a level of about 0.8.

Note: FRSIZE[2:0] has a big influence on the accuracy of the level estimation: big FRSIZE[2:0] values give better results.

Threshold programming with SADMOD = 01

Consider the case of a sound capture where the application wants to wake up the system when the captured sound is bigger than 63 dBSPL.

The sound capture can be performed with a digital microphone such as the MP45DT02.

The sensitivity of this microphone is typically -26 dBFS for an input signal of 94 dBSPL.

An acoustic signal at 63 dBSPL produces a digital signal of about:
- 26 dBFS - (94 - 63) = - 57 dBFS.

- SCALE value adjustment

  For this example, the filter configuration is the following:

  – CIC5 with a decimation by 16
  – RSFLT enabled with a decimation by 4
  – HPF enabled

  A SCALE value of 3.5 dB is recommended for this configuration. As DFTL0 provides samples only used for a sound detection (samples not provided to the application), a bigger gain value can be applied: it increases the SAD accuracy and a saturation does not affect the SAD behavior (for example, a SCALE value of 15.6 dB).

- Input signal amplitude

  The input signal is - 57 dBFS, corresponding to an amplitude

  Asin = $10^{(-57/20)}$ = 0.00141 LSB.

- Signal level at SAD input

  The total filter gain for the SAD is:

  $$G_{SAD} = 16^5 \times 10^{\frac{15.6}{20}} \times 10^{\frac{9.5}{20}} \times \frac{1}{256} = 73.68 \times 10^3 \text{ or } 97.3 \text{ dB}$$

  The signal amplitude received by the SAD is:

  $$Ain_{SAD} = 0.00141 \times G_{SAD} \sim 104 \text{ LSB}$$

  The gain can be increased if the expected amplitude is too small. For the targeted application, 104 LSB is fine.

  If the input signal is expected to be a sine, the sound level for a signal amplitude of 104 LSB is:

  $$SDLVL = \frac{Ain_{SAD} \times \sqrt{2}}{2} \times 0.9 \sim 66 \text{ LSB}$$

  where 0.9 is the correction factor to apply with respect to the RMS value.

- Program the trigger value

  ANMIN and SNTHR must be programmed to trigger the SAD when the input signal level reaches 66 LSB.

  For SADMOD[1:0] = 01, the threshold value is given by:

  $$THRH = ANMIN \times 10^{\frac{GdB_{SNTHR}}{20}}$$

  where GdB_{SNTHR} represents the decibel value selected by SNTHR[3:0].

  When SNTHR[3:0] = 6 dB for example, this formula becomes:

  $$THRH = 2 \times ANMIN$$

  So ANMIN = THRH/2 = 66 /2 = 33 LSB.

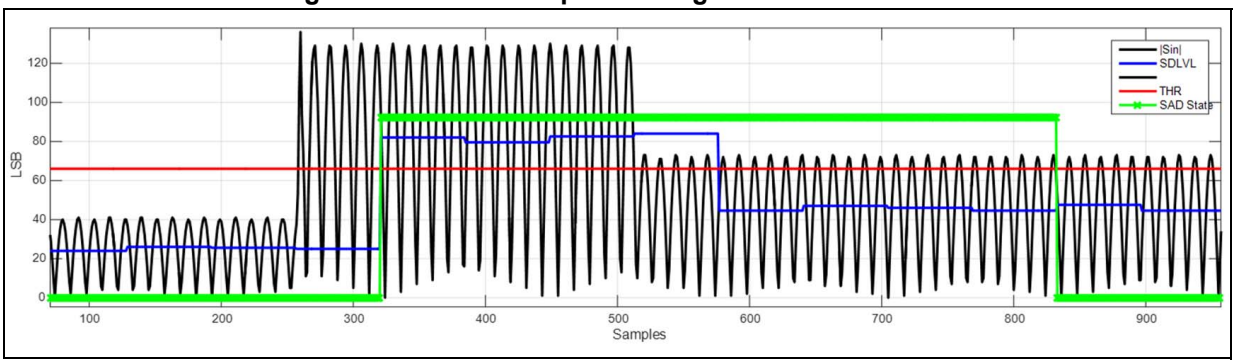
  In *Figure 401*, the trigger value (THRH in red) is fixed to 66 LSB. The input signal is at - 65dBFS during 256 samples, then its value goes to - 55 dB for 256 samples, and finally it is reduced to - 60 dBFS.

The blue curve is showing the sound level estimation (SDLVL) versus time. Fluctuation on the estimated value can be observed due to windowing effect of FRSIZE samples.

The SAD DETECT state (when green signal is high) is maintained during four additional frames due to hangover function value.

In this example ANSLP = FRSIZE = 3 (64 samples), LFRNB = 0 (2 frames), HGOVR = 0 (4 frames), SNTHR = 1 (6 dB) and ANMIN = 33.

Figure 402. SAD example working with SADMOD = 01



Threshold programming with SADMOD = 1x

Consider the case of a sound capture where the application wants to wake up the system when the captured sound is bigger than 57 dBSPL.

The sound capture can be performed with a digital microphone such as the MP45DT02. The sensitivity of this microphone is typically - 26 dBFS for an input signal of 94 dBSPL.

An acoustic signal at 57 dBSPL produces a digital signal of about:
- 26 dBFS - (94-63) = - 63 dBFS.

- Adjust SCALE value

  For this example, the filter configuration is the following:

  – CIC4 with a decimation by 48
  – RSFLT bypassed
  – HPF enabled

  A SCALE value of 3.5 dB is recommended for this configuration. The samples provided by DFTL0 are only used for a sound detection, without providing the samples to the application, a bigger gain value can be provided: it increases the SAD accuracy and a saturation does not affect the SAD behavior (for example, a SCALE value of 24 dB).

- Input signal amplitude

  The input signal is - 63 dBFS, corresponding to an amplitude:

  Asin = $10^{(-63/20)}$ = 0.000708 LSB.

- Signal level at SAD input

  The total filter gain for the SAD is:

$$G_{SAD} = 48^4 \times 10^{\frac{24}{20}} \times 0.003906 = 328.6 \times 10^3 \text{ or } 110.3 \text{ dB}$$

  The signal amplitude received by the SAD is:

$$Ain_{SAD} = 0.000708 \times G_{SAD} \sim 232 \text{ LSB}$$

The gain can be increased if the expected amplitude is too small.

If the input signal is expected to be a sine, the sound level for a signal amplitude of 232 LSB is:

$$SDLVL = \frac{Ain_{SAD} \times \sqrt{2}}{2} \times 0.9 \sim 148 \text{ LSB}$$

where 0.9 is the correction factor to apply with respect to the RMS value.

Note: ANLVL converges to average of SDLVL values, with a long constant time.
So SDLVL ~ ANLVL = 148 LSB for a constant input signal at 57 dBSPL.

- Programming trigger value

  For SADMOD = 1', the SAD compares the estimated ambient noise multiplied by the gain selected by SNTHR[3:0] to ANMIN[12:0] * 4.

  For simplification, SNTHR[3:0] is set to 1 (6 dB), meaning that ANLVL is multiplied by two.

  The SAD triggers if 2 * ANLVL > THRH.

  In this mode:

  $$THRH = 4 \times ANMIN$$

  So the SAD triggers if:

  $$ANLVL > 2 \times ANMIN$$

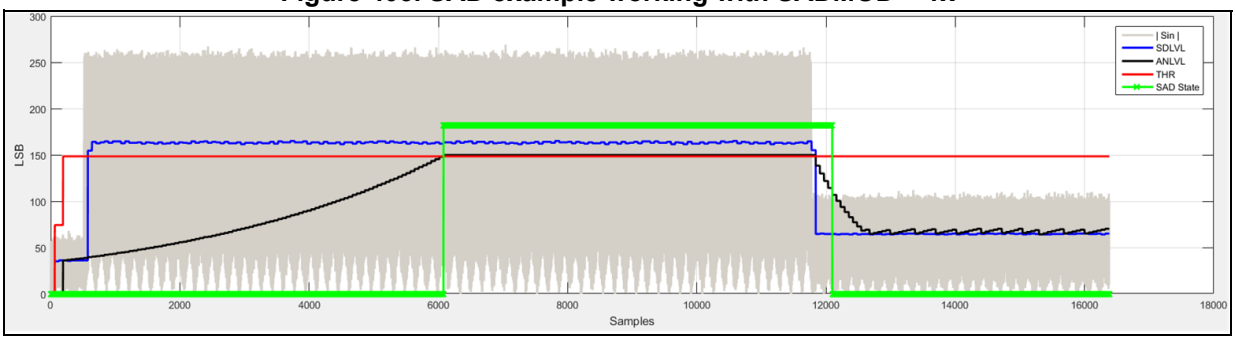
  So ANMIN = 148 / 2 = 74 LSB

  In *Figure 402*, the trigger value (THRH in red) is fixed to 148 LSB. The input signal is at - 75 dBFS during 512 samples, then its value goes to - 62 dB for 11000 samples, and finally it is reduced to - 70 dBFS.

  The blue curve shows the sound level estimation (SDLVL) versus time. The black curve shows the ambient noise estimation versus time, increasing or decreasing logarithmically. During the learning phase, it reaches the SDLVL value.

  In this example ANSLP = 6, FRSIZE = 3 (64 samples), LFRNB = 0 (2 frames), HGOVR = 0 (4 frames), SNTHR = 1 (6 dB) and ANMIN = 74.

Figure 403. SAD example working with SADMOD = 1x



37.8 ADF registers

All the ADF registers must be accessed either in word (32-bit) or half-word (16-bit) formats.

37.8.1 ADF global control register (ADF_GCR)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRGO
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **TRGO**: Trigger output control

This bit is set by software and reset by hardware. It is used to start the acquisition of several filters synchronously. It is also used to synchronize several ADF together by controlling the adf_trgo signal.

0: Write 0 has no effect. Read 0 means that the trigger can be set again to 1.

1: Write 1 generates a positive pulse on the adf_trgo signal and triggers the acquisition on enabled filter having their ACQMOD[2:0] = 01x and selecting TRGO as trigger. Read 1 means that the trigger pulse is still active.

37.8.2 ADF clock generator control register (ADF_CKGCR)

Address offset: 0x004

Reset value: 0x0000 0000

This register is used to control the clock generator. The clock adf_proc_ck must be enabled before enabling other ADF parts.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CKGACTIVE	PROCDIV[6:0]							Res.	Res.	Res.	Res.	CCKDIV[3:0]			
r	rw	rw	rw	rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRGSRC[3:0]				Res.	Res.	Res.	TRGSENS	Res.	CCK1DIR	CCK0DIR	CKGMOD	Res.	CCK1EN	CCK0EN	CKGDEN
rw	rw	rw	rw				rw		rw	rw	rw		rw	rw	rw

Bit 31 **CKGACTIVE**: Clock generator active flag

This bit is set and cleared by hardware. Ii is used by the application to check if the clock generator is effectively enabled (active) or not. The protected fields of this function can only be updated when CKGACTIVE = 0 (see *Section 37.4.12: Register protection* for details).

The delay between a transition on CKGDEN and a transition on CKGACTIVE is two periods of AHB clock and two 2 periods of adf_proc_ck.

0: The clock generator is not active and can be configured if needed.

1: The clock generator is active and protected fields cannot be configured.

Bits 30:24 **PROCDIV[6:0]**: Divider to control the serial interface clock

This bitfield is set and reset by software. It is used to adjust the frequency of the clock provided to the SITF.

$$F_{adf_itf_ck} = \frac{F_{adf_ker_ck}}{(PROCDIV + 1)}$$

This bitfield must not be changed if the filter is enabled (DFTEN = 1).

0: adf_ker_ck provided to the SITF

1: adf_ker_ck / 2 provided to the SITF

2: adf_ker_ck / 3 provided to the SITF

...

127: adf_ker_ck / 128 provided to the SITF

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **CCKDIV[3:0]**: Divider to control the ADF_CCK clock

This bitfield is set and reset by software. It is used to adjust the frequency of the ADF_CCK clock. The input clock of this divider is the clock provided to the SITF. More globally, the frequency of the ADF_CCK is given by the following formula:

$$F_{ADF_CCK} = \frac{F_{adf_ker_ck}}{(PROCDIV + 1) \times (CCKDIV + 1)}$$

This bitfield must not be changed if the filter is enabled (DFTEN = 1).

0000: The ADF_CCK clock is adf_proc_ck.

0001: The ADF_CCK clock is adf_proc_ck / 2.

0010: The ADF_CCK clock is adf_proc_ck / 3.

...

1111: The ADF_CCK clock is adf_proc_ck / 16.

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bits 15:12 **TRGSRC[3:0]**: Digital filter trigger signal selection

This bitfield is set and cleared by software. It is used to select which external signals trigger the corresponding filter. This bitfield is not significant if the CKGMOD = 0.

000x: TRGO selected

0010: adf_trg1 selected

Others: Reserved

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bits 11:9 Reserved, must be kept at reset value.

Bit 8 **TRGSENS**: CKGEN trigger sensitivity selection

This bit is set and cleared by software. It is used to select the trigger sensitivity of the trigger signals. This bit is not significant if the CKGMOD = 0.

0: A rising edge event triggers the activation of CKGEN dividers.

1: A falling edge even triggers the activation of CKGEN dividers.

Note: When the trigger source is TRGO, the sensitivity is forced to falling edge, thus TRGSENS value is not taken into account. This bit can be write-protected (see Section 37.4.12: Register protection for details).

Bit 7 Reserved, must be kept at reset value.

Bit 6 **CCK1DIR**: ADF_CCK1 direction

This bit is set and reset by software. It is used to control the direction of the ADF_CCK1 pin.

0: The ADF_CCK1 pin direction is in input.

1: The ADF_CCK1 pin direction is in output.

Note: This bit can be write-protected (see Section 37.4.12: Register protection for details).

Bit 5 **CCK0DIR**: ADF_CCK0 direction

This bit is set and reset by software. It is used to control the direction of the ADF_CCK0 pin.

0: The ADF_CCK0 pin direction is in input.

1: The ADF_CCK0 pin direction is in output.

Note: This bit can be write-protected (see Section 37.4.12: Register protection for details).

Bit 4 **CKGMOD**: Clock generator mode

This bit is set and reset by software. It is used to define the way the clock generator is enabled. This bit must not be changed if the filter is enabled (DFTEN = 1).

0: The kernel clock is provided to the dividers as soon as CKGDEN is set to 1.

1: The kernel clock is provided to the dividers when CKGDEN is set to 1 and the trigger condition met.

Note: This bit can be write-protected (see Section 37.4.12: Register protection for details).

Bit 3 Reserved, must be kept at reset value.

Bit 2 **CCK1EN**: ADF_CCK1 clock enable

This bit is set and reset by software. It is used to control the generation of the bitstream clock on the ADF_CCK1 pin.

0: Bitstream clock not generated

1: Bitstream clock generated on the ADF_CCK1 pin.

Bit 1 **CCK0EN**: ADF_CCK0 clock enable

This bit is set and reset by software. It is used to control the generation of the bitstream clock on the ADF_CCK0 pin.

0: Bitstream clock not generated

1: Bitstream clock generated on the ADF_CCK0 pin

Bit 0 **CKGDEN**: CKGEN dividers enable

This bit is set and reset by software. It is used to enable/disable the clock dividers of the CKGEN: PROCDIV and CCKDIV.

0: CKGEN dividers disabled

1: CKGEN dividers enabled

37.8.3 ADF serial interface control register 0 (ADF_SITF0CR)

Address offset: 0x080

Reset value: 0x0000 1F00

This register is used to control the serial interface SITF0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SITFACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	STH[4:0]					Res.	Res.	SITFMOD[1:0]		Res.	SCKSRC[1:0]		SITFEN
			rw	rw	rw	rw	rw			rw	rw		rw	rw	rw

Bit 31 **SITFACTIVE**: Serial interface active flag

This bit is set and cleared by hardware. It is used by the application to check if the serial interface is effectively enabled (active) or not. The protected fields of this function can only be updated when SITFACTIVE is set to 0 (see *Section 37.4.12: Register protection* for details).
The delay between a transition on SITFEN and a transition on SITFACTIVE is two periods of AHB clock and two periods of adf_proc_ck.
0: The serial interface is not active, and can be configured if needed.
1: The serial interface is active and protected fields cannot be configured.

Bits 30:13 Reserved, must be kept at reset value.

Bits 12:8 **STH[4:0]**: Manchester symbol threshold/SPI threshold

This bitfield is set and cleared by software. It is used for Manchester mode to define the expected symbol threshold levels (see *Manchester mode* for details on computation).
In addition this bitfield is used to define the timeout value for the clock absence detection in Normal SPI mode. STH[4:0] values lower than four are invalid.

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **SITFMOD[1:0]**: Serial interface type

This bitfield is set and cleared by software. It is used to define the serial interface type.
00: LF_MASTER SPI mode
01: Normal SPI mode
10: Manchester mode: rising edge = logic 0, falling edge = logic 1
11: Manchester mode: rising edge = logic 1, falling edge = logic 0

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bit 3 Reserved, must be kept at reset value.

Bits 2:1 **SCKSRC[1:0]**: Serial clock source

This bitfield is set and cleared by software. It is used to select the clock source of the serial interface.
00: Serial clock source is ADF_CCK0.
01: Serial clock source is ADF_CCK1.
others: reserved

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bit 0 **SITFEN**: Serial interface enable

This bit is set and cleared by software. It is used to enable/disable the serial interface.
0: Serial interface disabled
1: Serial interface enabled

37.8.4 ADF bitstream matrix control register 0 (ADF_BSMX0CR)

Address offset: 0x084

Reset value: 0x0000 0000

This register is used to select the bitstream to be provided to DFLT0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BSMXACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BSSEL[4:0]				
											rw	rw	rw	rw	rw

Bit 31 **BSMXACTIVE**: BSMX active flag

This bit is set and cleared by hardware. It is used by the application to check if the BSMX is effectively enabled (active) or not. BSSEL[4:0] can only be updated when BSMXACTIVE is set to 0. This BSMXACTIVE flag cannot go to 0 if DFLT0 is enabled.

0: BSMX is not active and can be configured if needed.

1: BSMX is active and protected fields cannot be configured.

Bits 30:5 Reserved, must be kept at reset value.

Bits 4:0 **BSSEL[4:0]**: Bitstream selection

This bitfield is set and cleared by software. It is used to select the bitstream to be processed for DFLT0.

00000: bs0_r provided to DFLT0

00001: bs0_f provided to DFLT0

others: reserved

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

37.8.5 ADF digital filter control register 0 (ADF_DFLT0CR)

Address offset: 0x088

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DFLTACTIVE	DFLTRUN	Res.	Res.	NBDIS[7:0]								Res.	Res.	Res.	Res.
r	r			rw	rw	rw	rw	rw	rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRGSRC[3:0]				Res.	Res.	Res.	TRGSENS	Res.	ACQMOD[2:0]			Res.	FTH	DMAEN	DFLTEN
rw	rw	rw	rw				rw		rw	rw	rw		rw	rw	w

Bit 31 **DFLTACTIVE**: DFLT0 active flag

This bit is set and cleared by hardware. It indicates if DFLT0 is active: can be running or waiting for events.

0: DFLT0 not active (can be re-enabled again, via DFLTEN bit, if needed)

1: DFLT0 active

Bit 30 **DFLTRUN**: DFLT0 run status flag
This bit is set and cleared by hardware. It indicates if DFLT0 is running or not.
0: DFLT0 not running and ready to accept a new trigger event
1: DFLT0running

Bits 29:28 Reserved, must be kept at reset value.

Bits 27:20 **NBDIS[7:0]**: Number of samples to be discarded
This bitfield is set and cleared by software. It is used to define the number of samples to be discarded every time DFLT0 is re-started.
0: No sample discarded
1: 1 sample discarded
2: 2 samples discarded
...
255: 255 samples discarded
Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bits 19:16 Reserved, must be kept at reset value.

Bits 15:12 **TRGSRC[3:0]**: DFLT0 trigger signal selection
This bitfield is set and cleared by software. It is used to select which external signals trigger DFLT0.
0000: TRGO selected
0010: adf_trgi selected
Others: Reserved
Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bits 11:9 Reserved, must be kept at reset value.

Bit 8 **TRGSENS**: DFLT0 trigger sensitivity selection
This bitfield is set and cleared by software. It is used to select the trigger sensitivity of the external signals
0: A rising edge event triggers the acquisition.
1: A falling edge even triggers the acquisition.
Note: When the trigger source is TRGO, TRGSENS value is not taken into account. When TRGO is selected, the sensitivity is forced to falling edge.
This bit can be write-protected (see Section 37.4.12: Register protection for details).

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **ACQMOD[2:0]**: DFLT0 trigger mode
This bitfield is set and cleared by software. It is used to select the filter trigger mode.
000: Asynchronous continuous acquisition mode
001: Asynchronous single-shot acquisition mode
010: Synchronous continuous acquisition mode
011: Synchronous single-shot acquisition mode
100: Window continuous acquisition mode
Others: Same as 000
Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bit 3 Reserved, must be kept at reset value.

Bit 2 **FTH**: RXFIFO threshold selection
This bit is set and cleared by software. It is used to select the RXFIFO threshold.
0: RXFIFO threshold event generated when the RXFIFO is not empty
1: RXFIFO threshold event generated when the RXFIFO is half-full
Note: This bit can be write-protected (see Section 37.4.12: Register protection for details).

Bit 1 **DMAEN**: DMA requests enable

This bit is set and cleared by software. It is used to control the generation of DMA request to transfer the processed samples into the memory.

0: DMA interface for the corresponding digital filter disabled

1: DMA interface for the corresponding digital filter enabled

Note: This bit can be write-protected (see Section 37.4.12: Register protection for details).

Bit 0 **DFLTEN**: DFLT0 enable

This bit is set and cleared by software. It is used to control the start of acquisition of the DFLT0 path. This bit behavior depends on ACQMOD[2:0] and external events. The serial or parallel interface delivering the samples must be enabled as well.

0: Acquisition immediately stopped

1: Acquisition immediately started if ACQMOD[2:0] = 00x or 101, or acquisition started when the proper trigger event occurs if ACQMOD[2:0] = 01x.

37.8.6 ADF digital filer configuration register 0 (ADF_DFLT0CICR)

Address offset: 0x08C

Reset value: 0x0000 0000

This register is used to control the main CIC filter.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	SCALE[5:0]						Res.	Res.	Res.	MCICD8
						rw	rw	rw	rw	rw	rw				rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MCICD[7:0]								Res.	CICMOD[2:0]			Res.	Res.	DATSRC[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw			rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:20 **SCALE[5:0]**: Scaling factor selection

This bitfield is set and cleared by software. It is used to select the gain to be applied at CIC output (see *Table 370* for details). If the application attempts to write a new gain value while the previous one is not yet applied, this new gain value is ignored. Reading back this bitfield informs the application on the current gain value.

000000: 0 dB

000001: + 3.5 dB

000010: + 6 dB or shift left by 1 bit

...

011000: + 72 dB or shift left by 12 bits

100000: - 48.2 dB or shift right by 8 bits (default value)

100001: - 44.6 dB

100010: - 42.1 dB or shift right by 7 bits

100011: - 38.6 dB

...

101110: -6 dB or shift right by 1 bit

101111: -2.5 dB

Others: Reserved

Bits 19:17 Reserved, must be kept at reset value.

Bits 16:8 **MCICD[8:0]**: CIC decimation ratio selection
This bitfield is set and cleared by software.It is used to select the CIC decimation ratio. A decimation ratio smaller than two is not allowed. The decimation ratio is given by (CICDEC+1).
0: Decimation ratio is 2.
1: Decimation ratio is 2.
2: Decimation ratio is 3.
3: Decimation ratio is 4.
...
511: Decimation ratio is 512.
Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **CICMOD[2:0]**: Select the CIC order
This bitfield is set and cleared by software. It is used to select the order of the MCIC.
100: MCIC configured in single $Sinc^4$ filter
101: MCIC configured in single $Sinc^5$ filter
Others: Reserved
Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **DATSRC[1:0]**: Source data for the digital filter
This bitfield is set and cleared by software.
0x: Stream coming from the BSMX selected
10: Stream coming from the ADCITF1 selected
11: Stream coming from the ADCITF2 selected
Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

37.8.7 ADF reshape filter configuration register 0 (ADF_DFLT0RSFR)

Address offset: 0x090

Reset value: 0x0000 0000

This register is used to control the reshape and HPF filter.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	HPFC[1:0]		HPFBYP	Res.	Res.	RSFLTD	Res.	Res.	Res.	RSFLTBYP
						rw	rw	rw			rw				rw

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:8 **HPFC[1:0]**: High-pass filter cut-off frequency
This bitfield is set and cleared by software. it is used to select the cut-off frequency of the high-pass filter. F_{PCM} represents the sampling frequency at HPF input.
00: Cut-off frequency = 0.000625 x FPCM
01: Cut-off frequency = 0.00125 x FPCM
10: Cut-off frequency = 0.00250 x FPCM
11: Cut-off frequency = 0.00950 x FPCM
Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bit 7 **HPFBYP**: High-pass filter bypass
This bit is set and cleared by software. It is used to bypass the high-pass filter.
0: HPF not bypassed (default value)
1: HPF bypassed
Note: This bit can be write-protected (see Section 37.4.12: Register protection for details).

Bits 6:5 Reserved, must be kept at reset value.

Bit 4 **RSFLTD**: Reshaper filter decimation ratio
This bit is set and cleared by software. It is used to select the decimation ratio for the reshape filter
0: Decimation ratio is 4 (default value).
1: Decimation ratio is 1.
Note: This bit can be write-protected (see Section 37.4.12: Register protection for details).

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **RSFLTBYP**: Reshaper filter bypass
This bit is set and cleared by software. It is used to bypass the reshape filter and its decimation block.
0: Reshape filter not bypassed (default value)
1: Reshape filter bypassed
Note: This bit can be write-protected (see Section 37.4.12: Register protection for details).

37.8.8 ADF delay control register 0 (ADF_DLY0CR)

Address offset: 0x0A4

Reset value: 0x0000 0000

This register is used for the adjustment stream delays.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SKPBF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SKPDLY[6:0]						
									rw	rw	rw	rw	rw	rw	rw

Bit 31 **SKPBF**: Skip busy flag
This bit is set and cleared by hardware. It is used to control if the delay sequence is completed.
0: ADF ready to accept a new value into SKPDLY[6:0]
1: Last valid SKPDLY[6:0] still under precessing

Bits 30:7 Reserved, must be kept at reset value.

Bits 6:0 **SKPDLY[6:0]**: Delay to apply to a bitstream

This bitfield is set and cleared by software. It defines the number of input samples that are skipped. Skipping is applied immediately after writing to this bitfield, if SKPBF = 0 and DFLTEN = 1. If SKPBF = 1, the value written into the register is ignored by the delay state machine.

0: No input sample skipped

1: 1 input sample skipped

...

127: 127 input samples skipped

37.8.9 ADF DFLT0 interrupt enable register (ADF_DFLT0IER)

Address offset: 0x0AC

Reset value: 0x0000 0000

This register is used for allowing or not the events to generate an interrupt.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	SDLVLIE	SDDETIE	RFOVRIE	CKABIE	SATIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DOVRIE	FTHIE
		rw	rw	rw	rw	rw								rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **SDLVLIE**: SAD sound-level value ready enable

This bit is set and cleared by software.

0: Sound-level-ready interrupt disabled

1: Sound-level-ready interrupt enabled

Bit 12 **SDDETIE**: Sound activity detection interrupt enable

This bit is set and cleared by software.

0: Sound-trigger interrupt disabled

1: Sound-trigger interrupt enabled

Bit 11 **RFOVRIE**: Reshape filter overrun interrupt enable

This bit is set and cleared by software.

0: Reshape filter overrun interrupt disabled

1: Reshape filter overrun interrupt enabled

Bit 10 **CKABIE**: Clock absence detection interrupt enable

This bit is set and cleared by software.

0: Clock absence interrupt disabled

1: Clock absence interrupt enabled

Bit 9 **SATIE**: Saturation detection interrupt enable

This bit is set and cleared by software.

0: Saturation interrupt disabled

1: Saturation interrupt enabled

Bits 8:2 Reserved, must be kept at reset value.

Bit 1 **DOVRIE**: Data overflow interrupt enable
This bit is set and cleared by software.
0: Data overflow interrupt disabled
1: Data overflow interrupt enabled

Bit 0 **FTHIE**: RXFIFO threshold interrupt enable
This bit is set and cleared by software.
0: RXFIFO threshold interrupt disabled
1: RXFIFO threshold interrupt enabled

37.8.10 ADF DFLT0 interrupt status register 0 (ADF_DFLT0ISR)

Address offset: 0x0B0

Reset value: 0x0000 0000

This register contains the status flags for the digital filter path.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	SDLVLF	SDDETF	RFOVRF	CKABF	SATF	Res.	Res.	Res.	Res.	Res.	RXNEF	Res.	DOVRF	FTHF
		rc_w1	rc_w1	rc_w1	rc_w1	rc_w1						r		rc_w1	r

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **SDLVLF**: Sound level value ready flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that new sound level value is not ready. Write 0 has no effect.
1: Read 1 means that new sound level value is ready. Write 1 clears this flag.

Bit 12 **SDDETF**: Sound activity detection flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no sound activity is detected. Write 0 has no effect.
1: Read 1 means that sound activity is detected. Write 1 clears this flag.

Bit 11 **RFOVRF**: Reshape filter overrun detection flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no reshape filter overrun is detected. Write 0 has no effect.
1: Read 1 means that reshape filter overrun is detected. Write 1 clears this flag.

Bit 10 **CKABF**: Clock absence detection flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no clock absence is detected. Write 0 has no effect.
1: Read 1 means that a clock absence is detected. Write 1 clears this flag.

Bit 9 **SATF**: Saturation detection flag
This bit is set by hardware and cleared by software by writing this bit to 1.
0: Read 0 means that no saturation is detected. Write 0 has no effect.
1: Read 1 means that a saturation is detected. Write 1 clears this flag.

Bits 8:4 Reserved, must be kept at reset value.

Bit 3 **RXNEF**: RXFIFO not empty flag

This bit is set and cleared by hardware according to the RXFIFO level.

0: RXFIFO empty

1: RXFIFO not empty

Bit 2 Reserved, must be kept at reset value.

Bit 1 **DOVRF**: Data overflow flag

This bit is set by hardware and cleared by software by writing this bit to 1.

0: Read 0 means that no overflow is detected. Write 0 has no effect.

1: Read 1 means that an overflow is detected; Write 1 clears this flag.

Bit 0 **FTHF**: RXFIFO threshold flag

This bit is set by hardware, and cleared by the hardware when the RXFIFO level is lower than the threshold.

0: RXFIFO threshold not reached

1: RXFIFO threshold reached

37.8.11 ADF SAD control register (ADF_SADCR)

Address offset: 0x0B8

Reset value: 0x0000 0000

This register is used for the configuration and the control of the sound activity detection.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SADACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	SADMOD[1:0]		Res.	FRSIZE[2:0]			HYSTEN	Res.	SADST[1:0]		DETCFG	DATCAP[1:0]		SADEN
		rw	rw		rw	rw	rw	rw		r	r	rw	rw	rw	rw

Bit 31 **SADACTIVE**: SAD Active flag

This bit is set and cleared by hardware. It is used to check if the SAD is effectively enabled (active) or not. The protected fields and registers of this function can only be updated when the SADACTIVE is set to 0 (see *Section 37.4.12: Register protection* for details).

The delay between a transition on SADEN and a transition on SADACTIVE is two periods of AHB clock and two periods of adf_proc_ck.

0: SAD not active and can be configured if needed

1: SAD active and protected fields cannot be configured.

Bits 30:14 Reserved, must be kept at reset value.

Bits 13:12 **SADMOD[1:0]**: SAD working mode

This bitfield is set and cleared by software. It is used to define the way the SAD works.

00: Threshold value computed according to the estimated ambient noise

The SAD triggers when the sound level (SDLVL) is bigger than the defined threshold. In this mode, the SAD works like a voice activity detector.

01: Threshold value equal to ANMIN[12:0], multiplied by the gain selected by SNTHR[3:0]

The SAD triggers when the sound level (SDLVL) is bigger than the defined threshold. In this mode, the SAD works like a sound detector.

1x: Threshold value given by 4 x ANMIN[12:0]

The SAD triggers when the estimated ambient noise (ANLVL), multiplied by the gain selected by SNTHR[3:0] is bigger than the defined threshold. In this mode, the SAD is working like an ambient noise estimator. Hysteresis function cannot be used in this mode.

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bit 11 Reserved, must be kept at reset value.

Bits 10:8 **FRSIZE[2:0]**: Frame size

This bitfield is set and cleared by software. it is used to define the size of one frame and also to define how many samples are taken into account to compute the short-term signal level.

000: 8 PCM samples used to compute the short-term signal level

001: 16 PCM samples used to compute the short-term signal level

010: 32 PCM samples used to compute the short-term signal level

011: 64 PCM samples used to compute the short-term signal level

100: 128 PCM samples used to compute the short-term signal level

101: 256 PCM samples used to compute the short-term signal level

11x: 512 PCM samples used to compute the short-term signal level

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bit 7 **HYSTEN**: Hysteresis enable

This bit is set and cleared by software. It is used to enable/disable the hysteresis function (see *Table 370* for details). This bit must be kept to 0 when SADMOD[1:0] = 1x.

0: Hysteresis function disabled. THR_H is always used.

1: Hysteresis function enabled. THR_H is used for MONITOR to DETECT transition and THR_L is used for DETECT to MONITOR transition.

Note: This bit can be write-protected (see Section 37.4.12: Register protection for details).

Bit 6 Reserved, must be kept at reset value.

Bits 5:4 **SADST[1:0]**: SAD state

This bitfield is set and cleared by hardware. It indicates the SAD state and is meaningful only when SADEN = 1. The SAD state can be:

- LEARN when the SAD is in learning phase or in SDLVL computation mode
- MONITOR when the SAD is in monitoring phase
- DETECT when the SAD detects a sound

00: SAD in LEARN state

01: SAD in MONITOR state

11: SAD in DETECT state

Bit 3 **DETCFG**: Sound trigger event configuration

This bit is set and cleared by software. It is used to define if the sddet_evt event is generated only when the SAD enters to MONITOR state or when the SAD enters or exits the DETECT state.

0: sddet_evt generated when SAD enters the MONITOR state

1: sddet_evt generated when SAD enters or exits the DETECT state

Note: This bit can be write-protected (see Section 37.4.12: Register protection for details).

Bits 2:1 **DATCAP[1:0]**: Data capture mode

This bitfield is set and cleared by software. It is used to define in which conditions, the samples provided by DLFT0 are stored into the memory.

00: Samples from DFLT0 not transfered into the memory

01: Samples from DFLT0 transfered into the memory when SAD is in DETECT state

1x: Samples from DFLT0 transfered into memory when SAD and DFLT0 are enabled

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bit 0 **SADEN**: Sound activity detector enable

This bit is set and cleared by software. It is used to enable/disable the SAD.

0: SAD disabled and SAD state reset

1: SAD enabled

37.8.12 ADF SAD configuration register (ADF_SADCFGR)

Address offset: 0x0BC

Reset value: 0x0000 0000

This register is used for the configuration of the sound activity detection.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	ANMIN[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	HGOVR[2:0]			Res.	LFRNB[2:0]			Res.	ANSLP[2:0]			SNTHR[3:0]			
	rw	rw	rw		rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:16 **ANMIN[12:0]**: Minimum noise level

This bitfield is set and cleared by software. It is used to define the minimum noise level and then the sensitivity. It represents a positive number.

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **HGOVR[2:0]**: Hangover time window

This bitfield is set and cleared by software. Once the SAD state is DETECT, this parameter is used to define the amount of time the sound is allowed to remain below the threshold, before switching the SAD to MONITOR state (see FRSIZE bitfield for the description of a frame).

000: SAD back to MONITOR state if sound is below threshold for 4 frames

001: SAD back to MONITOR state if sound is below threshold for 8 frames

010: SAD back to MONITOR state if sound is below threshold for 16 frames

011: SAD back to MONITOR state if sound is below threshold for 32 frames

100: SAD back to MONITOR state if sound is below threshold for 64 frames

101: SAD back to MONITOR state if sound is below threshold for 128 frames

110: SAD back to MONITOR state if sound is below threshold for 256 frames

111: SAD back to MONITOR state if sound is below threshold for 512 frames

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bit 11 Reserved, must be kept at reset value.

Bits 10:8 **LFRNB[2:0]**: Number of learning frames

This bitfield is set and cleared by software. It is used to define the number of learning frames to perform the first estimate of the noise level.

000: 2 frames used to compute the initial noise level
001: 4 frames used to compute the initial noise level
010: 8 frames used to compute the initial noise level
011: 16 frames used to compute the initial noise level
1xx: 32 frames used to compute the initial noise level

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **ANSLP[2:0]**: Ambient noise slope control

This bitfield is set and cleared by software. It is used to define the positive and negative slope of the noise estimator, in charge of updating the ANLVL (see *Ambient noise estimation (ANLVL)* for information about programming this bitfield).

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

Bits 3:0 **SNTHR[3:0]**: Signal to noise threshold

This bitfield is set and cleared by software. It is used to define THR_H (and THR_L if hysteresis is enabled). See *Table 370* for details.

0000: THR_H is 3.5 dB higher than ANLVL
0001: THR_H is 6.0 dB higher than ANLVL
0010: THR_H is 9.5 dB higher than ANLVL
0011: THR_H is 12 dB higher than ANLVL
0100: THR_H is 15.6 dB higher than ANLVL
0101: THR_H is 18 dB higher than ANLVL
0110: THR_H is 21.6 dB higher than ANLVL
0111: THR_H is 24.1 dB higher than ANLVL
1000: THR_H is 27.6 dB higher than ANLVL
1001: THR_H is 30.1dB higher than ANLVL
others: Reserved

Note: This bitfield can be write-protected (see Section 37.4.12: Register protection for details).

37.8.13 ADF SAD sound level register (ADF_SADSDLVR)

Address offset: 0x0C0

Reset value: 0x0000 0000

This register contains the short-term sound-level computed by the SAD.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	SDLVL[14:0]														
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:15 Reserved, must be kept at reset value.

Bits 14:0 **SDLVL[14:0]**: Short term sound level

This bitfield is set by hardware. It contains the latest sound level computed by the SAD. To refresh this value, SDLVLF must be cleared.

37.8.14 ADF SAD ambient noise level register (ADF_SADANLVR)

Address offset: 0x0C4

Reset value: 0x0000 0000

This register contains the ambient noise level computed by the SAD.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	ANLVL[14:0]														
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:15 Reserved, must be kept at reset value.

Bits 14:0 **ANLVL[14:0]**: Ambient noise level estimation

This bitfield is set by hardware. It contains the latest ambient noise level computed by the SAD. To refresh this bitfield, the SDLVLF flag must be cleared.

37.8.15 ADF digital filter data register 0 (ADF_DFLT0DR)

Address offset: 0x0F0

Reset value: 0x0000 0000

This register is used to read the data processed by the digital filter.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DR[23:8]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DR[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r	r	r	r								

Bits 31:8 **DR[23:0]**: Data processed by DFT0

Bits 7:0 Reserved, must be kept at reset value.

37.8.16 ADF register map

Table 383. ADF register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	ADF_GCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRGO
	Reset value																																0
0x004	ADF_CKGCR	CKGACTIVE	PROCDIV[6:0]							Res.	Res.	Res.	Res.	CCKDIV [3:0]				TRGSRC [3:0]				Res.	Res.	Res.	TRGSENS	Res.	CCK1DIR	CCK0DIR	CKGMOD	Res.	CCK1EN	CCK0EN	CKGDEN
	Reset value	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0				0		0	0	0		0	0	0

Table 383. ADF register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x008 - 0x07C	Reserved																																
0x080	ADF_SITF0CR	SITFACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STH[4:0]					Res.	Res.	SITFMOD [1:0]		Res.	SCKSRC [1:0]		SITFEN
	Reset value	0																			1	1	1	1	1			0	0		0	0	0
0x084	ADF_BSMX0CR	BSMXACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BSSEL[4:0]				
	Reset value	0																											0	0	0	0	0
0x088	ADF_DFLT0CR	DFLTACTIVE	DFLTRUN	Res.	Res.	NBDIS[7:0]								Res.	Res.	Res.	Res.	TRGSRC [3:0]				Res.	Res.	Res.	TRGSENS	Res.	ACQMOD [2:0]		Res.	FTH	DMAEN	DFLTEN
	Reset value	0	0			0	0	0	0	0	0	0	0					0	0	0	0				0		0	0	0		0	0	0
0x08C	ADF_DFLT0CICR	Res.	Res.	Res.	Res.	Res.	Res.	SCALE[5:0]						Res.	Res.	Res.	MCICD[8:0]									Res.	CICMOD[2:0]		Res.	Res.	DATSRC[1:0]	
	Reset value							0	0	0	0	0	0				0	0	0	0	0	0	0	0	0		0	0	0			0	0
0x090	ADF_ DFLT0RSFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HPFC[1:0]		HPFBYP	Res.	Res.	RSFLTD	Res.	Res.	Res.	RSFLTBYP
	Reset value																							0	0	0			0				0
0x094 - 0x0A0	Reserved																																
0x0A4	ADF_DLY0CR	SKPBF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SKPDLY[6:0]						
	Reset value	0																									0	0	0	0	0	0	0
0x0A8	Reserved																																
0x0AC	ADF_DFLT0IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SDLVLIE	SDDETIE	RFOVRIE	CKABIE	SATIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DOVRIE	FTHIE
	Reset value																			0	0	0	0	0	0	0			0		0	0	0
0x0B0	ADF_DFLT0ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SDLVLF	SDDETF	RFOVRF	CKABF	SATF	Res.	Res.	Res.	Res.	Res.	RXNEF	Res.	DOVRF	FTHF
	Reset value																			0	0	0	0	0						0		0	0
0x0B4	Reserved																																

Table 383. ADF register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0B8	ADF_SADCR	SADACTIVE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SADMOD[1:0]		Res.	FRSIZE[2:0]			HYSTEN	Res.	SADST[1:0]		DETCFG	DATCAP[1:0]		SADEN
	Reset value	0																		0	0		0	0	0	0		0	0	0	0	0	0
0x0BC	ADF_SADCFGR	Res.	Res.	Res.	ANMIN[12:0]													Res.	HGOVR [2:0]			Res.	LFRNB [2:0]			Res.	ANSLP[2:0]			Res.	SNTHR [2:0]		
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0
0x0C0	ADF_SADSDLVR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SDLVL[14:0]														
	Reset value																		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C4	ADF_SADANLVR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ANLVL[14:0]														
	Reset value																		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C8 - 0x0EC	Reserved																																
0x0F0	ADF_DFLT0DR	DR[23:0]																								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

38 Digital camera interface (DCMI)

38.1 DCMI introduction

The digital camera is a synchronous parallel interface able to receive a high-speed data flow from an external 8-, 10-, 12- or 14-bit CMOS camera module. It supports different data formats: YCbCr4:2:2/RGB565 progressive video and compressed data (JPEG).

38.2 DCMI main features

- 8-, 10-, 12- or 14-bit parallel interface
- Embedded/external line and frame synchronization
- Continuous or snapshot mode
- Crop feature
- Supports the following data formats:
  - 8/10/12/14-bit progressive video: either monochrome or raw Bayer
  - YCbCr 4:2:2 progressive video
  - RGB 565 progressive video
  - Compressed data: JPEG

38.3 DCMI functional description

The digital camera interface is a synchronous parallel interface that can receive high-speed data flows. It consists of up to 14 data lines (DCMI_D[13:0]) and a pixel clock line (DCMI_PIXCLK). The pixel clock has a programmable polarity, so that data can be captured on either the rising or the falling edge of the pixel clock.

The data are packed into a 32-bit data register (DCMI_DR) and then transferred through a general-purpose DMA channel. The image buffer is managed by the DMA, not by the camera interface.

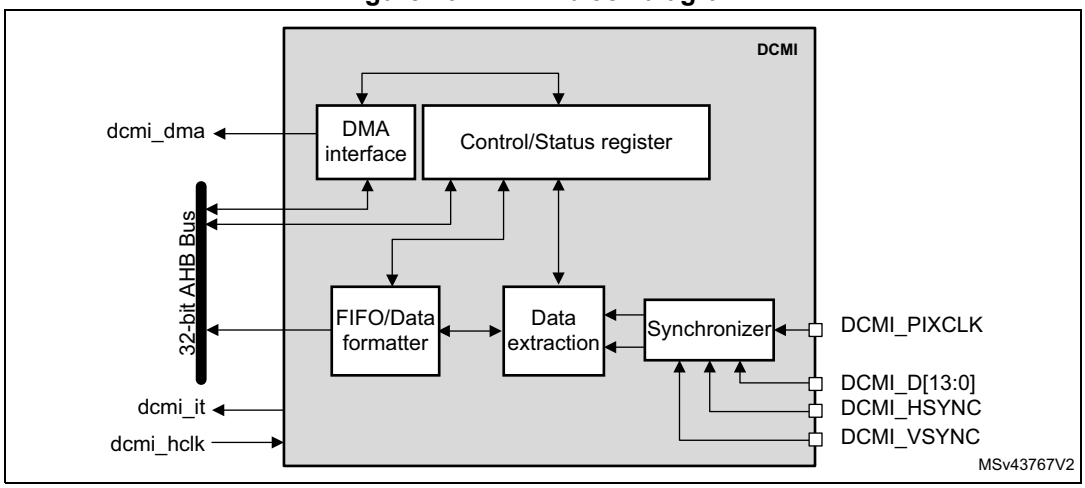
The data received from the camera can be organized in lines/frames (raw YUB/RGB/Bayer modes) or can be a sequence of JPEG images. To enable JPEG image reception, the JPEG bit (bit 3 of DCMI_CR register) must be set.

The data flow is synchronized either by hardware using the optional DCMI_HSYNC (horizontal synchronization) and DCMI_VSYNC (vertical synchronization) signals or by synchronization codes embedded in the data flow.

38.3.1 DCMI block diagram

Figure 404 shows the DCMI block diagram.

Figure 404. DCMI block diagram



38.3.2 DCMI pins and internal signals

The following table shows DCMI pins.

Table 384. DCMI input/output pins

Mode	Pin name	Signal type	Description
8 bits 10 bits 12 bits 14 bits	DCMI_D[7:0] DCMI_D[9:0] DCMI_D[11:0] DCMI_D[13:0]	Inputs	DCMI data
DCMI_PIXCLK		Input	Pixel clock
DCMI_HSYNC		Input	Horizontal synchronization / Data valid
DCMI_VSYNC		Input	Vertical synchronization

The following table shows DCMI internal signals.

Table 385. DCMI internal input/output signals

Internal signal name	Signal type	Description
dcmi_dma	Output	DCMI DMA request
dcmi_it	Output	DCMI interrupt request
dcmi_hclk	Input	DCMI interface clock

38.3.3 DCMI clocks

The digital camera interface uses two clock domains, DCMI_PIXCLK and HCLK. The signals generated with DCMI_PIXCLK are sampled on the rising edge of HCLK once they are stable. An enable signal is generated in the HCLK domain, to indicate that data coming from the camera are stable and can be sampled. The maximum DCMI_PIXCLK period must be higher than 2.5 HCLK periods.

38.3.4 DCMI DMA interface

The DMA interface is active when the CAPTURE bit of the DCMI_CR register is set. A DMA request is generated each time the camera interface receives a complete 32-bit data block in its register.

38.3.5 DCMI physical interface

The interface is composed of 11/13/15/17 inputs. Only the Slave mode is supported.

The camera interface can capture 8-bit, 10-bit, 12-bit or 14-bit data depending on the EDM[1:0] bits of the DCMI_CR register. If less than 14 bits are used, the unused input pins must be connected to ground.

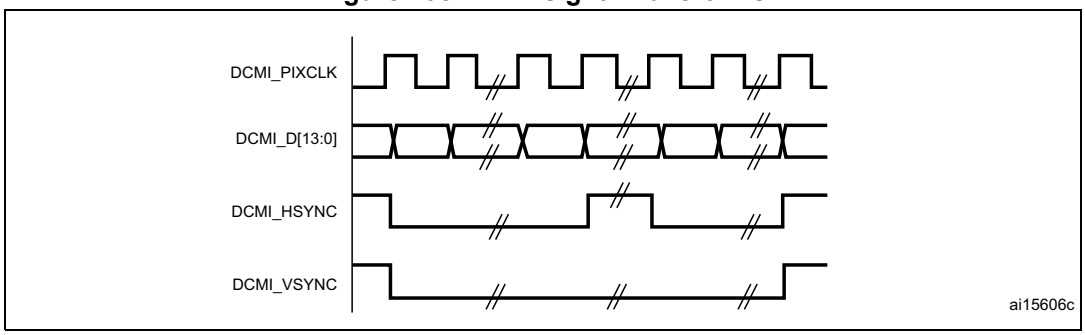
DCMI pins are shown in *Table 384*.

The data are synchronous with DCMI_PIXCLK and change on the rising/falling edge of the pixel clock depending on the polarity.

The DCMI_HSYNC signal indicates the start/end of a line.

The DCMI_VSYNC signal indicates the start/end of a frame

Figure 405. DCMI signal waveforms



1. The capture edge of DCMI_PIXCLK is the falling edge, the active state of DCMI_HSYNC and DCMI_VSYNC is 1.
2. DCMI_HSYNC and DCMI_VSYNC can change states at the same time.

8-bit data

When EDM[1:0] = 00 in DCMI_CR the interface captures 8 LSBs at its input (DCMI_D[7:0]) and stores them as 8-bit data. The DCMI_D[13:8] inputs are ignored. In this case, to capture a 32-bit word, the camera interface takes four pixel clock cycles.

The first captured data byte is placed in the LSB position in the 32-bit word and the 4th captured data byte is placed in the MSB position in the 32-bit word. The table below gives an example of the positioning of captured data bytes in two 32-bit words.

Table 386. Positioning of captured data bytes in 32-bit words (8-bit width)

Byte address	31:24	23:16	15:8	7:0
0	D_{n+3}[7:0]	D_{n+2}[7:0]	D_{n+1}[7:0]	D_n[7:0]
4	D_{n+7}[7:0]	D_{n+6}[7:0]	D_{n+5}[7:0]	D_{n+4}[7:0]

10-bit data

When EDM[1:0] = 01 in DCMI_CR, the camera interface captures 10-bit data at its input DCMI_D[9:0] and stores them as the 10 least significant bits of a 16-bit word. The remaining most significant bits of the DCMI_DR register (bits 11 to 15) are cleared to zero. So, in this case, a 32-bit data word is made up every two pixel clock cycles.

The first captured data are placed in the LSB position in the 32-bit word and the 2nd captured data are placed in the MSB position in the 32-bit word as shown in the table below.

Table 387. Positioning of captured data bytes in 32-bit words (10-bit width)

Byte address	31:26	25:16	15:10	9:0
0	0	D_{n+1}[9:0]	0	D_n[9:0]
4	0	D_{n+3}[9:0]	0	D_{n+2}[9:0]

12-bit data

When EDM[1:0] = 10 in DCMI_CR, the camera interface captures the 12-bit data at its input DCMI_D[11:0] and stores them as the 12 least significant bits of a 16-bit word. The remaining most significant bits are cleared to zero. So, in this case a 32-bit data word is made up every two pixel clock cycles.

The first captured data are placed in the LSB position in the 32-bit word and the 2nd captured data are placed in the MSB position in the 32-bit word as shown in the table below.

Table 388. Positioning of captured data bytes in 32-bit words (12-bit width)

Byte address	31:28	27:16	15:12	11:0
0	0	D_{n+1}[11:0]	0	D_n[11:0]
4	0	D_{n+3}[11:0]	0	D_{n+2}[11:0]

14-bit data

When EDM[1:0] = 11 in DCMI_CR, the camera interface captures the 14-bit data at its input DCMI_D[13:0] and stores them as the 14 least significant bits of a 16-bit word. The remaining most significant bits are cleared to zero. So, in this case a 32-bit data word is made up every two pixel clock cycles.

The first captured data are placed in the LSB position in the 32-bit word and the 2nd captured data are placed in the MSB position in the 32-bit word as shown in the table below.

Table 389. Positioning of captured data bytes in 32-bit words (14-bit width)

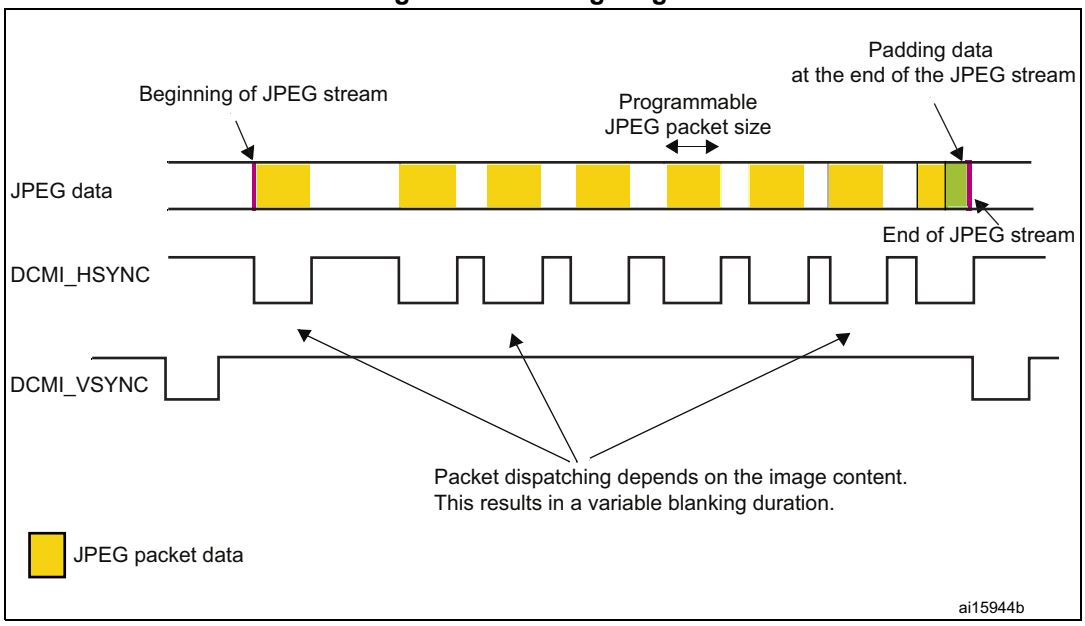
Byte address	31:30	29:16	15:14	13:0
0	0	D_{n+1}[13:0]	0	D_n[13:0]
4	0	D_{n+3}[13:0]	0	D_{n+2}[13:0]

38.3.6 DCMI synchronization

The digital camera interface supports embedded or hardware (DCMI_HSYNC and DCMI_VSYNC) synchronization. When embedded synchronization is used, it is up to the digital camera module to make sure that the 0x00 and 0xFF values are used ONLY for synchronization (not in data). Embedded synchronization codes are supported only for the 8-bit parallel data interface width (that is, in the DCMI_CR register, the EDM[1:0] bits must be cleared).

For compressed data, the DCMI supports only the hardware synchronization mode. In this case, DCMI_VSYNC is used as a start/end of the image, and DCMI_HSYNC is used as a Data Valid signal. *Figure 406* shows the corresponding timing diagram.

Figure 406. Timing diagram



Hardware synchronization mode

In hardware synchronization mode, the two synchronization signals (DCMI_HSYNC/DCMI_VSYNC) are used.

Depending on the camera module/mode, data may be transmitted during horizontal/vertical synchronization periods. The DCMI_HSYNC/DCMI_VSYNC signals act like blanking signals since all the data received during DCMI_HSYNC/DCMI_VSYNC active periods are ignored.

In order to correctly transfer images into the DMA/RAM buffer, data transfer is synchronized with the DCMI_VSYNC signal. When the hardware synchronization mode is selected, and

capture is enabled (CAPTURE bit set in DCMI_CR), data transfer is synchronized with the deactivation of the DCMI_VSYNC signal (next start of frame).

Transfer can then be continuous, with successive frames transferred by DMA to successive buffers or the same/circular buffer. To allow the DMA management of successive frames, a VSIF (Vertical synchronization interrupt flag) is activated at the end of each frame.

Embedded data synchronization mode

In this synchronization mode, the data flow is synchronized using 32-bit codes embedded in the data flow. These codes use the 0x00/0xFF values that are *not* used in data anymore. There are 4 types of codes, all with a 0xFF0000XY format. The embedded synchronization codes are supported only in 8-bit parallel data width capture (in the DCMI_CR register, the EDM[1:0] bits must be cleared). For other data widths, this mode generates unpredictable results and must not be used.

Note: Camera modules can have 8 such codes (in interleaved mode). For this reason, the interleaved mode is not supported by the camera interface (otherwise, every other half-frame would be discarded).

- Mode 2

  Four embedded codes signal the following events
  - Frame start (FS)
  - Frame end (FE)
  - Line start (LS)
  - Line end (LE)

  The XY values in the 0xFF0000XY format of the four codes are programmable (see *Section 38.5.7: DCMI embedded synchronization code register (DCMI_ESCR)*).

  A 0xFF value programmed as a “frame end” means that all the unused codes are interpreted as valid frame end codes.

  In this mode, once the camera interface has been enabled, the frame capture starts after the first occurrence of the frame end (FE) code followed by a frame start (FS) code.
- Mode 1

  An alternative coding is the camera mode 1. This mode is ITU656 compatible.

  The codes signal another set of events:
  - SAV (active line) - line start
  - EAV (active line) - line end
  - SAV (blanking) - end of line during interframe blanking period
  - EAV (blanking) - end of line during interframe blanking period

This mode can be supported by programming the following codes:

- FS $\leq$ 0xFF
- FE ≤ 0xFF
- LS ≤ SAV (active)
- LE ≤ EAV (active)

An embedded unmask code is also implemented for frame/line start and frame/line end codes. Using it, it is possible to compare only the selected unmasked bits with the programmed code. A bit can therefore be selected to compare in the embedded code and

detect a frame/line start or frame/line end. This means that there can be different codes for the frame/line start and frame/line end with the unmasked bit position remaining the same.

Example

FS = 0xA5

Unmask code for FS = 0x10

In this case the frame start code is embedded in the bit 4 of the frame start code.

38.3.7 DCMI capture modes

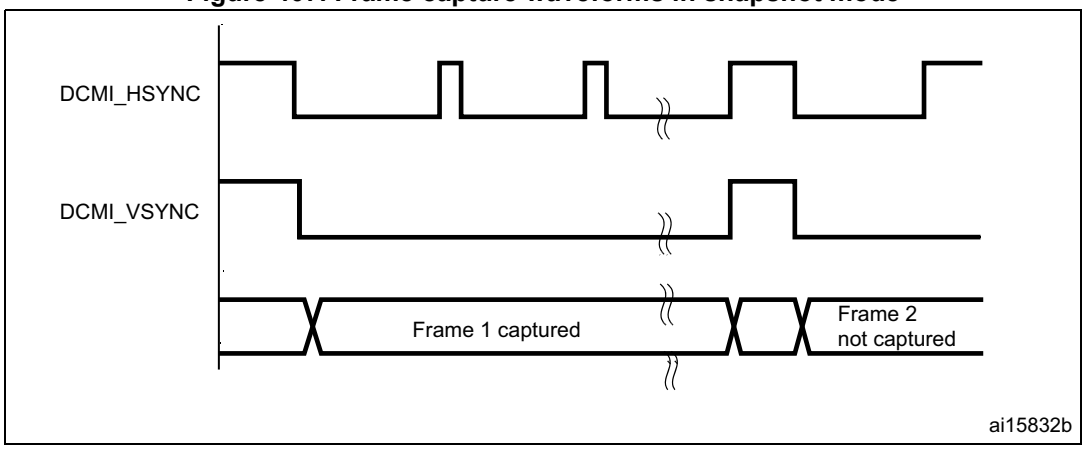
This interface supports two types of capture: snapshot (single frame) and continuous grab.

Snapshot mode (single frame)

In this mode, a single frame is captured (CM = 1 of the DCMI_CR register). After the CAPTURE bit is set in DCMI_CR, the interface waits for the detection of a start of frame before sampling the data. The camera interface is automatically disabled (CAPTURE bit cleared in DCMI_CR) after receiving the first complete frame. An interrupt is generated (IT_FRAME) if it is enabled.

In case of an overrun, the frame is lost and the CAPTURE bit is cleared.

Figure 407. Frame capture waveforms in snapshot mode

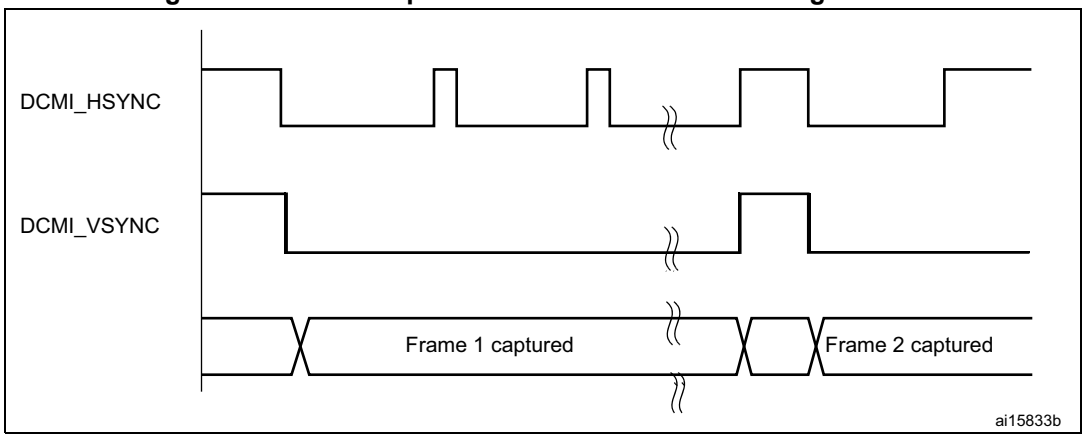


1. Here, the active state of DCMI_HSYNC and DCMI_VSYNC is 1.
2. DCMI_HSYNC and DCMI_VSYNC can change states at the same time.

Continuous grab mode

In this mode (CM bit = 0 in DCMI_CR), once the CAPTURE bit has been set in DCMI_CR, the grabbing process starts on the next DCMI_VSYNC or embedded frame start depending on the mode. The process continues until the CAPTURE bit is cleared in DCMI_CR. Once the CAPTURE bit has been cleared, the grabbing process continues until the end of the current frame.

Figure 408. Frame capture waveforms in continuous grab mode



1. Here, the active state of DCMI_HSYNC and DCMI_VSYNC is 1.
2. DCMI_HSYNC and DCMI_VSYNC can change states at the same time.

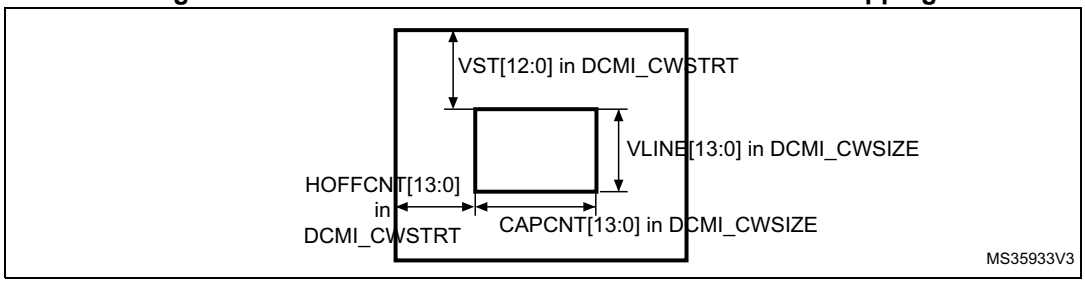
In continuous grab mode, the FCRC[1:0] bits in DCMI_CR can be configured to grab all pictures, every second picture or one out of four pictures to decrease the frame capture rate.

Note: In the hardware synchronization mode (ESS = 0 in DCMI_CR), the IT_VSYNC interrupt is generated (if enabled) even when CAPTURE = 0 in DCMI_CR so, to reduce the frame capture rate even further, the IT_VSYNC interrupt can be used to count the number of frames between 2 captures in conjunction with the Snapshot mode. This is not allowed by embedded data synchronization mode.

38.3.8 DCMI crop feature

With the crop feature, the camera interface can select a rectangular window from the received image. The start (upper left corner) coordinates and size (horizontal dimension in number of pixel clocks and vertical dimension in number of lines) are specified using two 32-bit registers (DCMI_CWSTRT and DCMI_CWSIZE). The size of the window is specified in number of pixel clocks (horizontal dimension) and in number of lines (vertical dimension).

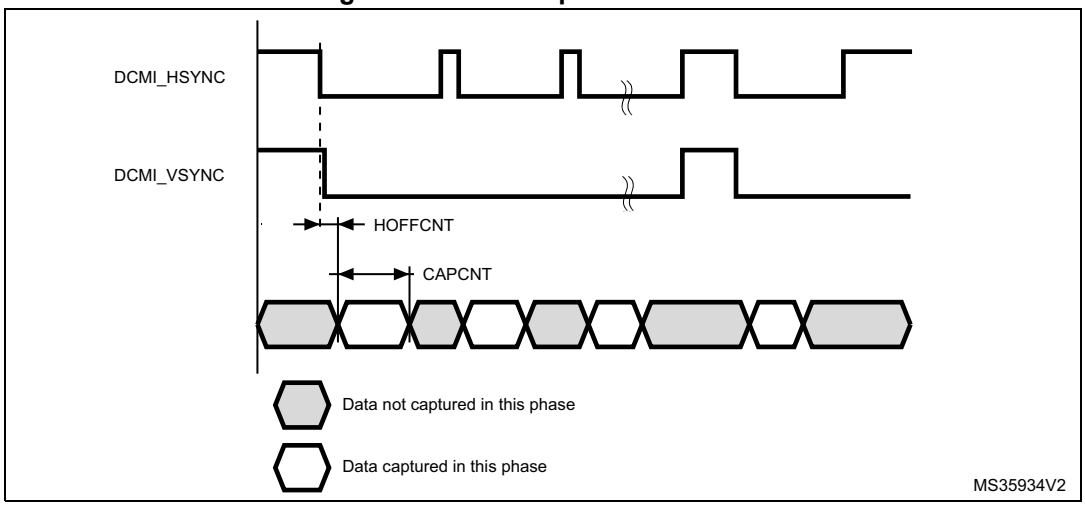
Figure 409. Coordinates and size of the window after cropping



These registers specify the coordinates of the starting point of the capture window as a line number (in the frame, starting from 0) and a number of pixel clocks (on the line, starting from 0), and the size of the window as a line number and a number of pixel clocks. The CAPCNT value can only be a multiple of 4 (two least significant bits are forced to 0) to allow the correct transfer of data through the DMA.

If the DCMI_VSYNC signal goes active before the number of lines is specified in the DCMI_CWSIZE register, then the capture stops and an IT_FRAME interrupt is generated when enabled.

Figure 410. Data capture waveforms



1. Here, the active state of DCMI_HSYNC and DCMI_VSYNC is 1.
2. DCMI_HSYNC and DCMI_VSYNC can change states at the same time.

38.3.9 DCMI JPEG format

To allow JPEG image reception, it is necessary to set the JPEG bit of the DCMI_CR register. JPEG images are not stored as lines and frames, so the DCMI_VSYNC signal is used to start the capture while DCMI_HSYNC serves as a data enable signal. The number of bytes in a line may not be a multiple of 4. This case must be carefully handled since a DMA request is generated each time a complete 32-bit word has been constructed from the captured data. When an end of frame is detected and the 32-bit word to be transferred has not been completely received, the remaining data are padded with zeros and a DMA request is generated.

The crop feature and embedded synchronization codes cannot be used in JPEG format.

38.3.10 DCMI FIFO

A 8-word FIFO is implemented to manage data rate transfers on the AHB. The DCMI features a simple FIFO controller with a read pointer incremented each time the camera interface reads from the AHB, and a write pointer incremented each time the camera interface writes to the FIFO. There is no overrun protection to prevent the data from being overwritten if the AHB interface does not sustain the data transfer rate.

In case of overrun or errors in the synchronization signals, the FIFO is reset and the DCMI interface waits for a new start of frame.

38.3.11 DCMI data format description

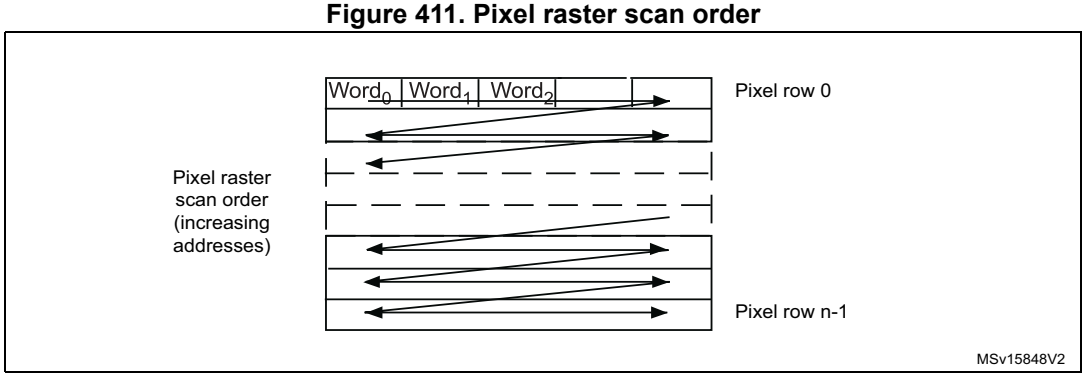
Data formats

The following types of data are supported:

- 8/10/12/14-bit progressive video: either monochrome or raw Bayer format
- YCbCr 4:2:2 progressive video
- RGB565 progressive video. A pixel coded in 16 bits (5 bits for blue, 5 bits for red, 6 bits for green) takes two clock cycles to be transferred
- compressed data: JPEG

For monochrome, RGB and YCbCr, the frame buffer is stored in raster mode. 32-bit words are used. Only the little-endian format is supported.

Figure 411. Pixel raster scan order



Monochrome format

Characteristics:

- Raster format
- 8 bits per pixel

The table below shows how the data are stored.

Table 390. Data storage in monochrome progressive video format

Byte address	31:24	23:16	15:8	7:0
0	n + 3	n + 2	n + 1	n
4	n + 7	n + 6	n + 5	n + 4

RGB format

Characteristics:

- Raster format
- RGB
- Interleaved: one buffer: R, G and B interleaved (such as BRGBRGBRG)
- Optimized for display output

The RGB planar format is compatible with standard OS frame buffer display formats.

Only 16 BPP (bits per pixel): RGB565 (2 pixels per 32-bit word) is supported.

The 24 BPP (palletized format) and gray-scale formats are not supported. Pixels are stored in a raster scan order, that is from top to bottom for pixel rows, and from left to right within a pixel row. Pixel components are R (red), G (green) and B (blue). All components have the same spatial resolution (4:4:4 format). A frame is stored in a single part, with the components interleaved on a pixel basis.

The table below shows how the data are stored.

Table 391. Data storage in RGB progressive video format

Byte address	31:27	26:21	20:16	15:11	10:5	4:0
0	Red n + 1	Green n + 1	Blue n + 1	Red n	Green n	Blue n
4	Red n + 4	Green n + 3	Blue n + 3	Red n + 2	Green n + 2	Blue n + 2

YCbCr format

Characteristics:

- Raster format
- YCbCr 4:2:2
- Interleaved: one buffer: Y, Cb and Cr interleaved (such as CbYCrYCbYCr)

Pixel components are Y (luminance or “luma”), Cb and Cr (chrominance or “chroma” blue and red). Each component is encoded in 8 bits. Luma and chroma are stored together (interleaved) as shown in the table below.

Table 392. Data storage in YCbCr progressive video format

Byte address	31:24	23:16	15:8	7:0
0	Y n + 1	Cr n	Y n	Cb n
4	Y n + 3	Cr n + 2	Y n + 2	Cb n + 2

YCbCr format - Y only

Characteristics:

- Raster format
- YCbCr 4:2:2
- The buffer only contains Y information - monochrome image

Pixel components are Y (luminance or “luma”), Cb and Cr (chrominance or “chroma” blue and red). In this mode, the chroma information is dropped. Only the luma component of each pixel, encoded in 8 bits, is stored as shown in *Table 393*.

The result is a monochrome image having the same resolution as the original YCbCr data.

Table 393. Data storage in YCbCr progressive video format - Y extraction mode

Byte address	31:24	23:16	15:8	7:0
0	Y n + 3	Y n + 2	Y n + 1	Y n
4	Y n + 7	Y n + 6	Y n + 5	Y n + 4

Half resolution image extraction

This is a modification of the previous reception modes, being applicable to monochrome, RGB or Y extraction modes.

This mode is used to only store a half resolution image. It is selected through OELS and LSM control bits.

38.4 DCMI interrupts

Five interrupts are generated. All interrupts are maskable by software. The global interrupt (dcmi_it) is the OR of all the individual interrupts. The table below gives the list of all interrupts.

Table 394. DCMI interrupts

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exits Sleep mode	Exists Stop and Standby modes
dcmi_it	End of line	LINE_RIS	LINE_IE	Set LINE_ISC	Yes	No
	End of frame capture	FRAME_RIS	FRAME_IE	Set FRAME_ISC	Yes	No
	Overrun of data reception	OVR_RIS	OVR_IE	Set OVR_ISC	Yes	No
	Synchronization frame	VSYNC_RIS	VSYNC_IE	Set VSYNC_ISC	Yes	No
	Detection of an error in the embedded synchronization frame detection	ERR_RIS	ERR_IE	Set ERR_ISC	Yes	No

38.5 DCMI registers

Refer to *Section 1.2 on page 128* for list of abbreviations used in register descriptions. All DCMI registers must be accessed as 32-bit words, otherwise a bus error occurs.

38.5.1 DCMI control register (DCMI_CR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OELS	LSM	OEBS	BSM[1:0]	
											rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	ENABLE	Res.	Res.	EDM[1:0]		FCRC[1:0]		VSPOL	HSPOL	PCKPOL	ESS	JPEG	CROP	CM	CAPTURE
	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **OELS:** Odd/Even Line Select (Line Select Start)

This bit works in conjunction with the LSM field (LSM = 1).

0: Interface captures first line after the frame start, second one being dropped.

1: Interface captures second line from the frame start, first one being dropped.

Bit 19 **LSM:** Line Select mode

0: Interface captures all received lines.

1: Interface captures one line out of two.

Bit 18 **OEBS:** Odd/Even Byte Select (Byte Select Start)

This bit works in conjunction with BSM field (BSM $\neq$ 00).

0: Interface captures first data (byte or double byte) from the frame/line start, second one being dropped.

1: Interface captures second data (byte or double byte) from the frame/line start, first one being dropped.

Bits 17:16 **BSM[1:0]:** Byte Select mode

00: Interface captures all received data.

01: Interface captures every other byte from the received data.

10: Interface captures one byte out of four.

11: Interface captures two bytes out of four.

Note: This mode only works for EDM[1:0] = 00. For all other EDM values, this field must be programmed to the reset value.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **ENABLE:** DCMI enable

0: DCMI disabled

1: DCMI enabled

Note: The DCMI configuration registers must be programmed correctly before enabling this bit.

Bits 13:12 Reserved, must be kept at reset value.

Bits 11:10 **EDM[1:0]:** Extended data mode

00: Interface captures 8-bit data on every pixel clock.

01: Interface captures 10-bit data on every pixel clock.

10: Interface captures 12-bit data on every pixel clock.

11: Interface captures 14-bit data on every pixel clock.

Bits 9:8 **FCRC[1:0]:** Frame capture rate control

These bits define the frequency of frame capture. They are meaningful only in Continuous grab mode. They are ignored in snapshot mode.

00: All frames are captured.

01: Every alternate frame captured (50% bandwidth reduction)

10: One frame out of four captured (75% bandwidth reduction)

11: reserved

Bit 7 **VSPOL:** Vertical synchronization polarity

This bit indicates the level on the DCMI_VSYNC pin when the data are not valid on the parallel interface.

0: DCMI_VSYNC active low

1: DCMI_VSYNC active high

Bit 6 **HSPOL:** Horizontal synchronization polarity

This bit indicates the level on the DCMI_HSYNC pin when the data are not valid on the parallel interface.

0: DCMI_HSYNC active low

1: DCMI_HSYNC active high

Bit 5 **PCKPOL:** Pixel clock polarity

This bit configures the capture edge of the pixel clock.

0: Falling edge active

1: Rising edge active

Bit 4 **ESS:** Embedded synchronization select

0: Hardware synchronization data capture (frame/line start/stop) is synchronized with the DCMI_HSYNC/DCMI_VSYNC signals.

1: Embedded synchronization data capture is synchronized with synchronization codes embedded in the data flow.

Note: Valid only for 8-bit parallel data. HSPOL/VSPOL are ignored when the ESS bit is set.

This bit is disabled in JPEG mode.

Bit 3 **JPEG:** JPEG format

0: Uncompressed video format

1: This bit is used for JPEG data transfers. The DCMI_HSYNC signal is used as data enable. The crop and embedded synchronization features (ESS bit) cannot be used in this mode.

Bit 2 **CROP:** Crop feature

0: The full image is captured. In this case the total number of bytes in an image frame must be a multiple of four.

1: Only the data inside the window specified by the crop register is captured. If the size of the crop window exceeds the picture size, then only the picture size is captured.

Bit 1 **CM:** Capture mode

0: Continuous grab mode - The received data are transferred into the destination memory through the DMA. The buffer location and mode (linear or circular buffer) is controlled through the system DMA.

1: Snapshot mode (single frame) - Once activated, the interface waits for the start of frame and then transfers a single frame through the DMA. At the end of the frame, the CAPTURE bit is automatically reset.

Bit 0 **CAPTURE:** Capture enable

0: Capture disabled

1: Capture enabled

The camera interface waits for the first start of frame, then a DMA request is generated to transfer the received data into the destination memory.

In snapshot mode, the CAPTURE bit is automatically cleared at the end of the first frame received.

In continuous grab mode, if the software clears this bit while a capture is ongoing, the bit is effectively cleared after the frame end.

Note: The DMA controller and all DCMI configuration registers must be programmed correctly before enabling this bit.

38.5.2 DCMI status register (DCMI_SR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FNE	VSYNC	HSYNC
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **FNE**: FIFO not empty

This bit gives the status of the FIFO.
1: FIFO contains valid data.
0: FIFO empty

Bit 1 **VSYNC**: Vertical synchronization

This bit gives the state of the DCMI_VSYNC pin with the correct programmed polarity. When embedded synchronization codes are used, the meaning of this bit is the following:
0: active frame
1: synchronization between frames
In case of embedded synchronization, this bit is meaningful only if the CAPTURE bit in DCMI_CR is set.

Bit 0 **HSYNC**: Horizontal synchronization

This bit gives the state of the DCMI_HSYNC pin with the correct programmed polarity. When embedded synchronization codes are used, the meaning of this bit is the following:
0: active line
1: synchronization between lines
In case of embedded synchronization, this bit is meaningful only if the CAPTURE bit in DCMI_CR is set.

38.5.3 DCMI raw interrupt status register (DCMI_RIS)

DCMI_RIS gives the raw interrupt status and is accessible in read only. When read, this register returns the status of the corresponding interrupt before masking with the DCMI_IER register value.

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_RIS	VSYNC_RIS	ERR_RIS	OVR_RIS	FRAME_RIS
											r	r	r	r	r

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **LINE_RIS**: Line raw interrupt status

This bit gets set when the DCMI_HSYNC signal changes from the inactive state to the active state. It goes high even if the line is not valid.

In the case of embedded synchronization, this bit is set only if the CAPTURE bit in DCMI_CR is set.

It is cleared by setting the LINE_ISC bit of the DCMI_ICR register.

Bit 3 **VSYNC_RIS**: DCMI_VSYNC raw interrupt status

This bit is set when the DCMI_VSYNC signal changes from the inactive state to the active state.

In the case of embedded synchronization, this bit is set only if the CAPTURE bit is set in DCMI_CR.

It is cleared by setting the VSYNC_ISC bit of the DCMI_ICR register.

Bit 2 **ERR_RIS**: Synchronization error raw interrupt status

0: No synchronization error detected

1: Embedded synchronization characters are not received in the correct order.

This bit is valid only in the embedded synchronization mode. It is cleared by setting the ERR_ISC bit of the DCMI_ICR register.

Note: This bit is available only in embedded synchronization mode.

Bit 1 **OVR_RIS**: Overrun raw interrupt status

0: No data buffer overrun occurred

1: A data buffer overrun occurred and the data FIFO is corrupted.

The bit is cleared by setting the OVR_ISC bit of the DCMI_ICR register.

Bit 0 **FRAME_RIS**: Capture complete raw interrupt status

0: No new capture

1: A frame has been captured.

This bit is set when a frame or window has been captured.

In case of a cropped window, this bit is set at the end of line of the last line in the crop. It is set even if the captured frame is empty (for example window cropped outside the frame).

The bit is cleared by setting the FRAME_ISC bit of the DCMI_ICR register.

38.5.4 DCMI interrupt enable register (DCMI_IER)

The DCMI_IER register is used to enable interrupts. When one of the DCMI_IER bits is set, the corresponding interrupt is enabled. This register is accessible in both read and write.

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_IE	VSYNC_IE	ERR_IE	OVR_IE	FRAME_IE
											rw	rw	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **LINE_IE**: Line interrupt enable
0: No interrupt generation when the line is received
1: An Interrupt is generated when a line has been completely received.

Bit 3 **VSYNC_IE**: DCMI_VSYNC interrupt enable
0: No interrupt generation
1: An interrupt is generated on each DCMI_VSYNC transition from the inactive to the active state.
The active state of the DCMI_VSYNC signal is defined by the VSPOL bit.

Bit 2 **ERR_IE**: Synchronization error interrupt enable
0: No interrupt generation
1: An interrupt is generated if the embedded synchronization codes are not received in the correct order.
Note: This bit is available only in embedded synchronization mode.

Bit 1 **OVR_IE**: Overrun interrupt enable
0: No interrupt generation
1: An interrupt is generated if the DMA was not able to transfer the last data before new data (32-bit) are received.

Bit 0 **FRAME_IE**: Capture complete interrupt enable
0: No interrupt generation
1: An interrupt is generated at the end of each received frame/crop window (in crop mode).

38.5.5 DCMI masked interrupt status register (DCMI_MIS)

This DCMI_MIS register is a read-only register. When read, it returns the current masked status value (depending on the value in DCMI_IER) of the corresponding interrupt. A bit in this register is set if the corresponding enable bit in DCMI_IER is set and the corresponding bit in DCMI_RIS is set.

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_MIS	VSYNC_MIS	ERR_MIS	OVR_MIS	FRAME_MIS
											r	r	r	r	r

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **LINE_MIS**: Line masked interrupt status
This bit gives the status of the masked line interrupt.
0: No interrupt generation when the line is received
1: An Interrupt is generated when a line has been completely received and the LINE_IE bit is set in DCMI_IER.

Bit 3 **VSYNC_MIS**: VSYNC masked interrupt status

This bit gives the status of the masked VSYNC interrupt.

0: No interrupt is generated on DCMI_VSYNC transitions.

1: An interrupt is generated on each DCMI_VSYNC transition from the inactive to the active state and the VSYNC_IE bit is set in DCMI_IER.

The active state of the DCMI_VSYNC signal is defined by the VSPOL bit.

Bit 2 **ERR_MIS**: Synchronization error masked interrupt status

This bit gives the status of the masked synchronization error interrupt.

0: No interrupt is generated on a synchronization error.

1: An interrupt is generated if the embedded synchronization codes are not received in the correct order and the ERR_IE bit in DCMI_IER is set.

Note: This bit is available only in embedded synchronization mode.

Bit 1 **OVR_MIS**: Overrun masked interrupt status

This bit gives the status of the masked overflow interrupt.

0: No interrupt is generated on overrun.

1: An interrupt is generated if the DMA was not able to transfer the last data before new data (32-bit) are received and the OVR_IE bit is set in DCMI_IER.

Bit 0 **FRAME_MIS**: Capture complete masked interrupt status

This bit gives the status of the masked capture complete interrupt

0: No interrupt is generated after a complete capture.

1: An interrupt is generated at the end of each received frame/crop window (in crop mode) and the FRAME_IE bit is set in DCMI_IER.

38.5.6 DCMI interrupt clear register (DCMI_ICR)

The DCMI_ICR register is write-only. Setting a bit of this register clears the corresponding flag in the DCMI_RIS and DCMI_MIS registers. Writing 0 has no effect.

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_ISC	VSYNC_ISC	ERR_ISC	OVR_ISC	FRAME_ISC
											w	w	w	w	w

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **LINE_ISC**: line interrupt status clear

Setting this bit clears the LINE_RIS flag in the DCMI_RIS register.

Bit 3 **VSYNC_ISC**: Vertical Synchronization interrupt status clear

Setting this bit clears the VSYNC_RIS flag in the DCMI_RIS register.

Bit 2 **ERR_ISC**: Synchronization error interrupt status clear

Setting this bit clears the ERR_RIS flag in the DCMI_RIS register.

Note: This bit is available only in embedded synchronization mode.

Bit 1 **OVR_ISC**: Overrun interrupt status clear
Setting this bit clears the OVR_RIS flag in the DCMI_RIS register.

Bit 0 **FRAME_ISC**: Capture complete interrupt status clear
Setting this bit clears the FRAME_RIS flag in the DCMI_RIS register.

38.5.7 DCMI embedded synchronization code register (DCMI_ESCR)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FEC[7:0]								LEC[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LSC[7:0]								FSC[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **FEC[7:0]**: Frame end delimiter code
This byte specifies the code of the frame end delimiter. The code consists of 4 bytes in the form of 0xFF, 0x00, 0x00, FEC.
If FEC is programmed to 0xFF, all the unused codes (0xFF0000XY) are interpreted as frame end delimiters.

Bits 23:16 **LEC[7:0]**: Line end delimiter code
This byte specifies the code of the line end delimiter. The code consists of 4 bytes in the form of 0xFF, 0x00, 0x00, LEC.

Bits 15:8 **LSC[7:0]**: Line start delimiter code
This byte specifies the code of the line start delimiter. The code consists of 4 bytes in the form of 0xFF, 0x00, 0x00, LSC.

Bits 7:0 **FSC[7:0]**: Frame start delimiter code
This byte specifies the code of the frame start delimiter. The code consists of 4 bytes in the form of 0xFF, 0x00, 0x00, FSC.
If FSC is programmed to 0xFF, no frame start delimiter is detected. But, the first occurrence of LSC after an FEC code is interpreted as a start of frame delimiter.

38.5.8 DCMI embedded synchronization unmask register (DCMI_ESUR)

Address offset: 0x1C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FEU[7:0]								LEU[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LSU[7:0]								FSU[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **FEU[7:0]**: Frame end delimiter unmask

This byte specifies the mask to be applied to the code of the frame end delimiter.
0: The corresponding bit in the FEC byte in DCMI_ESCR is masked while comparing the frame end delimiter with the received data.
1: The corresponding bit in the FEC byte in DCMI_ESCR is compared while comparing the frame end delimiter with the received data.

Bits 23:16 **LEU[7:0]**: Line end delimiter unmask

This byte specifies the mask to be applied to the code of the line end delimiter.
0: The corresponding bit in the LEC byte in DCMI_ESCR is masked while comparing the line end delimiter with the received data.
1: The corresponding bit in the LEC byte in DCMI_ESCR is compared while comparing the line end delimiter with the received data.

Bits 15:8 **LSU[7:0]**: Line start delimiter unmask

This byte specifies the mask to be applied to the code of the line start delimiter.
0: The corresponding bit in the LSC byte in DCMI_ESCR is masked while comparing the line start delimiter with the received data.
1: The corresponding bit in the LSC byte in DCMI_ESCR is compared while comparing the line start delimiter with the received data.

Bits 7:0 **FSU[7:0]**: Frame start delimiter unmask

This byte specifies the mask to be applied to the code of the frame start delimiter.
0: The corresponding bit in the FSC byte in DCMI_ESCR is masked while comparing the frame start delimiter with the received data.
1: The corresponding bit in the FSC byte in DCMI_ESCR is compared while comparing the frame start delimiter with the received data.

38.5.9 DCMI crop window start (DCMI_CWSTRT)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	VST[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	HOFFCNT[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:16 **VST[12:0]**: Vertical start line count

The image capture starts with this line number. Previous line data are ignored.
0x0000: line 1
0x0001: line 2
0x0002: line 3
....

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:0 **HOFFCNT[13:0]**: Horizontal offset count

This value gives the number of pixel clocks to count before starting a capture.

38.5.10 DCMI crop window size (DCMI_CWSIZE)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	VLINE[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CAPCNT[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:16 **VLINE[13:0]**: Vertical line count

This value gives the number of lines to be captured from the starting point.
0x0000: 1 line
0x0001: 2 lines
0x0002: 3 lines
....

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:0 **CAPCNT[13:0]**: Capture count

This value gives the number of pixel clocks to be captured from the starting point on the same line. It value must corresponds to word-aligned data for different widths of parallel interfaces.
0x0000: 1 pixel
0x0001: 2 pixels
0x0002: 3 pixels
....

38.5.11 DCMI data register (DCMI_DR)

Address offset: 0x28

Reset value: 0x0000 0000

The digital camera Interface packages all the received data in 32-bit format before requesting a DMA transfer. A 8-word deep FIFO is available to leave enough time for DMA transfers and avoid DMA overrun conditions.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BYTE3[7:0]								BYTE2[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BYTE1[7:0]								BYTE0[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 **BYTE3[7:0]**: Data byte 3

Bits 23:16 **BYTE2[7:0]**: Data byte 2

Bits 15:8 **BYTE1[7:0]**: Data byte 1

Bits 7:0 **BYTE0[7:0]**: Data byte 0

38.5.12 DCMI register map

Table 395. DCMI register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	DCMI_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OELS	LSM	OEBS	BSM[1:0]		Res.	ENABLE	Res.	Res.	EDM[1:0]		FCRC[1:0]		VSPOL	HSPOL	PCKPOL	ESS	JPEG	CROP	CM	CAPTURE
	Reset value												0	0	0	0	0		0			0	0	0	0	0	0	0	0	0	0	0	0
0x04	DCMI_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FNE	VSYNC	HSYNC
	Reset value																														0	0	0
0x08	DCMI_RIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_RIS	VSYNC_RIS	ERR_RIS	OVR_RIS	FRAME_RIS
	Reset value																												0	0	0	0	0
0x0C	DCMI_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_IE	VSYNC_IE	ERR_IE	OVR_IE	FRAME_IE
	Reset value																												0	0	0	0	0
0x10	DCMI_MIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_MIS	VSYNC_MIS	ERR_MIS	OVR_MIS	FRAME_MIS
	Reset value																												0	0	0	0	0
0x14	DCMI_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_ISC	VSYNC_ISC	ERR_ISC	OVR_ISC	FRAME_ISC
	Reset value																												0	0	0	0	0
0x18	DCMI_ESCR	FEC[7:0]								LEC[7:0]								LSC[7:0]								FSC[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	DCMI_ESUR	FEU[7:0]								LEU[7:0]								LSU[7:0]								FSU[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	DCMI_CWSTRT	Res.	Res.	Res.	VST[12:0]													Res.	Res.	HOFFCNT[13:0]													
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x24	DCMI_CWSIZE	Res.	Res.	VLINE[13:0]														Res.	Res.	CAPCNT[13:0]													
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	DCMI_DR	BYTE3[7:0]								BYTE2[7:0]								BYTE1[7:0]								BYTE0[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

39 Parallel synchronous slave interface (PSSI)

The PSSI peripheral and the DCMI (digital camera interface) use the same circuitry. As a result, these two peripherals cannot be used at the same time: when using the PSSI, the DCMI registers cannot be accessed, and vice-versa.

In addition, the PSSI and the DCMI share the same alternate functions and interrupt vector (see *Section 39.3.2: PSSI pins and internal signals*).

39.1 PSSI introduction

The PSSI is a generic synchronous 8/16-bit parallel data input/output slave interface. It enables the transmitter to send a data valid signal that indicates when the data is valid, and the receiver to output a flow control signal that indicates when it is ready to sample the data.

39.2 PSSI main features

The PSSI peripheral main features are the following:

- Slave mode operation
- 8-bit or 16-bit parallel data input or output
- 8-word (32-byte) FIFO
- Data enable (PSSI_DE) and Ready (PSSI_RDY) alternate function

  When selected, these signals can either enable the transmitter to indicate when the data is valid, allow the receiver to indicate when it is ready to sample the data, or both.

39.3 PSSI functional description

The PSSI is a synchronous parallel slave interface that can send or receive high-speed data flows. It consists of up to 16 data lines (PSSI_D[15:0]) plus a clock line (PSSI_PDCK). The clock polarity can be configured so that data can be captured or transmitted on either the clock rising or falling edge.

Usually, a general-purpose DMA channel is used to pass 32-bit packed data via the data register (PSSI_DR).

The data flow can either be continuous or synchronized by hardware using the optional PSSI_DE (Data enable), and PSSI_RDY (Ready) signals.

Figure 412 shows the PSSI block diagram.

39.3.1 PSSI block diagram

Figure 412. PSSI block diagram

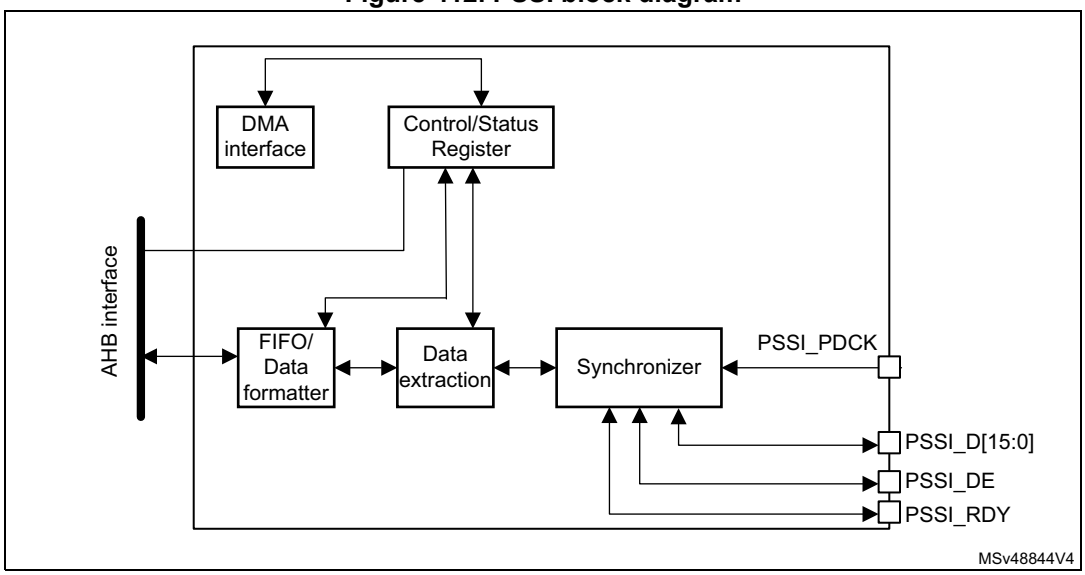
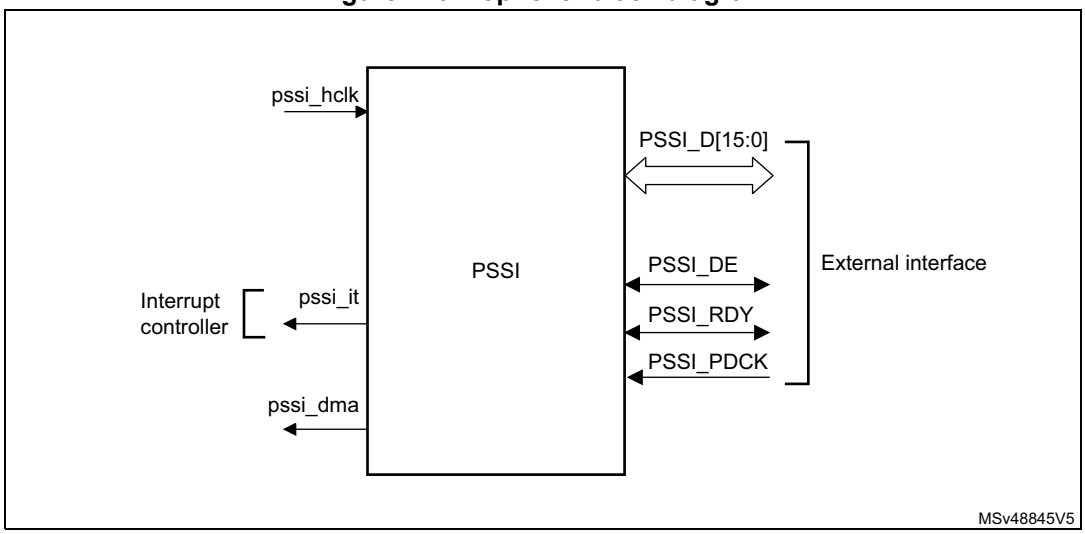


Figure 413. Top-level block diagram



39.3.2 PSSI pins and internal signals

The PSSI interface is composed of 19 pins, though nine signals are enough to transfer parallel data. *Table 396* shows the PSSI pins.

When the PSSI ENABLE bit (bit 14 of PSSI_CR) is set to 1, the alternate functions and the interrupt vector are associated with the PSSI. Otherwise, they are associated with the DCMI. The DCMI ENABLE bit (bit 15 of DCMI_CR) and the PSSI ENABLE bit (bit 14 of PSSI_CR) must not be set to 1 at the same time. As an example, if a GPIO is configured to use the alternate function PSSI_PDCK/DCMI_PIXCK, it is the PSSI_PDCK function which becomes active if PSSI_CR/ENABLE is set to 1.

Table 396. PSSI input/output pins

PSSI signal name	DCMI signal it is shared with	Signal type	Description
PSSI_PDCK	DCMI_PIXCK	Input	Parallel data clock input
PSSI_D[15:0]	DCMI_D[13:0]	Input/output	Data output when transmitting, data input when receiving
PSSI_DE	DCMI_HSYNC	Input/output	Data enable signal
PSSI_RDY	DCMI_VSYNC	Input/output	Ready signal

Table 397 shows the PSSI internal input/output signals.

Table 397. PSSI internal input/output signals

Internal signal name	Signal type	Description
pssi_it	Output	Interrupt
pssi_dma	Output	DMA request
pssi_hclk	Input	AHB clock

39.3.3 PSSI clock

The AHB clock frequency must be at least 2.5 times higher than the PSSI_PDCK frequency. At frequency ratios lower than 2.5, data might be corrupted or lost during transfers.

Data transfers are synchronous with PSSI_PDCK. The PSSI_PDCK polarity can be configured as follows, through CKPOL bit (bit 5 of PSSI_CR):

- When CKPOL = 0
  - Input pins are sampled on PSSI_PDCK falling edge
  - Output pins are driven on PSSI_PDCK rising edge
- When CKPOL = 1
  - Input pins are sampled on PSSI_PDCK rising edge
  - Output pins are driven on PSSI_PDCK falling edge

39.3.4 PSSI data management

Data direction

The direction of data transfers is configured through the OUTEN control bit (bit 31 of PSSI_CR):

- When OUTEN is cleared to 0 (default setting), the PSSI operates in receive mode and the data is input on the data pins.
- When OUTEN is set to 1, the peripheral operates in transmit mode and the data is output on the data pins.

OUTEN can be modified only when the ENABLE bit is cleared to 0.

Data register and DMA

Data are transferred from/to the FIFO using the PSSI_DR data register:

- In receive mode, data must be read from the FIFO by reading PSSI_DR.
- In transmit mode, data must be written to the FIFO by writing into PSSI_DR.

Word (32-bit) accesses to PSSI_DR and half-word (16-bit) accesses to PSSI_DR[15:0] are permitted in all modes. Byte (8-bit) accesses to PSSI_DR[7:0] are permitted only when the PSSI is configured to transfer 8 bits at a time (EDM=00 in the PSSI_CR register).

To reduce the load on the CPU, it is recommended to use the DMA to transfer data from/to the PSSI FIFO. When it is used, the DMA must be configured to transfer data via the PSSI_DR register. Using 32-bit transfers optimizes bandwidth and reduces the bus load. However, 8-bit and 16-bit transfers are also permitted.

To use the DMA, set the PSSI DMA enable bit (DMAEN in PSSI_CR) to 1 (default setting). When DMAEN is set to 1, a DMA transfer is initiated when the FIFO is ready for a 32-bit transfer (four valid bytes in receive mode or four empty bytes in transmit mode). As a result, in receive mode, no DMA transfers are initiated if there are three bytes or fewer in the FIFO, even if the DMA is configured to perform 8-bit transfers.

The RTT4B and RTT1B status bits (PSSI_SR) are useful when the CPU directly perform transfers to and from the FIFO. RTT4B set to 1 indicates that the FIFO is ready to transfer four bytes: at least four valid bytes in the FIFO in receive mode or at least four free bytes in transmit mode. RTT1B set to 1 indicates that the FIFO is ready to transfer one byte: at least one valid byte in the FIFO in receive mode or at least one free byte in transmit mode.

8-bit data

The PSSI parallel interface can transfer either 8-bit (using D[7:0]) or 16-bit data (using D[15:0]) depending on the EDM[1:0] control bits (bits 11:10 of PSSI_CR). If the 8-bit configuration is selected (EDM[1:0] set to 00), the unused D[15:0] pins can be used for GPIO or other functions.

When EDM[1:0] in PSSI_CR are programmed to 00, the interface transfers 8 bits using the D[7:0] pins. In this case, D[15:8] are not used and four PSSI_PDCK cycles are required to transfer a 32-bit word.

The least-significant byte (bits 7:0) correspond to the first byte transferred, and the most-significant byte (bits 31:28) corresponds to the forth byte transferred. *Table 398* illustrates the positioning of the data bytes in two 32-bit words.

Table 398. Positioning of captured data bytes in 32-bit words (8-bit width)

Byte address	31:24	23:16	15:8	7:0
0	D_{n+3}[7:0]	D_{n+2}[7:0]	D_{n+1}[7:0]	D_n[7:0]
4	D_{n+7}[7:0]	D_{n+6}[7:0]	D_{n+5}[7:0]	D_{n+4}[7:0]

16-bit data

When EDM[1:0] in PSSI_CR are programmed to 11, the interface transfers 16 bits using the D[15:0] pins. In this case, two PSSI_PDCK cycles are required to transfer a 32-bit word.

The least-significant half word (bits 15:0) correspond to the first half word transferred, and the most-significant half-word (bits 31:16) corresponds to the second half word transferred. *Table 399* illustrates the positioning of the data in two 32-bit words.

Table 399. Positioning of captured data bytes in 32-bit words (16-bit width)

Byte address	31:16	15:0
0	D_{n+1}[15:0]	D_n[15:0]
4	D_{n+3}[15:0]	D_{n+2}[15:0]

FIFO data buffer and error conditions

An eight-word FIFO helps improving performance and avoids overruns and underruns.

If the ready signal (PSSI_RDY) is disabled in receive mode, an overrun error is generated when a clock active edge occurs when the FIFO is full. In this case, the input data is lost.

If the data enable signal (PSSI_DE) is disabled in transmit mode, an underrun error is generated when a clock active edge occurs when the FIFO is empty. In this case, unpredictable data are output.

The OVR_RIS status bit indicates that either an overrun or an underrun occurred. An interrupt can be generated when these events occur.

39.3.5 PSSI optional control signals

Data Enable (PSSI_DE) alternate function input

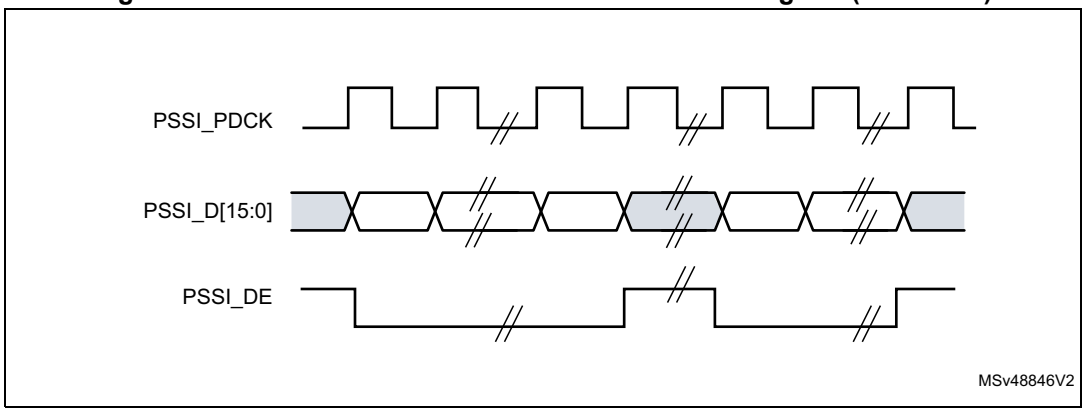
The data enable signal, PSSI_DE, is an optional signal. It is driven by the data source/transmitter in order to indicate that the data is valid to be transferred during the current cycle. When PSSI_DE is inactive, it means that the data must not be sampled by the receiver at the next clock edge.

This alternate function signal can be enabled using the DERDYCFG (bits 20:18 of PSSI_CR) control bits. PSSI_DE polarity is configured through DEPOL control bit (bit 6 of PSSI_CR). PSSI_DE is active low when DEPOL is cleared to 0, and high when DEPOL is et to 1.

The direction of the PSSI_DE signal is defined by the OUTEN value. It is the same as the data direction.

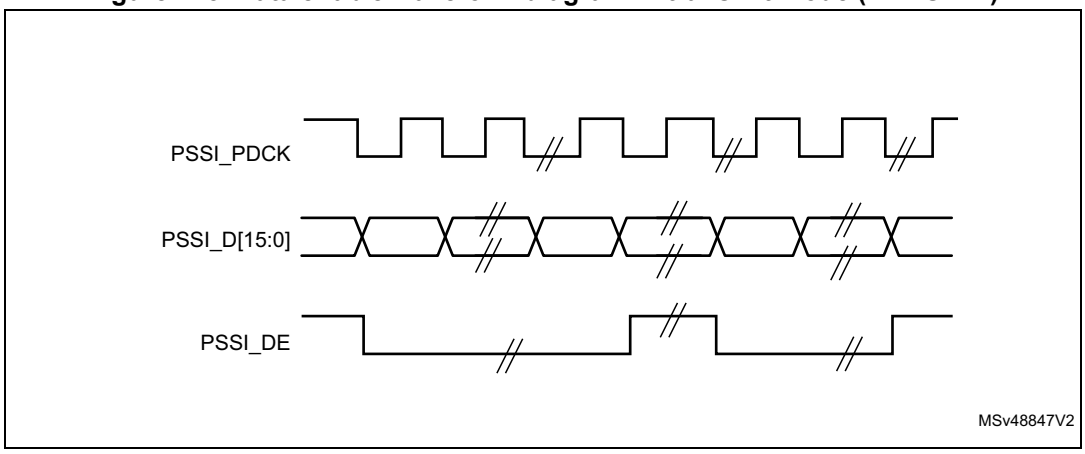
If the PSSI_DE alternate function input is enabled (through DERDYCFG) in receive mode (OUTEN cleared to 0), the PSSI samples PSSI_DE on the same PSSI_PDCK edge as the one used for sampling the data (D[15:0]). If PSSI_DE is active, the sampled data is saved in the FIFO. Otherwise, the sampled data is considered invalid and discarded. The transmitting device can use PSSI_DE as a data valid signal, driving it inactive when the data in the current cycle is not valid. This flow control function allows avoiding underrun errors.

Figure 414. Data enable in receive mode waveform diagram (CKPOL=0)



If the PSSI_DE alternate output function is enabled (through DERDYCFG) in transmit mode (OUTEN=1), the PSSI drives PSSI_DE on the same PSSI_PDCK edge that the one used to drive the data (D[15:0]). If a new 8 or 16-bit data (as programmed in the EDM[1:0] control bits in PSSI_CR) is available for transmission in the internal FIFO, this data is output on the data outputs (D[15:0]) and the PSSI_DE output becomes active on the current PSSI_PDCK edge. Otherwise (if the TX FIFO is empty), the D[15:0] outputs remains unchanged on the next clock edge and the PSSI_DE output becomes inactive.

Figure 415. Data enable waveform diagram in transmit mode (CKPOL=1)



Ready (PSSI_RDY) alternate function output

The ready signal, PSSI_RDY, is an optional signal. It is driven by the receiving device and indicates whether data is being accepted in the current cycle. When PSSI_RDY is inactive, it means that the data must not be sampled by the receiver at the next clock edge.

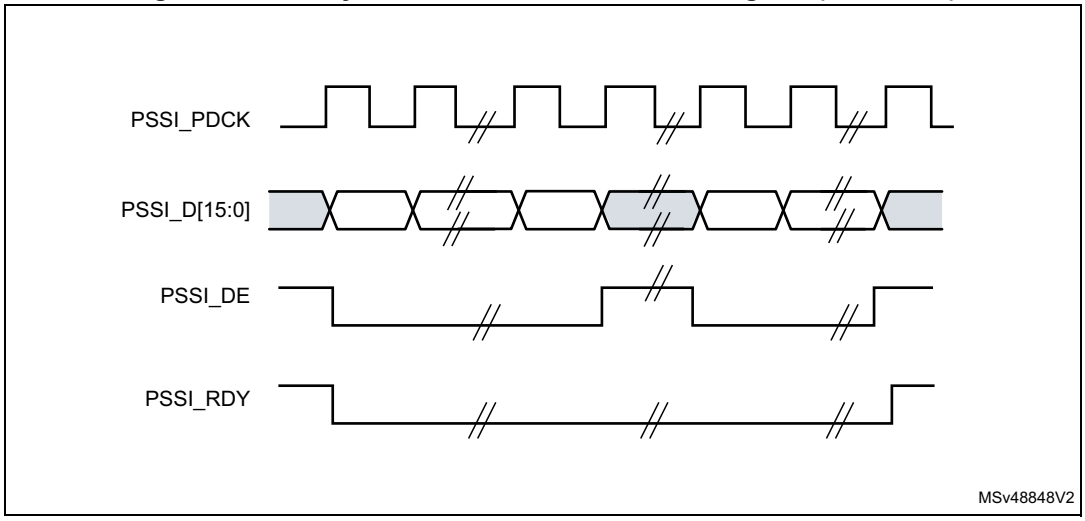
This alternate function signal can be enabled using the DERDYCFG control bits (bits 20:18 of PSSI_CR). PSSI_RDY polarity is configured through the RDYPOL control bit (bit 6 of PSSI_CR). PSSI_RDY is active low when RDYPOL is cleared to 0, and high when RDYPOL set to 1.

The direction of the PSSI_RDY signal is defined by the OUTEN (bit 31 of PSSI_CR). It is set in the opposite direction compared to the PSSI_DE and data signals.

If the PSSI_RDY alternate output function is enabled (through DERDYCFG) in receive mode (OUTEN=0), the PSSI drives PSSI_RDY one PSSI_PDCK half cycle after it samples

the data (D[15:0]). If the FIFO has enough free space to receive more data, the PSSI drives the PSSI_RDY signal active. Otherwise, if the FIFO is full and cannot accept more data, the PSSI drives the PSSI_RDY signal inactive. The transmitting device must repeat the current data in the next cycle when it detects that PSSI_RDY is inactive. This flow control function allows the PSSI to avoid overrun errors when the system (via the DMA) is unable to keep up with the data flow.

Figure 416. Ready in receive mode waveform diagram (CKPOL=0)



If the PSSI_RDY alternate input function is enabled (through DERDYCFG) in transmit mode (OUTEN=1), the PSSI samples the PSSI_RDY signal on the opposite PSSI_PDCK edge to the one at which D[15:0] are driven. If the PSSI_RDY signal is inactive, the PSSI keeps the same data (D[15:0]) and PSSI_DE signals that valid data are available during the next PSSI_PDCK clock cycle. Otherwise, if PSSI_RDY signal is sampled as active, the next data from the TX FIFO (if available) is output on the data outputs (D[15:0]). If no new data are available in the TX FIFO, the PSSI keeps the data output values and outputs the PSSI_DE signal as inactive (if enabled).

The receiving device uses the PSSI_RDY to control the data flow and avoid overrun errors when the system (via the DMA) is unable to keep up with the data flow.

Bidirectional PSSI_DE/PSSI_RDY signal

A single pin can be used for both data enable (PSSI_DE) and ready (PSSI_RDY) functions if DEPOL and RDYPOL are both set to 1 and DERDYCFG is set to 111 or 100 in the PSSI_CR register. In this case, the GPIO corresponding to selected alternate function (PSSI_DE when DERDYCFG=111 or PSSI_RDY when DERDYCFG=100) must be configured as open-drain. The other device must also be configured to drive the line as open-drain, and a weak pull-up must be applied to the line.

The signal thus becomes bidirectional. If either the sender drives the line low (to indicate that the data is not valid) or the receiver drives the line low (to indicate that it is not sampling the current data), then both devices know that the data is not being transferred in the current cycle.

Figure 417. Bidirectional PSSI_DE/PSSI_RDY waveform

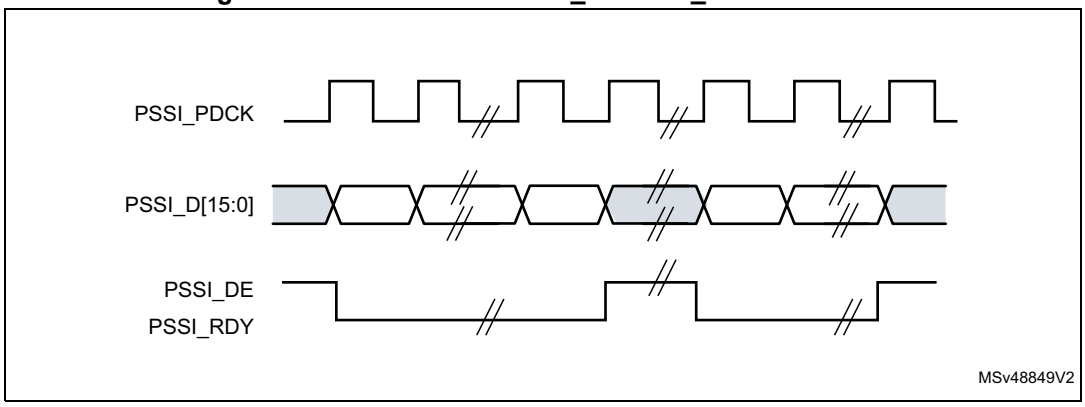
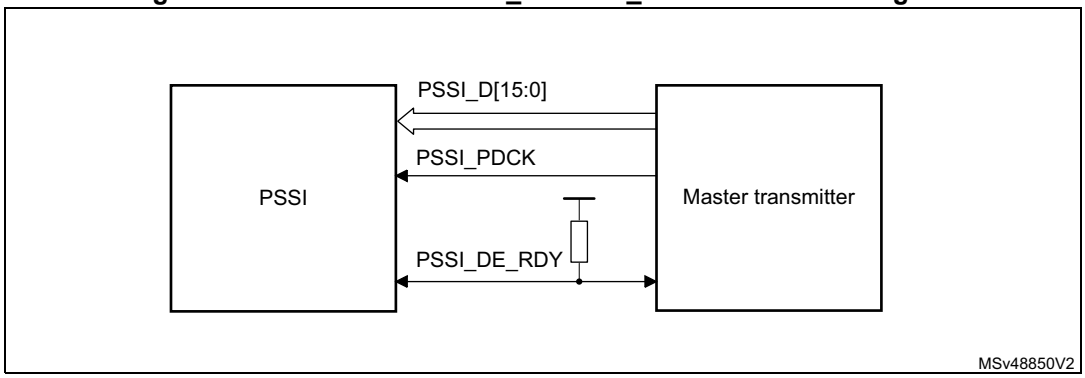


Figure 418. Bidirectional PSSI_DE/PSSI_RDY connection diagram



39.4 PSSI interrupts

The PSSI generates only one interrupt (IT_OVR). It is consequently equivalent to the global interrupt (pssi_it). Refer to *Table 400* for the list of interrupts.

The PSSI and the DCMI share the same interrupt vector. When the PSSI ENABLE bit (bit 14 of PSSI_CR) is set to 1, these interrupts are triggered by the PSSI. Otherwise, they are controlled by the DCMI.

The DCMI ENABLE bit (bit 14 of DCMI_CR) and PSSI ENABLE bit must not be set to 1 at the same time.

Table 400. PSSI interrupt requests

Interrupt acronym	Shared with DCMI	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit from low-power mode
IT_OVR	IT_OVR	indicates overrun in receive mode or underrun in transmit mode	OVR_RIS	OVR_IE	OVR_ISC	NA

39.5 PSSI registers

An 8-bit write or a 16-bit write operation to any PSSI register besides PSSI_DR, results in a bus error. 32-bit read and write operations are permitted.

39.5.1 PSSI control register (PSSI_CR)

Address offset: 0x00

Reset value: 0x4000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OUTEN	DMAEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DERDYCFG[2:0]			Res.	Res.
rw	rw										rw	rw	rw		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	ENABLE	Res.	Res.	EDM[1:0]		Res.	RDYPOL	Res.	DEPOL	CKPOL	Res.	Res.	Res.	Res.	Res.
	rw			rw	rw		rw		rw	rw					

Bit 31 **OUTEN:** Data direction selection bit

0: Receive mode: data is input synchronously with PSSI_PDCK

1: Transmit mode: data is output synchronously with PSSI_PDCK

Bit 30 **DMAEN:** DMA enable bit

0: DMA transfers are disabled. The user application can directly access the PSSI_DR register when DMA transfers are disabled.

1: DMA transfers are enabled (default configuration). A DMA channel in the general-purpose DMA controller must be configured to perform transfers from/to PSSI_DR.

Bits 29:21 Reserved, must be kept at reset value.

Bits 20:18 **DERDYCFG[2:0]:** Data enable and ready configuration

000: PSSI_DE and PSSI_RDY both disabled

001: Only PSSI_RDY enabled

010: Only PSSI_DE enabled

011: Both PSSI_RDY and PSSI_DE alternate functions enabled

100: Both PSSI_RDY and PSSI_DE features enabled - bidirectional on PSSI_RDY pin (see *Bidirectional PSSI_DE/PSSI_RDY signal on page 1659*)

101: Only PSSI_RDY function enabled, but mapped to PSSI_DE pin

110: Only PSSI_DE function enabled, but mapped to PSSI_RDY pin

111: Both PSSI_RDY and PSSI_DE features enabled - bidirectional on PSSI_DE pin (see *Bidirectional PSSI_DE/PSSI_RDY signal on page 1659*)

When the PSSI_RDY function is mapped to the PSSI_DE pin (settings 101 or 111), it is still the RDYPOL bit which determines its polarity. Similarly, when the PSSI_DE function is mapped to the PSSI_RDY pin (settings 110 or 111), it is still the DEPOL bit which determines its polarity.

Bits 17:15 Reserved, must be kept at reset value.

Bit 14 **ENABLE:** PSSI enable

0: PSSI disabled

1: PSSI enabled

The contents of the FIFO are flushed when ENABLE is cleared to 0.

Note: When ENABLE=1, the content of PSSI_CR must not be changed, except for the ENABLE bit itself. All configuration bits can change as soon as ENABLE changes from 0 to 1.

The DMA controller and all PSSI configuration registers must be programmed correctly before setting the ENABLE bit to 1.

The ENABLE bit and the DCMI ENABLE bit (bit 15 of DCMI_CR) must not be set to 1 at the same time.

Bits 13:12 Reserved, must be kept at reset value.

Bits 11:10 **EDM[1:0]:** Extended data mode

00: Interface captures 8-bit data on every parallel data clock

01: Reserved, must not be selected

10: Reserved, must not be selected

11: The interface captures 16-bit data on every parallel data clock

Bit 9 Reserved, must be kept at reset value.

Bit 8 **RDYPOL:** Ready (PSSI_RDY) polarity

This bit indicates the level on the PSSI_RDY pin when the data are not valid on the parallel interface.

0: PSSI_RDY active low (0 indicates that the receiver is ready to receive)

1: PSSI_RDY active high (1 indicates that the receiver is ready to receive)

Bit 7 Reserved, must be kept at reset value.

Bit 6 **DEPOL:** Data enable (PSSI_DE) polarity

This bit indicates the level on the PSSI_DE pin when the data are not valid on the parallel interface.

0: PSSI_DE active low (0 indicates that data is valid)

1: PSSI_DE active high (1 indicates that data is valid)

Bit 5 **CKPOL:** Parallel data clock polarity

This bit configures the capture edge of the parallel clock or the edge used for driving outputs, depending on OUTEN.

0: Falling edge active for inputs or rising edge active for outputs

1: Rising edge active for inputs or falling edge active for outputs.

Bits 4:0 Reserved, must be kept at reset value.

39.5.2 PSSI status register (PSSI_SR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RTT1B	RTT4B	Res.	Res.
												r	r		

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **RTT1B:** FIFO is ready to transfer one byte

1: FIFO is ready for a one byte transfer. In receive mode, this means that at least one valid data byte is in the FIFO. In transmit mode, this means that there is at least one byte free in the FIFO.

0: FIFO is not ready for a 1-byte transfer

Bit 2 **RTT4B:** FIFO is ready to transfer four bytes

1: FIFO is ready for a four-byte (32-bit) transfer. In receive mode, this means that at least four valid data bytes are in the FIFO. In transmit mode, this means that there are at least four bytes free in the FIFO.

0: FIFO is not ready for a four-byte transfer

Bits 1:0 Reserved, must be kept at reset value.

39.5.3 PSSI raw interrupt status register (PSSI_RIS)

Address offset: 0x08

Reset value: 0x0000 0000

PSSI_RIS gives the raw interrupt status. This register is read-only. When read, it returns the status of the corresponding interrupt before masking with the PSSI_IER register value.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_RIS	Res.
														r	

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **OVR_RIS:** Data buffer overrun/underrun raw interrupt status

0: No overrun/underrun occurred

1: An overrun/underrun occurred: overrun in receive mode, underrun in transmit mode. This bit is cleared by writing a 1 to the OVR_ISC bit in PSSI_ICR.

Bit 0 Reserved, must be kept at reset value.

39.5.4 PSSI interrupt enable register (PSSI_IER)

Address offset: 0x0C

Reset value: 0x0000 0000

The PSSI_IER register is used to enable interrupts. When one of the PSSI_IER bits is set, the corresponding interrupt is enabled. This register is accessible both in read and write modes.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_IE	Res.
														rw	

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **OVR_IE:** Data buffer overrun/underrun interrupt enable
0: No interrupt generation
1: An interrupt is generated if either an overrun or an underrun error occurred.

Bit 0 Reserved, must be kept at reset value.

39.5.5 PSSI masked interrupt status register (PSSI_MIS)

This PSSI_MIS register is read-only. When read, it returns the current masked status value of the corresponding interrupt (depending on the value in PSSI_IER). A bit in this register is set if the corresponding enable bit in PSSI_IER is set and the corresponding bit in PSSI_RIS is set.

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_MIS	Res.
														r	

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **OVR_MIS:** Data buffer overrun/underrun masked interrupt status
This bit is set to 1 only when PSSI_IER/OVR_IE and PSSI_RIS/OVR_RIS are both set to 1.
0: No interrupt is generated when an overrun/underrun error occurs
1: An interrupt is generated if there is either an overrun or an underrun error and the OVR_IE bit is set in PSSI_IER.

Bit 0 Reserved, must be kept at reset value.

39.5.6 PSSI interrupt clear register (PSSI_ICR)

Address offset: 0x14

Reset value: 0x0000 0000

The PSSI_ICR register is write-only. Writing a 1 into a bit of this register clears the corresponding bit in the PSSI_RIS and PSSI_MIS registers. Writing a 0 has no effect. Reading this register always gives zeros.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_ISC	Res.
														w	

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **OVR_ISC:** Data buffer overrun/underrun interrupt status clear
Writing this bit to 1 clears the OVR_RIS bit in PSSI_RIS.

Bit 0 Reserved, must be kept at reset value.

39.5.7 PSSI data register (PSSI_DR)

Address offset: 0x28

Reset value: 0x0000 0000

In receive mode (OUTEN = 0), the DMA controller must read the received data from this register. Write operations to PSSI_DR result in an error response. When more bytes than the number of valid bytes are read in the FIFO, the invalid bytes return zeros.

In transmit mode (OUTEN = 1), the DMA controller must write the data to be transmitted into this register. Read operations to PSSI_DR result in an error response.

32-bit, 16-bit, and 8-bit accesses are all supported for PSSI_DR. For instance, 16-bit read/write operations remove/add two bytes from/to the FIFO. However, 8-bit accesses are permitted only when the PSSI is configured to transfer 8 data bits at a time (EDM=00 in PSSI_CR). 8-bit accesses to PSSI_DR when EDM is not set to 0 result in an error response.

All accesses must include byte 0: 8-bit accesses must be performed to bits 7 to 0 and 16-bit accesses from bits 15 to 0. Accesses that do not include byte 0 results in an error response.

Accessing PSSI_DR when ENABLE bit in PSSI_CR is set to 0 results in an error response.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BYTE3[7:0]								BYTE2[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BYTE1[7:0]								BYTE0[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **BYTE3[7:0]**: Data byte 3

Bits 23:16 **BYTE2[7:0]**: Data byte 2

Bits 15:8 **BYTE1[7:0]**: Data byte 1

Bits 7:0 **BYTE0[7:0]**: Data byte 0

39.5.8 PSSI register map

Table 401. PSSI register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	PSSI_CR	OUTEN	DMAEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DERDYCFG			Res.	Res.	Res.	ENABLE[2:0]			EDM		Res.	RDYPOL	Res.	DEPOL	CKPOL	Res.	Res.	Res.	Res.	Res.
	Reset value	0	1										0	0	0				0			0	0		0		0	0					
0x04	PSSI_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RTT1B	RTT4B	Res.	Res.
	Reset value																													0	0		
0x08	PSSI_RIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_RIS	Res.
	Reset value																															0	
0x0C	PSSI_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.am	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_IE	Res.
	Reset value																															0	
0x10	PSSI_MIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_MIS	Res.
	Reset value																															0	
0x14	PSSI_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_ISC	Res.
	Reset value																															0	
0x18-0x24	Reserved	Res.																															
0x28	PSSI_DR	BYTE3[7:0]								BYTE2[7:0]								BYTE1[7:0]								BYTE0[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

40 LCD-TFT display controller (LTDC)

40.1 Introduction

The LCD-TFT (liquid crystal display - thin film transistor) display controller provides a parallel digital RGB (red, green, blue) and signals for horizontal, vertical synchronization, pixel clock and data enable as output to interface directly to a variety of LCD and TFT panels.

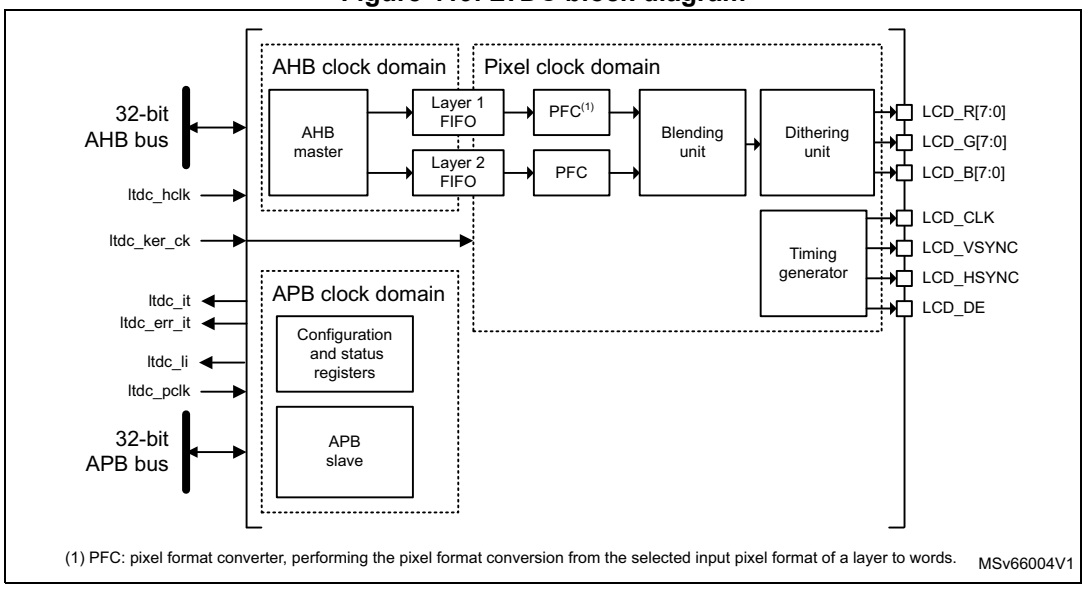
40.2 LTDC main features

- 24-bit RGB parallel pixel output; 8 bits-per-pixel (RGB888)
- 2 display layers with dedicated FIFO (64x32-bit)
- Color look-up table (CLUT) up to 256 color (256x24-bit) per layer
- Programmable timings for different display panels
- Programmable background color
- Programmable polarity for HSYNC, VSYNC and data enable
- Up to 8 input color formats selectable per layer:
  - ARGB8888
  - RGB888
  - RGB565
  - ARGB1555
  - ARGB4444
  - L8 (8-bit luminance or CLUT)
  - AL44 (4-bit alpha + 4-bit luminance)
  - AL88 (8-bit alpha + 8-bit luminance)
- Pseudo-random dithering output for low bits per channel
  - Dither width 2 bits for red, green, blue
- Flexible blending between two layers using alpha value (per pixel or constant)
- Color keying (transparency color)
- Programmable window position and size
- Supports thin film transistor (TFT) color displays
- AHB master interface with burst of 16 words
- Up to 4 programmable interrupt events

40.3 LTDC functional description

40.3.1 LTDC block diagram

Figure 419. LTDC block diagram



40.3.2 LTDC pins and internal signals

The table below summarizes the LTDC signal interface.

Table 402. LTDC external pins

LCD-TFT signals	Signal type	Description
LCD_CLK	Output	Clock output
LCD_HSYNC	Output	Horizontal synchronization
LCD_VSYNC	Output	Vertical synchronization
LCD_DE	Output	Not data enable
LCD_R[7:0]	Output	8-bit Red data
LCD_G[7:0]	Output	8-bit Green data
LCD_B[7:0]	Output	8-bit Blue data

The LTDC pins must be configured by the user application. The unused pins can be used for other purposes.

For LTDC outputs up to 24 bits (RGB888), if less than 8 bpp are used to output for example RGB565 or RGB666 to interface on 16- or 18-bit displays, the RGB display data lines must be connected to the MSB of the LTDC RGB data lines.

As an example, in the case of an LTDC interfacing with a RGB565 16-bit display, the LTDC display R[4:0], G[5:0] and B[4:0] data lines pins must be connected to the LCD_R[7:3], LCD_G[7:2] and LCD_B[7:3] pins.

The internal signals of the LTDC are given in the table below.

Table 403. LTDC internal signals

Names	Signal type	Description
ltdc_hclk	Input	LTDC AHB clock
ltdc_pclk	Input	LTDC APB clock for register access
ltdc_ker_ck	Input	LTDC kernel clock used for LCD_CLK (pixel clock) generation
ltdc_it	Output	LTDC global interrupt request
ltdc_err_it	Output	LTDC global error interrupt request
ltdc_li	Output	LTDC line interrupt flag

The table below shows how the LTDC flags are connected.

Table 404. LTDC trigger interconnection

Trigger name	Direction	Trigger source/destination
ltdc_li	Output	gpdma1_trigsel[63] gpdma2_trigsel[63]

40.3.3 LTDC reset and clocks

The LTDC controller peripheral uses the following clock domains:

- AHB clock domain (ltdc_aclk)

  This domain contains the LTDC AHB master interface for data transfer from the memories to the layer FIFO and the frame-buffer configuration register.
- APB clock domain (ltdc_pclk)

  This domain contains the global configuration registers and the interrupt register.
- Pixel clock domain (LCD_CLK)

  This domain contains the pixel data generation, the layer configuration register as well as the LTDC interface signal generator. The LCD_CLK output must be configured following the panel requirements. The LCD_CLK is generated from a specific PLL output (refer to the reset and clock control section).

The table below summarizes the clock domain for each register.

Table 405. Clock domain for each register

LTDC register	Clock domain
LTDC_LxCR	ltdc_hclk
LTDC_LxCFBAR	
LTDC_LxCFBLR	
LTDC_LxCFBLNR	

Table 405. Clock domain for each register (continued)

LTDC register	Clock domain
LTDC_SRCR	ltdc_pclk
LTDC_IER	
LTDC_ISR	
LTDC_ICR	
LTDC_SSCR	Pixel clock (LCD_CLK)
LTDC_BPCR	
LTDC_AWCR	
LTDC_TWCR	
LTDC_GCR	
LTDC_BCCR	
LTDC_LIPCR	
LTDC_CPSR	
LTDC_CDSR	
LTDC_LxWHPCR	
LTDC_LxWVPCR	
LTDC_LxCKCR	
LTDC_LxPFCR	
LTDC_LxCACR	
LTDC_LxDCCR	
LTDC_LxBFCR	
LTDC_LxCLUTWR	

Care must be taken while accessing the LTDC registers, the APB bus is stalled during:

- six ltdc_pclk periods + five LCD_CLK periods (five ltdc_hclk periods for register on AHB clock domain) for register write access and update
- seven ltdc_pclk periods + five LCD_CLK periods (five ltdc_hclk periods for register on AHB clock domain) for register read access

For registers on ltdc_pclk clock domain, APB bus is stalled for six ltdc_pclk periods during the register write accesses, and for seven ltdc_pclk periods during read accesses.

The LTDC controller can be reset by setting the corresponding bit in the RCC. It resets the three clock domains.

40.4 LTDC programmable parameters

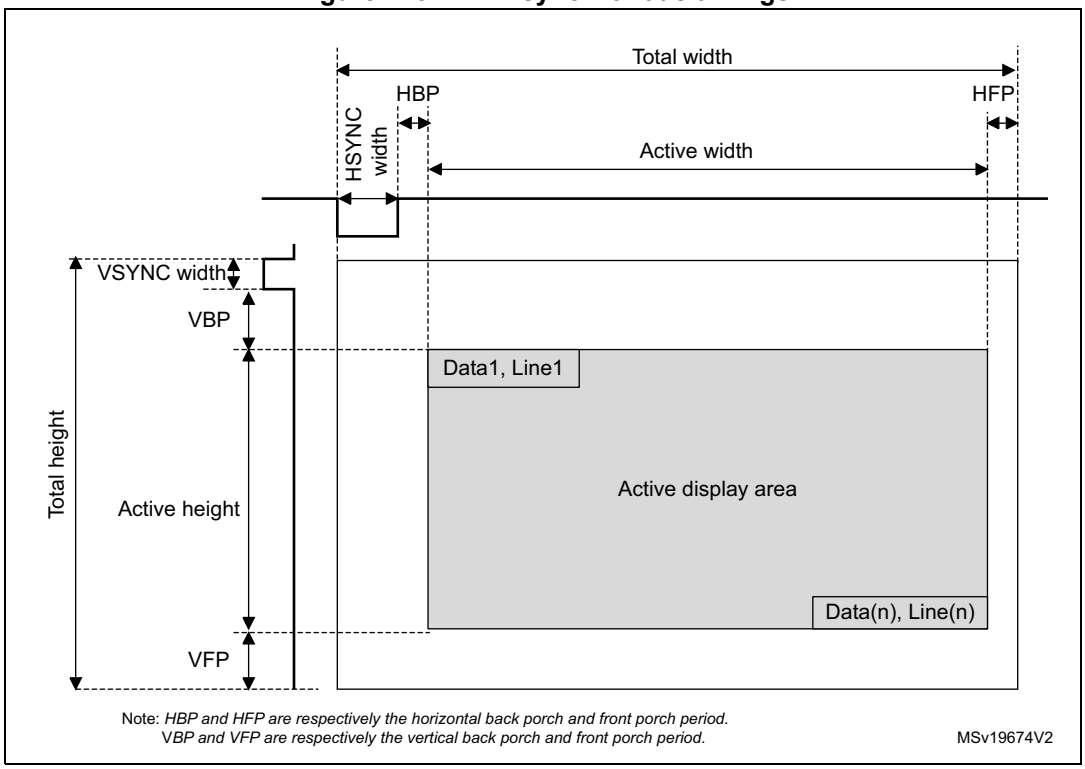
The LTDC controller provides flexible configurable parameters. It can be enabled or disabled through the LTDC_GCR register.

40.4.1 LTDC global configuration parameters

Synchronous timings

The figure below presents the configurable timing parameters generated by the synchronous timings generator block presented in the block diagram *Figure 419*. It generates the horizontal and vertical synchronization timings panel signals, the pixel clock and the data enable signals.

Figure 420. LTDC synchronous timings



The LTDC programmable synchronous timings are the following:

- HSYNC and VSYNC width: horizontal and vertical synchronization width, configured by programming a value of HSYNC width - 1 and VSYNC width - 1 in the LTDC_SSCR register
- HBP and VBP: horizontal and vertical synchronization back porch width, configured by programming the accumulated value HSYNC width + HBP - 1 and the accumulated value VSYNC width + VBP - 1 in the LTDC_BPCR register.
- Active width and active height: the active width and active height are configured by programming the accumulated value HSYNC width + HBP + active width - 1 and the

accumulated value VSYNC width + VBP + active height - 1 in the LTDC_AWCR register.

- Total width: the total width is configured by programming the accumulated value HSYNC width + HBP + active width + HFP - 1 in the LTDC_TWCR register. The HFP is the horizontal front porch period.
- Total height: the total height is configured by programming the accumulated value VSYNC height + VBP + active height + VFP - 1 in the LTDC_TWCR register. The VFP is the vertical front porch period.

Note: When the LTDC is enabled, the timings generated start with X/Y = 0/0 position as the first horizontal synchronization pixel in the vertical synchronization area and following the back porch, active data display area and the front porch.
When the LTDC is disabled, the timing generator block is reset to X = total width - 1, Y = total height - 1 and held the last pixel before the vertical synchronization phase and the FIFO are flushed. Therefore only blanking data is output continuously.

Example of synchronous timings configuration

LTDC timings (must be extracted from panel datasheet):

- horizontal and vertical synchronization width: 0xA pixels and 0x2 lines
- horizontal and vertical back porch: 0x14 pixels and 0x2 lines
- active width and active height: 0x140 pixels, 0xF0 lines (320x240)
- horizontal front porch: 0xA pixels
- vertical front porch: 0x4 lines

The programmed values in the LTDC timings registers are:

- LTDC_SSCR register to be programmed to 0x00090001
(HSW[11:0] is 0x9 and VSH[10:0] is 0x1)
- LTDC_BPCR register to be programmed to 0x001D0003
(AHBP[11:0] is 0x1D (0xA+ 0x13) and AVBP[10:0]A is 0x3 (0x2 + 0x1))
- LTDC_AWCR register to be programmed to 0x015D00F3
(AAW[11:0] is 0x15D (0xA +0x14 +0x13F) and AAH[10:0] is 0xF3 (0x2 + 0x2 + 0xEF))
- LTDC_TWCR register to be programmed to 0x00000167
(TOTALW[11:0] is 0x167 (0xA +0x14 +0x140 + 0x9))
- LTDC_THCR register to be programmed to 0x000000F7
(TOTALH[10:0]is 0xF7 (0x2 +0x2 + 0xF0 + 3))

Programmable polarity

The horizontal and vertical synchronization, data enable and pixel clock output signals polarity can be programmed to active high or active low through the LTDC_GCR register.

Background color

A constant background color (RGB888) can programmed through the LTDC_BCCR register. It is used for blending with the bottom layer.

Dithering

The dithering pseudo-random technique using an LFSR is used to add a small random value (threshold) to each pixel color channel (R, G or B) value, thus rounding up the MSB in

some cases when displaying a 24-bit data on 18-bit display. Thus the dithering technique is used to round data which is different from one frame to the other.

The dithering pseudo-random technique is the same as comparing LSBs against a threshold value and adding a 1 to the MSB part only, if the LSB part is ≥ the threshold. The LSBs are typically dropped once dithering was applied.

The width of the added pseudo-random value is two bits for each color channel: two bits for red, two bits for green and two bits for blue.

Once the LTDC is enabled, the LFSR starts running with the first active pixel and it is kept running even during blanking periods and when dithering is switched off. If the LTDC is disabled, the LFSR is reset.

The dithering can be switched on and off on the fly through the LTDC_GCR register.

Reload shadow registers

Some configuration registers are shadowed. The shadow registers values can be reloaded immediately to the active registers when writing to these registers or at the beginning of the vertical blanking period following the configuration in the LTDC_SRCR register. If the immediate reload configuration is selected, the reload must be activated only when all new registers have been written.

The shadow registers must not be modified again before the reload is done. Reading from the shadow registers returns the actual active value. The new written value can only be read after the reload has taken place.

A register reload interrupt can be generated if enabled in the LTDC_IER register.

The shadowed registers are all Layer1 and Layer2 registers except LTDC_LxCLUTWR.

Interrupt generation event

Refer to *Section 40.5: LTDC interrupts* for the interrupt configuration.

40.4.2 Layer programmable parameters

Up to two layers can be enabled, disabled and configured separately. The layer display order is fixed and it is bottom up. If two layers are enabled, the layer2 is the top displayed window.

Windowing

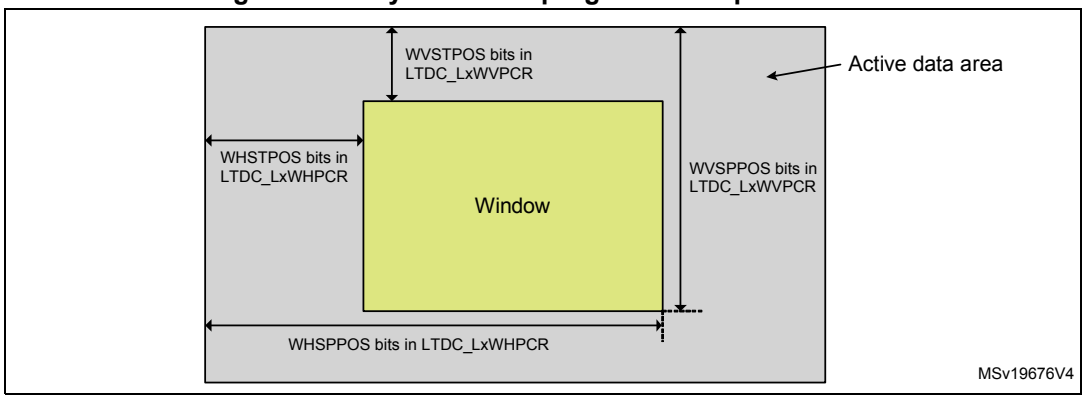
Every layer can be positioned and resized and it must be inside the active display area.

The window position and size are configured through the top-left and bottom-right X/Y positions and the internal timing generator that includes the synchronous, back porch size and the active data area. Refer to LTDC_LxWHPCR and LTDC_WVPCR registers.

The programmable layer position and size defines the first/last visible pixel of a line and the first/last visible line in the window. It allows to display either the full image frame or only a part of the image frame (see *Figure 421*):

- The first and the last visible pixel in the layer are set by configuring the WHSTPOS[11:0] and WHSPPOS[11:0] in the LTDC_LxWHPCR register.
- The first and the last visible lines in the layer are set by configuring the WVSTPOS[10:0] and WVSPPOS[10:0] in the LTDC_LxWVPCR register.

Figure 421. Layer window programmable parameters



Pixel input format

The programmable pixel format is used for the data stored in the frame buffer of a layer.

Up to eight input pixel formats can be configured for every layer through the LTDC_LxPFCR register

The pixel data is read from the frame buffer and then transformed to the internal 8888 (ARGB) format as follows: components having a width of less than 8 bits get expanded to 8 bits by bit replication. The selected bit range is concatenated multiple times until it is longer than 8 bits. Of the resulting vector, the 8 MSB bits are chosen. Example: 5 bits of an RGB565 red channel become (bit positions) 43210432 (the three LSBs are filled with the three MSBs of the five bits)

The table below describes the pixel data mapping depending on the selected format.

Table 406. Pixel data mapping versus color format

ARGB8888			
@+3 A_x[7:0]	@+2 R_x[7:0]	@+1 G_x[7:0]	@ B_x[7:0]
@+7 A_{x+1}[7:0]	@+6 R_{x+1}[7:0]	@+5 G_{x+1}[7:0]	@+4 B_{x+1}[7:0]
RGB888			
@+3 B_{x+1}[7:0]	@+2 R_x[7:0]	@+1 G_x[7:0]	@ B_x[7:0]
@+7 G_{x+2}[7:0]	@+6 B_{x+2}[7:0]	@+5 R_{x+1}[7:0]	@+4 G_{x+1}[7:0]
RGB565			
@+3 R_{x+1}[4:0] G_{x+1}[5:3]	@+2 G_{x+1}[2:0] B_{x+1}[4:0]	@+1 R_x[4:0] G_x[5:3]	@ G_x[2:0] B_x[4:0]
@+7 R_{x+3}[4:0] G_{x+3}[5:3]	@+6 G_{x+3}[2:0] B_{x+3}[4:0]	@+5 R_{x+2}[4:0] G_{x+2}[5:3]	@+4 G_{x+2}[2:0] B_{x+2}[4:0]
ARGB1555			

Table 406. Pixel data mapping versus color format (continued)

@+3 $A_{x+1}[0]R_{x+1}[4:0]$ $G_{x+1}[4:3]$	@+2 $G_{x+1}[2:0]$ $B_{x+1}[4:0]$	@+1 $A_x[0]$ $R_x[4:0]$ $G_x[4:3]$	@ $G_x[2:0]$ $B_x[4:0]$
@+7 $A_{x+3}[0]R_{x+3}[4:0]$ $G_{x+3}[4:3]$	@+6 $G_{x+3}[2:0]$ $B_{x+3}[4:0]$	@+5 $A_{x+2}[0]R_{x+2}[4:0]G_{x+2}[4:3]$	@+4 $G_{x+2}[2:0]$ $B_{x+2}[4:0]$
ARGB4444			
@+3 $A_{x+1}[3:0]R_{x+1}[3:0]$	@+2 $G_{x+1}[3:0]$ $B_{x+1}[3:0]$	@+1 $A_x[3:0]$ $R_x[3:0]$	@ $G_x[3:0]$ $B_x[3:0]$
@+7 $A_{x+3}[3:0]R_{x+3}[3:0]$	@+6 $G_{x+3}[3:0]$ $B_{x+3}[3:0]$	@+5 $A_{x+2}[3:0]R_{x+2}[3:0]$	@+4 $G_{x+2}[3:0]$ $B_{x+2}[3:0]$
L8			
@+3 $L_{x+3}[7:0]$	@+2 $L_{x+2}[7:0]$	@+1 $L_{x+1}[7:0]$	@ $L_x[7:0]$
@+7 $L_{x+7}[7:0]$	@+6 $L_{x+6}[7:0]$	@+5 $L_{x+5}[7:0]$	@+4 $L_{x+4}[7:0]$
AL44			
@+3 $A_{x+3}[3:0]$ $L_{x+3}[3:0]$	@+2 $A_{x+2}[3:0]$ $L_{x+2}[3:0]$	@+1 $A_{x+1}[3:0]$ $L_{x+1}[3:0]$	@ $A_x[3:0]$ $L_x[3:0]$
@+7 $A_{x+7}[3:0]$ $L_{x+7}[3:0]$	@+6 $A_{x+6}[3:0]$ $L_{x+6}[3:0]$	@+5 $A_{x+5}[3:0]$ $L_{x+5}[3:0]$	@+4 $A_{x+4}[3:0]$ $L_{x+4}[3:0]$
AL88			
@+3 $A_{x+1}[7:0]$	@+2 $L_{x+1}[7:0]$	@+1 $A_x[7:0]$	@ $L_x[7:0]$
@+7 $A_{x+3}[7:0]$	@+6 $L_{x+3}[7:0]$	@+5 $A_{x+2}[7:0]$	@+4 $L_{x+2}[7:0]$

Color look-up table (CLUT)

The CLUT can be enabled at run-time for every layer through the LTDC_LxCR register and it is only useful in case of indexed color when using the L8, AL44 and AL88 input pixel format.

First, the CLUT must be loaded with the R, G and B values that replace the original R, G, B values of that pixel (indexed color). Each color (RGB value) has its own address that is the position within the CLUT.

The R, G and B values and their own respective address are programmed through the LTDC_LxCLUTWR register:

- In case of L8 and AL88 input pixel format, the CLUT must be loaded by 256 colors. The address of each color is configured in the CLUTADD bits in the LTDC_LxCLUTWR register.

- In case of AL44 input pixel format, the CLUT must be loaded by only16 colors. The address of each color must be filled by replicating the 4-bit L channel to 8-bit as follows:
  - L0 (indexed color 0), at address 0x00
  - L1, at address 0x11
  - L2, at address 0x22
  - .....
  - L15, at address 0xFF

Color frame buffer address

Every layer has a start address for the color frame buffer configured through the LTDC_LxCFBAR register.

When a layer is enabled, the data is fetched from the color frame buffer.

Color frame buffer length

Every layer has a total line length setting for the color frame buffer in bytes and a number of lines in the frame buffer configurable in the LTDC_LxCFBLR and LTDC_LxCFBLNR register respectively.

The line length and the number of lines settings are used to stop the prefetching of data to the layer FIFO at the end of the frame buffer:

- If it is set to less bytes than required, a FIFO underrun interrupt is generated if it has been previously enabled.
- If it is set to more bytes than actually required, the useless data read from the FIFO is discarded. The useless data is not displayed.

Color frame buffer pitch

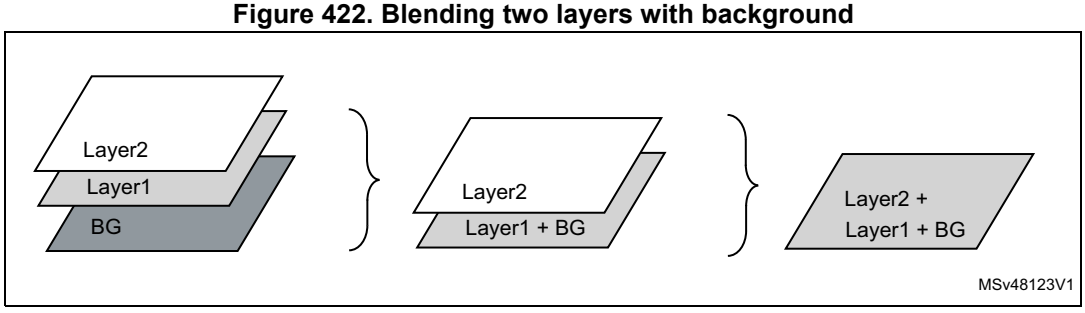
Every layer has a configurable pitch for the color frame buffer, that is the distance between the start of one line and the beginning of the next line in bytes. It is configured through the LTDC_LxCFBLR register.

Layer blending

The blending is always active and the two layers can be blended following the blending factors configured through the LTDC_LxBFCR register.

The blending order is fixed and it is bottom up. If two layers are enabled, first the Layer1 is blended with the Background color, then the layer2 is blended with the result of blended color of layer1 and the background. Refer to the figure below.

Figure 422. Blending two layers with background



Default color

Every layer can have a default color in the format ARGB which is used outside the defined layer window or when a layer is disabled.

The default color is configured through the LTDC_LxDCCR register.

The blending is always performed between the two layers even when a layer is disabled. To avoid displaying the default color when a layer is disabled, keep the blending factors of this layer in the LTDC_LxBFCR register to their reset value.

Color keying

A color key (RGB) can be configured to be representative for a transparent pixel.

If the color keying is enabled, the current pixels (after format conversion and before CLUT respectively blending) are compared to the color key. If they match for the programmed RGB value, all channels (ARGB) of that pixel are set to 0.

The color key value can be configured and used at run-time to replace the pixel RGB value.

The color keying is enabled through the LTDC_LxCKCR register.

The color keying is configured through the LTDC_LxCKCR register. The programmed value depends on the pixel format as it is compared to current pixel after pixel format conversion to ARGB888.

Example: if the a mid-yellow color (50 % red + 50 % green) is used as the transparent color key:

- In RGB565, the mid-yellow color is 0x8400. Set the LTDC_LxCKCR to 0x848200.
- In ARGB8888, the mid-yellow color is 0x808000. Set LTDC_LxCKCR to 0x808000.
- In all CLUT-based color modes (L8, AL88, AL44), set one of the palette entry to the mid-yellow color 0x808000 and set the LTDC_LxCKCR to 0x808000.

40.5 LTDC interrupts

The LTDC provides four maskable interrupts logically ORed to two interrupt vectors.

The interrupt sources can be enabled or disabled separately through the LTDC_IER register. Setting the appropriate mask bit to 1 enables the corresponding interrupt.

The two interrupts are generated on the following events:

- Line interrupt: generated when a programmed line is reached. The line interrupt position is programmed in the LTDC_LIPCR register
- Register reload interrupt: generated when the shadow registers reload is performed during the vertical blanking period
- FIFO underrun interrupt: generated when a pixel is requested from an empty layer FIFO
- Transfer error interrupt: generated when an AHB bus error occurs during data transfer

These interrupt events are connected to the NVIC controller as described in the figure below.

Figure 423. Interrupt events

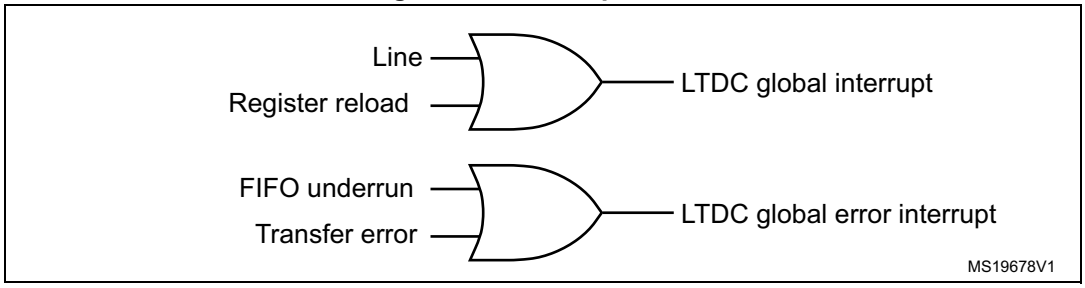


Table 407. LTDC interrupt requests

Interrupt event	Event flag	Enable control bit
Line	LIF	LIE
Register reload	RRIF	RRIEN
FIFO underrun	FUDERRIF	FUDERRIE
Transfer error	TERRIF	TERRIE

40.6 LTDC programming procedure

The steps listed below are needed to program the LTDC:

1. Enable the LTDC clock in the RCC register.
2. Configure the required pixel clock following the panel datasheet.
3. Configure the synchronous timings: VSYNC, HSYNC, vertical and horizontal back porch, active data area and the front porch timings following the panel datasheet as described in the *Section 40.4.1*.
4. Configure the synchronous signals and clock polarity in the LTDC_GCR register.
5. If needed, configure the background color in the LTDC_BCCR register.
6. Configure the needed interrupts in the LTDC_IER and LTDC_LIPCR register.
7. Configure the layer1/2 parameters by:
   - programming the layer window horizontal and vertical position in the LTDC_LxWHPCR and LTDC_WVPCR registers. The layer window must be in the active data area.
   - programming the pixel input format in the LTDC_LxPFCR register
   - programming the color frame buffer start address in the LTDC_LxCFBAR register
   - programming the line length and pitch of the color frame buffer in the LTDC_LxCFBLR register
   - programming the number of lines of the color frame buffer in the LTDC_LxCFBLNR register
   - if needed, loading the CLUT with the RGB values and its address in the LTDC_LxCLUTWR register
   - If needed, configuring the default color and the blending factors respectively in the LTDC_LxDCCR and LTDC_LxBFCR registers

8. Enable layer1/2 and if needed the CLUT in the LTDC_LxCR register.
9. If needed, enable dithering and color keying respectively in the LTDC_GCR and LTDC_LxCKCR registers. They can be also enabled on the fly.
10. Reload the shadow registers to active register through the LTDC_SRCR register.
11. Enable the LTDC controller in the LTDC_GCR register.
12. All layer parameters can be modified on the fly except the CLUT. The new configuration must be either reloaded immediately or during vertical blanking period by configuring the LTDC_SRCR register.

Note: All layer's registers are shadowed. Once a register is written, it must not be modified again before the reload has been done. Thus, a new write to the same register overrides the previous configuration if not yet reloaded.

40.7 LTDC registers

40.7.1 LTDC synchronization size configuration register (LTDC_SSCR)

Address offset: 0x008

Reset value: 0x0000 0000

This register defines the number of horizontal synchronization pixels minus 1 and the number of vertical synchronization lines minus 1. Refer to *Figure 420* and *Section 40.4* for an example of configuration.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	HSW[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	VSH[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **HSW[11:0]**: Horizontal synchronization width (in units of pixel clock period)
This bitfield defines the number of Horizontal Synchronization pixel minus 1.

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **VSH[10:0]**: Vertical synchronization height (in units of horizontal scan line)
This bitfield defines the vertical Synchronization height minus 1. It represents the number of horizontal synchronization lines.

40.7.2 LTDC back porch configuration register (LTDC_BPCR)

Address offset: 0x00C

Reset value: 0x0000 0000

This register defines the accumulated number of horizontal synchronization and back porch pixels minus 1 (HSYNC width + HBP - 1) and the accumulated number of vertical

synchronization and back porch lines minus 1 (VSYNC height + VBP - 1).
Refer to *Figure 420* and *Section 40.4* for an example of configuration.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	AHBP[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	AVBP[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **AHBP[11:0]**: Accumulated horizontal back porch (in units of pixel clock period)

These bits defines the accumulated horizontal back porch width that includes the horizontal synchronization and horizontal back porch pixels minus 1.
The horizontal back porch is the period between horizontal synchronization going inactive and the start of the active display part of the next scan line.

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **AVBP[10:0]:** Accumulated Vertical back porch (in units of horizontal scan line)

These bits define the accumulated vertical back porch width that includes the vertical synchronization and vertical back porch lines minus 1.
The vertical back porch is the number of horizontal scan lines at a start of frame to the start of the first active scan line of the next frame.

40.7.3 LTDC active width configuration register (LTDC_AWCR)

Address offset: 0x010

Reset value: 0x0000 0000

This register defines the accumulated number of horizontal synchronization, back porch and active pixels minus 1 (HSYNC width + HBP + active width - 1) and the accumulated number of vertical synchronization, back porch lines and active lines minus 1
(VSYNC height + VBP + active height - 1). Refer to *Figure 420* and *Section 40.4* for an example of configuration.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	AAW[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	AAH[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **AAW[11:0]**: Accumulated active width (in units of pixel clock period)

These bits define the accumulated active width which includes the horizontal synchronization, horizontal back porch and active pixels minus 1.
The active width is the number of pixels in active display area of the panel scan line.
Refer to device datasheet for maximum active width supported following maximum pixel clock.

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **AAH[10:0]**: Accumulated active height (in units of horizontal scan line)

These bits define the accumulated height which includes the vertical synchronization, vertical back porch and the active height lines minus 1. The active height is the number of active lines in the panel.

Refer to device datasheet for maximum active height supported following maximum pixel clock.

40.7.4 LTDC total width configuration register (LTDC_TWCR)

Address offset: 0x014

Reset value: 0x0000 0000

This register defines the accumulated number of horizontal synchronization, back porch, active and front porch pixels minus 1 (HSYNC width + HBP + active width + HFP - 1) and the accumulated number of vertical synchronization, back porch lines, active and front lines minus 1 (VSYNC height + VBP + active height + VFP - 1). Refer to *Figure 420* and *Section 40.4* for an example of configuration.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TOTALW[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	TOTALH[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **TOTALW[11:0]**: Total width (in units of pixel clock period)

These bits define the accumulated total width which includes the horizontal synchronization, horizontal back porch, active width and horizontal front porch pixels minus 1.

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **TOTALH[10:0]**: Total height (in units of horizontal scan line)

These bits define the accumulated height which includes the vertical synchronization, vertical back porch, the active height and vertical front porch height lines minus 1.

40.7.5 LTDC global control register (LTDC_GCR)

Address offset: 0x018

Reset value: 0x0000 2220

This register defines the global configuration of the LCD-TFT controller.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HSPOL	VSPOL	DEPOL	PCPOL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEN
rw	rw	rw	rw												rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	DRW[2:0]			Res.	DGW[2:0]			Res.	DBW[2:0]			Res.	Res.	Res.	LTDCEN
	r	r	r		r	r	r		r	r	r				rw

Bit 31 **HSPOL**: Horizontal synchronization polarity
This bit is set and cleared by software.
0: Horizontal synchronization polarity is active low.
1: Horizontal synchronization polarity is active high.

Bit 30 **VSPOL**: Vertical synchronization polarity
This bit is set and cleared by software.
0: Vertical synchronization is active low.
1: Vertical synchronization is active high.

Bit 29 **DEPOL**: Not data enable polarity
This bit is set and cleared by software.
0: Not data enable polarity is active low.
1: Not data enable polarity is active high.

Bit 28 **PCPOL**: Pixel clock polarity
This bit is set and cleared by software.
0: Pixel clock polarity is active low.
1: Pixel clock is active high.

Bits 27:17 Reserved, must be kept at reset value.

Bit 16 **DEN**: Dither enable
This bit is set and cleared by software.
0: Dither disabled
1: Dither enabled

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **DRW[2:0]**: Dither red width
These bits return the dither red bits.

Bit 11 Reserved, must be kept at reset value.

Bits 10:8 **DGW[2:0]**: Dither green width
These bits return the dither green bits.

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **DBW[2:0]**: Dither blue width
These bits return the dither blue bits.

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **LTDCEN**: LCD-TFT controller enable
This bit is set and cleared by software.
0: LTDC disabled
1: LTDC enabled

40.7.6 LTDC shadow reload configuration register (LTDC_SRCR)

Address offset: 0x024

Reset value: 0x0000 0000

This register allows to reload either immediately or during the vertical blanking period, the shadow registers values to the active registers. The shadow registers are all Layer1 and Layer2 registers except the LTDC_L1CLUTWR and the LTDC_L2CLUTWR.

The shadow registers read back the active values. Until the reload has been done, the 'old' value is read.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VBR	IMR
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **VBR**: Vertical blanking reload

This bit is set by software and cleared only by hardware after reload (it cannot be cleared through register write once it is set).

0: No effect

1: The shadow registers are reloaded during the vertical blanking period (at the beginning of the first line after the active display area).

Bit 0 **IMR**: Immediate reload

This bit is set by software and cleared only by hardware after reload.

0: No effect

1: The shadow registers are reloaded immediately.

40.7.7 LTDC background color configuration register (LTDC_BCCR)

Address offset: 0x02C

Reset value: 0x0000 0000

This register defines the background color (RGB888).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BCRED[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BCGREEN[7:0]								BCBLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **BCRED[7:0]**: Background color red value

These bits configure the background red value.

Bits 15:8 **BCGREEN[7:0]**: Background color green value
These bits configure the background green value.

Bits 7:0 **BCBLUE[7:0]**: Background color blue value
These bits configure the background blue value.

40.7.8 LTDC interrupt enable register (LTDC_IER)

Address offset: 0x034

Reset value: 0x0000 0000

This register determines which status flags generate an interrupt request by setting the corresponding bit to 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RRIE	TERRIE	FUIE	LIE
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **RRIE**: Register reload interrupt enable
This bit is set and cleared by software.
0: Register reload interrupt disable
1: Register reload interrupt enable

Bit 2 **TERRIE**: Transfer error interrupt enable
This bit is set and cleared by software.
0: Transfer error interrupt disable
1: Transfer error interrupt enable

Bit 1 **FUIE**: FIFO underrun interrupt enable
This bit is set and cleared by software.
0: FIFO underrun interrupt disable
1: FIFO underrun Interrupt enable

Bit 0 **LIE**: Line interrupt enable
This bit is set and cleared by software.
0: Line interrupt disable
1: Line interrupt enable

40.7.9 LTDC interrupt status register (LTDC_ISR)

Address offset: 0x038

Reset value: 0x0000 0000

This register returns the interrupt status flag.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RRIF	TERRIF	FUIF	LIF
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **RRIF**: Register reload interrupt flag

0: No register reload interrupt generated

1: Register reload interrupt generated when a vertical blanking reload occurs (and the first line after the active area is reached)

Bit 2 **TERRIF**: Transfer error interrupt flag

0: No transfer error interrupt generated

1: Transfer error interrupt generated when a bus error occurs

Bit 1 **FUIF**: FIFO underrun interrupt flag

0: No FIFO underrun interrupt generated

1: FIFO underrun interrupt generated, if one of the layer FIFOs is empty and pixel data is read from the FIFO

Bit 0 **LIF**: Line interrupt flag

0: No line interrupt generated

1: Line interrupt generated when a programmed line is reached

40.7.10 LTDC interrupt clear register (LTDC_ICR)

Address offset: 0x03C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CRRIF	CTERRIF	CFUIF	CLIF
												w	w	w	w

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **CRRIF**: Clear register reload interrupt flag

0: No effect

1: Clear the RRIF flag in the LTDC_ISR register

Bit 2 **CTERRIF**: Clear the transfer error interrupt flag
0: No effect
1: Clear the TERRIF flag in the LTDC_ISR register.

Bit 1 **CFUIF**: Clear the FIFO underrun interrupt flag
0: No effect
1: Clear the FUDERRIF flag in the LTDC_ISR register.

Bit 0 **CLIF**: Clear the line interrupt flag
0: No effect
1: Clear the LIF flag in the LTDC_ISR register.

40.7.11 LTDC line interrupt position configuration register (LTDC_LIPCR)

Address offset: 0x040

Reset value: 0x0000 0000

This register defines the position of the line interrupt. The line value to be programmed depends on the timings parameters. Refer to *Figure 420*.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	LIPOS[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:0 **LIPOS[10:0]**: Line interrupt position
These bits configure the line interrupt position.

40.7.12 LTDC current position status register (LTDC_CPSR)

Address offset: 0x044

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CXPOS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CYPOS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **CXPOS[15:0]**: Current X position
These bits return the current X position.

Bits 15:0 **CYPOS[15:0]**: Current Y position
These bits return the current Y position.

40.7.13 LTDC current display status register (LTDC_CDSR)

Address offset: 0x048

Reset value: 0x0000 000F

This register returns the status of the current display phase which is controlled by the HSYNC, VSYNC, and horizontal/vertical DE signals.

Example: if the current display phase is the vertical synchronization, the VSYNCS bit is set (active high). If the current display phase is the horizontal synchronization, the HSYNCS bit is active high.

The returned status does not depend on the configured polarity in the LTDC_GCR register, instead it returns the current active display phase.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSYNCS	VSYNCS	HDES	VDES
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **HSYNCS**: Horizontal synchronization display status
0: Active low
1: Active high

Bit 2 **VSYNCS**: Vertical synchronization display status
0: Active low
1: Active high

Bit 1 **HDES**: Horizontal data enable display status
0: Active low
1: Active high

Bit 0 **VDES**: Vertical data enable display status
0: Active low
1: Active high

40.7.14 LTDC layer x control register (LTDC_LxCR)

Address offset: 0x084 + 0x80 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLUTEN	Res.	Res.	COLKEN	LEN
											rw			rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **CLUTEN**: Color look-up table enable
This bit is set and cleared by software.
0: Color look-up table disable
1: Color look-up table enable
The CLUT is only meaningful for L8, AL44 and AL88 pixel format. Refer to *Color look-up table (CLUT)*

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **COLKEN**: Color keying enable
This bit is set and cleared by software.
0: Color keying disable
1: Color keying enable

Bit 0 **LEN**: Layer enable
This bit is set and cleared by software.
0: Layer disabled
1: Layer enabled

40.7.15 LTDC layer x window horizontal position configuration register (LTDC_LxWHPCR)

Address offset: 0x088 + 0x80 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the horizontal position (first and last pixel) of the layer 1 or 2 window.

The first visible pixel of a line is the programmed value of AHBP[11:0] bits + 1 in the LTDC_BPCR register.

The last visible pixel of a line is the programmed value of AAW[11:0] bits in the LTDC_AWCR register.

Example: The LTDC_BPCR register is configured to 0x000E0005 (AHBP[11:0] is 0xE) and the LTDC_AWCR register is configured to 0x028E01E5 (AAW[11:0] is 0x28E). To configure the horizontal position of a window size of 630x460, with horizontal start offset of 5 pixels in the active data area:

- layer window first pixel, WHSTPOS[11:0], must be programmed to 0x14 (0xE+1+0x5).
- layer window last pixel, WHSPPOS[11:0], must be programmed to 0x28A.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	WHSPPOS[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	WHSTPOS[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **WHSPPOS[11:0]**: Window horizontal stop position
These bits configure the last visible pixel of a line of the layer window.
WHSPPOS[11:0] must be ≥ AHBP[11:0] bits + 1 (programmed in LTDC_BPCR register).

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **WHSTPOS[11:0]**: Window horizontal start position
These bits configure the first visible pixel of a line of the layer window.
WHSTPOS[11:0] must be ≤ AAW[11:0] bits (programmed in LTDC_AWCR register).

40.7.16 LTDC layer x window vertical position configuration register (LTDC_LxWVPCR)

Address offset: 0x08C + 0x80 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the vertical position (first and last line) of the layer1 or 2 window.

The first visible line of a frame is the programmed value of AVBP[10:0] bits + 1 in the register LTDC_BPCR register.

The last visible line of a frame is the programmed value of AAH[10:0] bits in the LTDC_AWCR register.

Example:

The LTDC_BPCR register is configured to 0x000E0005 (AVBP[10:0] is 0x5) and the LTDC_AWCR register is configured to 0x028E01E5 (AAH[10:0] is 0x1E5).

To configure the vertical position of a window size of 630x460, with vertical start offset of eight lines in the active data area:

- layer window first line, WVSTPOS[10:0], must be programmed to 0xE (0x5 + 1 + 0x8).
- layer window last line, WVSPPOS[10:0] must be programmed to 0x1DA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	WVSPPOS[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	WVSTPOS[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bits 26:16 **WVSPPOS[10:0]**: Window vertical stop position
These bits configure the last visible line of the layer window.
WVSPPOS[10:0] must be ≥ AVBP[10:0] bits + 1 (programmed in LTDC_BPCR register).

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **WVSTPOS[10:0]**: Window vertical start position
These bits configure the first visible line of the layer window.
WVSTPOS[10:0] must be ≤ AAH[10:0] bits (programmed in LTDC_AWCR register).

40.7.17 LTDC layer x color keying configuration register (LTDC_LxCKCR)

Address offset: 0x090 + 0x80 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the color key value (RGB), that is used by the color keying.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CKRED[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CKGREEN[7:0]								CKBLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **CKRED[7:0]**: Color key red value

Bits 15:8 **CKGREEN[7:0]**: Color key green value

Bits 7:0 **CKBLUE[7:0]**: Color key blue value

40.7.18 LTDC layer x pixel format configuration register (LTDC_LxPFCR)

Address offset: 0x094 + 0x80 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the pixel format that is used for the stored data in the frame buffer of a layer. The pixel data is read from the frame buffer and then transformed to the internal format 8888 (ARGB).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PF[2:0]		
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **PF[2:0]**: Pixel format
These bits configure the pixel format
000: ARGB8888
001: RGB888
010: RGB565
011: ARGB1555
100: ARGB4444
101: L8 (8-bit luminance)
110: AL44 (4-bit alpha, 4-bit luminance)
111: AL88 (8-bit alpha, 8-bit luminance)

40.7.19 LTDC layer x constant alpha configuration register (LTDC_LxCACR)

Address offset: 0x098 + 0x80 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 00FF

This register defines the constant alpha value (divided by 255 by hardware), that is used in the alpha blending. Refer to LTDC_LxBFCR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CONSTA[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **CONSTA[7:0]**: Constant alpha

These bits configure the constant alpha used for blending. The constant alpha is divided by 255 by hardware.

Example: if the programmed constant alpha is 0xFF, the constant alpha value is 255 / 255 = 1.

40.7.20 LTDC layer x default color configuration register (LTDC_LxDCCR)

Address offset: 0x09C + 0x80 * (x - 1), (*x* = 1 to 2)

Reset value: 0x0000 0000

This register defines the default color of a layer in the format ARGB. The default color is used outside the defined layer window or when a layer is disabled. The reset value of 0x00000000 defines a transparent black color.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DCALPHA[7:0]								DCRED[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DCGREEN[7:0]								DCBLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **DCALPHA[7:0]**: Default color alpha

These bits configure the default alpha value.

Bits 23:16 **DCRED[7:0]**: Default color red

These bits configure the default red value.

Bits 15:8 **DCGREEN[7:0]**: Default color green

These bits configure the default green value.

Bits 7:0 **DCBLUE[7:0]**: Default color blue

These bits configure the default blue value.

40.7.21 LTDC layer x blending factors configuration register (LTDC_LxBFCR)

Address offset: 0x0A0 + 0x80 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0607

This register defines the blending factors F1 and F2.

The general blending formula is: BC = BF1 x C + BF2 x Cs

- BC = blended color
- BF1 = blend factor 1
- C = current layer color
- BF2 = blend factor 2
- Cs = subjacent layers blended color

The constant alpha value, is the programmed value in LTDC_LxCACR divided by 255 by hardware.

Example: Only layer1 is enabled, BF1 configured to constant alpha. BF2 configured to 1 - *constant alpha. The constant alpha programmed in LTDC_LxCACR is 240 (0xF0). Thus, the constant alpha value is 240 / 255 = 0.94. C: current layer color is 128.*
Cs: background color is 48. Layer1 is blended with the background color.
BC = constant alpha x C + *(1 - Constant Alpha*) x Cs = *0.94 x 128 + (1- 0.94) x 48 = 123.*

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	BF1[2:0]			Res.	Res.	Res.	Res.	Res.	BF2[2:0]		
					rw	rw	rw						rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:8 **BF1[2:0]**: Blending factor 1
These bits select the blending factor F1.
100: constant alpha
110: pixel alpha x constant alpha
Others: Reserved

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **BF2[2:0]**: blending factor 2
These bits select the blending factor F2
101: 1 - constant alpha
111: 1 - (pixel alpha x constant alpha)
Others: Reserved

40.7.22 LTDC layer x color frame buffer address register (LTDC_LxCFBAR)

Address offset: 0x0AC + 0x80 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the color frame buffer start address which has to point to the address where the pixel data of the top left pixel of a layer is stored in the frame buffer.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CFBADD[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CFBADD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CFBADD[31:0]**: Color frame buffer start address

These bits define the color frame buffer start address.

40.7.23 LTDC layer x color frame buffer length register (LTDC_LxCFBLR)

Address offset: 0x0B0 + 0x80 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the color frame buffer line length and pitch.

Example:

- A frame buffer having the format RGB565 (2 bytes per pixel) and a width of 256 pixels (total number of bytes per line is 256 * 2 = 512), where pitch = line length requires a value of 0x02000203 to be written into this register.
- A frame buffer having the format RGB888 (3 bytes per pixel) and a width of 320 pixels (total number of bytes per line is 320 * 3 = 960), where pitch = line length requires a value of 0x03C003C3 to be written into this register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	CFBP[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	CFBLL[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:16 **CFBP[12:0]**: Color frame buffer pitch in bytes

These bits define the pitch that is the increment from the start of one line of pixels to the start of the next line in bytes.

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:0 **CFBLL[12:0]**: Color frame buffer line length
These bits define the length of one line of pixels in bytes + 3.
The line length is computed as follows:
active high width * number of bytes per pixel + 3.

40.7.24 LTDC layer x color frame buffer line number register (LTDC_LxCFBLNR)

Address offset: 0x0B4 + 0x80 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the number of lines in the color frame buffer.

The number of lines and line length settings define how much data is fetched per frame for every layer. If it is configured to less bytes than required, a FIFO underrun interrupt is generated if enabled.

The start address and pitch settings on the other hand define the correct start of every line in memory.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	CFBLNBR[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:0 **CFBLNBR[10:0]**: Frame buffer line number
These bits define the number of lines in the frame buffer that corresponds to the active high width.

40.7.25 LTDC layer x CLUT write register (LTDC_LxCLUTWR)

Address offset: 0x0C4 + 0x80 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the CLUT address and the RGB value.

The CLUT write register must be configured only during blanking period or if the layer is disabled. The CLUT can be enabled or disabled in the LTDC_LxCR register.

The CLUT is only meaningful for L8, AL44 and AL88 pixel format.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CLUTADD[7:0]								RED[7:0]							
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GREEN[7:0]								BLUE[7:0]							
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:24 **CLUTADD[7:0]**: CLUT address
These bits configure the CLUT address (color position within the CLUT) of each RGB value.

Bits 23:16 **RED[7:0]**: Red value
These bits configure the red value.

Bits 15:8 **GREEN[7:0]**: Green value
These bits configure the green value.

Bits 7:0 **BLUE[7:0]**: Blue value
These bits configure the blue value.

40.7.26 LTDC register map

Table 408. LTDC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x008	LTDC_SSCR	Res.	Res.	Res.	Res.	HSW[11:0]												Res.	Res.	Res.	Res.	Res.	VSH[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x00C	LTDC_BPCR	Res.	Res.	Res.	Res.	AHBP[11:0]												Res.	Res.	Res.	Res.	Res.	AVBP[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x010	LTDC_AWCR	Res.	Res.	Res.	Res.	AAW[11:0]												Res.	Res.	Res.	Res.	Res.	AAH[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x014	LTDC_TWCR	Res.	Res.	Res.	Res.	TOTALW[11:0]												Res.	Res.	Res	Res	Res.	TOTALH[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x018	LTDC_GCR	HSPOL	VSPOL	DEPOL	PCPOL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEN	Res.	DRW[2:0]			Res.	DGW[2:0]			Res.	DBW[2:0]			Res.	Res.	Res.	LTDCEN
	Reset value	0	0	0	0												0		0	1	0		0	1	0		0	1	0				0
0x024	LTDC_SRCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VBR	IMR
	Reset value																															0	0
0x02C	LTDC_BCCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BCRED[7:0]								BCGREEN[7:0]								BCBLUE[7:0]							
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x030	Reserved	Reserved																															
0x034	LTDC_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RRIE	TERRIE	FUIE	LIE
	Reset value																													0	0	0	0
0x038	LTDC_ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RRIF	TERRIF	FUIF	LIF
	Reset value																													0	0	0	0

Table 408. LTDC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x03C	LTDC_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CRRIF	CTERRIF	CFUIF	CLIF
	Reset value																													0	0	0	0
0x040	LTDC_LIPCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LIPOS10:0]										
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x044	LTDC_CPSR	CXPOS[15:0]																CYPOS[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x048	LTDC_CDSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSYNCS	VSYNCS	HDES	VDES
	Reset value																													1	1	1	1
0x04C-0x080	Reserved	Reserved																															
0x084	LTDC_L1CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLUTEN	Res.	Res.	COLKEN	LEN
	Reset value																												0			0	0
0x088	LTDC_L1WHPCR	Res.	Res.	Res.	Res.	WHSPPOS[11:0]												Res.	Res.	Res.	Res.	WHSTPOS[11:0]											
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x08C	LTDC_L1WVPCR	Res.	Res.	Res.	Res.	Res.	WVSPPOS[10:0]											Res.	Res.	Res.	Res.	Res.	WVSTPOS[10:0]										
	Reset value						0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x090	LTDC_L1CKCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CKRED[7:0]								CKGREEN[7:0]								CKBLUE[7:0]							
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x094	LTDC_L1PFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PF[2:0]		
	Reset value																														0	0	0
0x098	LTDC_L1CACR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CONSTA[7:0]							
	Reset value																									1	1	1	1	1	1	1	1
0x09C	LTDC_L1DCCR	DCALPHA[7:0]								DCRED[7:0]								DCGREEN[7:0]								DCBLUE[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A0	LTDC_L1BFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BF1[2:0]			Res.	Res.	Res.	Res.	Res.	BF2[2:0]		
	Reset value																						1	1	0						1	1	1
0x0A4-0x0A8	Reserved	Reserved																															
0x0AC	LTDC_L1CFBAR	CFBADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B0	LTDC_L1CFBLR	Res.	Res.	Res.	CFBP[12:0]													Res.	Res.	Res.	CFBLL[12:0]												
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B4	LTDC_L1CFBLNR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CFBLNBR[10:0]										
	Reset value																						0	0	0	0	0	0	0	0	0	0	0

Table 408. LTDC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0B8-0x0C0	Reserved	Reserved																															
0x0C4	LTDC_L1CLUTWR	CLUTADD[7:0]								RED[7:0]								GREEN[7:0]								BLUE[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C8-0x100	Reserved	Reserved																															
0x104	LTDC_L2CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLUTEN	Res.	Res.	COLKEN	LEN
	Reset value																												0			0	0
0x108	LTDC_L2WHPCR	Res.	Res.	Res.	Res.	WHSPPOS[11:0]												Res.	Res.	Res.	Res.	WHSTPOS[11:0]											
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x10C	LTDC_L2WVPCR	Res.	Res.	Res.	Res.	Res.	WVSPPOS[10:0]											Res.	Res.	Res.	Res.	Res.	WVSTPOS[10:0]										
	Reset value						0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x110	LTDC_L2CKCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CKRED[7:0]								CKGREEN[7:0]								CKBLUE[7:0]							
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x114	LTDC_L2PFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PF[2:0]		
	Reset value																														0	0	0
0x118	LTDC_L2CACR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CONSTA[7:0]							
	Reset value																									1	1	1	1	1	1	1	1
0x11C	LTDC_L2DCCR	DCALPHA[7:0]								DCRED[7:0]								DCGREEN[7:0]								DCBLUE[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x120	LTDC_L2BFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BF1[2:0]			Res.	Res.	Res.	Res.	Res.	BF2[2:0]		
	Reset value																						1	1	0						1	1	1
0x124-0x128	Reserved	Reserved																															
0x12C	LTDC_L2CFBAR	CFBADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x130	LTDC_L2CFBLR	Res.	Res.	Res.	CFBP[12:0]													Res.	Res.	Res.	CFBLL[12:0]												
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0	0
0x134	LTDC_L2CFBLNR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CFBLNBR[10:0]										
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x138-0x140	Reserved	Reserved																															
0x144	LTDC_L2CLUTWR	CLUTADD[7:0]								RED[7:0]								GREEN[7:0]								BLUE[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3* for the register boundary addresses.

41 JPEG codec (JPEG)

41.1 JPEG introduction

The hardware 8-bit JPEG codec encodes an uncompressed image data stream or decodes JPEG-compressed image data stream. It also fully manages JPEG headers.

41.2 JPEG codec main features

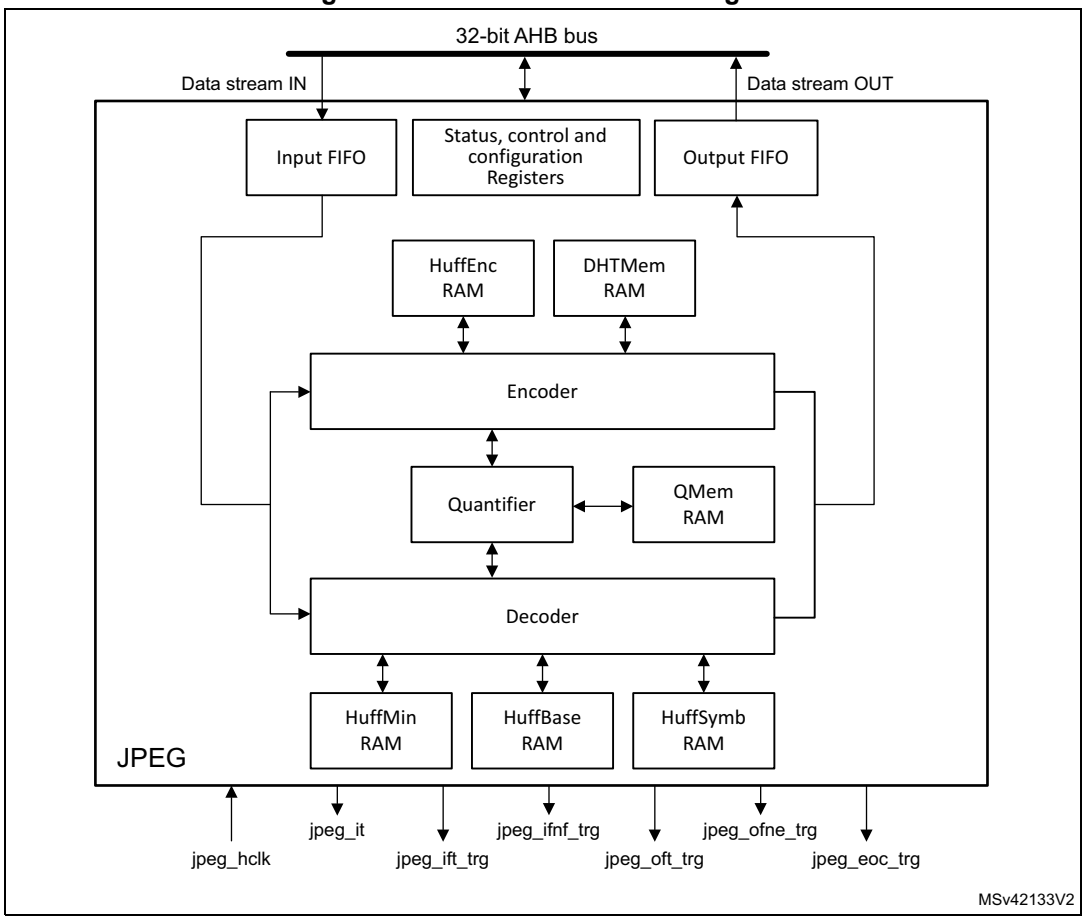
- High-speed fully synchronous operation
- Configurable as encoder or decoder
- Single-clock-per-pixel encode/decode
- RGB, YCbCr, YCMK, and BW (gray scale) image color space support
- 8-bit depth per image component at encode/decode
- JPEG header generator/parser with enable/disable
- Four programmable quantization tables
- Single-clock Huffman coding and decoding
- Fully programmable Huffman tables (two AC and two DC)
- Fully programmable minimum coded unit (MCU)
- Concurrent input and output data stream interfaces

41.3 JPEG codec block functional description

41.3.1 General description

The block diagram of the JPEG codec is shown in *Figure 424*.

Figure 424. JPEG codec block diagram



41.3.2 JPEG internal signals

Table 409 lists the JPEG internal signals.

Table 409. JPEG internal signals

Signal name	Signal type	Description
jpeg_hclk	Digital input	JPEG kernel and register interface clock
jpeg_it	Digital output	JPEG global interrupt
jpeg_ift_trg	Digital output	JPEG input FIFO threshold for DMA trigger
jpeg_ifnf_trg	Digital output	JPEG input FIFO not full for DMA trigger
jpeg_oft_trg	Digital output	JPEG output FIFO threshold for DMA trigger

Table 409. JPEG internal signals (continued)

Signal name	Signal type	Description
jpeg_ofne_trg	Digital output	JPEG output FIFO not empty for DMA trigger
jpeg_eoc_trg	Digital output	JPEG end of conversion for DMA trigger

Table 410. JPEG trigger connections

Trigger name	Direction	Trigger source/destination
jpeg_ift_trg	Output	gpdma1_trigsel[54] gpdma2_trigsel[54]
jpeg_ifnf_trg	Output	gpdma1_trigsel[55] gpdma2_trigsel[55]
jpeg_oft_trg	Output	gpdma1_trigsel[56] gpdma2_trigsel[56]
jpeg_ofne_trg	Output	gdma1_trigsel[57] gpdma2_trigsel[57]
jpeg_eoc_trg	Output	gpdma1_trigsel[58] gpdma2_trigsel[58]

41.3.3 JPEG decoding procedure

The JPEG codec can decode a JPEG stream as defined in the *ISO/IEC 10918-1* specification.

It can optionally parse the JPEG header and accordingly update the JPEG codec registers, the quantization tables, and the Huffman tables.

The JPEG codec is configured in decode mode setting the DE bit (decode enable) of the JPEG_CONFR1 register.

The JPEG decode starts by setting the START bit of the JPEG_CONFR0 register.

The JPEG codec requests data for its input FIFO through generating one of:

- DMA request
- DMA trigger
- Interrupts

DMA generation for input FIFO

A DMA request is generated when the 32-byte input FIFO becomes at least half-empty, that is, when there is free room for writing 16 bytes of data.

The DMA request generation is independent of the START bit of the JPEG_CONFR0 register. If the input FIFO can accept 16 bytes and the DMA for the input FIFO is enabled (setting the IDMAEN bit of the JPEG_CR register), a DMA request is generated regardless of the state of the JPEG codec kernel.

A burst transfer is launched by the DMA to write 16 bytes of data.

Writes are ignored if the input FIFO is full.

At the end of the decoding process, extra bytes may remain in the input FIFO and/or a DMA request may be pending. The FIFO can be flushed by setting the IFF bit (input FIFO flush) of the JPEG_CR register.

Prior to flushing the FIFO, the DMA for the input FIFO must be disabled to prevent unwanted DMA request upon flushing the FIFO.

The consequence of not flushing the FIFO at the end of the decoding process is that any remaining data is taken into the next JPEG decoding.

DMA requests are no more generated once the EOCF flag of the JPEG_SR register is set.

Interrupt or DMA trigger generation for input FIFO

Input FIFO can be managed using interrupts or DMA triggers through two flags according to the FIFO state:

- Input FIFO not full flag: a 32-bit value can be written in.
- Input FIFO threshold flag: 8 words (32 bytes) can be written in.

The interrupt or DMA trigger generation is independent of the START bit of the JPEG_CONFR0 register. The input FIFO flags are generated regardless of the state of the JPEG codec kernel.

Writes are ignored if the input FIFO is full.

At the end of the decoding process, extra bytes may remain in the input FIFO and/or an interrupt request / DMA trigger may be pending. The FIFO can be flushed by setting the IFF bit (Input FIFO Flush) of the JPEG_CR register.

Prior to flushing the FIFO:

- The interrupts for the input FIFO must be disabled to prevent an unwanted interrupt request upon flushing the FIFO.
- The DMA channel must be stopped to prevent an unwanted DMA trigger.

The consequence of not flushing the FIFO at the end of the decoding process is that any remaining data is taken into the next JPEG decoding.

Header parsing

The header parsing can be activated by setting the HDR bit of the JPEG_CONFR1 register.

The JPEG header parser supports all markers relevant to the JPEG baseline algorithm indicated in *Annex B* of the *ISO/IEC 10918-1*.

When parsing a supported marker, the JPEG header parser extracts the required parameters and stores them in shadow registers. At the end of the parsing the JPEG codec registers are updated.

If a DQT marker segment is located, quantization data associated with it is written into the quantization table memory.

If a DHT marker segment is located, the Huffman table data associated with it is converted into three different table formats (HuffMin, HuffBase, and HuffSymb) and stored in their respective memories.

Once the parsing operation is completed, the HPDF (header parsing done flag) bit of the JPEG_SR register is set. An interrupt is generated if the EHPIE (end of header parsing interrupt enable) bit of the JPEG_CR register is set.

JPEG decoding

Once the JPEG header is parsed or the JPEG codec registers and memories are properly programmed, the incoming data stream is decoded and the resulting MCUs are sent to the output FIFO.

When decoding two images successively, the START bit of the JPEG_CONFR0 register must be set again (even if already 1) after the header processing of the second image is completed.

DMA generation for output FIFO

A DMA request is generated when the 32-byte output FIFO becomes at least half-full, that is, when there are at least 16 bytes of data.

A burst transfer is launched by the DMA to read 16 bytes of data.

Reads return 0 if the output FIFO is empty.

Once the decoding process is done, no extra bytes must remain in the output FIFO and no DMA request must be pending as the JPEG decoding generates blocks of 64 bytes.

In case of abort of the JPEG codec operations by resetting the START bit of the JPEG_CONFR0 register, the output FIFO can be flushed by setting the OFF bit (input FIFO flush) of the JPEG_CR register.

Prior to flushing the FIFO, the DMA for the output FIFO must be disabled to prevent an unwanted DMA request upon flushing the FIFO.

Interrupt or DMA trigger generation for output FIFO

The output FIFO can be managed using interrupts or DMA triggers through two flags according to the FIFO state:

- Output FIFO not empty flag: a 32-bit value can be read out.
- Output FIFO threshold flag: 8 words (32 bytes) can be read out.

Reads return 0 if the output FIFO is empty.

In case of abort of the JPEG codec operations by resetting the START bit of the JPEG_CONFR0 register, the output FIFO can be flushed. If the FIFO needs to be flushed, it must be done by software setting the FF bit (FIFO flush) of the JPEG_CR register.

Prior to flushing the FIFO:

- The interrupts for the output FIFO must be disabled to prevent unwanted interrupt request upon flushing the FIFO.
- The DMA channel must be stopped to prevent an unwanted DMA trigger.

The output FIFO must be flushed at the end of processing before any JPEG configuration change.

41.3.4 JPEG encoding procedure

The JPEG codec can encode a JPEG stream as defined in the *ISO/IEC 10918-1* specification.

It can optionally generate the JPEG header.

The JPEG codec is configured in encode mode resetting the DE bit (decode enable) of the JPEG_CONFR1 register.

The configuration used for encoding the JPEG must be loaded in the JPEG codec:

- JPEG codec configuration registers
- Quantization tables
- Huffman tables

The JPEG codec is started setting the START bit of the JPEG_CONFR0 register.

Once the JPEG codec has been started, it requests data for its input FIFO generating one of:

- DMA request
- DMA trigger
- Interrupts

DMA generation for input FIFO

A DMA request is generated when the 32-byte input FIFO becomes at least half-empty, that is, when there is free room for writing 16 bytes of data.

The DMA request generation is independent of the START bit of the JPEG_CONFR0 register. If the input FIFO can accept 16 bytes and the DMA for the input FIFO is enabled (setting the IDMAEN bit of the JPEG_CR register), a DMA request is generated regardless of the state of the JPEG codec kernel.

A burst transfer is launched by the DMA to write 16 bytes of data.

Writes are ignored if the input FIFO is full.

At the end of the encoding process, extra bytes may remain in the input FIFO and/or a DMA request may be pending. The FIFO can be flushed by setting the IFF bit (input FIFO flush) of the JPEG_CR register.

Prior to flushing the FIFO, the DMA for the input FIFO must be disabled to prevent unwanted DMA request upon flushing the FIFO.

The consequence of not flushing the FIFO at the end of the encoding process is that any remaining data is taken into the next JPEG encoding.

The DMA requests are no more generated once the EOCF flag of the JPEG_SR register is set.

Interrupt or DMA trigger generation for input FIFO

Input FIFO can be managed using interrupts or DMA triggers through two flags according to the FIFO state:

- Input FIFO not full flag: a 32-bit value can be written in.
- Input FIFO threshold flag: 8 words (32 bytes) can be written in.

The interrupt or DMA trigger generation is independent of the START bit of the JPEG_CONFR0 register. The input FIFO flags are generated regardless of the state of the JPEG codec kernel.

Writes are ignored if the input FIFO is full.

At the end of the encoding process, extra bytes may remain in the input FIFO and/or an interrupt request / DMA trigger may be pending. The FIFO can be flushed by setting the IFF bit (input FIFO flush) of the JPEG_CR register.

Prior to flushing the FIFO:

- The interrupts for the input FIFO must be disabled to prevent an unwanted interrupt request upon flushing the FIFO.
- The DMA channel must be stopped to prevent an unwanted DMA trigger.

The consequence of not flushing the FIFO at the end of the encoding process is that any remaining data is taken into the next JPEG encoding.

JPEG encoding

Once the JPEG header is generated, the incoming MCUs are encoded and the resulting data stream sent to the output FIFO.

DMA generation for output FIFO

A DMA request is generated when the 32-byte output FIFO becomes at least half-full, that is, when there are at least 16 bytes of data.

A burst transfer is launched by the DMA to read 16 bytes of data.

Read returns 0 if the output FIFO is empty.

At the end of the encoding process, the last bytes may remain in the output FIFO as the stream padding may not be on 16 bytes.

These additional bytes must be managed by the CPU using the output FIFO not empty flag.

In case of abort of the JPEG codec operations by resetting the START bit of the JPEG_CONFR0 register, the output FIFO can be flushed. The FIFO can be flushed by setting the OFF bit (output FIFO flush) of the JPEG_CR register.

Prior to flushing the FIFO, the DMA for the input FIFO must be disabled to prevent an unwanted DMA request upon flushing the FIFO.

Interrupt or DMA trigger generation for output FIFO

Output FIFO can be managed using interrupts or DMA triggers through two flags according to the FIFO state:

- Output FIFO not empty flag: a 32-bit value can be read out.
- Output FIFO threshold flag: 8 words (32 bytes) can be read out.

Reads return 0 if the output FIFO is empty.

In case of abort of the JPEG codec operations by resetting the START bit of the JPEG_CONFR0 register, the output FIFO can be flushed. The FIFO can be flushed by setting the FF bit (FIFO flush) of the JPEG_CR register.

Prior to flushing the FIFO:

- The interrupts for the output FIFO must be disabled to prevent an unwanted interrupt request upon flushing the FIFO.
- The DMA channel must be stopped to prevent an unwanted DMA trigger.

The output FIFO must be flushed at the end of processing before any JPEG configuration change.

The EOCF bit (end of conversion flag) of the JPEG_SR register can only be cleared when the output FIFO is empty.

Clearing either of the HDR bit (header processing) of the JPEG_CONFR1 register and the JCEN bit (JPEG codec enable) of the JPEG_CR register is allowed only when the EOCF bit of the JPEG_SR register is cleared.

41.4 JPEG codec interrupts

An interrupt can be produced on the following events:

- input FIFO threshold reached
- input FIFO not full
- output FIFO threshold reached
- output FIFO not empty
- end of conversion
- header parsing done

Separate interrupt enable bits are available for flexibility.

Table 411. JPEG codec interrupt requests

Interrupt event	Event flag	Enable Control bit
Input FIFO threshold reached	IFTF	IFTIE
Input FIFO not full	IFNFF	IFNFIE
Output FIFO threshold reached	OFTF	OFTIE
Output FIFO not empty	OFNEF	OFNEIE
End of conversion	EOCF	EOCIE
Header parsing done	HPDF	HPDIE

41.5 JPEG codec registers

41.5.1 JPEG codec control register (JPEG_CONFR0)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	START
															w

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **START**: Start
This bit start or stop the encoding or decoding process.
0: Stop/abort
1: Start
Note: Reads always return 0.

41.5.2 JPEG codec configuration register 1 (JPEG_CONFR1)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
YSIZE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDR	NS[1:0]		COLSPACE[1:0]		DE	Res.	NF[1:0]	
							rw	rw	rw	rw	rw	rw		rw	rw

Bits 31:16 **YSIZE[15:0]**: Y Size
This field defines the number of lines in source image.

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **HDR**: Header processing
This bit enables the header processing (generation/parsing).
0: Disable
1: Enable

Bits 7:6 **NS[1:0]**: Number of components for scan
This field defines the number of components minus 1 for scan header marker segment.

Bits 5:4 **COLSPACE[1:0]**: Color space
This filed defines the number of quantization tables minus 1 to insert in the output stream.
00: Grayscale (1 quantization table)
01: YUV (2 quantization tables)
10: RGB (3 quantization tables)
11: CMYK (4 quantization tables)

Bit 3 **DE**: Codec operation as coder or decoder
This bit selects the code or decode process
0: Code
1: Decode

Bit 2 Reserved, must be kept at reset value.

Bits 1:0 **NF[1:0]**: Number of color components
This field defines the number of color components minus 1.
00: Grayscale (1 color component)
01: - (2 color components)
10: YUV or RGB (3 color components)
11: CMYK (4 color components)

41.5.3 JPEG codec configuration register 2 (JPEG_CONFR2)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	NMCU[25:16]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NMCU[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:0 **NMCU[25:0]**: Number of MCUs

For encoding: this field defines the number of MCU units minus 1 to encode.

For decoding: this field indicates the number of complete MCU units minus 1 to be decoded (this field is updated after the JPEG header parsing). If the decoded image size has not a X or Y size multiple of 8 or 16 (depending on the sub-sampling process), the resulting incomplete or empty MCU must be added to this value to get the total number of MCUs generated.

41.5.4 JPEG codec configuration register 3 (JPEG_CONFR3)

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
XSIZE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:16 **XSIZE[15:0]**: X size

This field defines the number of pixels per line.

Bits 15:0 Reserved, must be kept at reset value.

41.5.5 JPEG codec configuration register x (JPEG_CONFRx)

Address offset: 0x000 + 0x4 * x, (x = 4 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HSF[3:0]				VSF[3:0]				NB[3:0]				QT[1:0]		HA	HD
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **HSF[3:0]**: Horizontal sampling factor
Horizontal sampling factor for component {x-4}.

Bits 11:8 **VSF[3:0]**: Vertical sampling factor
Vertical sampling factor for component {x-4}.

Bits 7:4 **NB[3:0]**: Number of blocks
Number of data units minus 1 that belong to a particular color in the MCU.

Bits 3:2 **QT[1:0]**: Quantization table
Selects quantization table used for component {x-4}.
00: Quantization table 0
01: Quantization table 1
10: Quantization table 2
11: Quantization table 3

Bit 1 **HA**: Huffman AC
Selects the Huffman table for encoding AC coefficients.
0: Huffman AC table 0
1: Huffman AC table 1

Bit 0 **HD**: Huffman DC
Selects the Huffman table for encoding DC coefficients.
0: Huffman DC table 0
1: Huffman DC table 1

41.5.6 JPEG control register (JPEG_CR)

Address offset: 0x030

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	OFF	IFF	ODMAEN	IDMAEN	Res.	Res.	Res.	Res.	HPDIE	EOCIE	OFNEIE	OFTIE	IFNFIE	IFTIE	JCEN
	w	w	rw	rw					rw	rw	rw	rw	rw	rw	rw

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **OFF**: Output FIFO flush
This bit flushes the output FIFO.
0: No effect
1: Output FIFO is flushed
Note: Reads always return 0.

Bit 13 **IFF**: Input FIFO flush
This bit flushes the input FIFO.
0: No effect
1: Input FIFO is flushed
Note: Reads always return 0.

Bit 12 **ODMAEN**: Output DMA enable
Enables DMA request generation for the output FIFO.
0: Disabled
1: Enabled

Bit 11 **IDMAEN**: Input DMA enable
Enables DMA request generation for the input FIFO.
0: Disabled
1: Enabled

Bits 10:7 Reserved, must be kept at reset value.

Bit 6 **HPDIE**: Header parsing done interrupt enable
This bit enables interrupt generation upon the completion of the header parsing operation.
0: Disabled
1: Enabled

Bit 5 **EOCIE**: End of conversion interrupt enable
This bit enables interrupt generation at the end of conversion.
0: Disabled
1: Enabled

Bit 4 **OFNEIE**: Output FIFO not empty interrupt enable
This bit enables interrupt generation when the output FIFO is not empty.
0: Disabled
1: Enabled

Bit 3 **OFTIE**: Output FIFO threshold interrupt enable
This bit enables interrupt generation when the output FIFO reaches a threshold.
0: Disabled
1: Enabled

Bit 2 **IFNFIE**: Input FIFO not full interrupt enable
This bit enables interrupt generation when the input FIFO is not empty.
0: Disabled
1: Enabled

Bit 1 **IFTIE**: Input FIFO threshold interrupt enable
This bit enables interrupt generation when the input FIFO reaches a threshold.
0: Disabled
1: Enabled

Bit 0 **JCEN**: JPEG core enable
This bit enables the JPEG codec core.
0: Disabled (internal registers are reset).
1: Enabled (internal registers are accessible).

41.5.7 JPEG status register (JPEG_SR)

Address offset: 0x034

Reset value: 0x0000 0006

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COF	HPDF	EOCF	OFNEF	OFTF	IFNFF	IFTF	Res.
								r	r	r	r	r	r	r	

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **COF**: Codec operation flag
This bit flags code/decode operation in progress.
0: Not in progress
1: In progress

Bit 6 **HPDF**: Header parsing done flag
In decode mode, this bit flags the completion of header parsing and updating internal registers.
0: Not completed
1: Completed

Bit 5 **EOCF**: End of conversion flag
This bit flags the completion of encode/decode process and data transfer to the output FIFO.
0: Not completed
1: Completed

Bit 4 **OFNEF**: Output FIFO not empty flag

This bit flags that data is available in the output FIFO. This flag must not be considered when using DMA.

0: Empty (data not available)

1: Not empty (data available)

Bit 3 **OFTF**: Output FIFO threshold flag

This bit flags that the amount of data in the output FIFO reaches or exceeds a threshold. This flag must not be considered when using DMA.

0: Below threshold

1: At or above threshold

Bit 2 **IFNFF**: Input FIFO not full flag

This bit flags that the input FIFO is not full (data can be written). This flag must not be considered when using DMA.

0: Full

1: Not full

Bit 1 **IFTF**: Input FIFO threshold flag

This bit flags that the amount of data in the input FIFO is below a threshold. This flag must not be considered when using DMA.

0: At or above threshold

1: Below threshold.

Bit 0 Reserved, must be kept at reset value.

41.5.8 JPEG clear flag register (JPEG_CFR)

Address offset: 0x038

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CHPDF	CEOCF	Res.	Res.	Res.	Res.	Res.
									rt_w1	rt_w1					

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **CHPDF**: Clear header parsing done flag

Writing 1 clears the HPDF bit of the JPEG_SR register.

0: No effect

1: Clear

Bit 5 **CEOCF**: Clear end of conversion flag

Writing 1 clears the ECF bit of the JPEG_SR register.

0: No effect

1: Clear

Bits 4:0 Reserved, must be kept at reset value.

41.5.9 JPEG data input register (JPEG_DIR)

Address offset: 0x040

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATAIN[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATAIN[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **DATAIN[31:0]**: Data input FIFO
Input FIFO data register

41.5.10 JPEG data output register (JPEG_DOR)

Address offset: 0x044

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATAOUT[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATAOUT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **DATAOUT[31:0]**: Data output FIFO
Output FIFO data register.

41.5.11 JPEG quantization memory x (JPEG_QMEMx_y)

Address offset: 0x050 + 0x40 * x + 0x4 * y, (x = 0 to 3; y = 0 to 15)

Reset value: 0xXXXX XXXX

Four quantization tables as specified by ISO documentation.

For decoding with header parsing, no quantization table programming is required, the coefficients are directly written in the quantization memories by the header parser.

For decoding without header parsing or for encoding, the quantization table must be written by software in zig zag order.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
QCOEF{4*y+3}[7:0]								QCOEF{4*y+2}[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
QCOEF{4*y+1}[7:0]								QCOEF{4*y}[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **QCOEF{4*y+3}[7:0]**: Quantization coefficient {4*y+3}
8-bit quantization coefficient.

Bits 23:16 **QCOEF{4*y+2}[7:0]**: Quantization coefficient {4*y+2}
8-bit quantization coefficient.

Bits 15:8 **QCOEF{4*y+1}[7:0]**: Quantization coefficient {4*y+1}
8-bit quantization coefficient.

Bits 7:0 **QCOEF{4*y}[7:0]**: Quantization coefficient {4*y}
8-bit quantization coefficient.

41.5.12 JPEG Huffman min (JPEG_HUFFMINx_y)

Address offset: 0x150 + 0x10 * x + 0x4 * y, (x = 0 to 3; y = 0 to 2)

Reset value: 0xXXXX XXXX

This memory stores the minimum Huffman values used internally by the JPEG decoder. The memory content is written by hardware during the header parsing.

- DATA0: Min AC0 value
- DATA1: Min DC0 value
- DATA2: Min AC1 value
- DATA3: Min DC1 value

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATA{x}[{32*y+31}:{32*y+16}]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA{x}[{32*y+15}:{32*y}]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DATA{x}[{32*y+31}:{32*y}]**: Minimum Huffman value
100-bit minimum Huffman value used internally by the JPEG decoder.

41.5.13 JPEG Huffman min x (JPEG_HUFFMINx_y)

Address offset: 0x150 + 0x10 * x + 0x4 * y, (x = 0 to 3; y = 3)

Reset value: 0xXXXX XXXX

This memory stores the minimum Huffman values used internally by the JPEG decoder. The memory content is written by hardware during the header parsing.

- DATA0: Min AC0 value
- DATA1: Min DC0 value
- DATA2: Min AC1 value
- DATA3: Min DC1 value

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATA{x}[99: 96]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **DATA{x}[99:96]**: Minimum Huffman value
100-bit minimum Huffman value used internally by the JPEG decoder.

41.5.14 JPEG Huffman base (JPEG_HUFFBASEx)

Address offset: 0x190 + 0x4*x, (x = 0 to 31)

Reset value: 0xXXXX XXXX

This memory stores the base Huffman values used internally by the JPEG decoder. The memory content is written by hardware during the header parsing:

- DATA0 to DATA15: Base AC0 value
- DATA16 to DATA31: Base DC0 value
- DATA32 to DATA47: Base AC1 value
- DATA48 to DATA63: Base DC1 value

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATA{2*x+1}[8:0]								
							rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATA{2*x}[8:0]								
							rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 24:16 **DATA{2*x+1}[8:0]**: Data {2*x+1}
Base Huffman value.

Bits 15:9 Reserved, must be kept at reset value.

Bits 8:0 **DATA{2*x}[8:0]**: Data {2*x}
Base Huffman value.

41.5.15 JPEG Huffman symbol (JPEG_HUFFSYMBx)

Address offset: 0x210 + 0x4 * x, (x = 0 to 83)

Reset value: 0xXXXX XXXX

This memory stores the Huffman symbols used internally by the JPEG decoder. The memory content is written by hardware during the header parsing:

- DATA0 to DATA161: AC0 symbols
- DATA162 to DATA173: DC0 and DC1 symbols
- DATA174 to DATA335: AC1 symbols

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATA{4*x+3}[7:0]								DATA{4*x+2}[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA{4*x+1}[7:0]								DATA{4*x}[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **DATA{4*x+3}[7:0]**: Data {4*x+3}
Huffman symbol.

Bits 23:16 **DATA{4*x+2}[7:0]**: Data {4*x+2}
Huffman symbol.

Bits 15:8 **DATA{4*x+1}[7:0]**: Data {4*x+1}
Huffman symbol.

Bits 7:0 **DATA{4*x}[7:0]**: Data {4*x}
Huffman symbol.

41.5.16 JPEG DHT memory (JPEG_DHTMEMx)

Address offset: 0x360 + 0x4 * x, (x = 0 to 102)

Reset value: 0xXXXX XXXX

For encoding process with header generation, this memory stores the DHT marker segment AC and DC Huffman tables in the ISO/IEC specification format:

- DATA0 to DATA27: DC Huffman table0
- DATA28 to DATA205: AC Huffman table0
- DATA206 to DATA233: DC Huffman table1
- DATA234 to DATA411: AC Huffman table1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATA{4*x+3}[7:0]								DATA{4*x+2}[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA{4*x+1}[7:0]								DATA{4*x}[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **DATA{4*x+3}[7:0]**: Huffman table data {4*x+3}
Huffman table data for DHT marker segment generation.

Bits 23:16 **DATA{4*x+2}[7:0]**: Huffman table data {4*x+2}
Huffman table data for DHT marker segment generation.

Bits 15:8 **DATA{4*x+1}[7:0]**: Huffman table data {4*x+1}
Huffman table data for DHT marker segment generation.

Bits 7:0 **DATA{4*x}[7:0]**: Huffman table data {4*x}
Huffman table data for DHT marker segment generation.

41.5.17 JPEG Huffman encoder ACx (JPEG_HUFFENC_ACx_y)

Address offset: 0x500 + 0x160 * x + 0x4 * y, (x = 0 to 1; y = 0 to 87)

Reset value: 0xXXXX XXXX

This memory defines the Huffman codes used during the encoding process of AC components.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	HLEN{2*y+1}[3:0]				HCODE{2*y+1}[7:0]							
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	HLEN{2*y}[3:0]				HCODE{2*y}[7:0]							
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **HLEN{2*y+1}[3:0]**: Huffman length {2*y+1}
Number of bits in the Huffman code HCODE{2*y+1} minus 1.

Bits 23:16 **HCODE{2*y+1}[7:0]**: Huffman code {2*y+1}
8 least significant bits of the Huffman code.
If the Huffman code is less than 8 bits long, the unused bits must be 0.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **HLEN{2*y}[3:0]**: Huffman length {2*y}
Number of bits in the Huffman code HCODE{2*y} minus 1.

Bits 7:0 **HCODE{2*y}[7:0]**: Huffman code {2*y}
8 least significant bits of the Huffman code.
If the Huffman code is less than 8 bits long, the unused bits must be 0.

41.5.18 JPEG Huffman encoder DCx (JPEG_HUFFENC_DCx_y)

Address offset: 0x7C0 + 0x20*x + 0x4*y, (x = 0 to 1; y = 0 to 7)

Reset value: 0xXXXX XXXX

This memory defines the Huffman codes used during the encoding process of DC components.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	HLEN{2*y+1}[3:0]				HCODE{2*y+1}[7:0]							
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	HLEN{2*y}[3:0]				HCODE{2*y}[7:0]							
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **HLEN{2*y+1}[3:0]**: Huffman length {2*y+1}
Number of bits in the Huffman code HCODE{2*y+1} minus 1.

Bits 23:16 **HCODE{2*y+1}[7:0]**: Huffman code {2*y+1}
8 least significant bits of the Huffman code.
If the Huffman code is less than 8 bits long, the unused bits must be 0.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **HLEN{2*y}[3:0]**: Huffman length {2*y}
Number of bits in the Huffman code HCODE{2*y} minus 1.

Bits 7:0 **HCODE{2*y}[7:0]**: Huffman code {2*y}
8 least significant bits of the Huffman code.
If the Huffman code is less than 8 bits long, the unused bits must be 0.

41.5.19 JPEG codec register map

The following table summarizes the JPEG codec registers. Refer to the register boundary addresses table for the JPEG codec register base address.

Table 412. JPEG codec register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	JPEG_CONFR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	START
	Reset value																																0
0x004	JPEG_CONFR1	YSIZE[15:0]																Res.	Res.	Res.	Res.	Res.	Res.	Res.	HDR	NS[1:0]		COLSPACE [1:0]		DE	Res.	NF[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								0	0	0	0	0	0		0	0
0x008	JPEG_CONFR2	Res.	Res.	Res.	Res.	Res.	Res.	NMCU[25:0]																									
	Reset value							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C	JPEG_CONFR3	XSIZE[15:0]																Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																
0x010	JPEG_CONFR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSF[3:0]				VSF[3:0]				NB[3:0]				QT[1:0]		HA	HD
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	JPEG_CONFR5	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSF[3:0]				VSF[3:0]				NB[3:0]				QT[1:0]		HA	HD
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x018	JPEG_CONFR6	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSF[3:0]				VSF[3:0]				NB[3:0]				QT[1:0]		HA	HD
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x01C	JPEG_CONFR7	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSF[3:0]				VSF[3:0]				NB[3:0]				QT[1:0]		HA	HD
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020-0x02C	Reserved	Reserved																															
0x030	JPEG_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OFF	IFF	ODMAEN	IDMAEN	Res.	Res.	Res.	Res.	HPDIE	EOCIE	OFNEIE	OFTIE	IFNFIE	IFTIE	JCEN
	Reset value																		0	0	0	0					0	0	0	0	0	0	0
0x034	JPEG_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COF	HPDF	EOCF	OFNEF	OFTF	IFNFF	IFTF	Res.
	Reset value																									0	0	0	0	0	1	1	
0x038	JPEG_CFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CHPDF	CEOCF	Res.	Res.	Res.	Res.	Res.
	Reset value																										0	0					
0x040	JPEG_DIR	DATAIN[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x044	JPEG_DOR	DATAOUT[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x048-0x04C	Reserved	Reserved																															
0x050-0x08C	JPEG_QMEM0	QCOEF{4*y+3}[7:0]								QCOEF{4*y+2}[7:0]								QCOEF{4*y+1}[7:0]								QCOEF{4*y}[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 412. JPEG codec register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x090-0x0CC	JPEG_QMEM1	QCOEF{4*y+3}[7:0]								QCOEF{4*y+2}[7:0]								QCOEF{4*y+1}[7:0]								QCOEF{4*y}[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x0D0-0x10F	JPEG_QMEM2	QCOEF{4*y+3}[7:0]								QCOEF{4*y+2}[7:0]								QCOEF{4*y+1}[7:0]								QCOEF{4*y}[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x110-0x14C	JPEG_QMEM3	QCOEF{4*y+3}[7:0]								QCOEF{4*y+2}[7:0]								QCOEF{4*y+1}[7:0]								QCOEF{4*y}[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x150-0x18C	JPEG_HUFFMIN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATA{x}[99:96]			
		DATA{x}[95:64]																															
		DATA{x}[63:32]																															
		DATA{x}[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x190-0x20C	JPEG_HUFFBASE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATA{2*x+1}[8:0									Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATA{2*x}[8:0								
	Reset value								X	X	X	X	X	X	X	X	X								X	X	X	X	X	X	X	X	X
0x210-0x35C	JPEG_HUFFSYMB	DATA{4*x+3}[7:0]								DATA{4*x+2}[7:0]								DATA{4*x+1}[7:0]								DATA{4*x}[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x360-0x4F8	JPEG_DHTMEM	DATA{4*x+3}[7:0]								DATA{4*x+2}[7:0]								DATA{4*x+1}[7:0]								DATA{4*x}[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x4FC	Reserved	Res.																															
0x500-0x65C	JPEG_HUFFENC_AC0	Res.	Res.	Res.	Res.	HLEN{2*y+1}[3:0]				HCODE{2*y+1}[7:0]								Res.	Res.	Res.	Res.	HLEN{2*y}[3:0]				HCODE{2*y}[7:0]							
	Reset value					X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
0x660-0x7BC	JPEG_HUFFENC_AC1	Res.	Res.	Res.	Res.	HLEN{2*y+1}[3:0]				HCODE{2*y+1}[7:0]								Res.	Res.	Res.	Res.	HLEN{2*y}[3:0]				HCODE{2*y}[7:0]							
	Reset value					X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
0x7C0-0x7DC	JPEG_HUFFENC_DC0	Res.	Res.	Res.	Res.	HLEN{2*y+1}[3:0]				HCODE{2*y+1}[7:0]								Res.	Res.	Res.	Res.	HLEN{2*y}[3:0]				HCODE{2*y}[7:0]							
	Reset value					X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
0x7E0-0x7FC	JPEG_HUFFENC_DC1	Res.	Res.	Res.	Res.	HLEN{2*y+1}[3:0]				HCODE{2*y+1}[7:0]								Res.	Res.	Res.	Res.	HLEN{2*y}[3:0]				HCODE{2*y}[7:0]							
	Reset value					X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

42 Coupling and chaining bridge (CCB)

42.1 CCB introduction

The coupling and chaining bridge (CCB) is a sophisticated security mechanism designed to ensure that private keys are protected, even against CPU access, and are wrapped with unique device keys, and stored securely in a secure storage.

The CCB can be programmed to implement special coupling and chaining operations required to protect private keys used in PKA protected operations.

These coupling and chaining operations involve the PKA, the SAES, and sometimes the RNG peripherals.

42.2 CCB main features

The principal features of the CCB are listed below:

- AHB system slave port, mapping multiple peripherals (see *Section 42.3*)
- AHB configuration slave port (CCB peripheral), accessible in write through 32-bit word single accesses only (otherwise an AHB bus error is generated, and write accesses are ignored). There is no limitation for reads.
- Optional coupling of PKA RAM writes to SAES input data register
- Support for multiple optional chaining options:
  - Read and write chaining between PKA RAM and SAES
  - SAES to CCB read chaining, with comparison to a 128-bit reference tag
  - RNG output chaining with either PKA RAM or SAES_IVR registers
- Dedicated sequences to support three PKA protected operations (modular exponentiation, scalar multiplication, ECDSA signature)
  - One-time sequence to prepare a PKA protected operation (blob creation)
  - Many-time sequence to execute PKA protected operation (blob usage)
- Optional private key generation for ECDSA signature, and for ECC private key cryptography (key never accessible to the application in clear-text)
- Possibility to encrypt, with AES-256, any PKA blob encryption key using the device unique secret key DHUK (in the SAES), which makes the PKA encrypted blob usable only on this device
- Software-reset capability
- Repository for cryptographic subsystem tamper event flags

42.3 CCB implementation

The CCB connects the peripherals listed in *Table 413*.

Table 413. Peripherals connected by CCB interconnect

Peripheral	Coupling and chaining feature(1)	Tamper status flag in CCB_SR
RNG	Yes	TAMP_EVT0
SAES	Yes	TAMP_EVT1
PKA	Yes	TAMP_EVT2 (registers + PKA RAM)
		TAMP_EVT3 (PKA operations)
CCB	Yes	TAMP_EVT4
AES	No	TAMP_EVT5
HASH	No	-

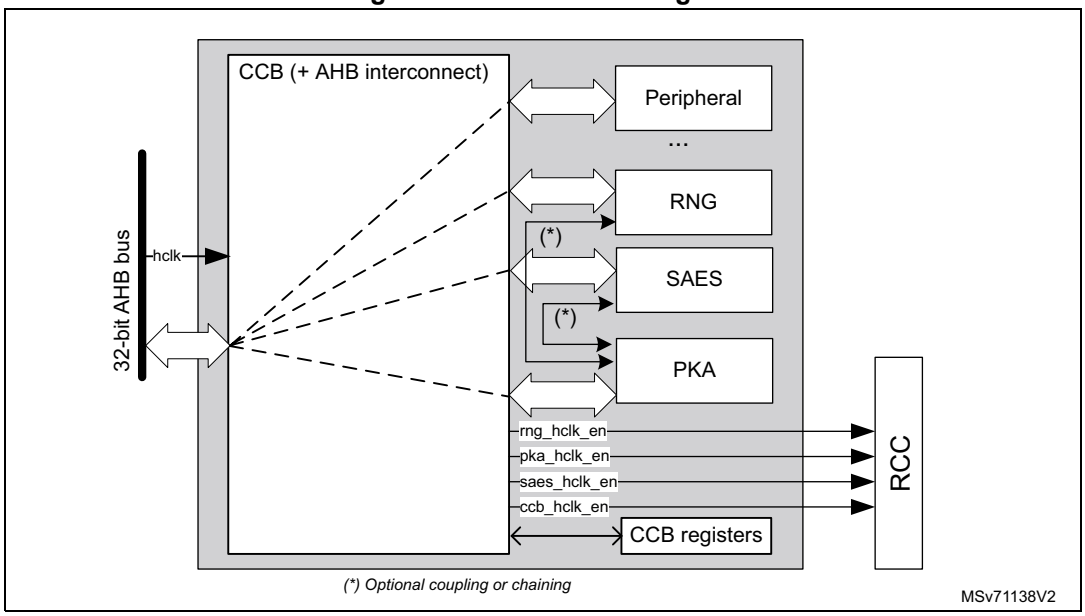
1. See *Section 42.4.4* for details.

42.4 CCB functional description

42.4.1 CCB block diagram

Figure 425 shows the CCB block diagram. Peripherals connected to the CCB interconnect, with optional coupling/chaining features, are defined in *Section 42.3*.

Figure 425. CCB block diagram



42.4.2 CCB internal signals

Table 414 describes the relevant internal signals interfacing the CCB peripheral. Signals targeting peripherals connected to the CCB are not listed.

Table 414. CCB internal input/output signals

Signal name	Signal type	Description
hclk	Digital input	Interconnect system clock input
ccb_hclk_en	Digital output	CCB clock request to the RCC
x_hclk_en	Digital output	Peripheral x clock request to the RCC (x = SAES, PKA, or RNG)

42.4.3 CCB reset and clocks

The CCB shares the same clock used by the AHB bus. Once the CCB clock is activated in the RCC, and coupling and chaining activity is activated by setting CCOP ≠ 0 in CCB_CR, the CCB automatically requests the RCC to enable RNG, SAES, and PKA clocks . These clocks remain enabled until the application gates them in the RCC, with CCOP cleared in the CCB_CR register.

The CCB has a dedicated reset bit in the RCC, and a system reset input. Locally to the CCB it is also possible to trigger a reset of the peripheral based on IPRST (do not use it when the application does not use CCB)in the CCB_CR register (refer to the bitfield description for details). Status register CCB_SR has a specific reset behavior (see *Section 42.7.2*).

When at least a cryptographic peripheral raises a tamper event, the CCB requests its clock to the RCC. The tamper status TAMP_EVTi of these peripherals can be found in the CCB_SR register, as defined in *Section 42.3*.

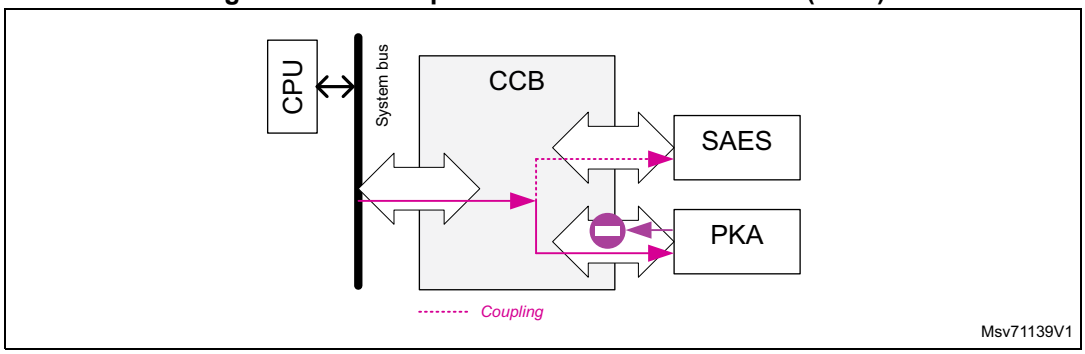
42.4.4 CCB coupling and chaining

Note: The selection of these chaining modes is defined in Section 42.5. In most of these operations, a read of the PKA RAM returns 0 (shown with a purple circle in the following figures).

Coupling CPU → PKA + SAES (write)

When the corresponding OPSTEP is selected, the CCB takes the write requests that go to the PKA RAM, and sends them to SAES_DINR, as shown in *Figure 426*. Write to SAES_DINR is not coupled to the PKA. The CCB sends both data and address to SAES_DINR.

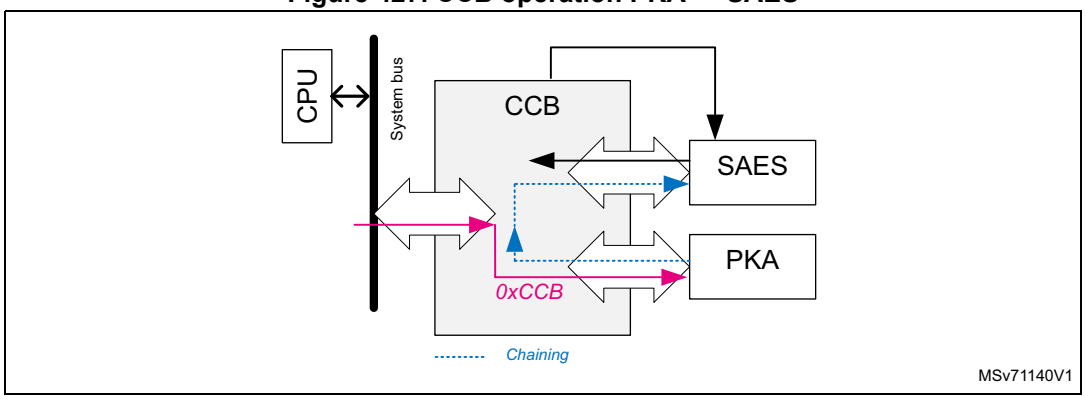
Figure 426. CCB operation CPU → PKA + SAES (write)



Chaining PKA → SAES

When the corresponding OPSTEP is selected, for each 32-bit write request to the PKA RAM of magic number 0xCCB, the CCB generates a read request from the write target (in the PKA RAM) to SAES_DINR.

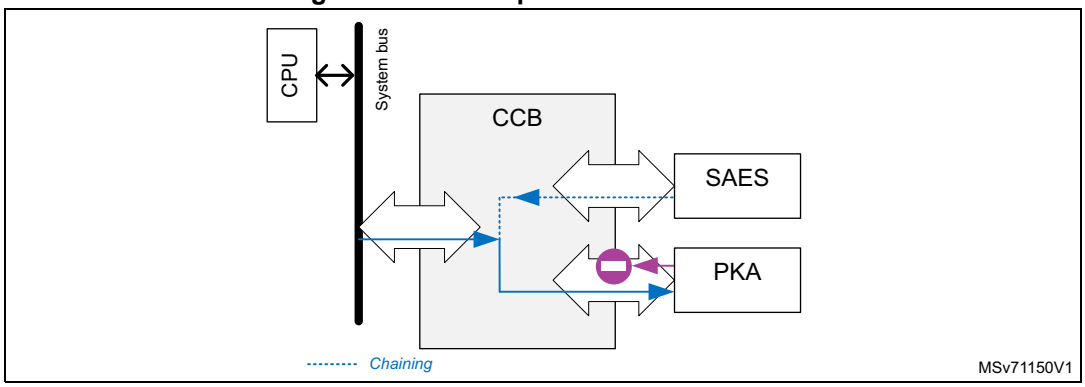
Figure 427. CCB operation PKA → SAES



Chaining SAES → PKA

When the corresponding OPSTEP is selected, the CCB takes the write requests that go to the PKA RAM, and substitutes these data by a 32-bit word coming from SAES_DOUTR. When available, this chaining is activated when the application writes 0xCCB to PKA RAM.

Figure 428. CCB operation SAES → PKA

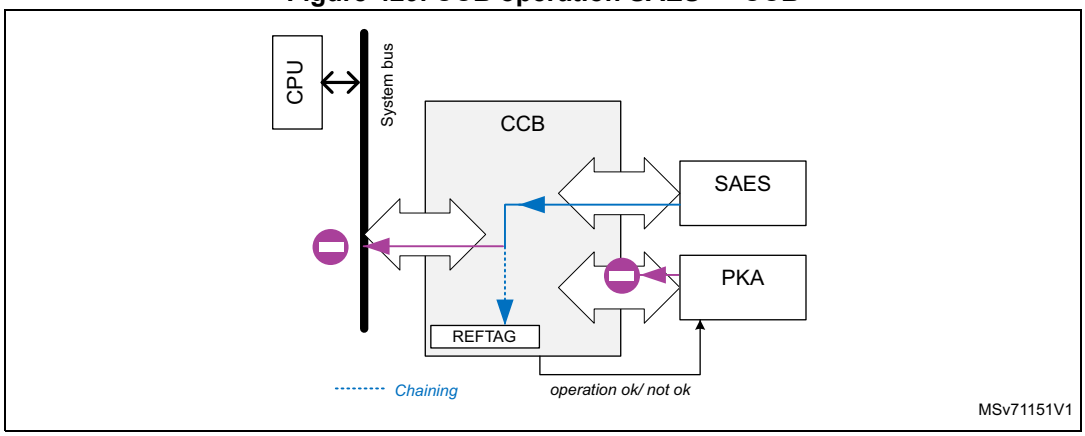


Chaining SAES → CCB

When the corresponding OPSTEP is selected, the CCB takes the read requests to SAES_DOUTR, and sends them to the system interconnect and to CCB_REFTAGRx holding the reference TAG information. For confidentiality reason, read data toward system bus are zeroed by the CCB.

If the CCB finds that the transfered value matches its reference information, it signals to the PKA that it can proceed with the protected PKA operation (START bit can be set).

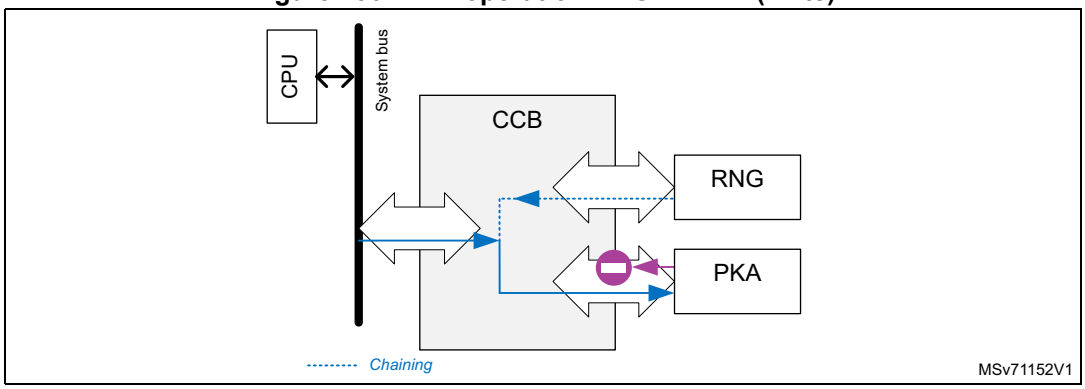
Figure 429. CCB operation SAES → CCB



Chaining RNG → PKA (write)

When the corresponding OPSTEP is selected, the CCB takes the write requests that go to the PKA RAM, and substitutes these data with random numbers coming from RNG_DR. For consistency, the application can write 0xCCB to activate this chaining.

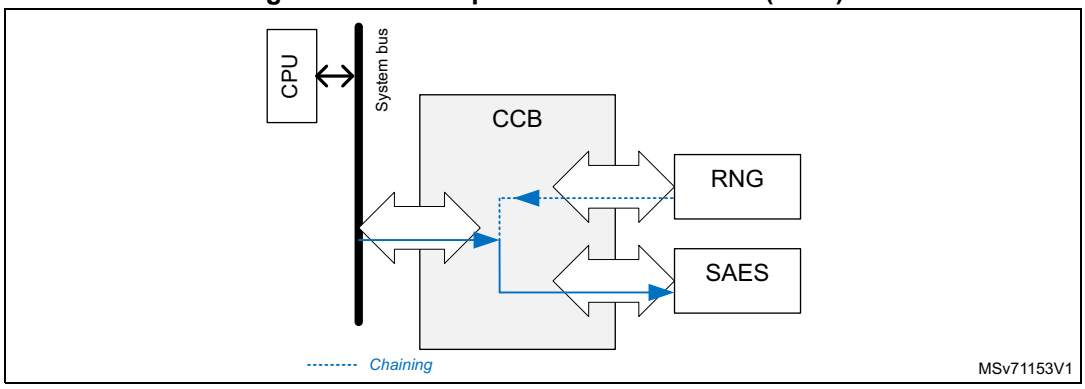
Figure 430. CCB operation RNG → PKA (write)



Chaining RNG → SAES (write)

When the corresponding OPSTEP is selected, the CCB takes the write requests that go to SAES_IVR1 to IVR3, and substitutes these data with random numbers coming from RNG_DR. For consistency, the application can write 0xCCB to activate this chaining.

Figure 431. CCB operation RNG → SAES (write)



42.4.5 CCB error management

When the CCB detects an error during a coupling and chaining operation (see *Section 42.5*), it sets accordingly OPERR[5:0] in CCB_SR (see *Section 42.7.2* for the possible errors).

When OPERR[5:0] ≠ 0 in CCB_SR, the CCB raises IPRST in CCB_CR, sets OPSTEP[4:0] to 0x1F, and sets CCB_BUSY bit to 1. The application must clear IPRST to be able to use again the CCB and the peripheral(s) used by the coupling and chaining operation.

42.5 CCB coupling and chaining operations

When an application must enforce private key confidentiality by wrapping them with a 256-bit hardware unique key, the following steps are needed:

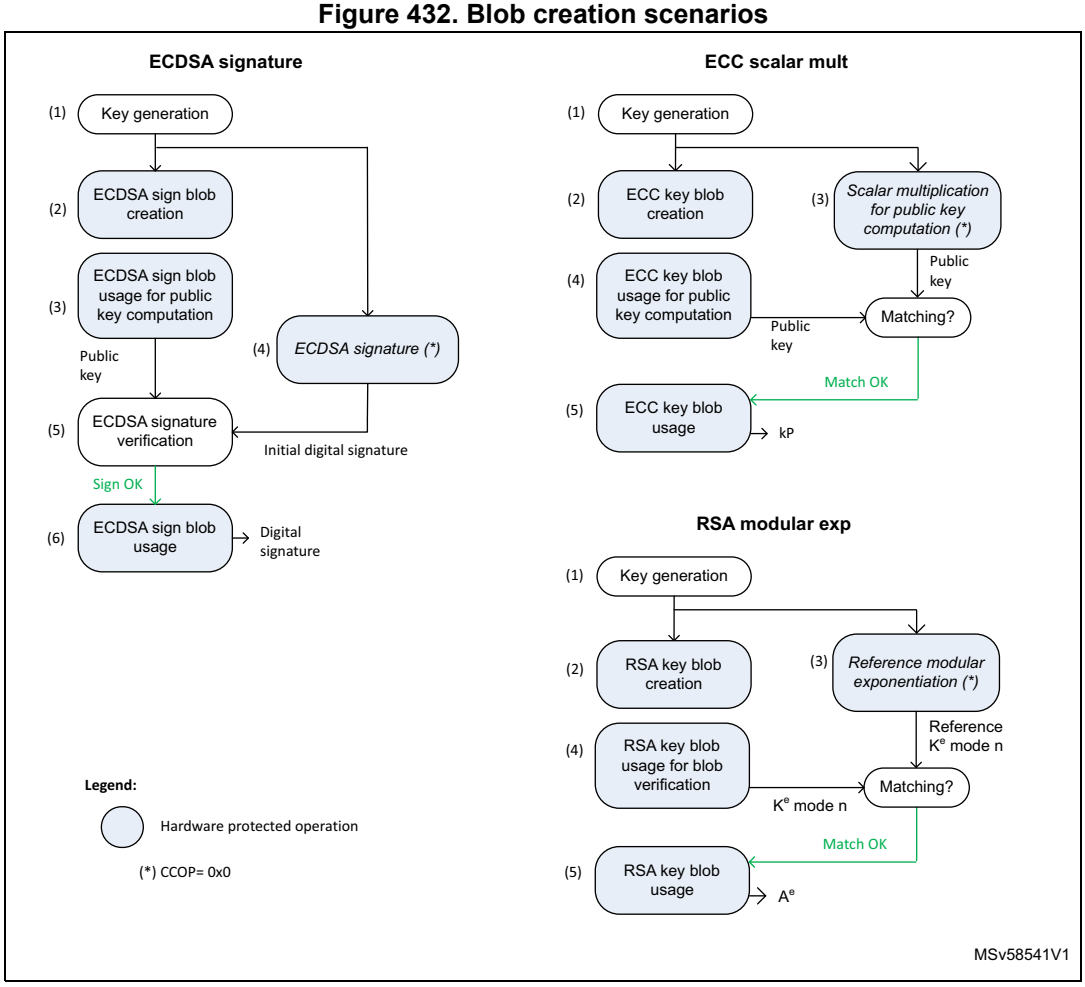
1. Select the protected operation in the PKA that uses this private key (ECDSA signature, scalar multiplication, modular exponentiation). Then, choose the CCOP value in the CCB that corresponds to the selected operation, as defined in this section. Then, as multiple cryptographic peripherals are used, make sure to follow the guidelines described in *Section 42.5.1*
2. When CCB is active (OPSTEP=0x1), select in the SAES the DHUK (with optional XOR with BHK), or unwrap in the SAES an existing blob encryption key that has been encrypted (in wrapped-key mo.de) using the DHUK. A 256-bit KEYSIZE must be selected.
   As the DHUK value is different when CCB is active or inactive, the operation of wrapping or unwrapping blob encryption key in SAES (with KMOD[1:0]=0x1) must be done when OPSTEP=0x1. Refer to operation with wrapped keys in *Section 45: Secure AES coprocessor (SAES)* for details.
3. When the application uses this protected operation in the PKA, it must load the related blob information in the PKA RAM and in SAES_DINR.
   – If the information exactly matches the conditions of the blob generation (choice and order of the writes of protected parameters in the PKA RAM, selection of blob

encryption key, use of original encrypted secrets), the CCB allows the application to set START bit in PKA_CR.

– If the blob information does not match the conditions of the blob generation, the application can only reset the sequence by setting IPRST bit in CCB_CR. CCB, PKA, and SAES become available when CCB_BUSY is cleared in CCB_SR.

4. At any time, the application can abort the executing protected operation by using the IPRST bit in CCB_CR.When creating a blob, always use it once before trusting it to be stored in non-volatile memory or given to a less trusted code (see *Figure 432*). More specifically, each time a blob is created:
   – For ECDSA signature blob: use it to compute the public key, and use this key to verify the signature computed during the blob creation.
   – For ECC key blob: use it to compute the public key, and verify key coordinates match those of the key computed during the blob creation.
   – For RSA key blob: use it to compute a reference modular exponentiation and verify it matches the one computed during the blob creation.

Figure 432. Blob creation scenarios



This section describes how to do the above steps, for all available protected operations in the PKA. Note that:

- **Bold** elements in the following tables are key inputs that the application must save in non-volatile memory after the newly created blob has been confirmed by its first usage.
- The CCB automatically goes to the next step, updating the OPSTEP value, when the application clears or performs the end-step event described in tables of *Section 42.5.2* to *Section 42.5.4*.
- When an incremental read or write is mentioned, the application must write four bytes in the PKA memory, with an incremental memory address (modulo 0x8). Otherwise, the CMF error flag is triggered, and the process must be restarted.
- When writing to SAES_CR register the application must write the configuration expected by the CCB, otherwise an OPERR might be raised. Refer to the OPSTEP “CPU action” instructions in the application tables (*Table 415* through *Table 421*).
- When the CCB uses the RNG, the application must check in RNG_SR that no error occurred (SEIS = CEIS = 0), and that a random number is ready (DRDY = 1). In case of issue, RNGOKF is not set, and the application must ensure that the RNG is functional before running again the OPSTEP sequence that uses the RNG.
- For each OPSTEP>0, the application must manage the error flags that could occur in the RNG, SAES or PKA blocks. During a normal protected operation, no error flags are expected. Refer to *Section 42.4.5: CCB error management* for details on CCB error management.
- When CCB draws random number to compute ECC private keys, it implements the testing candidates method defined by NIST in FIPS PUB 186-4 section B.4.

Note: It is not possible to generate RSA key pairs with the CCB, they must be generated outside the device.

42.5.1 Preliminary steps before any protected operation

The following steps are required before running any operation described in this section:

1. Initialize the GTZC using the same security/privilege configuration protections for the SAES, PKA, RNG and CCB peripherals (see *Section 5: Global TrustZone® controller (GTZC)*). Otherwise OPERR=0x1A occurs (see *Section 42.7.2*).
2. Activate both RNG clocks, then initialize the peripheral to be fully functional, without pending errors.
3. Activate the PKA clock, then release the PKA reset. The PKA is functional once its RAM is automatically erased, and it has fetched the necessary random numbers. For further details refer to enabling/disabling PKA in *Section 47: Public key accelerator (PKA)*.
4. Activate the SAES clock, then release the SAES reset. The SAES is functional once it has fetched necessary random numbers.
5. Activate the CCB clock, set IPRST bit in CCB_CR, then clear it when CCB_BUSY=0x0 in CCB_SR.

Note: Step 4 can be done before step 3, as CCOP = 0x0.

42.5.2 ECDSA signature

This PKA operation is protected against side-channel attacks. When CCOP = 0x0, all parameters loaded in the PKA RAM are managed in the clear by the application. When CCOP = 0xC3, the private key d can be manipulated by the application only if encrypted, using a special blob called “ECDSA signature blob”.

ECDSA signature blob creation

The ECDSA signing operation is prepared by generating and then encrypting the private key d, and computing the reference GCM tag. This process is summarized *Table 415*, with coupling and chaining operations described in *Section 42.4.4*. This sequence starts by generating the ECDSA private key before setting CCOP to 0xC0 in CCB_CR register (usage of 0xC2 value is not recommended).

Table 415. Blob creation steps for ECDSA signature (CCOP = 0b110000<i>0)

OP STEP	MODE in PKA	GCMPH in SAES	Coupling or chaining	End-step event(1)	CPU action in the step
0x1	N/A	N/A	N/A	AES GCM selected, GCMPH = 0x0	– Enable the PKA in the correct mode, writing in PKA_CR MODE= 0x24 and EN=1 (repeat if EN bit stays clear). Wait for INITOK=1 in PKA_SR. – Optionally decrypt the blob encryption key in the SAES, using DHUK in 256-bit wrapped key mode. – Set AES-GCM up in 256-bit encryption mode, with the DHUK or the decrypted key in register (if applicable). –
0x2		0x0	RNG -> SAES	GCMPH = 0x1 (following GCM initialization)	– Complete GCM initialization in encryption mode. SAES_IVR1 to SAES_IVR3 are loaded with randoms. – Read back **blob IV** in SAES_IVR registers.
0x3	0x24	0x1	CPU -> PKA + SAES	GCMPH = 0x2	Write ECC signature parameters in the PKA RAM, clearing CCF flags in the SAES triggered after each 2x32-bit write.
0x6 (<i>=1)	0x24	0x2	RNG -> PKA	RNGOKF set	Write incrementally d in the PKA, using 0xCCB magic number. Values are drawn from the RNG. The PKA runs a special sanity check to verify random compliance with NIST standard (RNGERRF is set if sanity check fails).
0x4 (<i>=0)			n/a	DATAOKF set	Write incrementally d in the PKA.
0x8	0x24		PKA -> SAES	DATAOKF set, GCMPH = 0x3	– Read incrementally d from the PKA (writing 0xCCB magic numbers), and run AES encryption rounds. Special rule must be used for the last 64-bit word (see step 7 after the table). – Read **encrypted d** in SAES_DOUTR. – Repeat for each 16 bytes block of data.
0xA		0x3	N/A	IPRST set in the CCB	– Complete GCM final. Read **reference tag** in the SAES.In this step keep the SAES enabled (EN bit set).
0x0	N/A	N/A	N/A	N/A	– Clear the IPRST bit in CCB when CCB_BUSY and OPSTEP are cleared in CCB_SR. – Verify the newly created blob, running the *ECDSA signature blob use for public-key computation* with it.

1. The application must clear and/or perform the described event for the CCB to automatically go to the next step.

The sequence described in *Table 415* is detailed below. Refer to the table for OPSTEP values and related coupling/chaining modes.

1. Write CCOP = 0xC0 in CCB_CR.
2. Enable the PKA in the correct mode, writing in PKA_CR MODE=0x24 and EN=1 (repeat if the EN bit stays clear). Wait for INITOK=1 in PKA_SR.
3. Initialize the ECC signature blob key in the SAES. This key can be the DHUK (KEYSEL = 0x1 or 0x4), or a key decrypted in 256-bit wrapped key mode by the DHUK (KEYSEL = 0x1 or 0x4, KMOD = 0x1, MODE = 0x1 or 0x2). See *Section 45: Secure AES coprocessor (SAES)* for details.
4. In the SAES, set the GCM chaining mode in encryption mode (CHMOD = 0x3, GCMPH = 0x0, MODE = 0x0, DATATYPE = 0x0). Then:
   a) Configure the 256-bit key size using KEYSIZE.
   b) Write SAES_IVRx, with any value (except SAES_IVR0 that must be equal to 0x2). For SAES_IV1 to IV3, random values are loaded into the SAES by the CCB. If an error occurs, RNGERRF is set in CCB_SR.
   c) Read back SAES_IVR1 to SAES_IVR3, and **save the value** in non-volatile memory after blob verification.
   d) Set EN in SAES_CR, and wait until CCF = 1 in SAES_ISR (end of GCM init).
   e) Clear CCF flag in SAES_ICR.
5. Select the header phase of the running GCM chaining mode (GCMPH = 0x1). Write the protected operation (ECDSA signature) mandatory parameters in the PKA RAM, as described in *Section 47: Public key accelerator (PKA)*. Do the following when writing data in the PKA:
   a) Write two 32-bit word in the PKA RAM, then wait until CCF is set in SAES_ISR. An SAES interrupt can be triggered when this flag is set.
   b) Clear CCF in SAES_ICR.
6. Select the payload phase of the running GCM chaining mode (GCMPH = 0x2). Write the private key *d* in the PKA RAM using the following sequence:
   a) If CCOP = 0xC0, write the private key d value in the PKA RAM. If CCOP = 0xC2, write the 32-bit magic number 0xCCB to the private key d parameter addresses in the PKA memory. The CCB then draws the value of *d* from the RNG, with PKA running a special sanity check to verify random compliance with NIST standard.
   b) Complete parameter information with the mandatory two 32-bit zeroed words. At the end of this process, the private key d of size *d_size* is written in the PKA RAM. Clear the error flag, then restart step 6 if the PKA sets RNGERRF when BUSY is cleared.
7. When the PKA sets its completion flag (RNGOKF if CCOP = 0xC2, DATAOKF if CCOP = 0xC0), clear it, then read the private key d in the PKA RAM using the sequence below (starting from the LSB word in the PKA RAM, and increasing the addresses modulo 0x8):
   a) For each 64-bit word in the PKA RAM, write twice the 32-bit magic number 0xCCB to the private key d parameter addresses in the PKA memory. The target content of the PKA memory is transfered to SAES_DINR by the CCB. Wait until CCF is set

in SAES_ISR (end of AES encryption). An SAES interrupt can be triggered when this flag is set.

b) Clear CCF flag in SAES_ICR. Then read the encrypted private key d in SAES_DOUT, **to save it** in the non-volatile memory after blob verification.

c) For the final 64-bit word (mandatory zeroed word): if the *d_size* is proportional to 16 bytes (for example, for 192- and 521-bit curves), the final 64 bits must be written to with two 32-bit magic numbers 0xCCB. If the *d_size* is not proportional to 16 bytes (for example, for 256- and 512-bit curves), the final 64 bits must be written with 0s.

8. When the DATAOKF completion flag is set (private key d OK), and BUSY is cleared in SAES_SR, select the final phase of the running GCM chaining mode (GCMPH = 0x3), after having cleared DATAOKF. Write the last GCM block in SAES_DINR, then wait until CCF is set in SAES_ISR (end of GCM final).
9. Read SAES_DOUTR four times to retrieve the ECDSA signature blob reference tag. Save it in the non-volatile memory after blob verification. Do not disable SAES by clearing the EN bit.
10. Clear CCOP by setting IPRST bit in CCB_CR. After CCB_BUSY is cleared in CCB_SR, clear the IPRST bit. The SAES, and PKA can again be used for any tasks. They are unprotected by the CCB until CCOP is written different from 0.

ECDSA signature blob usage for ECDSA signature

Table 416 summarizes the ECDSA signing operation using the encrypted private key d, the reference blob IV, and the computed GCM tag of *Table 415*. Coupling and chaining traffic options are described in *Section 42.4.4*. This sequence starts by setting CCOP to 0xC3 in the CCB_CR register.

Table 416. Blob use steps for ECDSA signature (CCOP = 0b11000011)

OPSTEP	MODE in PKA	GCMPH	Coupling or chaining operations	End-step event(1)	CPU action in step
0x1	N/A	N/A	N/A	AES GCM selected, GCMPH = 0x0	– Enable the PKA in the correct mode, writing in PKA_CR MODE= 0x24 and EN=1 (repeat if EN bit stays clear). Wait for INITOK=1 in PKA_SR. – Optionally decrypt the blob encryption key in the SAES, using DHUK in 256-bit wrapped key mode. – Set AES-GCM up in 256-bit encryption mode, with the DHUK or the decrypted key in register (if applicable). –
0x12		0x0	N/A	GCMPH = 0x1 (following GCM initialization)	– Complete GCM initialization in decryption mode, using saved random IV. – Write reference tag in CCB_REFTAGR.

Table 416. Blob use steps for ECDSA signature (CCOP = 0b11000011) (continued)

OPSTEP	MODE in PKA	GCMPH	Coupling or chaining operations	End-step event(1)	CPU action in step
0x13	0x24	0x1	CPU –> PKA + SAES	GCMPH = 0x2	Write ECC signature parameters in the PKA RAM, clearing CCF flags in the SAES, triggered after each 64-bit write.
0x14		0x2	SAES –> PKA	DATAOKF set	– Write encrypted d in SAES_DINR, and runs AES decryption round. – Write incrementally private key d in the PKA, using 0xCCB magic number. A special rule must be used for the last 64-bit write (see step 7 in the sequence detailed after this table). – Repeat for each 16-byte block of data.
0x16			RNG –> PKA	RNGOKF set, GCMPH = 0x3	Write incrementally k in the PKA, using 0xCCB magic number. Values are drawn from the RNG. The PKA runs a special sanity check to verify random compliance with NIST standard (RNGERRF is set if the sanity check fails).
0x17		0x3	SAES –> CCB	Tag matches REFTAGR?	– Complete GCM final. – Read computed tag in the SAES (returns 0).
0x18	0x24	N/A	N/A	START = 0x1	Start the operation in PKA setting START bit in PKA_CR.
0x19(2)		N/A	N/A	PROCENDF set	The PKA computes the operation, PKA RAM is read as 0.
0x1A		N/A	N/A	N/A	Read **signature (r,s)** in the PKA RAM.

1. The application must clear and/or perform the described event for the CCB to automatically go to the next step.
2. SAES cannot be used for any operations, for security reasons..

The sequence described in *Table 416* is detailed below. Refer to the table for the OPSTEP values and related coupling and chaining modes.

1. Write CCOP = 0xC3 in CCB_CR.
2. Enable the PKA in the correct mode, writing in PKA_CR MODE=0x24 and EN=1(repeat if the EN bit stays clear). Wait for INITOK=1 in PKA_SR.
3. Write the hash of the message in the PKA RAM
4. Initialize the ECC signature blob key in the SAES. This key can be the DHUK (KEYSEL = 0x1 or 0x4), or a key decrypted in 256-bit wrapped key mode by the DHUK (KEYSEL = 0x1 or 0x4, KMOD = 0x1, MODE = 0x1). Refer to *Section 45: Secure AES coprocessor (SAES)* for details.
5. Set the GCM chaining mode in decryption in the SAES (CHMOD = 0x3, GCMPH = 0x0, MODE = 0x2, DATATYPE = 0x0). Then:
   a) Configure the 256-bit key size using KEYSIZE.
   b) Write to SAES_IVRx registers the value saved in non-volatile memory.
   c) Set EN in SAES_CR, and wait until CCF is set in SAES_ISR (end of GCM init).
   d) Clear CCF flag in SAES_ICR.
   e) Write to CCB_REFTAGR registers, the ECDSA signature blob reference tag value saved in non-volatile memory.
6. Select the header phase of the running GCM chaining mode (GCMPH = 0x1). Write the protected operation (ECDSA signature) mandatory parameters in the PKA RAM,

exactly as done during the blob creation. See step 5 in *ECDSA signature blob creation* for details.

7. Select the payload phase of the running GCM chaining mode (GCMPH = 0x2). Write the protected private key d in the PKA RAM, following the below sequence (starting from the LSB word in the PKA RAM, and increasing the addresses modulo 0x8):
   a) Writetwo 64-bit words of encrypted private key d in SAES_DINR. Wait until CCF is set in SAES_ISR (end of AES decryption). An SAES interrupt can be triggered when this flag is set.
   b) Clear the CCF flag in the SAES_ICR register. Then, for both 64-bit words, write four times the 32-bit magic number 0xCCB to the private key d parameter addresses in the PKA memory. The CCB transfers the clear-text content of SAES_DOUTR to the PKA.
   c) For the final 64-bit word (mandatory zeroed word): If *d_size* defined in step 6 in *ECDSA signature blob creation* is not proportional to 16-bytes (for example, for 256- and 512-bit curves), the final 64 bits must be written with 0s.
8. When DATAOKF = 1 in PKA_SR (private key d ok), clear this flag. Then write to the integer k parameter addresses in the PKA memory, starting from the LSB word in the PKA RAM, and increasing the addresses modulo 0x8. The CCB draws the value of k from the RNG. The PKA then runs a special sanity check to verify random compliance with NIST standard. Clear the error flag, then restart step 7 if the PKA sets RNGERRF when BUSY is cleared.
9. When RNGOKF = 1 in PKA_SR (random k ok), clear this flag. Then select the final phase of the running GCM chaining mode (GCMPH = 0x3). Write the last GCM block in SAES_DINR. Then wait until CCF is set in SAES_ISR (end of GCM final).
10. Read four times SAES_DOUTR (returns 0s). If PKA parameters were written exactly like during the blob creation, and the correct private key d was used, and all expected DATAOKF/RNGOKF flags were raised then cleared, the application can set START bit in PKA_CR to run the ECDSA signature operation. Otherwise, IPRST in CCB_CR must be used to restart the sequence from step 1.
11. Clear CCOP by setting IPRST in CCB_CR. After CCB_BUSY is cleared in CCB_SR, clear the IPRST bit. The SAES, and PKA can again be used for any tasks. They are unprotected by the CCB until CCOP in CCB_CR is written different from 0.

ECDSA signature blob use for public-key computation

The ECC public key computation using the encrypted private key d, the reference blob IV, and the computed GCM tag of *Table 415* is summarized in *Table 417*. The additional ECDSA verification at the end of the sequence must be used before saving a new ECDSA signature blob in non-volatile memory.Shown coupling and chaining traffic options are described in *Section 42.4.4*. This sequence starts by setting CCOP to 0x81 in the CCB_CR register.

Table 417. Blob use steps for signing public key computation (CCOP = 0b10000001)

OPSTEP	MODE in PKA	GCMPH in SAES	Coupling or chaining operations	End-step event[1]	CPU action
0x1	N/A	N/A	N/A	AES GCM selected, GCMPH = 0x0	– Enable the PKA in the correct mode, writing in PKA_CR MODE= 0x20 and EN=1 (repeat if EN bit stays clear). Wait for INITOK=1 in PKA_SR. – Optionally decrypt blob encryption key in the SAES, using DHUK in 256-bit wrapped key mode. – Set up AES-GCM in decryption mode with DHUK or the decrypted key in register (if applicable).
0x12	0x20	0x0	N/A	GCMPH = 0x1 (following GCM initialization)	– Complete GCM initialization in decryption mode, using saved random IV. – Write reference tag in CCB_REFTAGR.
0x13		0x1	CPU -> PKA + SAES	GCMPH = 0x2	Write ECC signature parameters in the PKA RAM, clearing CCF flags in SAES, triggered after each 2x32-bit write.
0x14		0x2	SAES -> PKA	DATAOKF set, GCMPH = 0x3	– Write encrypted d in SAES DINR and run AES decryption round. – Write incrementallyscalar multiplier k in the PKA, using 0xCCB magic number. – Repeat for each 16 bytes block of data.
0x17		0x3	SAES -> CCB	Tag matches REFTAGR?	– Complete GCM final. – Read computed tag in the SAES (returns 0).
0x18	0x20	N/A	N/A	START = 0x1	Start the operation in PKA setting START bit in PKA_CR.
0x19[2]		N/A	N/A	PROCENDF set	The PKA computes the operation. PKA RAM is read as 0.

Table 417. Blob use steps for signing public key computation (CCOP = 0b10000001)

OPSTEP	MODE in PKA	GCMPH in SAES	Coupling or chaining operations	End-step event(1)	CPU action
0x1A	0x20	N/A	N/A	IPRST set in the CCB	– Read public key point Q in PKA RAM – Set IPRST in CCB
0x0	0x26	N/A	N/A	N/A	Clear the IPRST bit in CCB when CCB_BUSY and OPSTEP are cleared in CCB_SR. – Before writing new ECDSA signature blob in non-volatile memory do an initial digital signature, as summarized in *Figure 432.* – Enable the PKA – Write MODE= 0x24 in the PKA – Write hash z & random nonce k in PKA RAM – Write in PKA RAM the same curve parameters and private key d as the current ECDSA signature blob – Start the operation setting START bit in PKA_CR – Wait for PROCENDF bit is set. If error code= 0xD60D save the computed signature in temporary RAM. – Finally, verify the above generated ECDSA signature. – Write MODE= 0x26 in the PKA – Write the same hash z as above in PKA RAM – Write ECDSA verification parameters in PKA, including the public key coordinates computed in step 0x1A. – Start the operation setting START bit in PKA_CR – Wait for PROCENDF bit is set. If the signature is valid save the created blob in non-volatile memory.

1. The application must clear and/or perform described event for CCB to automatically go to the next step.
2. SAES cannot be used for any operations, for security reasons.

42.5.3 ECC scalar multiplication

This operation consists in the computation of k x P, where P is a point on a curve over prime fields, and “x” is the elliptic curve scalar point multiplication. The computation result is a point that belongs to the same curve, or a point at infinity.

The scalar multiplication operation is protected against side-channel attacks. When CCOP = 0x0 in CCB_CR, all parameters loaded in the PKA RAM are managed in the clear by the application. When CCOP = 0x81, the scalar multiplier k can be manipulated by the application only if encrypted, using a special blob called “ECC key blob”.

Scalar multiplication “ECC key” blob creation

The scalar multiplication operation is prepared by generating then encrypting the scalar multiplier k, and computing the reference GCM tag. This process is summarized in *Table 418*. Coupling and chaining operations described in *Section 42.4.4*. This sequence starts by generating the scalar multiplier k before setting CCOP to 0x80 in CCB_CR register (usage of 0x82 value is not recommended).

Table 418. Blob creation steps for scalar multiplication (CCOP = 0b100000<i>0)

OPSTEP	MODE in PKA	GCMPH in SAES	Coupling or chaining operations	End-step event(1)	CPU action in step
0x1	N/A	N/A	N/A	AES GCM selected, GCMPH = 0x0	– Enable the PKA in the correct mode, writing in PKA_CR MODE= 0x20 and EN=1 (repeat if EN bit stays clear). Wait for INITOK=1 in PKA_SR. – Optionally decrypt blob encryption key in the SAES, using DHUK in 256-bit wrapped key mode. – Set up AES-GCM in 256-bit encryption mode with DHUK or the decrypted key in register (if applicable) –
0x2		0x0	RNG –> SAES	GCMPH = 0x1 (following GCM initialization)	– Complete GCM initialization in encryption mode. Registers IVR1 to 3 are loaded with randoms. – Read back **blob IV** in IVR registers.
0x3	0x20	0x1	CPU –> PKA + SAES	GCMPH = 0x2	Write ECC scalar multiplication parameters in the PKA RAM, clearing CCF flags in SAES, triggered after each 64-bit write.
0x6 (<i>=1)	0x20	0x2	RNG –> PKA	RNGOKF set	Write incrementally k in the PKA, using 0xCCB magic number. Values are drawn from the RNG. The PKA runs a special sanity check to verify random compliance with NIST standard (RNGERRF is set if the sanity check fails).
0x4 (<i>=0)			N/A	DATAOKF set	Write incrementally k in the PKA.
0x8	0x20	0x2	PKA –> SAES	DATAOKF set, GCMPH = 0x3	– Read incrementally k from the PKA (writing 0xCCB magic numbers), and runs AES encryption rounds. – Read **encrypted k** in SAES DOUTR. – Repeat for each 16-byte block of data..
0xA		0x3	N/A	IPRST set in the CCB	– Complete GCM final. Read **reference tag** in the SAES.In this step keep the SAES enabled (EN bit set).
0x0	N/A	N/A	N/A	N/A	Clear the IPRST bit in CCB when CCB_BUSY and OPSTEP are cleared in CCB_SR. Before writing new ECC key blob in non-volatile memory do a public key computation, as summarized in *Figure 432*. – Enable the PKA – Write MODE= 0x20 in the PKA – Write base point G coordinates as input in PKA RAM – Write in PKA RAM the same curve parameters and scalar multiplier k as the current ECC key blob – Start the operation setting START bit in PKA_CR – Wait for PROCENDF bit is set. If error code= 0xD60D save this reference public key in temporary RAM. Finally, verify the newly created blob by using it for public key computation (see *Table 419*)

1. The application must clear and/or perform described event for CCB to automatically go to the next step.

Scalar multiplication blob use for example for ECC decryption

ECC scalar multiplication computation using the encrypted k, the reference blob IV and the computed GCM tag of *Table 418* is summarized in *Table 419*. Shown coupling and chaining traffic options are described in *Section 42.4.4*. This sequence starts by setting CCOP to 0x81 in CCB_CR register.

Table 419. Blob use steps for scalar multiplication (CCOP = 0b10000001)

OPSTEP	MODE in PKA	GCMPH in SAES	Coupling or chaining operations	End-step event(1)	CPU action
0x1	N/A	N/A	N/A	AES GCM selected, GCMPH = 0x0	– Enable the PKA in the correct mode, writing in PKA_CR MODE= 0x20 and EN=1 (repeat if EN bit stays clear). Wait for INITOK=1 in PKA_SR. – Optionally, decrypt blob encryption key in the SAES, using DHUK in 256-bit wrapped key mode. – Set up AES-GCM in decryption mode with DHUK or the decrypted key in register (if applicable). – Write input point P coordinates in the PKA RAM. When computing a public key, write basepoint G coordinates.
0x12	0x20	0x0	N/A	GCMPH = 0x1 (following GCM initialization)	– Complete GCM initialization in decryption mode, using saved random IV. – Write reference tag in CBB_REFTAGR.
0x13		0x1	CPU -> PKA + SAES	GCMPH = 0x2	Write ECC scalar multiplication parameters in the PKA RAM, clearing CCF flags in the SAES, triggered after each 64-bit write.
0x14		0x2	SAES -> PKA	DATAOKF set, GCMPH = 0x3	– Write encrypted k in SAES_DINR, and runs AES decryption round. – Write incrementally scalar multiplier k in the PKA, using 0xCCB magic number. – Repeat for each 16 bytes block of data.
0x17		0x3	N/A	Tag matches REFTAGR?	– Complete GCM final. – Read computed tag in the SAES (returns 0).
0x18	0x20	N/A	N/A	START = 0x1	Start the operation in PKA setting START bit in PKA_CR. Do not use SAES during this step (under reset).
0x19(2)				PROCENDF set	The PKA computes the operation. The PKA RAM is read as 0.
0x1A				N/A	Read **kP point coordinates** in the PKA RAM. If this point is the public key verify it matches the reference public key computed in *Table 418* before saving the created blob in non-volatile memory.

1. The application must clear and/or perform described event for CCB to automatically go to the next step.
2. SAES cannot be used for any operations, for security reasons.

42.5.4 RSA modular exponentiation

The modular exponentiation operation is commonly used to perform a single-step RSA operation. It consists in the computation of A^e mod n.

This modular exponentiation operation (MODE = 0x3) is protected against side-channel attacks. When CCOP = 0x0, all parameters loaded in the PKA RAM are managed in the clear by the application. When CCOP = 0x45, the exponent e and phi value can only be manipulated encrypted by application, using a special blob called “RSA key blob”.

Modular exponentiation “RSA key” blob creation

Modular exponentiation operation is prepared by generating then encrypting the scalar multiplier *k* and computing the reference GCM tag. This process is summarized in *Table 420*. The coupling and chaining operations described in *Section 42.4.4*. This sequence starts by setting CCOP to 0x44 in CCB_CR register.

Table 420. Blob creation steps for modular exponentiation (CCOP = 0b01000100)

OPSTEP	MODE in PKA	GCMPH in SAES	Coupling or chaining operations	End-step event(1)	CPU action in step
0x1	N/A	N/A	N/A	AES GCM selected, GCMPH = 0x0	– Enable the PKA in the correct mode, writing in PKA_CR MODE= 0x3 and EN=1 (repeat if EN bit stays clear). Wait for INITOK=1 in PKA_SR. – Optionally decrypt blob encryption key in the SAES, using DHUK in 256-bit wrapped key mode. – Set up AES-GCM in 256-bit encryption mode with DHUK or the decrypted key in register (if applicable).
0x2		0x0	RNG -> SAES	GCMPH = 0x1 (following GCM initialization)	– Complete GCM initialization in encryption mode. SAES_IVR1 to 3 registers are loaded with randoms. – Read back blob IV in SAES_IVR registers.
0x3	0x03	0x1	CPU -> PKA + SAES	GCMPH = 0x2	Write protected modular exponentiation parameters (PKA mode 0x3) in the PKA RAM, clearing CCF flags in the SAES triggered after each 2x32-bit write.
0x4	0x3	0x2	N/A	DATAOKF set	Write incrementally clear-text exponent e.
0x5				DATAOKF set	Write incrementally clear-text phi.
0x8			PKA -> SAES	DATAOKF set	– Read incrementallye from the PKA (writing 0xCCB magic numbers), and runs AES encryption rounds. – Read **encrypted e** in SAES_DOUTR. – Repeat for each 16 bytes block of data.
0x9				DATAOKF set, GCMPH = 0x3	– Read incrementally phi from the PKA (writing 0xCCB magic numbers), and run AES encryption rounds. – Read **encrypted phi** in SAES_DOUTR. – Repeat for each 16 bytes block of data

Table 420. Blob creation steps for modular exponentiation (CCOP = 0b01000100)

OPSTEP	MODE in PKA	GCMPH in SAES	Coupling or chaining operations	End-step event(1)	CPU action in step
0xA	0x3	0x3	N/A	IPRST set in the CCB	– Complete GCM final. – Read **reference tag** in the SAES. In this step keep the SAES enabled (EN bit set).
0x0	N/A	N/A	N/A	N/A	Clear the IPRST bit in CCB when CCB_BUSY and OPSTEP are cleared in CCB_SR. Before writing new RSA key blob in non-volatile memory do a reference modular exponentiation computation, as summarized on *Figure 432*. – Enable the PKA – Write MODE= 0x3 in the PKA – Write a constant K as operand A in the PKA RAM – Write in PKA RAM the same base parameters, phi and exponent e as the current RSA key blob – Start the operation setting START bit in PKA_CR – Wait for PROCENDF bit is set. If error code= 0xD60D save this reference Ke in temporary RAM. Finally, verify the newly created blob by using it for Ke computation (see *Table 421*).

1. The application must clear and/or perform described event for CCB to automatically go to the next step.

Modular exponentiation blob use (for example for RSA decryption)

The modular exponentiation computation using the encrypted *e* and *phi*, the reference blob IV, and the computed GCM tag of *Table 420* is summarized on *Table 421*. Shown coupling and chaining traffic options are described in *Section 42.4.4*. This sequence starts by setting CCOP to 0x45 in CCB_CR register.

Table 421. Blob use steps for modular exponentiation (CCOP = 0b01000101)

OPSTEP	MODE in PKA	GCMPH in SAES	Coupling or chaining operations	End-step event(1)	CPU action
0x1	N/A	N/A	N/A	AES GCM selected, GCMPH = 0x0	– Enable the PKA in the correct mode, writing in PKA_CR MODE= 0x3 and EN=1 (repeat if EN bit stays clear). Wait for INITOK=1 in PKA_SR. – Optionally decrypt blob encryption key in the SAES, using DHUK in 256-bit wrapped key mode. – Set up AES-GCM in decryption mode with DHUK or the decrypted key in register (if applicable). – Write operand A in the PKA RAM.Write constant K as operand A defined in *Table 420* when verifying the created blob.

Table 421. Blob use steps for modular exponentiation (CCOP = 0b01000101)

OPSTEP	MODE in PKA	GCMPH in SAES	Coupling or chaining operations	End-step event(1)	CPU action
0x12	0x03	0x0	N/A	GCMPH = 0x1 (following GCM initialization)	– Complete GCM initialization in decryption mode, using saved random IV. – Write reference tag in CCB_REFTAGR.
0x13		0x1	CPU –> PKA + SAES	GCMPH = 0x2	Write protected modular exponentiation parameters (PKA mode 0x3) in the PKA RAM, clearing CCF flags in the SAES, triggered after each -bit write.
0x14		0x2	SAES –> PKA	DATAOKF set	– Write encrypted e in SAES_DINR, and runs AES decryption round. – Write incrementally exponent e in the PKA, using 0xCCB magic number. – Repeat for each 16-byte block of data.
0x15				DATAOKF set, GCMPH = 0x3	– Write encrypted phi in SAES_DINR, and runs AES decryption round. – Write incrementally phi in the PKA, using 0xCCB magic number. – Repeat for each 16-byte block of data.
0x17		0x3	SAES –> CCB	Tag matches REFTAGR?	– Complete GCM final. – Read computed tag in the SAES (returns 0).
0x18	0x03	N/A	N/A	START = 0x1	Start the operation in PKA setting START bit in PKA_CR.
0x19(2)				PROCENDF set	The PKA computes the operation, PKA RAM is read as 0.
0x1A				N/A	Read $\mathbf{A^e}$ **mod** n in the PKA RAM. If the result is K^e mod n verify it matches the reference computed in *Table 420* before saving the created blob in non-volatile memory.

1. The application must clear and/or perform described event for CCB to automatically go to the next step.
2. SAES cannot be used for any operations, for security reasons.

42.6 CCB interrupts

The CCB does not support any interrupt.

42.7 CCB registers

The following section provides information on registers.

Reserved bits (marked as Res.) must be kept at their reset values, unless otherwise specified.

For general information relative to register description, refer to Document conventions.

These registers are accessible through the AHB interface of the CCB (32-bit words only). All reads are supported. Writes accesses must be 32-bit word only (other access types generate an AHB error).

42.7.1 CCB control register (CCB_CR)

Address offset: 0x000

Reset value: 0x0000 0000

Following a CCB hardware reset, the above reset value applies if OPERR[5:0] = 0x0 and no TAMP_EVT bit is set.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IPRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCOP[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **IPRST**: CCB reset

Set this bit to start or abort any PKA protected operation defined in *Section 42.5*. IPRST bit must be low while writing to any CCB register.
After setting this bit, the application must clear it when CCB_BUSY and OPSTEP are cleared in CCB_SR (IPRST clear is ignored otherwise). After this clear all CCB registers are read with their reset valuesSetting IPRST clears any data stored in the SAES and the PKA.
When IPRST and CCB_BUSY are set, SAES registers are not accessible (read as 0, write ignored), and writes to EN and START bits in PKA_CR are ignored.
This bit is set by CCB when OPERR[5:0] ≠ 0 or any TAMP_EVT bit is set.

Bits 30:8 Reserved, must be kept at reset value.

Bits 7:0 **CCOP[7:0]**: Coupling and chaining operation

These bits must be set according to the chosen PKA protected operation (see *Section 42.5*).

0x044: Modular exponentiation blob creation with priv key from the CPU

0x045: Modular exponentiation blob use

0x080: ECC scalar multiplication blob creation with priv key from the CPU

0x082: ECC scalar multiplication blob creation with priv key from the RNG

0x081: ECC scalar multiplication blob use, or ECDSA signature blob use for public key computation

0x0C0: ECDSA signature blob creation with priv key from the CPU

0x0C2: ECDSA signature blob creation with priv key from the RNG

0x0C3: ECDSA signature blob use for ECDSA signature

Note: When an operation not listed here is written by the application, the write to CCOP[7:0] is ignored. All these operations implement protections against side-channel attacks. Write to CCOP is ignored when CCB_BUSY is set in CCB_SR.

42.7.2 CCB status register (CCB_SR)

Address offset: 0x004

Reset value: 0x0000 0000

This register is reset by a system reset, or after clearing IPRST in CCB_CR. The CCB reset input from the RCC has no effect on this register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	TAMP_EVT5	TAMP_EVT4	TAMP_EVT3	TAMP_EVT2	TAMP_EVT1	TAMP_EVT0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCB_BUSY
		r	r	r	r	r	r								r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	OPERR[5:0]						Res.	Res.	Res.	OPSTEP[4:0]				
		r	r	r	r	r	r				r	r	r	r	r

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:24 **TAMP_EVTi**: Tamper i flag (i = 5 to 0)

0: No event

1: Tamper event i has been raised. Global tamper event is raised. See *Section 42.3* for details on the events.

This bit is cleared by writing 0 to IPRST bit in CCR_CR. When at least one TAMP_EVT bit is set, CCB sets IPRST bit.

Bits 23:17 Reserved, must be kept at reset value.

Bit 16 **CCB_BUSY**: CCB busy

This flag is set when CCB is busy, or when OPSTEP[4:0] ≠ 0 following a CCB reset (hardware reset or use of IPRST in CCB_CR).

0: CCB idle

1: CCB busy or PKA RAM is being cleared following a peripheral reset.

When IPRST and CCB_BUSY are set, the SAES registers are not accessible (write ignored, read returns 0), and writes to EN or START bits in PKA_CR are ignored.

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:8 **OPERR[5:0]**: Operation error

When an error is detected during a protected PKA operation, the CCB raises IPRST in CCB_CR, and OPSTEP[4:0] is set to 0x1F. The bitfield is cleared by setting IPRST to 0.

0x0: No error detected during protected PKA operation (if applicable)

0x1: CCB RCC reset has been detected when OPSTEP > 0x0

0x2: SAES RCC reset has been detected when OPSTEP > 0x0

0x3: PKA RCC reset has been detected when OPSTEP > 0x0

0x4: RNG RCC reset has been detected when OPSTEP > 0x0

0x5: The RCC has gated the CCB clock when OPSTEP > 0x0.

0x6: The RCC has gated the SAES clock when OPSTEP > 0x0.

0x7: The RCC has gated the PKA clock when OPSTEP > 0x0.

0x8: The RCC has gated the RNG clock when OPSTEP > 0x0.

0x9: Random in SAES_IV1 is trivial (all 0s or all 1s) when OPSTEP = 0x2

0xA: Random in SAES_IV2 is trivial (all 0s or all 1s) when OPSTEP = 0x2

0xB: Random in SAES_IV3 is trivial (all 0s or all 1s) when OPSTEP = 0x2

0xC: When OPSTEP = 0x17 SAES GCM TAG comparison with CCB_REFTAG failed, or a register different from SAES_DOUT was read in the SAES.

0xD: KEYSIZE ≠ 256 bits in SAES_CR when the SAES is enabled, and OPSTEP > 0x0.

0xE: CHMOD ≠ GCM in SAES_CR when 0x1 < OPSTEP < 0x18, or the SAES is not enabled, or KEYVALID is cleared when GCMPH > 0x0.

0xF: KMOD different from wrapped key mode in SAES_CR when the SAES is enabled, and OPSTEP = 0x1, or 0x1A.

0x10: KEYSEL ≠ 0x1 or 0x4 in SAES_CR when the SAES is enabled, KEYVALID is set, and OPSTEP = 0x1.

0x11: GCMPH not correct (not incremented) in SAES_CR when OPSTEP > 0x1.

0x12: MODE in SAES_CR does not match the expected value (selected by CCOP in CCB_CR) when OPSTEP > 0x1.

0x13: BUSY = 1 in SAES_SR when OPSTEP= 0x18 or 0x19. SAES must not be used when PKA is computing a protected operation.

0x14: EN = 0 in PKA_CR when OPSTEP > 0x2 (except 0x12). In other words, PKA must be enabled in any OPSTEP except 0x1, 0x2, or 0x12.

0x15: INITOK = 0 in PKA_SR when OPSTEP > 0x2 (except 0x12).

0x16: Authorized by local firewall, but unexpected AHB error detected when OPSTEP > 0x0.

0x17: LMF = 1 in PKA_SR (only ECDSA verification available) when OPSTEP > 0x0.

0x18: CCB_REFTAGRx registers are equal to 0 when OPSTEP > 0x12.

0x1A: Security, privilege protections inconsistent (see *Section 5: Global TrustZone® controller (GTZC)*) for the peripherals SAES, PKA, RNG, and CCB when OPSTEP > 0x0. This error is also triggered when the protections change while OPSTEP > 0x0,

0x1B: MODE in PKA_CR does not match the expected value (selected by CCOP in CCB_CR) when OPSTEP > 0x0.

0x1C: OPSTEP end-step event not found at OPSTEP= 0x0 (SAES KEYVALID is set). Use CCB IPRST before starting a coupling and chaining operation.

0x1D: OPSTEP end-step event not found at OPSTEP = 0x1.

0x1E: OPSTEP end-step event not found at OPSTEP = 0x2.

0x1F: OPSTEP end-step event not found at OPSTEP = 0x3.

0x20: OPSTEP end-step event not found at OPSTEP = 0xA.

0x21: OPSTEP end-step event not found at OPSTEP = 0x12.

0x22: OPSTEP end-step event not found at OPSTEP = 0x13.

0x23: OPSTEP end-step event not found at OPSTEP = 0x17.

For error codes 0x1C to 0x23, details on end-step events are found in *Section 42.5*. Those errors are also triggered when values written in SAES_CR register do not correspond to the selected CCOP and the expectations in the current OPSTEP.

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **OPSTEP[4:0]**: Operation step

This read-only information indicates the current step of the coupling and chaining operation (indicated by CCOP). See *Section 42.5* for details. .

This bitfield can be cleared only using IPRST in CCB_CR. OPSTEP[4:0] = 0x1F when the IPRST procedure is in progress.

42.7.3 CCB reference tag register (CCB_REFTAGRx)

Address offset: 0x010 + 0x4 * x (x = 0 to 3)

Reset value: 0x0000 0000

Writes to this register are ignored when CCB_BUSY is set in the CCB_SR register. The register is cleared when IPRST is set and CCB_BUSY is cleared.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REFTAG{i + 32 * x}															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REFTAG{i + 32 * x}															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **REFTAG{i + 32 * x}**: Reference tag bits {i + 32 * x} (i = 31 to 0)

The application must write in these registers, the reference GCM tag of the required operation blob (respectively ECC signature, ECC key, or RSA key). This enables the PKA protected operation (respectively ECC signature/public key computation, scalar multiplication, or modular exponentiation). Refer to *Section 42.5* for details.

Write to this register is ignored unless OPSTEP = 0x12 in CCB_SR.

42.7.4 CCB register map

Table 422. CCB register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	CCB_CR	IPRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCOP[7:0]							
	Reset value	0																								0	0	0	0	0	0	0	0
0x004	CCB_SR	Res.	Res.	TAMP_EVT5	TAMP_EVT4	TAMP_EVT3	TAMP_EVT2	TAMP_EVT1	TAMP_EVT0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCB_BUSY	Res.	Res.	OPERR[5:0]						Res.	Res.	Res.	OPSTEP[4:0]				
	Reset value			0	0	0	0	0	0								0			0	0	0	0	0	0				0	0	0	0	0
0x010 + 0x4 * x (x=0 to 3)	CCB_ REFTAGRx	REFTAG{i + 32 * x} (i = 31 to 0)																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

43 True random number generator (RNG)

43.1 RNG introduction

The RNG is a true random number generator that provides full entropy outputs to the application as 32-bit samples. It is composed of a live entropy source (analog) and an internal conditioning component.

The RNG is an NIST SP 800-90B compliant entropy source that can be used to construct a nondeterministic random bit generator (NDRBG).

The RNG true random number generator can be certified NIST SP 800-90B. It can also be tested using the German BSI statistical tests of AIS-31 (T0 to T8).

43.2 RNG main features

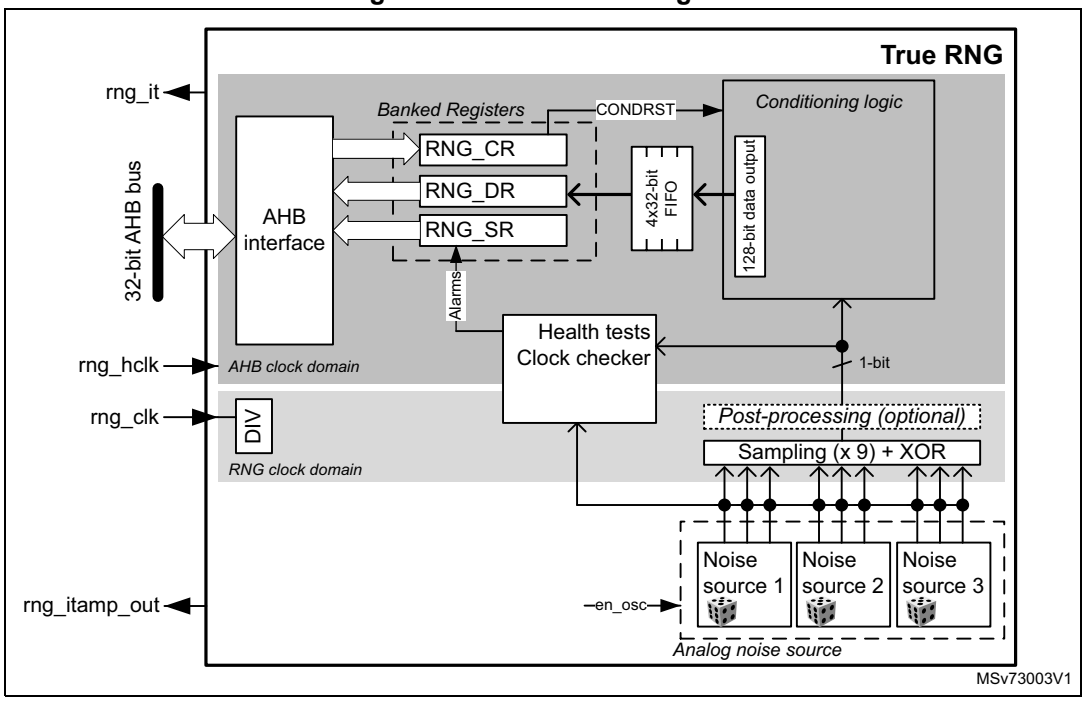
- The RNG delivers 32-bit true random numbers, produced by an analog entropy source conditioned by an NIST SP800-90B approved conditioning stage.
- It can be used as the entropy source to construct a non-deterministic random bit generator (NDRBG).
- In the default configuration, it produces four 32-bit random samples every 412 AHB clock cycles if $f_{AHB} < f_{threshold}$ (256 RNG clock cycles otherwise).
- Embeds startup and NIST SP800-90B approved continuous health tests (repetition count and adaptive proportion tests), associated with specific error management.
- Can be disabled to reduce power consumption, or enabled with an automatic low power mode (default configuration).
- Has an AMBA® AHB slave peripheral, accessible through 32-bit word single accesses only (else an AHB bus error is generated, and the write accesses are ignored).

43.3 RNG functional description

43.3.1 RNG block diagram

Figure 433 shows the RNG block diagram.

Figure 433. RNG block diagram



43.3.2 RNG internal signals

Table 423 describes internal signals available at the RNG level, not at the STM32 product level (on pads).

Table 423. RNG internal input/output signals

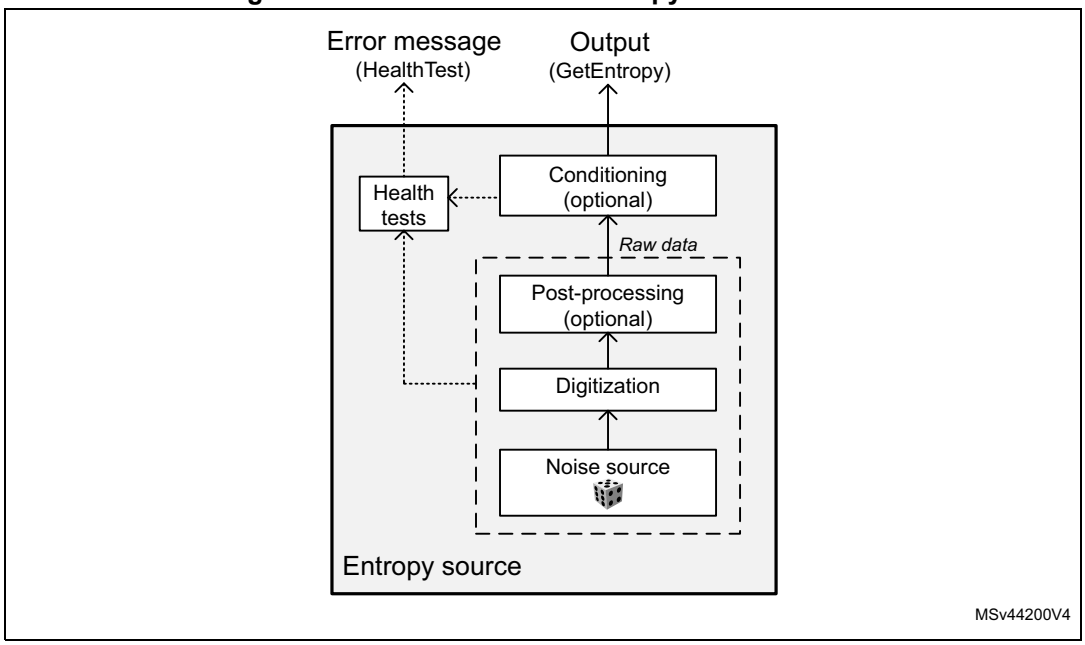
Signal name	Signal type	Description
rng_it	Digital output	RNG global interrupt request
rng_hclk	Digital input	AHB clock
rng_clk	Digital input	RNG dedicated clock, asynchronous to rng_hclk
rng_itamp_out	Digital output	RNG internal tamper event signal to TAMP (XOR-ed), triggered when an unexpected hardware fault occurs. When this signal is triggered, RNG stops delivering random samples. A reset and a new initialization are needed to use it again.

43.3.3 Random number generation

The true random number generator (RNG) delivers truly random data through its AHB interface at deterministic intervals.

Within its boundary, it integrates all the required NIST components shown in *Figure 434*: an analog noise source, a digitization stage, a conditioning algorithm, a health monitoring block, and two interfaces used to interact with the entropy source (GetEntropy and HealthTest).

Figure 434. NIST SP800-90B entropy source model



Noise source

This component contains the nondeterministic, entropy-providing activity, ultimately responsible for the uncertainty associated with the bit string output by the entropy source. This noise source provides 1-bit samples. It is composed of:

- Multiple analog noise sources (x3), each based on three XOR-ed free-running ring oscillator outputs. It is possible to disable those analog oscillators to save power, as described in *Section 43.3.8*. Multiple oscillators are also disabled for configuration A (see *Table 425*).
- The XOR-ing of all the noise sources into a single analog output.
- A sampling stage of this output is clocked by a dedicated clock input (rng_clk with integrated divider), delivering a 1-bit raw data output.

This noise source sampling is independent from the AHB interface clock frequency (rng_hclk), with the possibility, for the software, to decrease the sampling frequency by using the integrated divider.

Note: The recommended clock frequencies and associated divider value are detailed in Section 43.6.

Post processing

In the NIST configuration no post-processing is applied to the sampled noise source. In the non-NIST configuration B (as defined in *Section 43.6.2*) a normalization debiasing is applied: half of the bits are taken from the sampled noise source, the other half from the inverted sampled noise source.

Conditioning

The conditioning component in the RNG is a deterministic function that increases the entropy rate of the resulting fixed-length bit string output (128-bit). The NIST SP800-90B target is full entropy on the output (128-bit).

The time intervals required between two random number generations, and between the RNG initialization and availability of the first sample are detailed in *Section 43.5*.

Output buffer

A data output buffer can store up to four 32-bit words that have been output from the conditioning component. When four words have been read from the output FIFO through the RNG_DR register, the content of the 128-bit conditioning output register is pushed into the output FIFO, and a new conditioning round is automatically started. Four new words are added to the conditioning output register after a number of clock cycles specified in *Section 43.5*.

Whenever a random number is available through the RNG_DR register, the DRDY flag changes from 0 to 1. This flag remains high until the output buffer becomes empty after reading four words from the RNG_DR register.

Note: When the interrupts are enabled, an interrupt is generated when this flag transitions from 0 to 1. The interrupt is then cleared automatically by the RNG, as explained above.

Health checks

This component ensures that the entire entropy source (with its noise source) starts, then operates as expected, obtaining the assurance that failures are caught quickly, with high probability and reliability.

The RNG implements the following health check features in accordance with NIST SP800-90B. The described thresholds correspond to the default RNG_HTCR0 configuration.

1. Startup health tests, performed after reset and before the first use of the RNG as entropy source:
   - Repetition count test, flagging an error when the noise source has provided more than 28 consecutive bits at a constant value (0 or 1).
   - Adaptive proportion test running on a window of 1024 consecutive bits: the RNG verifies that the first bit on the outputs of the noise source is not repeated more than 684 times.
   - Known-answer tests, to verify the conditioning stage.
2. Continuous health tests, running indefinitely on the outputs of the noise source (XORed output and individual oscillator outputs, see *Figure 433: RNG block diagram*):
   - Repetition count test, similar to the one running in startup tests.
   - Adaptive proportion test, similar to the one running in startup tests.
3. Vendor specific continuous test:

- Real-time “too slow” sampling clock detector, flagging an error when one RNG clock cycle (before divider) is smaller than the AHB clock cycle divided by 32.

4. On-demand test of digitized noise source (raw data)
   - Supported by restarting the entropy source and rerunning the startup tests (see software reset sequence in *Section 43.3.4*). Other kinds of on-demand testing (software based) are *not supported*.

The CECS and SECS status bits in the RNG_SR register indicate when an error condition is detected, as detailed in *Section 43.3.7*.

Note: An interrupt can be generated when an error is detected.

The health test thresholds are modified by changing the value in the corresponding RNG_HTCRx registers. See Section 43.6 for details.

43.3.4 RNG initialization

The RNG simplified state machine is shown in *Figure 435*.

After enabling the RNG (RNGEN = 1 in RNG_CR), the following chain of events occurs:

1. The analog noise source is enabled, and by default the RNG waits 16 RNG clock cycles (before divider) before starting to sample the analog output and filling the 128-bit conditioning shift register.
2. The conditioning hardware initializes, automatically triggering the startup behavior test on the raw data samples and known-answer tests.
3. Start-up health tests are completed, with the conditioning stage ready to use.
4. The conditioning stage internal input data buffer is filled again with 128-bit and a number of conditioning rounds defined by the RNG configuration (NIST or non-NIST) is performed. The output buffer is then filled with the post processing result.
5. The output buffer is refilled automatically according to the RNG usage.

The associated initialization time can be found in *Section 43.5*.

Figure 435. RNG initialization overview

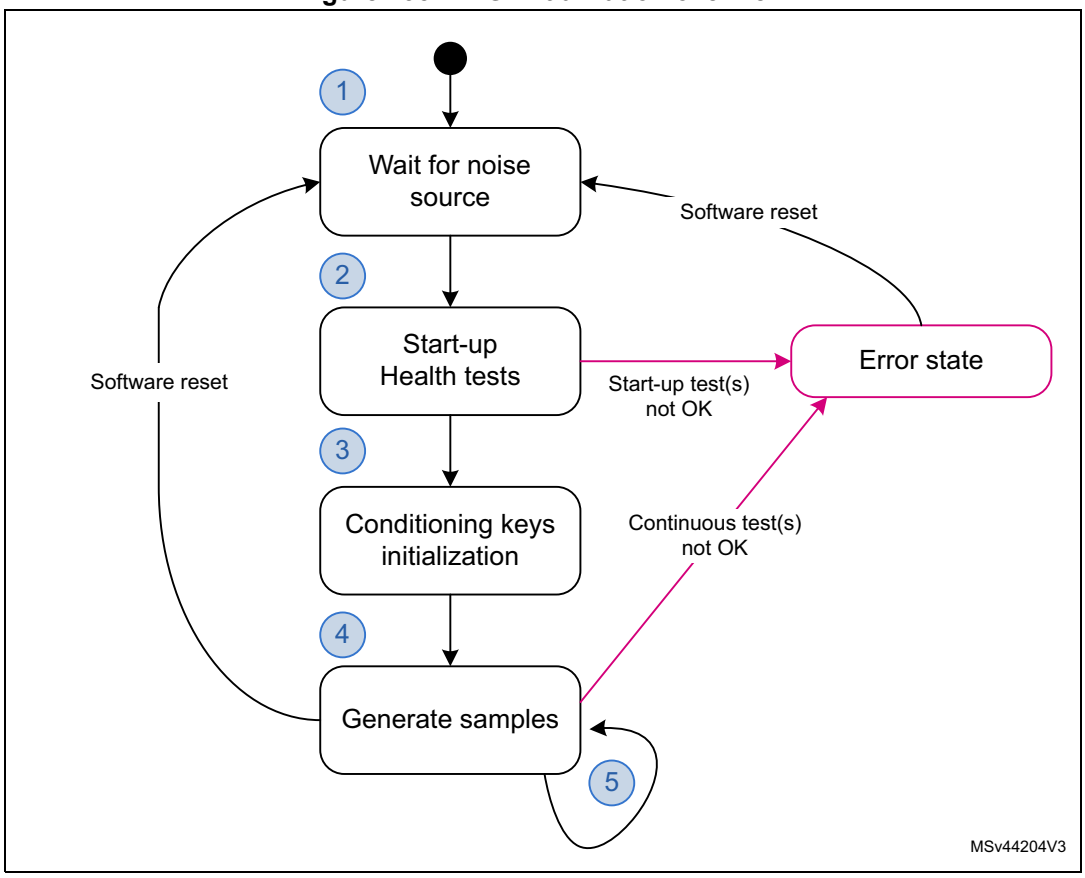


Figure 435 also highlights a possible software reset sequence, implemented by:

1. Write RNGEN = 0, then wait for BUSY = 0 in the RNG_SR register.
2. Write bits RNGEN = 0 and CONDRST = 1 in the RNG_CR register with the same RNG configuration and a new CLKDIV if needed.
3. Write RNGEN = 1 and CONDRST = 0 in the RNG_CR register.
4. Wait for a random number to be ready, after initialization completes.

Note: When the RNG is reset by RCC (hardware reset), the configuration for optimal randomness is lost in the registers.

43.3.5 RNG operation

Normal operation

To run the RNG using interrupts, the following steps are recommended:

1. Check in *Section 43.6* if a specific RNG configuration is required for the application.
   – If this is the case, when bits RNGEN and BUSY=0, write in the RNG_CR register bit CONDRST = 1, together with the correct RNG configuration. Then perform a second write with bit CONDRST = 0, interrupt enable bit IE = 1, and RNG enable bit RNGEN = 1.

- If this is not the case, perform a write to the RNG_CR register with interrupt enable bit IE = 1 and RNG enable bit RNGEN = 1.

2. An interrupt is now generated when a random number is ready or when an error occurs. Therefore, at each interrupt, check that:
   - No error occurred. The SEIS and CEIS bits must be set to 0 in the RNG_SR register.
   - A random number is ready. The DRDY bit must be set to 1 in the RNG_SR register.
   - If the above two conditions are true the content of the RNG_DR register can be read up to four consecutive times. If valid data are available in the conditioning output buffer, four additional words can be read by the application (in this case the DRDY bit is still high). If one or both of the above conditions are false, the RNG_DR register must not be read. If an error occurred, the error recovery sequence described in *Section 43.3.7* must be used.

To run the RNG in polling mode the following steps are recommended:

1. Check in *Section 43.6* if a specific RNG configuration is required for the application.
   - If this is the case, when bits RNGEN and BUSY = 0, write in the RNG_CR register bit CONDRST = 1, together with the correction RNG configuration. Then perform a second write to the RNG_CR register with bit CONDRST = 0 and the RNG enable bit RNGEN = 1.
   - If this is not the case, only enable the RNG by setting the RNGEN bit to 1 in the RNG_CR register.
2. Read the RNG_SR register and check that:
   - No error occurred (the SEIS and CEIS bits must be set to 0)
   - A random number is ready (the DRDY bit must be set to 1)
3. If the above conditions are true, read the content of the RNG_DR register up to four consecutive times. If valid data are available in the conditioning output buffer, four additional words can be read by the application (in this case the DRDY bit is still high). If one or both of the above conditions are false, the RNG_DR register must not be read. If an error occurred, use the recovery sequence described in *Section 43.3.7*.

Note: When data are not ready (DRDY = 0) RNG_DR returns 0. It is recommended to verify that RNG_DR is different from 0. When this happens, a seed error occurred between RNG_SR polling and RND_DR output reading (a rare event).

If the random number generation period is a concern to the application and if NIST compliance is not required, it is possible to select a faster configuration by using the configuration B, described in *Section 43.6*. The gain in random number generation speed is summarized in *Section 43.5*.

Low-power operation

If power consumption is a concern, low-power strategies can be used, as described in *Section 43.3.8*.

Software post-processing

No specific software post-processing/conditioning is expected to meet the AIS-31 or NIST SP800-90B approvals.

Built-in health check functions are described in *Section 43.3.3*.

43.3.6 RNG clocking

The RNG runs on two different clocks: the AHB bus clock and a dedicated RNG clock.

The AHB clock is used to clock the AHB banked registers and conditioning component. The RNG clock, coupled with a programmable divider (see CLKDIV bitfield in the RNG_CR register) is used for noise source sampling. Recommended clock configurations are detailed in *Section 43.6*.

*Note: When the CED bit in the RNG_CR register is set to 0, the RNG clock frequency before the internal divider **must be higher** than the AHB clock frequency divided by 32, otherwise the clock checker flags a clock error (CECS = 1 in the RNG_SR register).*

See *Section 43.3.1* for details (AHB and RNG clock domains).

43.3.7 Error management

In parallel to random number generation a health check block verifies the correct noise source behavior and the frequency of the RNG source clock as detailed in this section. Associated error state is also described.

Clock error detection

When the clock error detection is enabled (CED = 0) and if the RNG clock frequency is too low, the RNG sets to 1 both the CEIS and CECS bits to indicate that a clock error occurred. In this case, the application must check that the RNG clock is configured correctly (see *Section 43.3.6*), and then it must clear the CEIS bit interrupt flag. The CECS bit is automatically cleared when the clocking condition is normal.

When CECS is set, values are available in the RNG_DR register, but it must not be used as described in *Section 43.3.5*.

Note: CEIS is set only when CECS is set to 1 by RNG.

Noise source error detection

When a noise source (or seed) error occurs, the RNG stops generating random numbers and sets to 1 both SEIS and SECS bits to indicate that a seed error occurred.

When SECS is set, values are available in the RNG_DR register, but it must not be used as described in *Section 43.3.5*.

To manage a seed error, follow the recommended sequence below. It requires the CONFIGLOCK bit to be cleared.

- When ARDIS is cleared (auto-reset enabled):
  - Clear the SEIS bit in the RNG_SR register
  - If SECS is cleared RNG can be used as usual. If SECS is still set in RNG_SR it means a new seed error occurred (unlikely). In this case, executes following step 1)
- When ARDIS is set (auto-reset disabled) the following sequence must be used to recover from a seed error.

1. Read both RNG_HTSRx registers. Using the previous HTSR values saved in RAM, compute the accumulated number of errors per oscillator (can be RPERR or ADERR errors). In a *nsmr* variable, mask the oscillators with accumulated number of errors greater than 3. This variable is used in step 3). Save the updated HTSR values in RAM.
   - During the first iteration, initialize *nsmr* variable with the RNG_NSCR value.
2. If fewer than 6 oscillators are active in the *nsmr* variable, reinitialize it with the RNG_NSCR value.
   - When RNG configuration is Configuration B, and the third time you reach this loop, go to Step 3 changing the RNG configuration to Configuration C. Both configurations are defined in *Section 43.6.2*.
3. Write CONDRST at 1 in RNG_CR, then update RNG_NSMR with *nsmr* value. Refer to *Section 43.7.8* for details.
4. Write CONDRST at 0 to finalize the reset of the RNG conditioning logic.
5. Wait for the CONDRST bit to be cleared by hardware, or poll for BUSY bit= 0. Then clear the SEIS interrupt status bit in the RNG_SR register.
6. If SECS is still set in RNG_SR it means a new seed error occurred (unlikely). In this case go back to step 1). If SECS is cleared, restart the generation of random numbers by setting RNGEN in RNG_CR.

If application has set the CONFIGLOCK bit (not recommended), do the following:

- When ARDIS is cleared (auto-reset enabled) clear the SEIS interrupt status bit in the RNG_SR register before drawing random numbers again.
- When ARDIS is set (auto-reset disabled), the following sequence must be used to fully recover from a seed error:

1. Write CONDRST at 1 and at 0 in the RNG_CR register to reset the conditioning logic.
2. Wait for the CONDRST bit to be cleared by hardware, or poll for BUSY = 0. Then clear the SEIS interrupt status bit in the RNG_SR register.
3. If SECS is still set in RNG_SR it means a new seed error occurred (unlikely). In this case go back to step 1).

Note: After a seed error RNG restarts generating random numbers when SECS is cleared.

RNG tamper errors

When an unexpected error is found by the RNG, an internal tamper event is triggered in the TAMP peripheral, and the RNG stops delivering random data.

When this event occurs, the secure application needs to reset the RNG peripheral, using the central reset management or the global SoC reset. A proper initialization of the RNG is required again.

Note: Seed errors do not trigger tamper errors.

43.3.8 RNG low-power use

If power consumption is a concern, the RNG can be disabled as soon as the DRDY bit is set to 1 by setting the RNGEN bit to 0 in the RNG_CR register. As the post-processing logic and the output buffer remain operational while the RNGEN = 0, the following features are available to the software:

- If there are valid words in the output buffer, four random numbers can still be read from the RNG_DR register.
- If there are valid bits in the conditioning output internal register, four additional random numbers can be still be read from the RNG_DR register. If it is not the case, RNG must be re-enabled by the application until the expected new noise source bits threshold is reached (128-bit in NIST mode), and a complete conditioning round is done. Four new random words are then available only if the expected number of conditioning round is reached (two if NISTC = 0). The overall time can be found in *Section 43.5*.

When disabling the RNG, the user deactivates all the analog seed generators, whose power consumption is given in the datasheet electrical characteristics section. The user also gates all the logic clocked by the RNG clock. Note that this strategy is adding latency before a random sample is available on the RNG_DR register, because of the RNG initialization time.

If the RNG block is disabled during initialization (that is well before the DRDY bit rises for the first time), the initialization sequence resumes from where it was stopped when the RNGEN bit is set to 1, unless the application resets the conditioning logic using the CONDRST bit in the RNG_CR register.

When the application wants to gate the RNG kernel clock, the software must issue the following sequence: first, disable the RNG by clearing the RNGEN bit in the RNG_CR register, then wait for the BUSY bit to be cleared in the RNG_SR, and finally, disable the RNG kernel clock using the RCC.

Before entering a power mode where RNG is deactivated (like Stop mode), the software must first disable the RNG by clearing the RNGEN bit in the RNG_CR register, then wait for the BUSY bit to be cleared in the RNG_SR.

Note: The power modes where RNG is deactivated (retained or not available) can be found in the PWR section.

43.4 RNG interrupts

In the RNG an interrupt can be produced on the following events:

- Data ready flag
- Seed error, see *Section 43.3.7*
- Clock error, see *Section 43.3.7*

Dedicated interrupt enable control bits are available as shown in *Table 424*.

Table 424. RNG interrupt requests

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method
RNG	Data ready flag	DRDY	IE	None (automatic)
	Seed error flag	SEIS	IE	Write CONDRST to 1 then to 0 unless ARDIS is cleared (see *Section 43.3.7*). Write 0 to SEIS.
	Clock error flag	CEIS	IE	Write 0 to CEIS

The user can enable or disable the above interrupt sources globally by using the general interrupt control bit IE in the RNG_CR register. The status of the individual interrupt sources can be read from the RNG_SR register.

Note: Interrupts are generated only when RNG is enabled.

43.5 RNG processing time

In the recommended configuration described in *Table 425*, the time between two sets of four 32-bit data is either:

- 206 x N AHB cycles if $f_{AHB} < f_{threshold}$ (conditioning stage is limiting), or
- 128 x N RNG cycles $f_{AHB} \geq f_{threshold}$ (noise source stage is limiting).

If f_{RNG}= 48 MHz, $f_{threshold}$ = 1.6 x f_{RNG} = 77 MHz. The value of N is defined in *Section 43.6*.

Note: When CLKDIV is different from 0, f_{RNG} must take into account the internal divider ratio.

43.6 RNG entropy source validation

43.6.1 Introduction

To assess the amount of entropy available from the RNG, the peripheral has been tested using the German BSI AIS-31 statistical tests (T0 to T8), and NIST SP800-90B test suite.

43.6.2 Validation conditions

The RNG true random number generator has been tested in the following conditions:

- RNG clock rng_clk = 48 MHz, with CED bit cleared in RNG_CR.
- Configurations are described in *Table 425* and *Table 426*. Only configuration A can be certified NIST SP800-90B. Refer to *Table 427* to select the best configuration for the application.
- Configuration B or C can be used when configuration A is not present in AN4230, or is not flagged as certified.

Table 425. RNG configurations

Configuration	RNG_CR bits					Loop number (N)	RNG_HTCR0 register	RNG_NSCR register
	NISTC bit	RNG_CONFIG1 [7:0]	CLKDIV [3:0]	RNG_CONFIG2 [2:0]	RNG_CONFIG3 [3:0](1)			
A	Refer to *NIST compliant RNG configuration* table in AN4230 available from *www.st.com*. This application note also indicates if this configuration is part of an existing NIST SP800-90B Entropy Certificate listed on *https://csrc.nist.gov/projects/cryptographic-module-validation-program.*							
B	1	0x83	0x0	0x0	0xF	3	0x0000 AAC7(2)	Default
C	1	0x84	0x5(3)	0x0	0xF	4		Default

1. RNG_CONFIG1[3:0] = i defines the loop number N. If i = 0, N =1. If NISTC = 0, N = 2 regardless of i.
2. This value can be fixed in the RNG driver (it does not depend upon the STM32 product).
3. The noise source sampling must be 48 MHz or less. If the RNG clock is different from 48 MHz, this value of CLKDIV must be adapted. See the CLKDIV bitfield description in *Section 43.7.1* for details.

Table 426. Additional health test configurations

Configuration	RNG_HTCR1 register (oscillator set 1)	RNG_HTCR2 register (oscillator set 2)	RNG_HTCR3 register (oscillator set 3)
A	Refer to NIST compliant RNG configuration table in AN4230 available from www.st.com.		
B and C	default	default	default

Table 427. Configuration selection

Section criteria	Configuration A	Configuration B	Configuration C
Suitable to generate NIST compliant cryptographic keys	Yes	No	
Entropy(1)	Certified	Not certified	
Speed(2)	Baseline	Faster	Baseline

1. For configurations B and C entropy is verified using the AIS-31 test suite (T0 to T8).
2. When the speed is not enough for the application, an NIST compliant DRBG can be used to increase throughput.

For details on data collection and the running of statistical test suites refer to AN4230 "*Introduction to random number generation validation using the NIST statistical test suite for STM32 MCUs and MPUs*", available on *www.st.com*.

43.7 RNG registers

The RNG is associated with a control register, a data register, and a status register.

43.7.1 RNG control register (RNG_CR)

Address offset: 0x000

Reset value: 0x0080 0D00

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CONFIGLOCK	CONDRST	Res.	Res.	RNG_CONFIG1[7:0]								CLKDIV[3:0]			
rs	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RNG_CONFIG2[2:0]			NISTC	RNG_CONFIG3[3:0]				ARDIS	Res.	CED	Res.	IE	RNGEN	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw		rw		rw	rw		

Bit 31 **CONFIGLOCK**: RNG configuration lock

Set this bit to lock the RNG configuration. Since CONFIGLOCK prevents the implementation of robust seed error management described in *Section 43.3.7*, it is recommended not to use it.

0: Writes to the RNG_NSMR, RNG_NSCR, RNG_HTCR and the RNG_CR configuration bits [29:4] are allowed.

1: Writes to the RNG_NSMR, RNG_NSCR, RNG_HTCR and the RNG_CR configuration bits [29:4] are ignored until the next RNG reset.

Once set, this bit can only be cleared when RNG is reset (set once bit).

Bit 30 **CONDRST**: Conditioning soft reset

Write 1 and then write 0 to reset the conditioning logic, clear all the FIFOs and start a new RNG initialization process, with RNG_SR cleared. Registers RNG_NSMR, RNG_NSCR, RNG_CR and RNG_HTCR are not changed by CONDRST.

This bit must be set to 1 in the same access that sets any configuration bits [29:4]. In other words, when CONDRST bit is set to 1 correct configuration in bits [29:4] must also be written.

Before setting this bit to 1 RNGEN must be set to 0, and BUSY flag must be cleared in RNG_SR.

When CONDRST is set to 0, wait for BUSY flag to be cleared in RNG_SR. CONDRST bit then reads as 0.

Bits 29:28 Reserved, must be kept at reset value.

Bits 27:20 **RNG_CONFIG1[7:0]:** RNG configuration 1

Reserved to the RNG configuration (bitfield 1). Must be initialized using the recommended value documented in *Section 43.6*.

Writing to this bitfield is only effective when CONFIGLOCK = 0. The new value is only taken into account if CONDRST bit is set in the same access.

Bits 19:16 **CLKDIV[3:0]**: Clock divider factor

This value used to configure an internal programmable divider (from 1 to 16) acting on the incoming RNG clock. These bits can be written only when the core is disabled (RNGEN = 0).

0x0: internal RNG clock after divider is similar to incoming RNG clock.

0x1: two RNG clock cycles per internal RNG clock.

0x2: 2^2 (= 4) RNG clock cycles per internal RNG clock.

...

0xF: 2^{15} RNG clock cycles per internal clock (for example. an incoming 48 MHz RNG clock becomes a 1.5 kHz internal RNG clock)

Writing to this bitfield is only effective when CONFIGLOCK = 0. The new value is only taken into account if CONDRST bit is set in the same access.

Bits 15:13 **RNG_CONFIG2[2:0]:** RNG configuration 2

Reserved to the RNG configuration (bitfield 2). Refer to the RNG_CONFIG1 bitfield for details.

Bit 12 **NISTC**: NIST custom

0: Hardware default values for NIST compliant RNG. In this configuration for 128-bit output, two conditioning loops are performed and 256 bits of noise source are used.

1: Custom values for NIST compliant RNG. See *Section 43.6* for recommended configurations.

Writing to this bit is only effective when CONFIGLOCK = 0. The new value is only taken into account if the CONDRST bit is set in the same access.

Bits 11:8 **RNG_CONFIG3[3:0]:** RNG configuration 3

Reserved to the RNG configuration (bitfield 3). Refer to RNG_CONFIG1 bitfield for details.

If the NISTC bit is cleared in this register RNG_CONFIG3 bitfield values are ignored by RNG.

Bit 7 **ARDIS**: Auto reset disable

Set this bit to deactivate the auto-reset feature.

0: Auto-reset is enabled

1: Auto-reset is disabled

Keeping the auto-reset enabled (automatic clearance of the SECS bit) simplifies the management of noise source errors, as described in *Section 43.3.7*.

Writing to this bit is only effective when CONFIGLOCK = 0. The new value is only taken into account if the CONDRST bit is set in the same access.

Bit 6 Reserved, must be kept at reset value.

Bit 5 **CED:** Clock error detection

0: Clock error detection is enabled.

1: Clock error detection is disabled

The clock error detection cannot be enabled nor disabled on-the-fly when the RNG is enabled, that is to enable or disable CED, the RNG must be disabled.

Writing to this bit is only effective when CONFIGLOCK = 0. The new value is only taken into account if the CONDRST bit is set in the same access.

Bit 4 Reserved, must be kept at reset value.

Bit 3 **IE:** Interrupt enable

0: RNG interrupt is disabled

1: RNG interrupt is enabled. An interrupt is pending as soon as the DRDY, SEIS, or CEIS flag is set in the RNG_SR register.

Bit 2 **RNGEN:** True random number generator enable
This bit enables/disables the true random number generator.
0: True random number generator disabled.
1: True random number generator enabled.
Clearing RNGEN powers off the analog noise sources and gates the logic clocked by the RNG clock.
When clearing this bit verify that BUSY flag is cleared in RNG_SR before updating this register again.

Bits 1:0 Reserved, must be kept at reset value.

43.7.2 RNG status register (RNG_SR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEIS	CEIS	BUSY	Res.	SECS	CECS	DRDY
									rc_w0	rc_w0	r		r	r	r

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **SEIS:** Seed error interrupt status
This bit is set at the same time as SECS. It is cleared by writing 0 (unless CONDRST is used). Writing 1 has no effect.
0: No faulty sequence detected
1: At least one faulty sequence is detected. See SECS bit description for details.
An interrupt is pending if IE = 1 in the RNG_CR register.

Bit 5 **CEIS:** Clock error interrupt status
This bit is set at the same time as CECS. It is cleared by writing 0. Writing 1 has no effect.
0: The RNG clock is correct ($f_{RNGCLK} > f_{HCLK}/32$)
1: The RNG clock before the internal divider is detected too slow ($f_{RNGCLK} < f_{HCLK}/32$)
An interrupt is pending if IE = 1 in the RNG_CR register.

Bit 4 **BUSY:** Busy
This flag indicates whether RNG is idle or busy.
0: Idle
1: Busy
RNG is flagged as busy when a conditioning soft reset (using CONDRST) is in progress. It is also flagged busy when RNG is activated by application setting RNGEN bit, or when a connected peripheral fetches randoms via the dedicated RNG hardware bus.
More information on BUSY usage can also be found in *Section 43.3.8*.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **SECS:** Seed error current status

0: No faulty sequence has currently been detected. If the SEIS bit is set, this means that a faulty sequence was detected and the situation has been recovered.

1: At least one of the following faulty sequence has been detected:

– Start-up or continuous repetition count test on noise source failed.

– Start-up or continuous adaptive proportion test on noise source failed.

– Start-up post-processing/conditioning sanity check failed.

After enabling the RNG, SECS bit clears once startup health tests completes successfully. If SECS does not clear, run the software reset sequence with CONDRST described in *Section 43.3.4*.

Bit 1 **CECS:** Clock error current status

0: The RNG clock is correct ($f_{RNGCLK} > f_{HCLK}/32$). If the CEIS bit is set, this means that a slow clock was detected and the situation has been recovered.

1: The RNG clock is too slow ($f_{RNGCLK} < f_{HCLK}/32$).

CECS bit is valid only if the CED bit in the RNG_CR register is set to 0.

Bit 0 **DRDY:** Data ready

This flag is raised to indicate valid (non-0) random data available in the RNG_DR register. It is cleared by hardware upon reading the RNG_DR register (which empties the RNG buffer). The DRDY flag can also be raised upon disabling RNG (upon clearing the RNGEN bit).

0: No valid random data ready.

1: Valid random data ready.

Raising DRDY generates an interrupt if enabled with the IE bit of the RNG_CR register.

43.7.3 RNG data register (RNG_DR)

Address offset: 0x008

Reset value: 0x0000 0000

This register is a read-only register that delivers a 32-bit random value when read. The content of this register is valid when the DRDY = 1 and the value is not 0x0, even if RNGEN = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RNDATA[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RNDATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RNDATA[31:0]:** Random data

32-bit random data, valid when DRDY = 1. When DRDY = 0, the RNDATA value is 0.

The 0 value means that a seed error occurred between RNG_SR polling and RND_DR output reading (a rare event).

43.7.4 RNG noise source control register (RNG_NSCR)

Address offset: 0x00C

Reset value: 0x0000 01FF

Writing in RNG_NSCR is taken into account only if the CONDRST bit is set, and the CONFIGLOCK bit is cleared in RNG_CR. Writing to this register is ignored if CONFIGLOCK= 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	EN_OSC3[2:0]			EN_OSC2[2:0]			EN_OSC1[2:0]		
							rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bits 8:6 **EN_OSC3[2:0]:**

When the RNG is enabled (RNGEN bit set), each bit of this bitfield enables one of the three inputs from the oscillator instance number 3. The bitfield has no effect otherwise.

Bits 5:3 **EN_OSC2[2:0]:**

When the RNG is enabled (RNGEN bit set), each bit of this bitfield enables one of the three inputs from the oscillator instance number 2. The bitfield has no effect otherwise.

Bits 2:0 **EN_OSC1[2:0]:**

When the RNG is enabled (RNGEN bit set), each bit of this bitfield enables one of the three inputs from the oscillator instance number 1. The bitfield has no effect otherwise.

43.7.5 RNG health test control register x (RNG_HTCRx)

Address offset: 0x010 + 0x4 * x (x=0 to 3)

Reset value: 0x0000 72AC, 0x0003 FFFF, 0x0003 FFFF, 0x0003 FFFF

Writing in RNG_HTCR is taken into account only if the CONDRST bit is set, and the CONFIGLOCK bit is cleared in the RNG_CR. Writing to this register is ignored if CONFIGLOCK = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HTCFG[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HTCFG[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **HTCFG[31:0]:** health test configuration

This configuration is used by RNG to configure the health tests (repetition count test, adaptive proportion test) at position x. See *Section 43.6* for the recommended value. With its default value, health tests have a very small probability of triggering any error at position x.

Note: The RNG behavior, including the read to this register, is not guaranteed if a different value from the recommended value is written.

43.7.6 RNG health test status register 0 (RNG_HTSR0)

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	RPERR9	RPERR8	RPERR7	RPERR6	RPERR5	RPERR4	RPERR3	RPERR2	RPERR1	RPERRX
						r	r	r	r	r	r	r	r	r	r

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:1 **RPERR{i}:** Repetitive error for oscillator *i* (i=1 to 9)

This bit is set when the health test logic associated to the oscillator *i* finds a repetitive test error. The bit is cleared when application clears SEIS bit in RNG_SR. If ARDIS is cleared auto-reset prevents RNG to capture more than one test error. Repetition count test is defined in *Health checks* section.

0: No repetitive test error found in oscillator *i*.
1: Repetitive test error found in oscillator *i*.

Bit 0 **RPERRX:** Repetitive error after the XOR

This bit is set when the health test logic finds a repetitive test error after the XOR clock tree (see *Figure 433*). The bit is cleared when application clears SEIS bit in RNG_SR. If ARDIS is cleared auto-reset prevents RNG to capture more than one test error.

0: No repetitive test error found after the XOR clock tree.
1: Repetitive test error found after the XOR clock tree.

43.7.7 RNG health test status register 1 (RNG_HTSR1)

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	ADERR9	ADERR8	ADERR7	ADERR6	ADERR5	ADERR4	ADERR3	ADERR2	ADERR1	ADERRX
						r	r	r	r	r	r	r	r	r	r

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:1 **ADERR{i}:** Adaptative error for oscillator *i* (i=1 to 9)

This bit is set when the health test logic associated to the oscillator *i* finds an adaptative test error. The bit is cleared when application clears SEIS bit in RNG_SR. If ARDIS is cleared auto-reset prevents RNG to capture more than one test error. Adaptive proportion test is defined in *Health checks* section.

0: No adaptative test error found in oscillator *i*.
1: Adaptative test error found in oscillator *i*.

Bit 0 **ADERRX:** Adaptative error after the XOR

This bit is set when the health test logic finds an adaptative test error after the XOR clock tree (see *Figure 433*). The bit is cleared when application clears SEIS bit in RNG_SR If ARDIS is cleared auto-reset prevents RNG to capture more than one test error.

0: No adaptative test error found after the XOR clock tree.
1: Adaptative test error found after the XOR clock tree.

43.7.8 RNG noise source mask register (RNG_NSMR)

Address offset: 0x030

Reset value: 0x0000 01FF

Writing to this register is ignored if CONFIGLOCK = 1. It is recommended to have at least 6 oscillators running when loop number N = 3 (or higher). See *Section 43.6.2* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	MOSC 9	MOSC 8	MOSC 7	MOSC 6	MOSC 5	MOSC 4	MOSC 3	MOSC 2	MOSC 1
							rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bits 8:0 **MOSC{i}:** Mask oscillator i (i = 1 to 9)

Clear this bit to masks the oscillator *i*, and deactivate its related health tests. The bit has no effect if the oscillator *i* is deactivated with the bit RNG_NSCR[i].

Application can mask an oscillator when it is not contributing to the generation of entropy.

0: Oscillator *i* is masked, and related health tests are deactivated.
1: Oscillator *i* is not masked. Related health tests are running.

43.7.9 RNG register map

Table 428. RNG register map and reset map

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	RNG_CR	CONFIGLOCK	CONDRST	Res.	Res.	RNG_CONFIG1[7:0]								CLKDIV[3:0]				RNG_ CONFIG2 [2:0]			NISTC	RNG_ CONFIG3 [3:0]				ARDIS	Res.	CED	Res.	IE	RNGEN	Res.	Res.
	Reset value	0	0			0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0		0		0	0		
0x004	RNG_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEIS	CEIS	BUSY	Res.	SECS	CECS	DRDY
	Reset value																										0	0	0		0	0	0
0x008	RNG_DR	RNDATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C	RNG_NSCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EN_OSC3 [2:0]		EN_OSC2 [2:0]			EN_OSC1 [2:0]			
	Reset value																								1	1	1	1	1	1	1	1	1
0x010	RNG_HTCR0	HTCFG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	1	0	1	0	1	1	0	0
0x014	RNG_HTCR1	HTCFG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x018	RNG_HTCR2	HTCFG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x01F	RNG_HTCR3	HTCFG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x020	RNG_HTSR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RPERR9	RPERR8	RPERR7	RPERR6	RPERR5	RPERR4	RPER3	RPERR2	RPERR1	RPERRX
	Reset value																							0	0	0	0	0	0	0	0	0	0
0x024	RNG_HTSR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADERR9	ADERR8	ADERR7	ADERR6	ADERR5	ADERR4	ADERR3	ADERR2	ADERR1	ADERRX
	Reset value																							0	0	0	0	0	0	0	0	0	0
0x030	RNG_MSMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MOSC9	MOSC8	MOSC7	MOSC6	MOSC5	MOSC4	MOSC3	MOSC2	MOSC1
	Reset value																								1	1	1	1	1	1	1	1	1

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

44 AES hardware accelerator (AES)

44.1 AES introduction

The AES hardware accelerator (AES) encrypts or decrypts data in compliance with the advanced encryption standard (AES) defined by NIST.

AES supports ECB, CBC, CTR, GCM, GMAC, and CCM chaining modes for key sizes of 128 or 256 bits.

AES has the possibility to load by hardware the key stored in SAES peripheral, under SAES control.

The peripheral supports DMA single transfers for incoming and outgoing data (two DMA channels are required).

44.2 AES main features

- Compliant with NIST FIPS publication 197 *"Advanced encryption standard (AES)"* (November 2001)
- Encryption and decryption with multiple chaining modes:
  - Electronic codebook (ECB) mode
  - Cipher block chaining (CBC) mode
  - Counter (CTR) mode
  - Galois counter mode (GCM)
  - Galois message authentication code (GMAC) mode
  - Counter with CBC-MAC (CCM) mode
- 128-bit data block processing, supporting cipher key lengths of 128-bit and 256-bit
  - 51 or 75 clock cycle latency in ECB mode for processing one 128-bit block with, respectively, 128-bit or 256-bit key
- Using dedicated key bus, optional key sharing with side-channel resistant SAES peripheral (shared-key mode), controlled by SAES
- Integrated key scheduler to compute the last round key for ECB/CBC decryption
- 256-bit of write-only registers for storing cryptographic keys (eight 32-bit registers)
- 128-bit of registers for storing initialization vectors (four 32-bit registers)
- 32-bit buffer for data input and output
- Automatic data flow control supporting two direct memory access (DMA) channels, one for incoming data, one for processed data. Only single transfers are supported.
- Data-swapping logic to support 1-, 8-, 16-, or 32-bit data
- AMBA AHB slave peripheral, accessible through 32-bit word single accesses only. Other access types generate an AHB error, and other than 32-bit writes may corrupt the register content.
- Possibility for software (in CPU mode only, not in DMA mode) to suspend a message if AES needs to process another message with a higher priority, then resume the original message

44.3 AES implementation

The devices have one AES peripheral, implemented as per the following table. It can use the key generated by the SAES peripheral. For comparison, the SAES peripheral is also included in the table.

Table 429. AES versus SAES features

Modes or features(1)	AES	SAES
ECB, CBC chaining	X	X
CTR, CCM, GCM chaining	X	X
AES 128-bit ECB encryption in cycles	51	480
DHUK and BHK key selection	-	X
Resistance to side-channel attacks	-	X
Shared key between SAES and AES	X	
Key sizes in bits	128, 256	128, 256

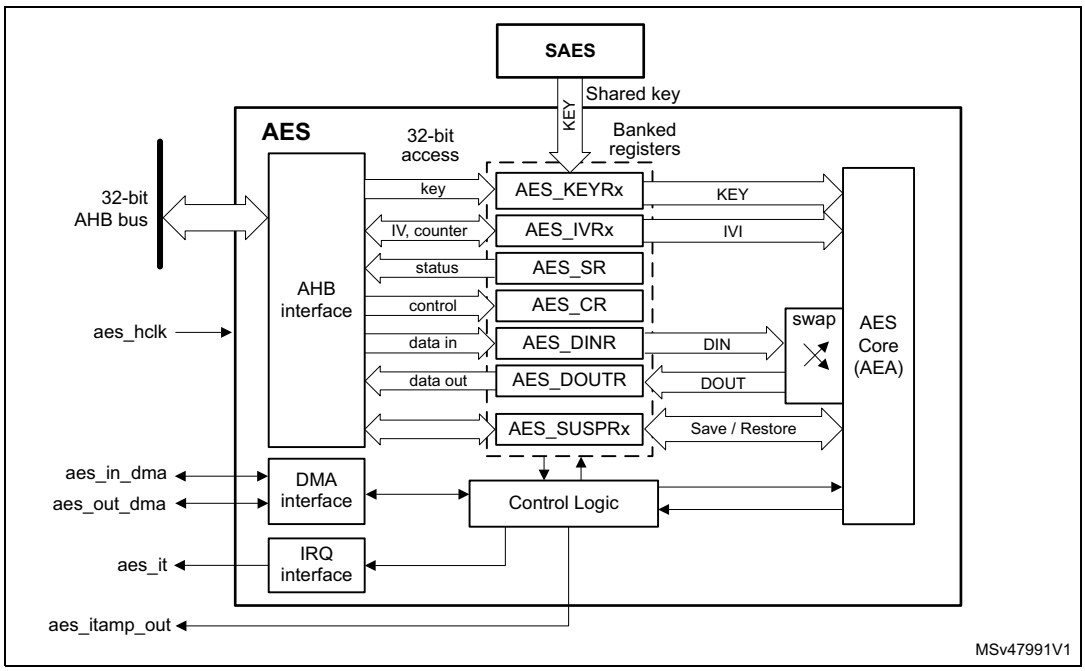
1. X = supported.

44.4 AES functional description

44.4.1 AES block diagram

Figure 436 shows the block diagram of AES.

Figure 436. AES block diagram



44.4.2 AES internal signals

Table 430 describes the user relevant internal signals interfacing the AES peripheral.

Table 430. AES internal input/output signals

Signal name	Signal type	Description
aes_hclk	Input	AHB bus clock
aes_it	Output	AES interrupt request
aes_in_dma	Input/Output	AES incoming data DMA single request/acknowledge
aes_out_dma	Input/Output	AES processed data DMA single request/acknowledge
aes_itamp_out	Output	Tamper event signal to TAMP (XOR-ed), triggered when an unexpected hardware fault occurs. When this signal is triggered, AES automatically clears key registers. A reset is required for AES to be usable again.

44.4.3 AES reset and clocks

The AES peripheral is clocked by the AHB bus clock. It has a dedicated reset bit controlled through the RCC.

44.4.4 AES symmetric cipher implementation

The AES hardware accelerator (AES) is a 32-bit AHB peripheral that encrypts or decrypts 16-byte blocks of data using the advanced encryption standard (AES). It also implements a set of approved AES symmetric key security functions summarized in *Table 431*. Those functions can be certified NIST PUB 140-3.

Table 431. AES approved symmetric key functions

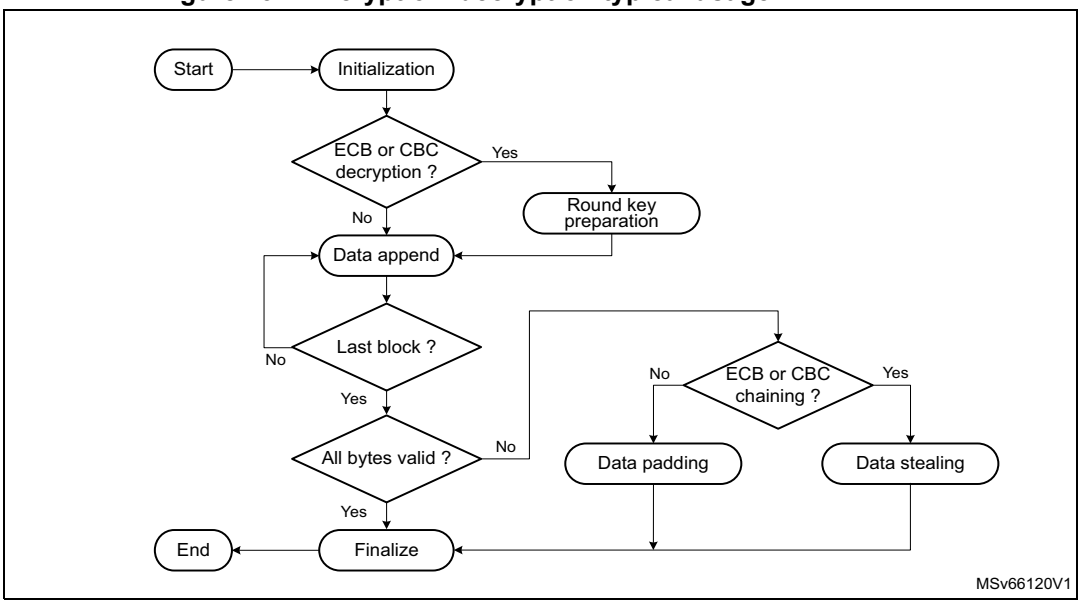
Operations	Algorithm	Specification	Key bit lengths	Chaining modes
Encryption, decryption	AES	FIPS PUB 197 NIST SP800-38A	128, 256	ECB, CBC, CTR
Authenticated encryption or decryption		NIST SP800-38C NIST SP800-38D		GCM, CCM
Cipher-based message authentication code		NIST SP800-38D		GMAC

AES can be used directly by the CPU, or indirectly, using two DMA channels (one for the plaintext, one for the ciphertext).
It is possible to suspend then resume any AES processing, following the sequence described in *Section 44.4.8*.

44.4.5 AES encryption or decryption typical usage

The following figure shows a typical operation for encryption or decryption.

Figure 437. Encryption/ decryption typical usage



Initialization

The AES peripheral is initialized according to the chaining mode. Refer to *Section 44.4.9: AES basic chaining modes (ECB, CBC)* and *Section 44.4.10: AES counter (CTR) mode* for details.

Data append

This section describes different ways of appending data for processing. For ECB or CBC chaining modes, refer to *Section 44.4.7: AES ciphertext stealing and data padding* if the size of data to process is not a multiple of 16 bytes. The last block management in these cases is more complex than what is described in this section.

Appending data using the CPU in polling mode

This method uses flag polling to control the data append through the following sequence:

1. Enable the AES peripheral when KEYVALID is set, by setting the EN bit of the AES_CR register (if not already done).
2. Repeat the following sub-sequence until the payload is entirely processed:
   a) Write four input data words into the AES_DINR register.
   b) Wait until the status flag CCF is set in the AES_ISR register, then read the four data words from the AES_DOUTR register.
   c) Clear the CCF flag, by setting the CCF bit of the AES_ICR register.
   d) If the next processing block is the last block, pad (when applicable) the data with zeros to obtain a complete block, and specify the number of non-valid bytes (using

NPBLB[3:0]) in case of GCM payload encryption or CCM payload decryption (otherwise the tag computation is wrong).

3. As the data block just processed is the last block of the message, optionally discard the data that is not part of the message/payload, then disable the AES peripheral by clearing EN.

Note: Up to three wait cycles are automatically inserted between two consecutive writes to the AES_DINR register, to allow sending the key to the AES processor.

NPBLB[3:0] bitfield is not used in header phase of GCM, GMAC and CCM chaining modes.

Appending data using the CPU in interrupt mode

The method uses interrupt from the AES peripheral to control the data append, through the following sequence:

1. Enable interrupts from AES, by setting the CCFIE bit of the AES_IER register.
2. Enable the AES peripheral when KEYVALID is set, by setting EN (if not already done).
3. Write first four input data words into the AES_DINR register.
4. Handle the data in the AES interrupt service routine. Upon each interrupt:
   a) Read four output data words from the AES_DOUTR register.
   b) Clear the CCF flag and thus the pending interrupt, by setting the CCF bit of the AES_ICR register.
   c) If the next processing block is the last block of the message, pad (when applicable) the data with zeros to obtain a complete block, and specify the number of non-valid bytes (through NPBLB[3:0]) in case of GCM payload encryption or CCM payload decryption (otherwise the tag computation is wrong). Then proceed with point 4e).
   d) If the data block just processed is the last block of the message, optionally discard the data that are not part of the message/payload, then disable the AES peripheral by clearing EN and quit the interrupt service routine.
   e) Write next four input data words into the AES_DINR register and quit the interrupt service routine.

Note: AES is tolerant of delays between consecutive read or write operations, which allows, for example, an interrupt from another peripheral to be served between two AES computations.

The NPBLB[3:0] bitfield is not used in the header phase of GCM, GMAC, and CCM chaining modes.

Appending data using DMA

With this method, all the transfers and processing are managed by DMA and AES. Proceed as follows:

1. If the last block of the message to process is shorter than 16 bytes, prepare the last four-word data block by padding the remainder of the block with zeros.
2. Configure the DMA controller so as to transfer the data to process from the memory to the AES peripheral input and the processed data from the AES peripheral output to the memory, as described in *Section 44.6: AES DMA requests*. Configure the DMA controller so as to generate an interrupt on transfer completion. For GCM payload encryption or CCM payload decryption, the DMA transfer **must not** include the last four-word block if padded with zeros. The sequence described in *Appending data using the CPU in polling mode* must be used instead for this last block, because the

NPBLB[3:0] bitfield must be set up before processing the block, for AES to compute a correct tag.

3. Enable the AES peripheral when KEYVALID is set, by setting EN (if not already done).
4. Enable DMA requests, by setting DMAINEN and DMAOUTEN.
5. Upon DMA interrupt indicating the transfer completion, get the AES-processed data from the memory.

When appending data using DMA, the suspend/resume operation as described in *Section 44.4.8* is not supported.

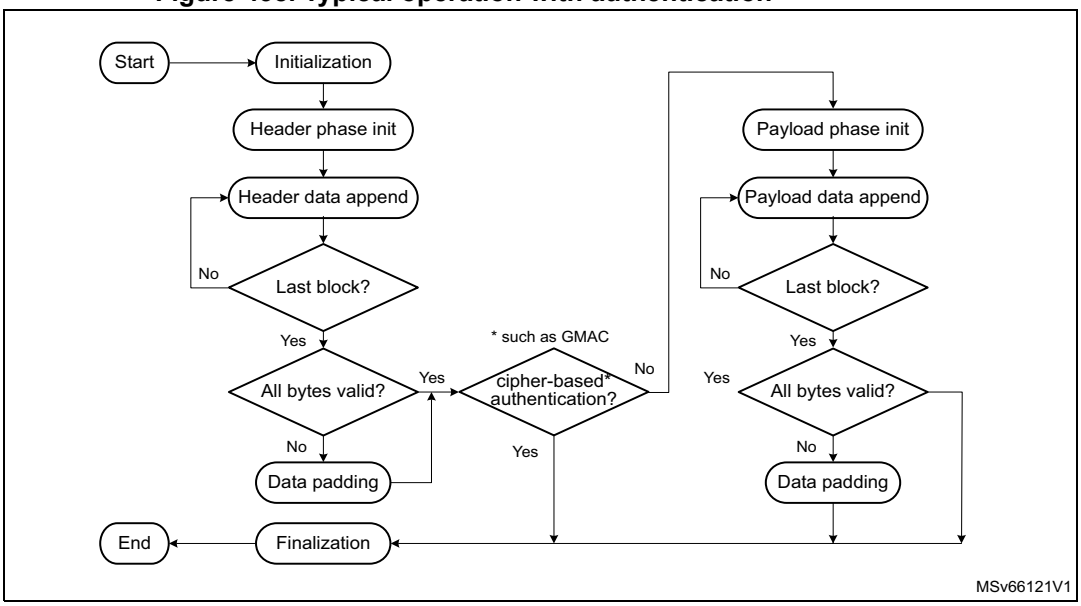
Note: The CCF flag has no use with this method because the reading of the AES_DOUTR register is managed by DMA automatically, without any software action, at the end of the computation phase.

The NPBLB[3:0] bitfield is not used in the header phase of GCM, GMAC, and CCM chaining modes.

44.4.6 AES authenticated encryption, decryption, and cipher-based message authentication

The following figure shows a typical operation for authenticated encryption or decryption, and for cipher-based message authentication.

Figure 438. Typical operation with authentication



Section 44.4.11: AES Galois/counter mode (GCM) and *Section 44.4.13: AES counter with CBC-MAC (CCM)* describe detailed sequences supported by AES.

Cipher-based message authentication flow omits the payload phase, as shown in the figure. Detailed sequence supported by AES is described in *Section 44.4.12: AES Galois message authentication code (GMAC)*.

44.4.7 AES ciphertext stealing and data padding

When using AES in ECB or CBC modes to manage messages the size of which is not a multiple of the block size (16 bytes), the application must use ciphertext stealing techniques

such as those described in NIST Special Publication 800-38A, *Recommendation for Block Cipher Modes of Operation: Three Variants of Ciphertext Stealing for CBC Mode*. Since AES does not implement such techniques, the application must complete the *last block* of input data using data from the *second last* block.

Note: Ciphertext stealing techniques are not documented in this reference manual.

Similarly, in modes other than ECB or CBC, an incomplete input data block (that is, a block with input data shorter than 16 bytes) must be padded with zeros prior to encryption. That is, extra bits must be appended to the trailing end of the data string. After decryption, the extra bits must be discarded. Since AES does not implement automatic data padding operation to the *last block*, the application must follow the recommendation given in this document to manage messages the size of which is not a multiple of 16 bytes.

44.4.8 AES suspend and resume operations

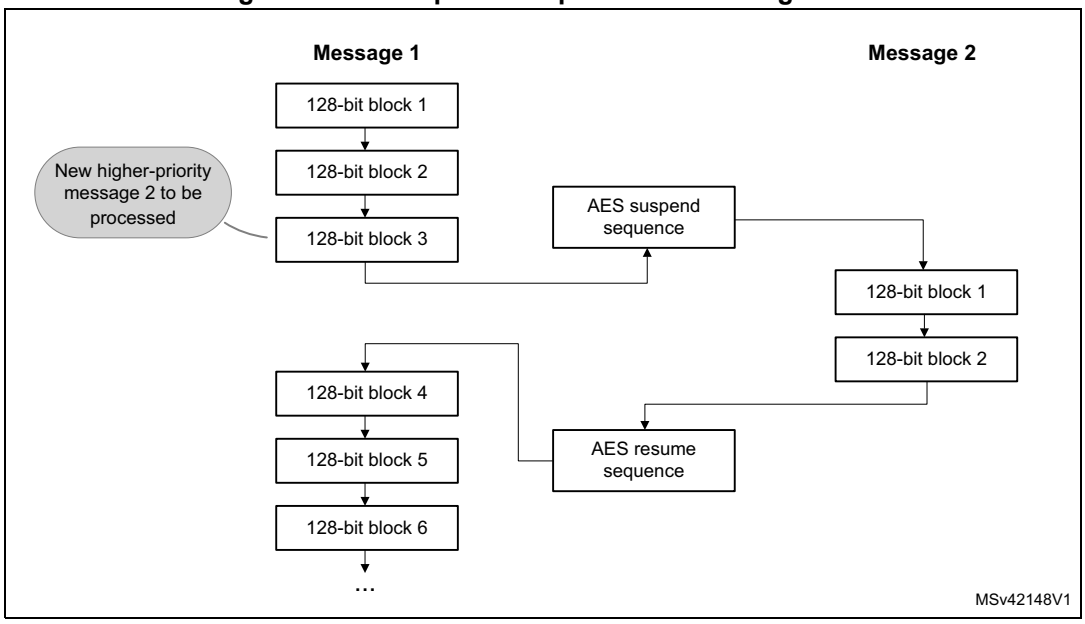
A message can be suspended to process another message with a higher priority. When the higher-priority message is sent, the suspended message can resume. This applies to both encryption and decryption mode.

Suspend and resume operations do not break the chaining operation. The message processing can resume as soon as AES is enabled again, to receive a next data block.

The suspend and resume operations are only supported when AES is used in CPU mode, not in DMA mode.

Figure 439 gives an example of suspend and resume operations: Message 1 is suspended in order to send a shorter and higher-priority Message 2.

Figure 439. Example of suspend mode management



A detailed description of suspend and resume operations is in the sections dedicated to each chaining mode.

44.4.9 AES basic chaining modes (ECB, CBC)

ECB is the simplest mode of operation. There are no chaining operations, and no special initialization stage. The message is divided into blocks and each block is encrypted or decrypted separately. When decrypting in ECB, a special key scheduling is required before processing the first block.

Figure 440 and *Figure 441* describe the electronic codebook (ECB) chaining implementation in encryption and in decryption, respectively. To select ECB chaining mode, write CHMOD[2:0] with 0x0.

Figure 440. ECB encryption

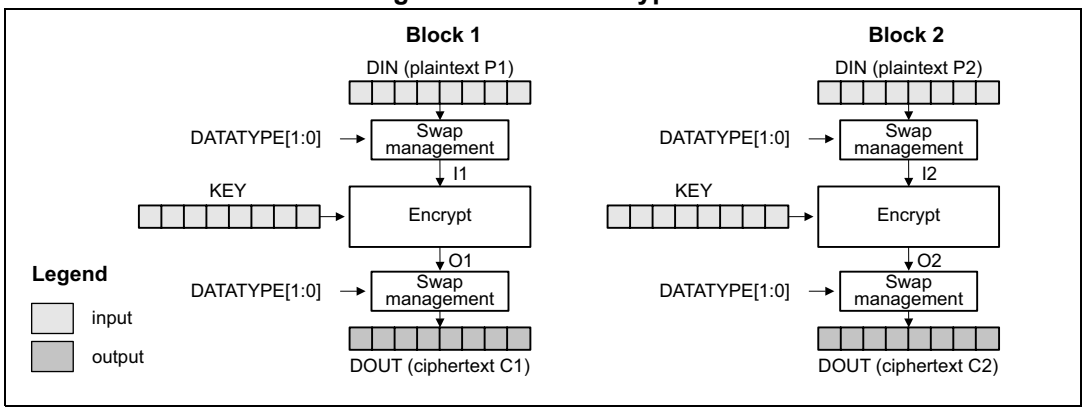
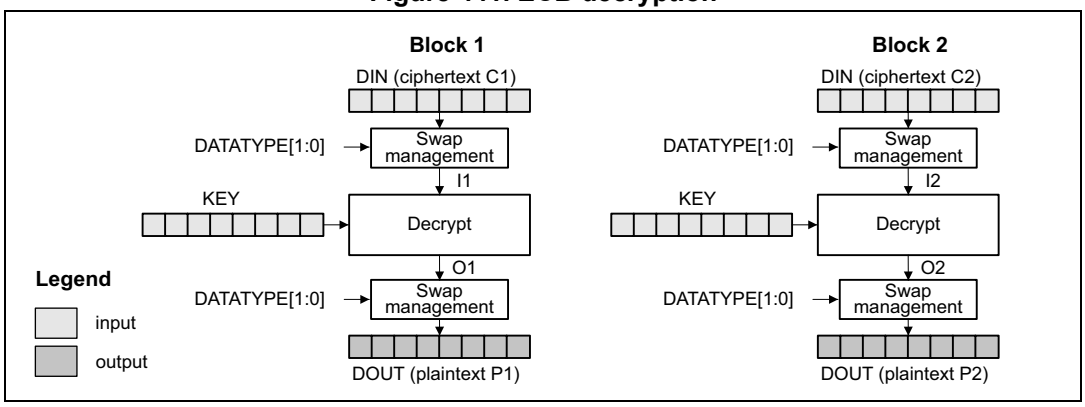


Figure 441. ECB decryption



In CBC encryption mode the output of each block chains with the input of the following block. To make each message unique, an initialization vector is used during the first block processing. When decrypting in CBC, a special key scheduling is required before processing the first block.

Figure 442 and *Figure 443* describe the cipher block chaining (CBC) implementation in encryption and in decryption, respectively. To select this chaining mode, write CHMOD[2:0] with 0x1.

Figure 442. CBC encryption

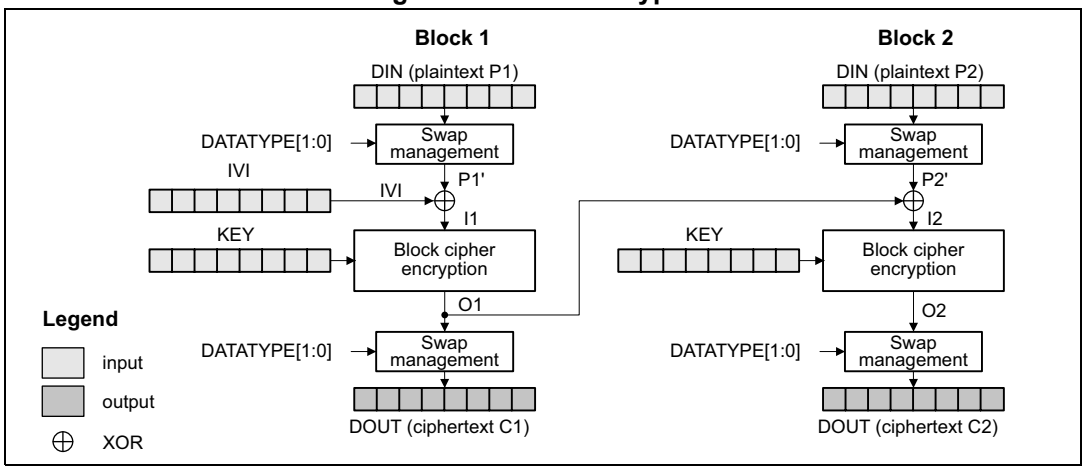
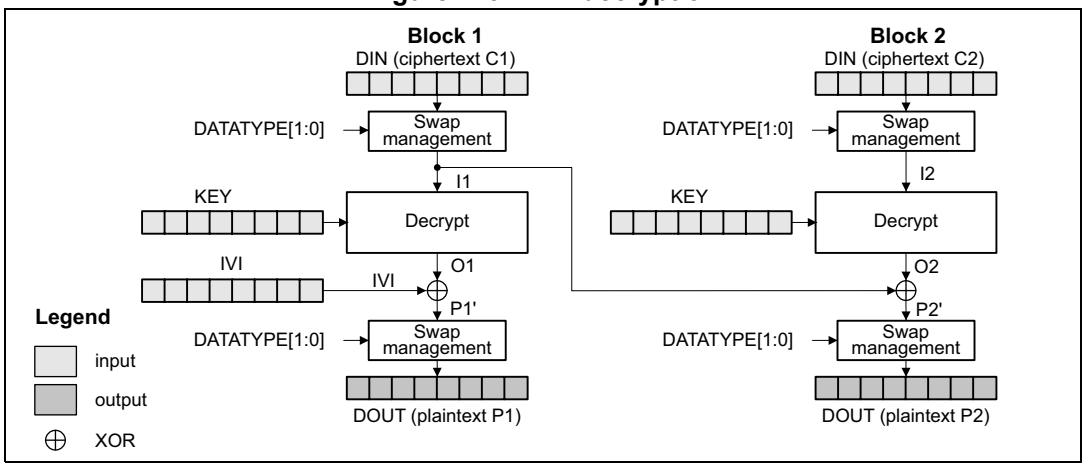


Figure 443. CBC decryption



For more details, refer to NIST Special Publication 800-38A, *Recommendation for Block Cipher Modes of Operation.*

ECB and CBC encryption process

This process is described in *Section 44.4.5*, with the following sequence of events:

1. Disable the AES peripheral, by clearing EN.
2. Initialize the AES_CR register as follows:
   - Select ECB or CBC chaining mode (write CHMOD[2:0] with 0x0 or 0x1) in *encryption* mode (write MODE[1:0] with 0x0).
   - Configure the data type, through DATATYPE[1:0].
   - Configure the key size, through KEYSIZE.
   - Select the key mode, using KMOD[1:0]. If the key comes from the SAES peripheral, write KMOD[1:0] with 0x2, otherwise keep it at 0x0.

3. Write the initialization vector into the AES_IVRx registers if CBC mode is selected in the previous step.
4. Write the key into the AES_KEYRx registers if KMOD[1:0] is at 0x0. If KMOD[1:0] is at 0x2, the key is transferred from the SAES peripheral (see *Section 44.4.14*).
5. Wait until KEYVALID is set (the key loading completed).
6. Enable the AES peripheral, by setting EN.
7. Append cleartext data:
   a) If it is the second-last or the last block and the plaintext size of the message is not a multiple of 16 bytes, follow the guidance in *Section 44.4.7*.
   b) Append the cleartext block into AES as described in *Section 44.4.5*, then read the AES_DOUTR register four times to save the ciphertext block.
   c) Repeat the step *b)* until the third-last plaintext block is encrypted. For the last two blocks, follow the steps *a)* and *b)*.
8. Finalize the sequence: disable the AES peripheral, by clearing EN.

ECB/CBC decryption process

This process is described in *Section 44.4.5*, with the following sequence of events:

1. Disable the AES peripheral, by clearing EN.
2. Initialize the AES_CR register as follows:
   – Select the *key derivation* mode (write MODE[1:0] with 0x1). The CHMOD[2:0] bitfield is not significant during this operation.
   – Configure the data type, through DATATYPE[1:0].
   – Configure the key size, through KEYSIZE.
   – Select the key mode, using KMOD[1:0]. If the key comes from the SAES peripheral, write KMOD[1:0] with 0x2, otherwise keep it at 0x0.
3. Write the key into the AES_KEYRx registers if KMOD[1:0] is at 0x0. If KMOD[1:0] is at 0x2, the key is transferred from the SAES peripheral (see *Section 44.4.14*).
4. Wait until KEYVALID is set (the key loading completed).
5. Enable the AES peripheral, by setting EN. The peripheral immediately starts an AES round for key preparation.
6. Wait until the CCF flag in the AES_ISR register is set.
7. Clear the CCF flag, by setting the CCF bit of the AES_ICR register. The decryption key is available in the AES core and AES is disabled automatically.
8. Select ECB or CBC chaining mode (write CHMOD[2:0] with 0x0 or 0x1) in *decryption* mode (write MODE[1:0] with 0x2). Do not change other parameters.
9. Write the initialization vector into the AES_IVRx registers if CBC mode is selected in the previous step.
10. Enable the AES peripheral, by setting EN.

11. Append encrypted data:
    a) If it is the second-last or the last block and the ciphertext size of the message is not a multiple of 16 bytes, follow the guidance in *Section 44.4.7*.
    b) Append the ciphertext block into AES as described in *Section 44.4.5*, then read the AES_DOUTR register four times to save the cleartext block (MSB first).
    c) Repeat the step *b)* until the third-last ciphertext block is decrypted. For the last two blocks, follow the steps *a)* and *b)*.
12. Finalize the sequence: disable the AES peripheral, by clearing EN.

Suspend/resume operations in ECB/CBC modes

The suspend and resume operations are only supported when AES is used in CPU mode, not in DMA mode.

To suspend the processing of a message, proceed as follows:

1. Wait until the CCF flag in the AES_ISR register is set (computation completed).
2. Read four times the AES_DOUTR register to save the last processed block.
3. Clear the CCF flag, by setting the CCF bit of the AES_ICR register.
4. Save initialization vector registers (only required in CBC mode as the AES_IVRx registers are altered during the data processing).
5. Disable the AES peripheral, by clearing EN.
6. Save the AES_CR register and clear the key registers if they are not needed, to process the higher-priority message.

To resume the processing of a message, proceed as follows:

1. Disable the AES peripheral, by clearing EN.
2. Restore the AES_CR register (with correct KEYSIZE) then restore the AES_KEYRx registers. If KMOD[1:0] is at 0x2, the key must be transferred again from the SAES peripheral (see *Section 44.4.14*).
3. Prepare the decryption key, as described in *ECB/CBC decryption process* (only required for ECB or CBC decryption).
4. Restore the AES_IVRx registers, using the saved configuration (only required in CBC mode).
5. Enable the AES peripheral, by setting EN.

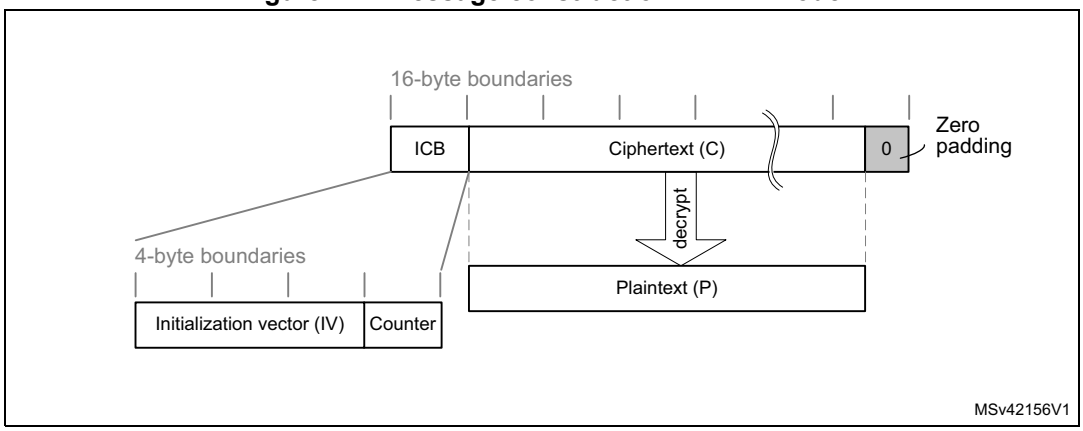
Note: It is not required to save the key registers as the application knows the original key.

44.4.10 AES counter (CTR) mode

The CTR mode uses the AES core to generate a key stream. The keys are then XOR-ed with the plaintext to obtain the ciphertext. Unlike with ECB and CBC modes, no key scheduling is required for the CTR decryption since the AES core is always used in encryption mode.

A typical message construction in CTR mode is given in *Figure 444*.

Figure 444. Message construction in CTR mode



The structure of this message is:

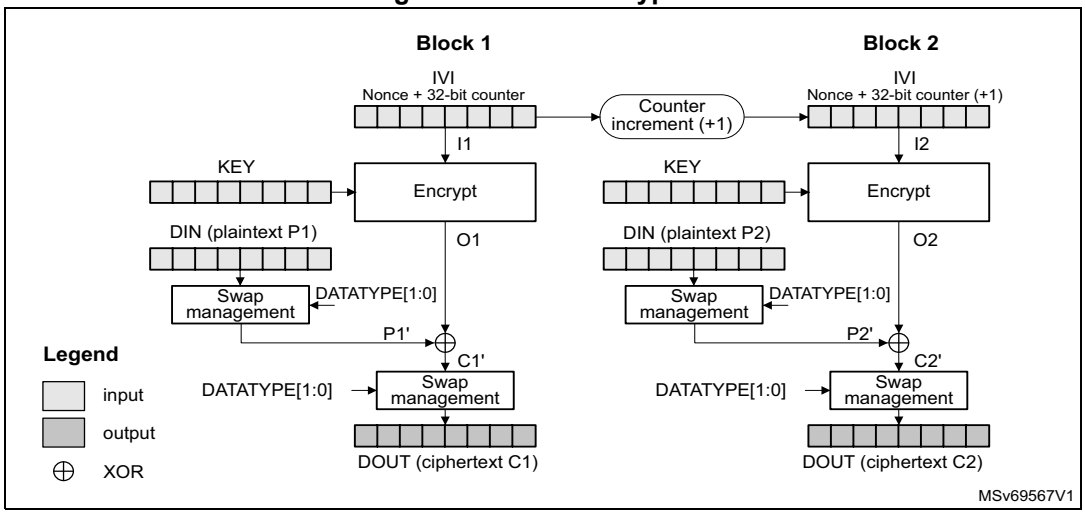
- A 16-byte initial counter block (ICB), composed of two distinct fields:
  - **Initialization vector** (IV): a 96-bit value that must be unique for each encryption cycle with a given key.
  - **Counter**: a 32-bit big-endian integer that is incremented each time a block processing is completed. The initial value of the counter must be set to 1.
- The plaintext P is encrypted as ciphertext C, with a known length. This length can be non-multiple of 16 bytes, in which case a plaintext padding is required.

For more details, refer to NIST *Special Publication 800-38A, Recommendation for Block Cipher Modes of Operation.*

CTR encryption and decryption

Figure 445 describes the counter (CTR) chaining implementation in the AES peripheral (encryption). To select this chaining mode, write CHMOD[2:0] with 0x2.

Figure 445. CTR encryption



Initialization vectors in AES must be initialized as shown in *Table 432*.

Table 432. Counter mode initialization vector definition

AES_IVR3[31:0]	AES_IVR2[31:0]	AES_IVR1[31:0]	AES_IVR0[31:0]
IVI[127:96]	IVI[95:64]	IVI[63:32]	IVI[31:0] 32-bit counter = 0x0001

CTR encryption and decryption process

This process is described in *Section 44.4.5*, with the following sequence of events:

1. Disable the AES peripheral, by clearing EN.
2. Initialize the AES_CR register:
   - Select CTR chaining mode (write CHMOD[2:0] with 0x2) in encryption or decryption mode (write MODE[1:0] with 0x0 or 0x2).
   - Configure the data type, through DATATYPE[1:0].
   - Configure the key size, through KEYSIZE.
   - Select the key mode, using KMOD[1:0]. If the key comes from the SAES peripheral, write KMOD[1:0] with 0x2, otherwise keep it at 0x0.
3. Write the initialization vector into the AES_IVRx registers according to *Table 432*.
4. Write the key into the AES_KEYRx registers if KMOD[1:0] is at 0x0. If KMOD[1:0] is at 0x2, the key is transferred from the SAES peripheral (see *Section 44.4.14*).
5. Wait until KEYVALID is set (the key loading completed).
6. Enable the AES peripheral, by setting EN.
7. Append data:
   a) If it is the last block and the plaintext (encryption) or ciphertext (decryption) size in the block is less than 16 bytes, pad the remainder of the block with zeros.
   b) Append the data block into AES as described in *Section 44.4.5*, then read the AES_DOUTR register four times to save the resulting block (MSB first).
   c) Repeat the step *b)* until the second-last block is processed. For the last block of plaintext (encryption only), follow the steps *a)* and *b)*. For the last block, discard the bits that are not part of the message when the last block is smaller than 16 bytes.
8. Finalize the sequence: disable the AES peripheral, by clearing EN.

Suspend/resume operations in CTR mode

Like for the CBC mode, it is possible to interrupt a message to send a higher-priority message, then resume the interrupted message. Detailed CBC suspend and resume sequence is described in *Section 44.4.9: AES basic chaining modes (ECB, CBC)*.

The suspend and resume operations are only supported when AES is used in CPU mode, not in DMA mode.

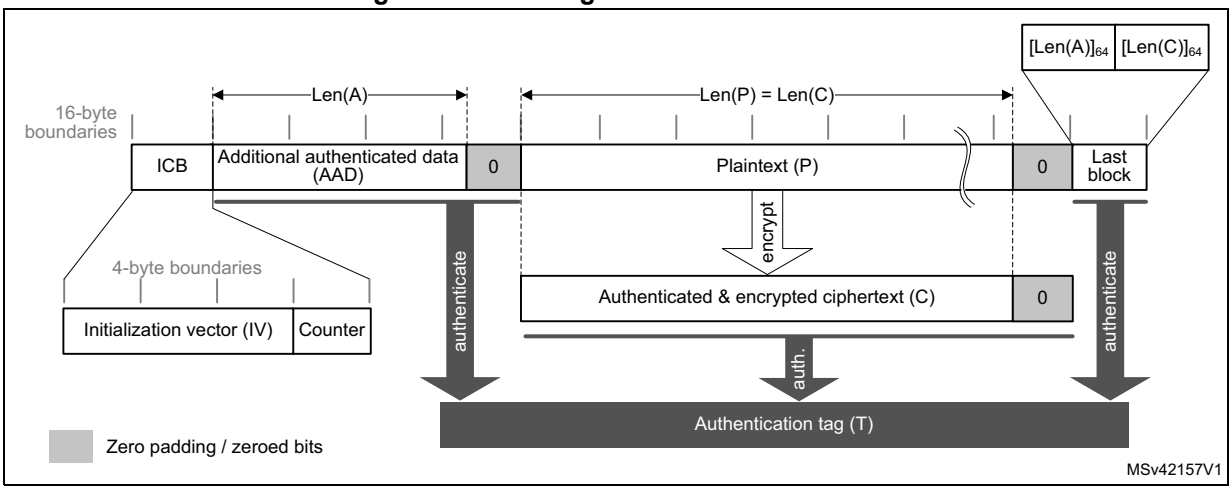
Note: Like for CBC mode, the IV registers must be reloaded during the resume operation.

44.4.11 AES Galois/counter mode (GCM)

The AES Galois/counter mode (GCM) allows encrypting and authenticating a plaintext message into the corresponding ciphertext and tag (also known as message authentication code).

GCM mode is based on AES in counter mode for confidentiality. It uses a multiplier over a fixed finite field for computing the message authentication code. The following figure shows a typical message construction in GCM mode.

Figure 446. Message construction in GCM



The message has the following structure:

- **16-byte initial counter block (ICB)**, composed of two distinct fields:
  - **Initialization vector (IV):** a 96-bit value that must be unique for each encryption cycle with a given key. The GCM standard supports IVs with less than 96 bits, but in this case strict rules apply.
  - **Counter:** a 32-bit big-endian integer that is incremented each time a block processing is completed. According to NIST specification, the counter value is 0x2 when processing the first block of payload.
- **Authenticated header AAD** (also knows as additional authentication data) has a known length Len(A) that may be a non-multiple of 16 bytes, and must not exceed $2^{64} – 1$ bits. This part of the message is only authenticated, not encrypted.
- **Plaintext message P** is both authenticated and encrypted as ciphertext C, with a known length Len(P) that may be non-multiple of 16 bytes, and cannot exceed 2^{32} - 2 16-byte blocks.
- **Last block** contains the AAD header length (bits [32:63]) and the payload length (bits [96:127]) information, as shown in *Table 434*.

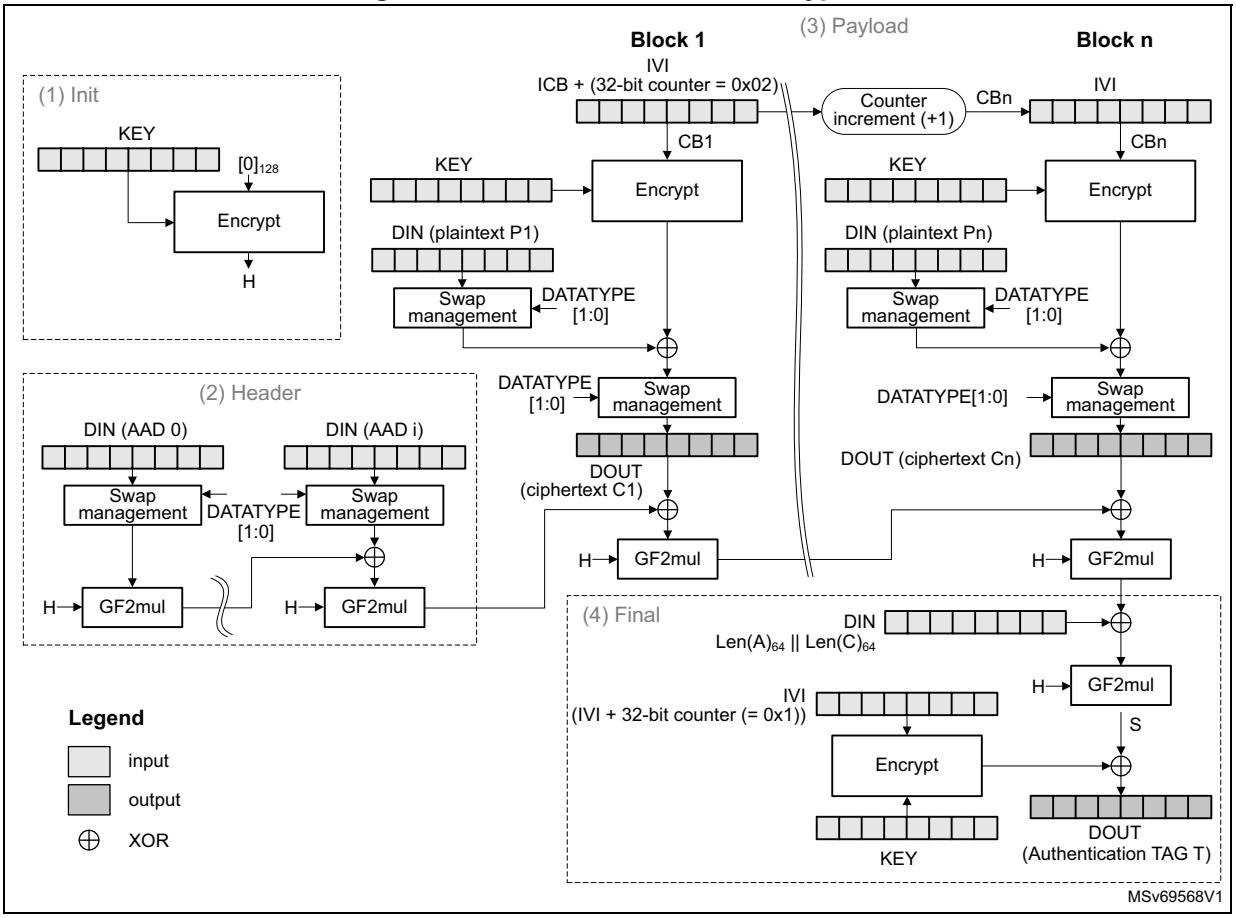
The GCM standard specifies that ciphertext C has the same bit length as the plaintext P.

When a part of the message (AAD or P) has a length that is a non-multiple of 16-bytes a special padding scheme is required.

For more details, refer to NIST Special Publication 800-38D*, Recommendation for Block Cipher Modes of Operation - Galois/Counter Mode (GCM) and GMAC.*

Figure 447 describes the GCM chaining implementation in the AES peripheral (encryption). To select this chaining mode, write CHMOD[2:0] with 0x3.

Figure 447. GCM authenticated encryption



The first counter block (CB1) is derived from the initial counter block ICB by the application software, as defined in *Table 433*.

Table 433. Initialization of IV registers in GCM mode

AES_IVR3[31:0]	AES_IVR2[31:0]	AES_IVR1[31:0]	AES_IVR0[31:0]
ICB[127:96]	ICB[95:64]	ICB[63:32]	ICB[31:0] 32-bit counter = 0x0002

The last block of a GCM message contains the AAD header length and the payload length information, as shown in *Table 434*.

Table 434. GCM last block definition

Word order to AES_DINR	First word	Second word	Third word	Fourth word
Input data	AAD length[63:32]	AAD length[31:0]	Payload length[63:32]	Payload length[31:0]

GCM encryption and decryption process

This process is described in *Section 44.4.6*, with the following sequence of events:

GCM initialize

1. Disable the AES peripheral, by clearing EN.
2. Initialize the AES_CR register:
   - Select GCM chaining mode (write CHMOD[2:0] with 0x3) in encryption or decryption mode (write MODE[1:0] with 0x0 or 0x2). Do not write MODE[1:0] with 0x1.
   - Configure the data type, through DATATYPE[1:0]
   - Configure the key size, through KEYSIZE.
   - Select the key mode, using KMOD[1:0]. If the key comes from the SAES peripheral, write KMOD[1:0] with 0x2, otherwise keep it at 0x0.
   - Select the GCM initialization phase, by writing GCMPH[1:0] with 0x0.
3. Write the initialization vector in AES_IVRx registers according to *Table 433*.
4. Write the key into the AES_KEYRx registers if KMOD[1:0] is at 0x0. If KMOD[1:0] is at 0x2, the key is transferred from the SAES peripheral (see *Section 44.4.14*).
5. Wait until KEYVALID is set (the key loading completed).
6. Set EN to start the calculation of the hash key. EN is automatically cleared when the calculation is completed.
7. Wait until the CCF flag is set in the AES_ISR register, indicating that the GCM hash subkey (H) computation is completed.
8. Clear the CCF flag by setting the CCF bit of the AES_ICR register.

GCM header phase

9. Initialize header phase:
   a) Select the GCM header phase, by writing 0x1 to GCMPH[1:0]. Do not change the other configurations written during GCM initialization.
   b) Enable the AES peripheral, by setting EN.
10. Append header data:
    a) If it is the last block and the AAD in the block is smaller than 16 bytes, pad the remainder of the block with zeros.
    b) Append the data block into AES as described in *Section 44.4.5*.
    c) Repeat the step *b)* until the second-last AAD data block is processed. For the last block, follow the steps *a)* and *b)*.

Note: This phase can be skipped if there is no AAD, that is, Len(A) = 0.

No data are read during header phase.

GCM payload phase

11. Initialize payload phase:
    a) Select the GCM payload phase, by writing GCMPH[1:0] with 0x2. Do not change the other configurations written during GCM initialization.
    b) If the header phase is skipped, enable the AES peripheral by setting EN.

12. Append payload data:
    a) If it is the last block and the message in the block is smaller than 16 bytes, pad the remainder of the block with zeros.
    b) Append the data block into AES as described in *Section 44.4.5*, then read the AES_DOUTR register four times to save the resulting block
    c) Repeat the step *b)* until the second-last plaintext block is encrypted or until the last block of ciphertext is decrypted. For the last block of plaintext (encryption only), follow the steps *a)* and *b)*. For the last block, discard the bits that are not part of the payload when the last block is smaller than 16 bytes.

Note: This phase can be skipped if there is no payload, that is, Len(C)=0 (see GMAC mode).

GCM finalization

13. Select the GCM final phase, by writing GCMPH[1:0] with 0x3. Do not change the other configurations written during GCM initialization.
14. Write the final GCM block into the AES_DINR register. It is the concatenated AAD bit and payload bit lengths, as shown in *Table 434*.
15. Wait until the CCF flag in the AES_ISR register is set.
16. Get the GCM authentication tag, by reading the AES_DOUTR register four times.
17. Clear the CCF flag, by setting the CCF bit of the AES_ICR register.
18. Disable the AES peripheral, by clearing EN. If it is an authenticated decryption, compare the generated tag with the expected tag passed with the message.

Note: In the final phase, data are written to AES_DINR normally (no swapping), while swapping is applied to tag data read from AES_DOUTR.

When transiting from the header or the payload phase to the final phase, the AES peripheral must not be disabled, otherwise the result is wrong.

Suspend/resume operations in GCM mode

The suspend and resume operations are only supported when AES is used in CPU mode, not in DMA mode.

To suspend the processing of a message, proceed as follows:

1. Wait until the CCF flag in the AES_ISR register is set (computation completed).
2. In the payload phase, read four times the AES_DOUTR register to save the last-processed block.
3. Clear the CCF flag of the AES_ISR register, by setting the CCF bit of the AES_ICR register. When GCM encryption payload phase is selected, verify that BUSY is cleared in AES_SR, to ensure that GF2mul hash function is completed.
4. Save the AES_SUSPRx registers in the memory.
5. In the payload phase, save the AES_IVRx registers as, during the data processing, they changed from their initial values. In the header phase, this step is not required.
6. Disable the AES peripheral, by clearing EN.
7. Save the current AES_CR configuration in the memory. Key registers do not need to be saved as the original key value is known by the application.

To resume the processing of a message, proceed as follows:

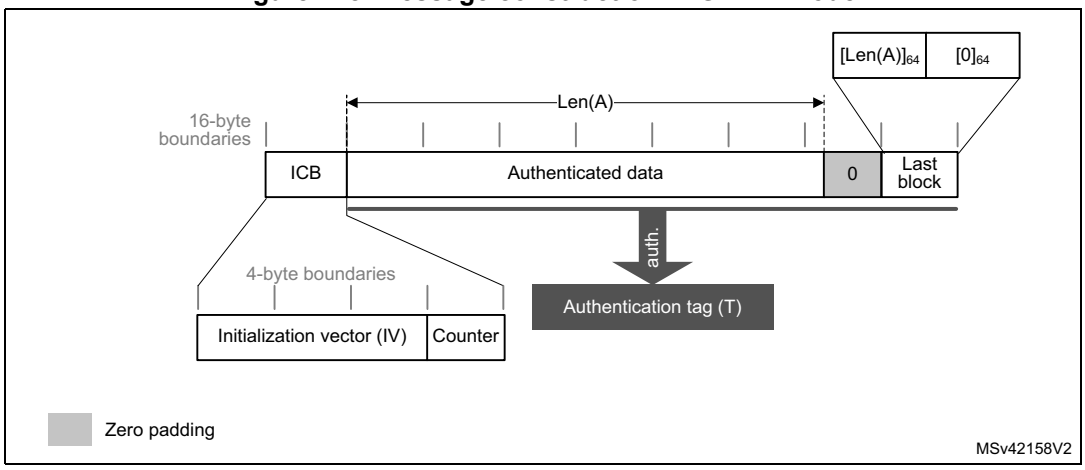
1. Disable the AES peripheral, by clearing EN.
2. Write the suspend register values, previously saved in the memory, back into their corresponding AES_SUSPRx registers.
3. In the payload phase, write the initialization vector register values, previously saved in the memory, back into their corresponding AES_IVRx registers. In the header phase, write initial setting values back into the AES_IVRx registers.
4. Restore the initial setting values in the AES_CR and AES_KEYRx registers if KMOD[1:0] is at 0x0. If KMOD[1:0] is at 0x2, the key is transferred from the SAES peripheral (see *Section 44.4.14*).
5. Enable the AES peripheral, by setting EN.

44.4.12 AES Galois message authentication code (GMAC)

The Galois message authentication code (GMAC) allows the authentication of a plaintext, generating the corresponding tag information (also known as message authentication code).

GMAC is similar to GCM, except that it is applied on a message composed only by plaintext authenticated data (that is, only header, no payload). The following figure shows typical message construction for GMAC.

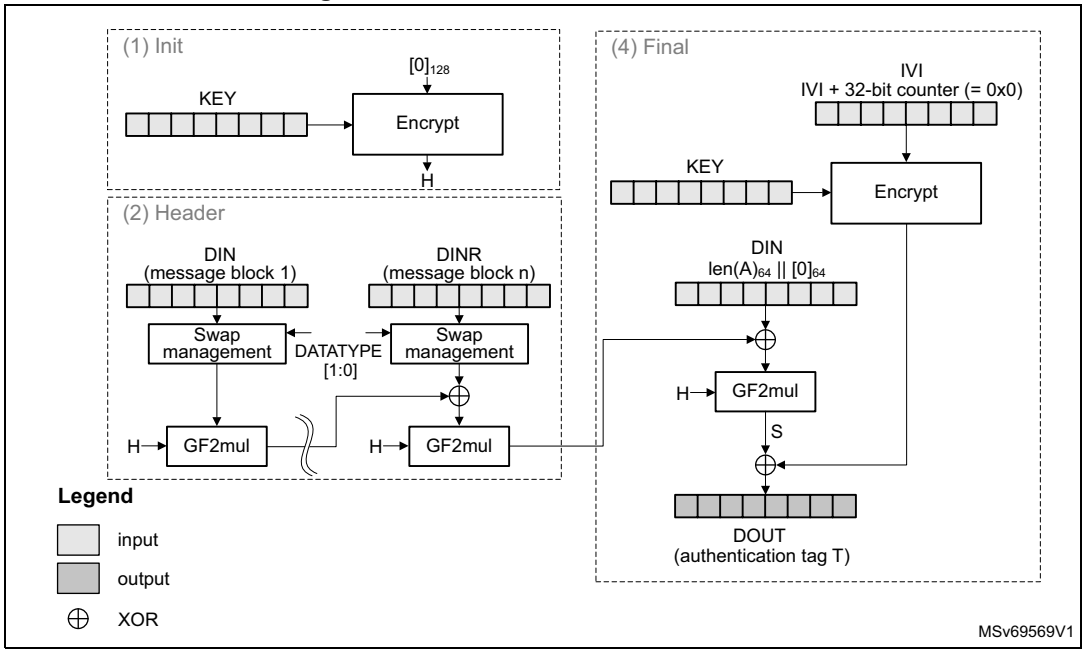
Figure 448. Message construction in GMAC mode



For more details, refer to NIST Special Publication 800-38D*, Recommendation for Block Cipher Modes of Operation - Galois/Counter Mode (GCM) and GMAC.*

Figure 449 describes the GMAC chaining implementation in the AES peripheral. To select this chaining mode, write CHMOD[2:0] with 0x3.

Figure 449. GMAC authentication mode



The GMAC algorithm corresponds to the GCM algorithm applied on a message that only contains a header. As a consequence, all steps and settings are the same as with the GCM, except that the payload phase is omitted.

Suspend/resume operations in GMAC

In GMAC mode, the sequence described for the GCM applies except that only the header phase can be interrupted.

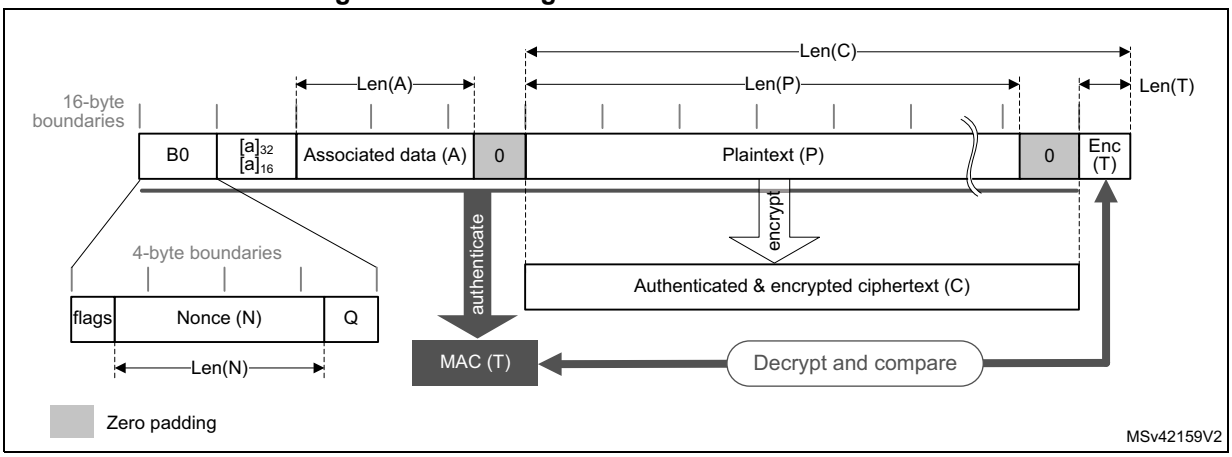
44.4.13 AES counter with CBC-MAC (CCM)

The AES counter with cipher block chaining-message authentication code (CCM) algorithm allows encryption and authentication of plaintext, generating the corresponding ciphertext and tag (also known as message authentication code). To ensure confidentiality, the CCM algorithm is based on AES counter mode processing. It uses cipher block chaining technique to generate the message authentication code. This is commonly called CBC-MAC.

Note: NIST does not approve CBC-MAC as an authentication mode outside the context of the CCM specification.

The following figure shows typical message construction for CCM.

Figure 450. Message construction in CCM mode



The structure of the message is:

- **16-byte first authentication block (B0)**, composed of three distinct fields:
  - **Q:** a bit string representation of the octet length of P (Len(P))
  - **Nonce (N):** a single-use value (that is, a new nonce must be assigned to each new communication) of Len(N) size. The sum Len(N) + Len(P) must be equal to 15 bytes.
  - **Flags:** most significant octet containing four flags for control information, as specified by the standard. It contains two 3-bit strings to encode the values **t** (MAC length expressed in bytes) and **Q** (plaintext length such that Len(P) < 2^{8Q} bytes). The counter blocks range associated to **Q** is equal to 2^{8Q-4}, that is, if the maximum value of **Q** is 8, the counter blocks used in cipher must be on 60 bits.
- **16-byte blocks (B)** associated to the associated data (A).
  This part of the message is only authenticated, not encrypted. This section has a known length Len(A) that can be a non-multiple of 16 bytes (see *Figure 450*). The standard also states that, on MSB bits of the first message block (B1), the associated data length expressed in bytes (a) must be encoded as follows:
  - If $0 < a < 2^{16} - 2^8$, then it is encoded as $[a]_{16}$, that is, on two bytes.
  - If $2^{16} - 2^8 < a < 2^{32}$, then it is encoded as 0xff || 0xfe || $[a]_{32}$, that is, on six bytes.
  - If $2^{32} < a < 2^{64}$, then it is encoded as 0xff || 0xff || $[a]_{64}$, that is, on ten bytes.
- **16-byte blocks (B)** associated to the plaintext message P, which is both authenticated and encrypted as ciphertext C, with a known length Len(P). This length can be a non-multiple of 16 bytes (see *Figure 450*).
- **Encrypted MAC (T)** of length Len(T) appended to the ciphertext C of overall length Len(C).

When a part of the message (A or P) has a length that is a non-multiple of 16-bytes, a special padding scheme is required.

Note: CCM chaining mode can also be used with associated data only (that is, no payload).

As an example, the C.1 section in NIST Special Publication 800-38C gives the following values (hexadecimal numbers):

N: 10111213 141516 (Len(N) = 56 bits or 7 bytes)

A: 00010203 04050607 (Len(A) = 64 bits or 8 bytes)

P: 20212223 (Len(P) = 32 bits or 4 bytes)

T: 6084341B (Len(T) = 32 bits or t = 4)

B0: 4F101112 13141516 00000000 00000004
B1: 00080001 02030405 06070000 00000000
B2: 20212223 00000000 00000000 00000000

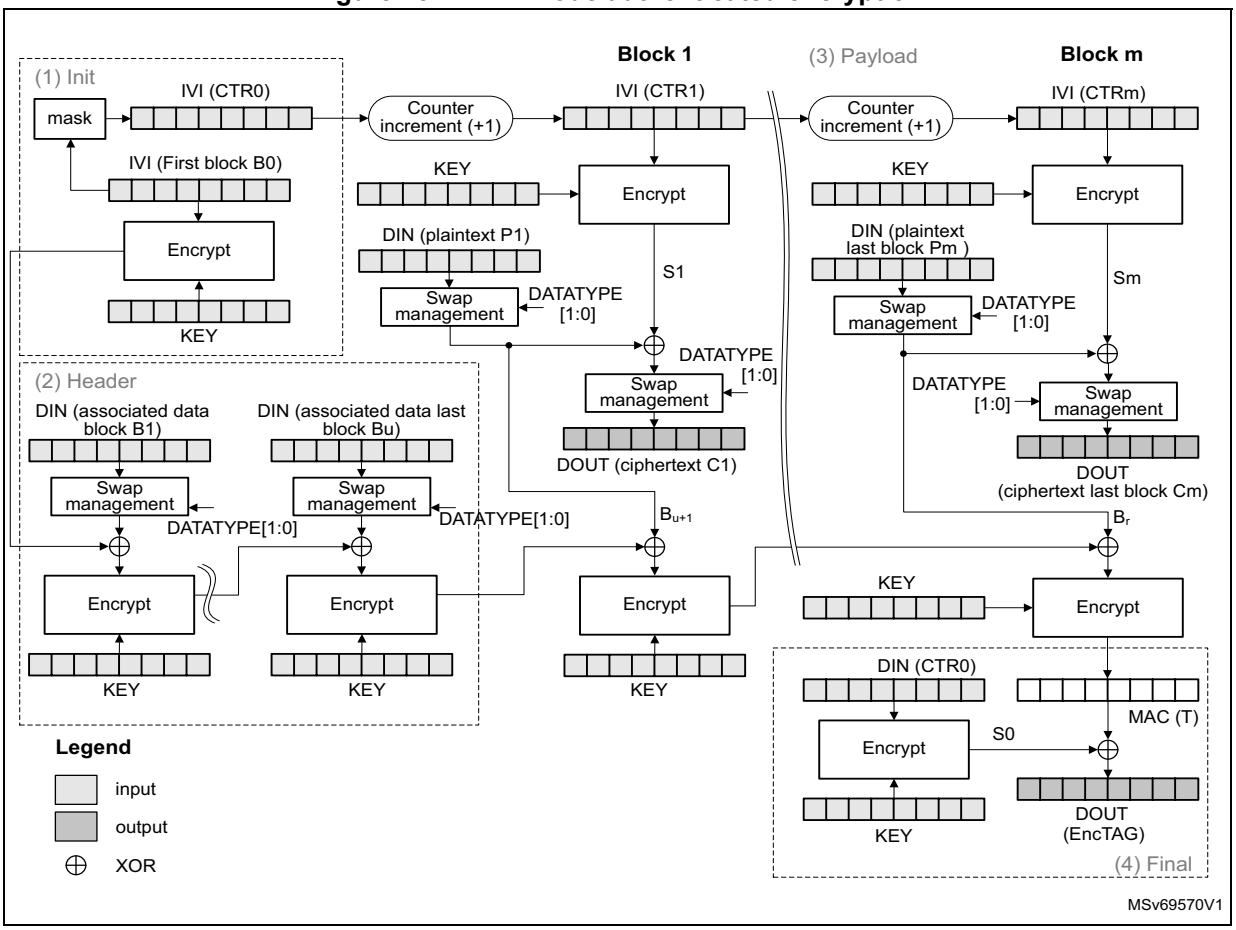
CTR0: 0710111213 141516 00000000 00000000

CTR1: 0710111213 141516 00000000 00000001

For more details, refer to NIST Special Publication 800-38C, *Recommendation for Block Cipher Modes of Operation - The CCM Mode for Authentication and Confidentiality*.

Figure 451 describes the CCM chaining implementation in the AES peripheral (encryption). To select this chaining mode, write CHMOD[2:0] with 0x4.

Figure 451. CCM mode authenticated encryption



The first block of a CCM message (B0) must be prepared by the application as defined in *Table 435*.

Table 435. Initialization of IV registers in CCM mode

AES_IVR3[31:0]	AES_IVR2[31:0]	AES_IVR1[31:0]	AES_IVR0[31:0]
B0[127:96](1)	B0[95:64]	B0[63:32]	B0[31:0](2)

1. The five most significant bits are cleared (flag bits).
2. Q length bits are cleared, except for the bit 0 that is set.

AES supports counters up to 64 bits, as specified by NIST.

CCM encryption and decryption process

This process is described in *Section 44.4.6*, with the following sequence of events:

CCM initialize

1. Disable the AES peripheral, by clearing EN.
2. Initialize the AES_CR register:
   - Select CCM chaining mode (write CHMOD[2:0] with 0x4) in encryption or decryption mode (write MODE[1:0] with 0x0 or 0x2). Do not write MODE[1:0] with 0x1.
   - Configure the data type, through DATATYPE[1:0]
   - Configure the key size, through KEYSIZE.
   - Select the key mode, using KMOD[1:0]. If the key comes from the SAES peripheral, write KMOD[1:0] with 0x2, otherwise keep it at 0x0.
   - Select the CCM initialization phase, by writing GCMPH[1:0] with 0x0.
3. Write the B0 data in AES_IVRx registers according to *Table 435*.
4. Write the key into the AES_KEYRx registers if KMOD[1:0] is at 0x0. If KMOD[1:0] is at 0x2, the key is transferred from the SAES peripheral (see *Section 44.4.14*).
5. Wait until KEYVALID is set (the key loading completed).
6. Set EN to start the first mask calculation. The EN bit is automatically cleared when the calculation is completed.
7. Wait until the CCF flag in the AES_ISR register is set.
8. Clear the CCF flag, by setting the CCF bit of the AES_ICR register.

CCM header phase

9. Initialize header phase:
   a) Prepare the first block of the (B1) data associated with the message, in accordance with CCM chaining rules.
   b) Select the CCM header phase, by writing GCMPH[1:0] with 0x1. Do not change the other configurations written during the CCM initialization.
   c) Enable the AES peripheral, by setting EN.
10. Append header data:
    a) If it is the last block and the associated data in the block is smaller than 16 bytes, pad the remainder of the block with zeros.
    b) Append the data block into AES as described in *Section 44.4.5*.
    c) Repeat the step *b)* until the second-last associated data block is processed. For the last block, follow the steps *a)* and *b)*.

Note: This phase can be skipped if there is no associated data, that is, Len(A) = 0

No data are read during the header phase.

CCM payload phase

11. Initialize payload phase:
    a) Select the CCM payload phase, by writing GCMPH[1:0] with 0x2. Do not change the other configurations written during the CCM initialization.
    b) If the header phase is skipped, enable the AES peripheral, by setting EN.
12. Append payload data:
    a) In encryption only, if it is the last block and the plaintext in the block is smaller than 16 bytes, pad the remainder of the block with zeros.
    b) Append the data block into AES as described in *Section 44.4.5*, then read the AES_DOUTR register four times to save the resulting block.
    c) Repeat the step *b)* until the second-last plaintext block is encrypted or until the last block of ciphertext is decrypted. For the last block of plaintext (encryption only), follow the steps *a)* and *b)*. For the last block, discard the bits that are not part of the payload when the last block is smaller than 16 bytes.

Note: This phase can be skipped if there is no payload, that is, Len(P) = 0 or Len(C) = Len(T).

Remove $LSB_{Len(T)}(C)$ encrypted tag information when decrypting ciphertext C.

CCM finalization

13. Select the CCM final phase, by writing GCMPH[1:0] with 0x3. Do not change the other configurations written during the CCM initialization.
14. Wait until CCF flag in the AES_ISR register is set.
15. Get the CCM authentication tag, by reading the AES_DOUTR register four times.
16. Clear the CCF flag, by setting the CCF bit of the AES_ICR register.
17. Disable the AES peripheral, by clearing EN. If it is an authenticated decryption, compare the generated tag with the expected tag passed with the message. Mask the authentication tag output with tag length to obtain a valid tag.

Note: In the final phase, swapping is applied to tag data read from AES_DOUTR register.

When transiting from the header or the payload phase to the final phase, the AES peripheral must not be disabled, otherwise the result is wrong.

Suspend and resume operations in CCM mode

The suspend and resume operations are only supported when AES is used in CPU mode, not in DMA mode.

To suspend the processing of a message in header or payload phase, proceed as follows:

1. Wait until the CCF flag of the AES_ISR register is set (computation completed).
2. In the payload phase, read four times the AES_DOUTR register to save the last-processed block.
3. Clear the CCF flag in the AES_ISR register, by setting the CCF bit of the AES_ICR register.
4. Save the AES_SUSPRx registers in the memory.
5. Save the IV registers as they are altered during the data processing.
6. Disable the AES peripheral, by clearing EN.

7. Save the current AES_CR configuration in the memory. Key registers do not need to be saved as the original key value is known by the application.

To resume the processing of a message, proceed as follows:

1. Disable the AES peripheral, by clearing EN.
2. Write the suspend register values, previously saved in the memory, back into their corresponding AES_SUSPRx registers.
3. Restore AES_IVRx registers using the saved configuration.
4. Restore the initial setting values in the AES_CR and AES_KEYRx registers if KMOD[1:0] is at 0x0. If KMOD[1:0] is at 0x2, the key must be transferred again from the SAES peripheral (see *Section 44.4.14*).
5. Enable the AES peripheral, by setting EN.

44.4.14 AES key sharing with secure AES co-processor

The AES peripheral can use the SAES peripheral as security co-processor. The secure application prepares the key in the robust SAES peripheral and when it is ready, the AES application can load this prepared key through a dedicated hardware key bus.

The recommended sequence is described hereafter and in the section *SAES operations with shared keys* in the *SAES* section of this document.

1. In SAES peripheral, the application encrypts (wraps) the key to share in Shared-key mode (KMOD[1:0] at 0x2).
2. Each time the shared key is required in AES peripheral, the application decrypts it in the SAES peripheral in Shared-key mode (KMOD[1:0] at 0x2).
3. Once the shared key is decrypted (unwrapped) and loaded in SAES_KEYRx registers it can be shared with AES. To load the shared key in AES, the application sets KEYSIZE as appropriate and writes KMOD[1:0] with 0x2. When KEYVALID is cleared, the key is automatically transfered by hardware into the AES_KEYRx registers and the BUSY flag in the AES_SR register set.
4. Once the key transfer is completed, the BUSY flag is cleared and the KEYVALID flag set in the AES_SR register. If KEYVALID is not set when BUSY bit is cleared, or if the KEIF flag is set in the AES_ISR register, either the KEYSIZE value is incorrect or an unexpected event occurred during the transfer (such as DPA error, tamper event or KEYVALID cleared before the end of the transfer). When such errors occur, reset both peripherals through their IPRST bits and restart the whole key sharing process.

When the key sharing sequence is completed, the AES is initialized with a valid, shared key. The application can then process data in normal key mode, by writing KMOD[1:0] with 0x0.

Note: This sequence in AES peripheral can be run multiple times (for example, to manage a suspend/resume situation), as long as SAES peripheral is unused and duly remains in key sharing state.

44.4.15 AES data registers and data swapping

Data input and output

A 16-byte data block enters the AES peripheral with four successive 32-bit word writes into the AES_DINR register (bitfield DIN[31:0]), the most significant word (bits [127:96]) first, the least significant word (bits [31:0]) last.

A 16-byte data block is retrieved from the AES peripheral with four successive 32-bit word reads of the AES_DOUTR register (bitfield DOUT[31:0]), the most significant word (bits [127:96]) first, the least significant word (bits [31:0]) last.

The four 32-bit words of a 16-byte data block must be stored in the memory consecutively and in big-endian order, that is, with the most significant word on the lowest address. See *Table 436* “no swapping” option for details.

Data swapping

The AES peripheral can be configured to perform a bit-, a byte-, a half-word-, or no swapping on the input data word in the AES_DINR register, before loading it to the AES processing core, and on the data output from the AES processing core, before sending it to the AES_DOUTR register. The choice depends on the type of data. For example, a byte swapping is used for an ASCII text stream.

The data swap type is selected through DATATYPE[1:0]. The selection applies to both AES input and output.

Note: The data in AES key registers (AES_KEYRx) and initialization vector registers (AES_IVRx) are not sensitive to the swap mode selection.

The AES data swapping feature is summarized in *Table 436* and *Figure 452*.

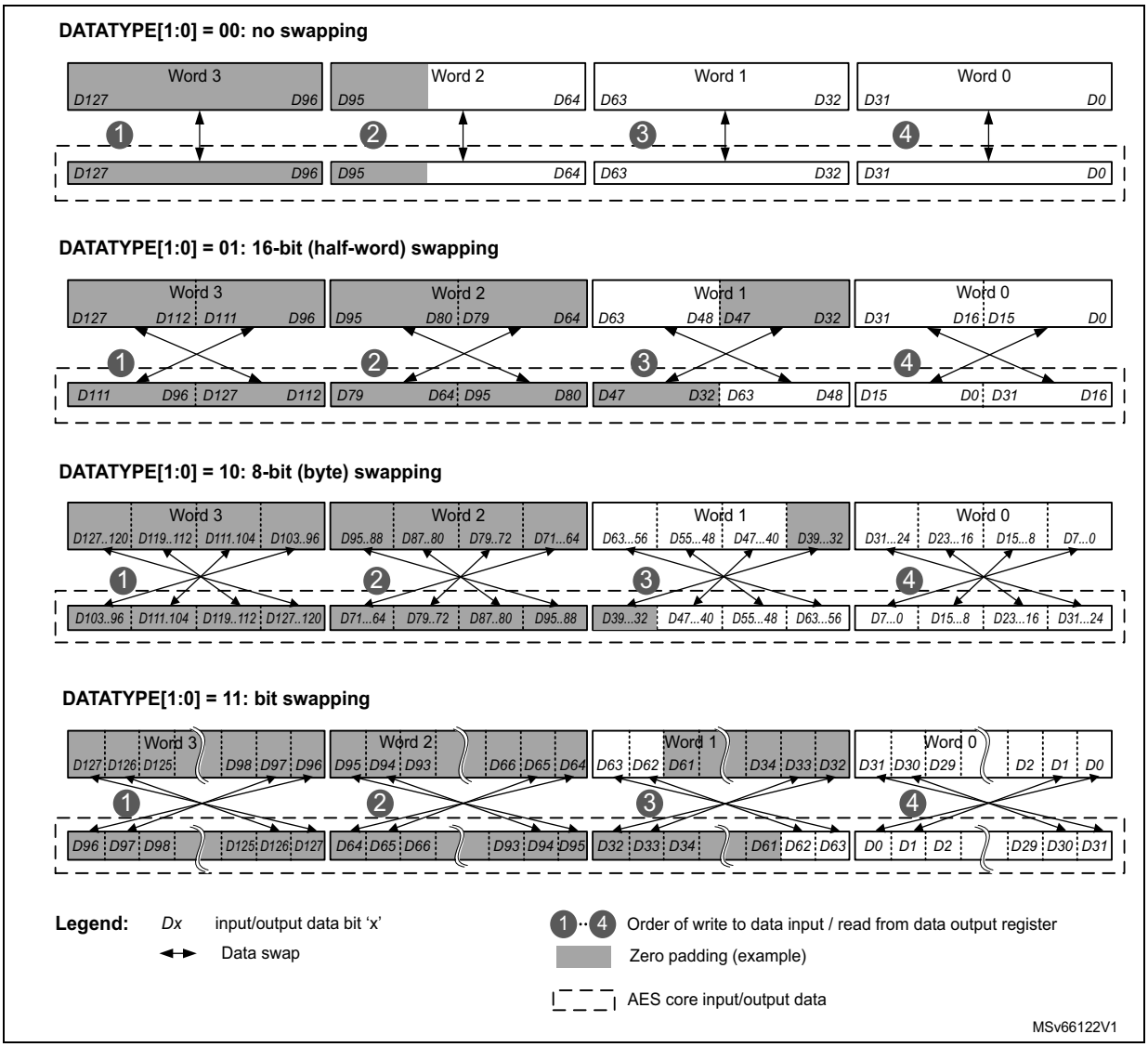
Table 436. AES data swapping example

DATATYPE[1:0]	Swapping performed	Data block
		System memory data (big-endian)
0x0	No swapping	Block[127..64]: 0x04EEF672 2E04CE96 Block[63..0]: 0x4E6F7720 69732074
		Address @, word[127..96]: 0x04EEF672 Address @ + 0x4, word[95..64]: 0x2E04CE96 Address @ + 0x8, word[63..32]: 0x4E6F7720 Address @ + 0xC, word[31..0]: 0x69732074
0x1	Half-word (16-bit) swapping	Block[63..0]: 0x**4E6F** 7720 **6973** 2074
		Address @, word[63..32]: 0x7720 **4E6F** Address @ + 0x4, word[31..0]: 0x2074 **6973**
0x2	Byte (8-bit) swapping	Block[63..0]: 0x**4E** 6F **77** 20 **69** 73 **20** 74
		Address @, word[63..32]: 0x20**77** 6F**4E** Address @ + 0x4, word[31..0]: 0x74**20** 73**69**

Table 436. AES data swapping example (continued)

DATATYPE[1:0]	Swapping performed	Data block
		System memory data (big-endian)
0x3	Bit swapping	Block[63..32]: 0x4E6F7720 0100 1110 0110 1111 0111 0111 0010 0000 Block[31..0]: 0x69732074 0110 1001 0111 0011 0010 0000 0111 0100
		Address @, word[63..32]: 0x04EE F672 0000 0100 1110 1110 1111 0110 0111 0010 Address @ + 0x4, word[31..0]: 0x2E04 CE96 0010 1110 0000 0100 1100 1110 1001 0110

Figure 452. 128-bit block construction according to the data type



Data padding

Figure 452 also gives an example of memory data block padding with zeros such that the zeroed bits after the data swap form a contiguous zone at the MSB end of the AES core input buffer. The example shows the padding of an input data block containing:

- 84 message bits, with DATATYPE[1:0] = 0x0
- 48 message bits, with DATATYPE[1:0] = 0x1
- 56 message bits, with DATATYPE[1:0] = 0x2
- 34 message bits, with DATATYPE[1:0] = 0x3

44.4.16 AES key registers

The eight AES_KEYRx write-only registers store the encryption or decryption key information, as shown on *Table 437*. Reads are not allowed for security reason.

Note: In memory and in AES *key registers, keys are stored in little-endian format, with most significant byte on the highest address.*

Table 437. Key endianness in AES_KEYRx registers (128/256-bit keys)

AES_KEYR7 [31:0]	AES_KEYR6 [31:0]	AES_KEYR5 [31:0]	AES_KEYR4 [31:0]	AES_KEYR3 [31:0]	AES_KEYR2 [31:0]	AES_KEYR1 [31:0]	AES_KEYR0 [31:0]
-	-	-	-	KEY[127:96]	KEY[95:64]	KEY[63:32]	KEY[31:0]
KEY[255:224]	KEY[223:192]	KEY[191:160]	KEY[159:128]	KEY[127:96]	KEY[95:64]	KEY[63:32]	KEY[31:0]

The key registers are not affected by the data swapping feature controlled by the DATATYPE[1:0] bitfield.

Write operations to the AES_KEYRx registers are ignored when AES peripheral is enabled (EN bit set). The application must check this before modifying key registers.

The entire key must be written before starting an AES computation.

In normal key mode (KMOD[1:0] at 0x0), the key registers must always be written in either ascending or descending order. The write sequence becomes:

- AES_KEYRx (x = 0 to 3 or x=3 to 0) for KEYSIZE cleared
- AES_KEYRx (x = 0 to 7 or x=7 to 0) for KEYSIZE set

Note: KEYSIZE must be written before the key.

As soon as the first key register is written, the KEYVALID flag is cleared. Once the key registers writing sequence is completed, KEYVALID is set and EN becomes writable. If an error occurs, KEYVALID is cleared and KEIF set (see *Section 44.4.18*).

44.4.17 AES initialization vector registers

The four AES_IVRx registers store the initialization vector (IV) information, as shown in *Table 438*. They can only be written if the AES peripheral is disabled (EN cleared).

Note: In memory and in AES IV registers, initialization vectors are stored in little-endian format, with most significant byte on the highest address.

Table 438. IVI bitfield spread over AES_IVRx registers

AES_IVR3[31:0]	AES_IVR2[31:0]	AES_IVR1[31:0]	AES_IVR0[31:0]
IVI[127:96]	IVI[95:64]	IVI[63:32]	IVI[31:0]

Initialization vector information depends on the chaining mode selected. When used, AES_IVRx registers are updated upon each AES computation cycle (useful for managing suspend mode).

The initialization vector registers are not affected by the data swapping feature controlled through DATATYPE[1:0].

44.4.18 AES error management

The AES peripheral manages the errors described in this section.

Read error flag (RDERRF)

Unexpected read attempt of the AES_DOUTR register returns zero, setting the RDERRF flag and the RWEIF flag. RDERRF is triggered during the computation phase or during the input phase.

Note: AES is not disabled when RDERRF rises and it continues processing.

An interrupt is generated if the RWEIE bit is set. For more details, refer to *Section 44.5: AES interrupts*.

The RDERRF and RWEIF flags are cleared by setting the RWEIF bit of the AES_ICR register.

Write error flag (WRERRF)

Unexpected write attempt of the AES_DINR register is ignored, setting the WRERRF and the RWEIF flags. WRERRF is triggered during the computation phase or during the output phase.

Note: AES is not disabled when WRERRF rises and it continues processing.

An interrupt is generated if the RWEIE bit is set. For more details, refer to *Section 44.5: AES interrupts*.

The WRERRF and RWEIF flags are cleared by setting the RWEIF bit of the AES_ICR register.

Key error interrupt flag (KEIF)

There are multiple sources of errors that set the KEIF flag of the AES_ISR register and clear the KEYVALID bit of the AES_SR register:

- **Key writing sequence error:** triggered upon detecting an incorrect sequence of writing key registers. See *Section 44.4.16: AES key registers* for details.
- **Key sharing size mismatch error:** triggered when KMOD[1:0] is at 0x2 and KEYSIZE in AES peripheral does not match KEYSIZE in SAES peripheral.

- **Key sharing error:** triggered upon failing transfer of SAES shared key to AES peripheral. See *Section 44.4.14: AES key sharing with secure AES co-processor* for details.

The KEIF flag is cleared with corresponding bit of the AES_ICR register. An interrupt is generated if the KEIE bit of the AES_IER register is set. For more details, refer to *Section 44.5: AES interrupts*.

Upon a key sharing error, reset both AES and SAES peripherals through the IPRST bit of their corresponding control register, then restart the key sharing sequence.

Note: For any key error, clear KEIF flag prior to disabling and re-configuring AES.

44.5 AES interrupts

There are multiple individual maskable interrupt sources generated by the AES peripheral to signal the following events:

- computation completed (CCF)
- read error (RDERRF)
- write error (WRERRF)
- key error (KEIF)

See *Section 44.4.18: AES error management* for details on AES errors.

These sources are combined into a common interrupt signal from the AES peripheral that connects to the Cortex® CPU interrupt controller. Application can enable or disable AES interrupt sources individually by setting/clearing the corresponding enable bit of the AES_IER register.

The status of the individual maskable interrupt sources can be read from the AES_ISR register. They are cleared by setting the corresponding bit of the AES_ICR register.

Table 439 gives a summary of the available features.

Table 439. AES interrupt requests

Interrupt acronym	Interrupt event	Event flag	Enable bit	Interrupt clear method
AES	computation completed flag	CCF	CCFIE	set CCF(1)
	read error flag	RDERRF(2)	RWEIE	set RWEIF(1)
	write error flag	WRERRF(2)		
	key error flag	KEIF	KEIE	set KEIF(1)

1. Bit of the AES_ICR register.
2. Flag of the AES_SR register, mirrored by the flag RWEIF of the AES_ISR register.

44.6 AES DMA requests

The AES peripheral provides an interface to connect to the DMA (direct memory access) controller. The DMA operation is controlled through the DMAINEN and DMAOUTEN bits of the AES_CR register. When key derivation is selected (MODE[1:0] is at 0x1), setting those bits has no effect.

AES only supports single DMA requests.

Suspend and resume operations are not supported in DMA mode.

Detailed usage of DMA with AES can be found in *Appending data using DMA* subsection of *Section 44.4.5: AES encryption or decryption typical usage*.

Data input using DMA

Setting DMAINEN enables DMA writing into AES. AES then initiates, during the input phase, a set of single DMA requests for each 16-byte data block to write to the AES_DINR register (quadruple 32-bit word, MSB first).

Note: According to the algorithm and the mode selected, special padding / ciphertext stealing might be required (see Section 44.4.7).

Data output using DMA

Setting DMAOUTEN enables DMA reading from AES. AES then initiates, during the output phase, a set of single DMA requests for each 16-byte data block to read from the AES_DOUTR register (quadruple 32-bit word, MSB first).

After the output phase, at the end of processing of a 16-byte data block, AES switches automatically to a new input phase for the next data block, if any.

In DMA mode, the CCF flag has no use because the reading of the AES_DOUTR register is managed by DMA automatically at the end of the computation phase. The CCF flag must only be cleared when transiting back to managing the data transfers by software.

Note: According to the message size, extra bytes might need to be discarded by application in the last block.

Stopping DMA transfers

All DMA request signals are de-asserted when AES is disabled (EN cleared) or the DMA enable bit (DMAINEN for input data, DMAOUTEN for output data) is cleared.

44.7 AES processing latency

The following tables provide the 16-byte data block processing latency per operating mode.

Table 440. Processing latency for ECB, CBC and CTR

Key size	Mode of operation	Chaining algorithm	Clock cycles
128-bit	Encryption or decryption(1)	ECB, CBC, CTR	51
	Key preparation	-	59
256-bit	Encryption or decryption(1)	ECB, CBC, CTR	75
	Key preparation	-	82

1. Excluding key preparation time (ECB and CBC only).

Table 441. Processing latency for GCM and CCM (in clock cycles)

Key size	Mode of operation	Chaining algorithm	Initialization phase	Header phase(1)	Payload phase(1)	Final phase(1)
128-bit	Encryption/ Decryption	GCM	64	35	51	59
		CCM	63	55	114	58
256-bit	Encryption/ Decryption	GCM	88	35	75	75
		CCM	87	79	162	82

1. Data insertion can include wait states forced by AES on the AHB bus (maximum 3 cycles, typical 1 cycle).

44.8 AES registers

The registers are accessible through 32-bit word single accesses only. Other access types generate an AHB error, and other than 32-bit writes may corrupt the register content.

44.8.1 AES control register (AES_CR)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IPRST	Res.	Res.	Res.	Res.	Res.	KMOD[1:0]		NPBLB[3:0]				Res.	KEYSIZE	Res.	CHMOD[2]
rw						rw	rw	rw	rw	rw	rw		rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	GCMPH[1:0]		DMAOUTEN	DMAINEN	Res.	Res.	Res.	Res.	CHMOD[1:0]		MODE[1:0]		DATATYPE[1:0]		EN
	rw	rw	rw	rw					rw	rw	rw	rw	rw	rw	rw

Bit 31 **IPRST**: AES peripheral software reset

Setting the bit resets the AES peripheral, putting all registers to their default values, except the IPRST bit itself. Hence, any key-relative data are lost. For this reason, it is recommended to set the bit before handing over the AES to a less secure application.

The bit must be kept low while writing any configuration registers.

Bits 30:26 Reserved, must be kept at reset value.

Bits 25:24 **KMOD[1:0]**: Key mode selection

The bitfield defines how the AES key can be used by the application. KEYSIZE must be correctly initialized when setting KMOD[1:0] different from zero.

0x0: Normal key mode. Key registers are freely usable.

0x2: Shared key mode. If shared key mode is properly initialized in SAES peripheral, the AES peripheral automatically loads its key registers with the data stored in the SAES key registers. The key value is available in AES key registers when BUSY bit is cleared and KEYVALID is set in the AES_SR register. Key error flag KEIF is set otherwise in the AES_ISR register.

Others: Reserved

Attempts to write the bitfield are ignored when BUSY is set, as well as when EN is set before the write access and it is not cleared by that write access.

Bits 23:20 **NPBLB[3:0]:** Number of padding bytes in last block

This padding information must be filled by software before processing the last block of GCM payload encryption or CCM payload decryption, otherwise authentication tag computation is incorrect.

0x0: All bytes are valid (no padding)

0x1: Padding for the last LSB byte

...

0xF: Padding for the 15 LSB bytes of last block.

Bit 19 Reserved, must be kept at reset value.

Bit 18 **KEYSIZE:** Key size selection
This bitfield defines the key length in bits of the key used by AES.
0: 128-bit
1: 256-bit
Attempts to write the bit are ignored when BUSY is set, as well as when the EN is set before the write access and it is not cleared by that write access.

Bit 17 Reserved, must be kept at reset value.

Bit 15 Reserved, must be kept at reset value.

Bits 14:13 **GCMPH[1:0]:** GCM or CCM phase selection
This bitfield selects the phase, applicable only with GCM, GMAC or CCM chaining modes.
0x0: Initialization phase
0x1: Header phase
0x2: Payload phase
0x3: Final phase

Bit 12 **DMAOUTEN**: DMA output enable
This bit enables automatic generation of DMA requests during the data phase, for outgoing data transfers from AES via DMA.
0: Disable
1: Enable
Setting this bit is ignored when MODE[1:0] is at 0x1 (key derivation).

Bit 11 **DMAINEN**: DMA input enable
This bit enables automatic generation of DMA requests during the data phase, for incoming data transfers to AES via DMA.
0: Disable
1: Enable
Setting this bit is ignored when MODE[1:0] is at 0x1 (key derivation).

Bits 10:7 Reserved, must be kept at reset value.

Bits 16, 6:5 **CHMOD[2:0]**: Chaining mode
This bitfield selects the AES chaining mode:
0x0: Electronic codebook (ECB)
0x1: Cipher-block chaining (CBC)
0x2: Counter mode (CTR)
0x3: Galois counter mode (GCM) and Galois message authentication code (GMAC)
0x4: Counter with CBC-MAC (CCM)
others: Reserved
Attempts to write the bitfield are ignored when BUSY is set, as well as when EN is set before the write access and it is not cleared by that write access.

Bits 4:3 **MODE[1:0]**: Operating mode
This bitfield selects the AES operating mode:
0x0: Encryption
0x1: Key derivation (or key preparation), for ECB/CBC decryption only
0x2: Decryption
0x3: Reserved
Attempts to write the bitfield are ignored when BUSY is set, as well as when EN is set before the write access and it is not cleared by that write access.

Bits 2:1 **DATATYPE[1:0]**: Data type

This bitfield defines the format of data written in the AES_DINR register or read from the AES_DOUTR register, through selecting the mode of data swapping. This swapping is defined in *Section 44.4.15: AES data registers and data swapping*.

0x0: No swapping (32-bit data).

0x1: Half-word swapping (16-bit data)

0x2: Byte swapping (8-bit data)

0x3: Bit-level swapping

Attempts to write the bitfield are ignored when BUSY is set, as well as when EN is set before the write access and it is not cleared by that write access.

Bit 0 **EN**: Enable

This bit enables/disables the AES peripheral.

0: Disable

1: Enable

At any moment, clearing then setting the bit re-initializes the AES peripheral. When KMOD[1:0] is different from 0x0, using IPRST bit is recommended instead.

This bit is automatically cleared by hardware upon the completion of the key preparation (MODE[1:0] at 0x1) and upon the completion of GCM/GMAC/CCM initialization phase.

– The bit cannot be set as long as KEYVALID is cleared

44.8.2 AES status register (AES_SR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEYVALID	Res.	Res.	Res.	BUSY	WRERRF	RDERRF	Res.
								r				r	r	r	

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **KEYVALID**: Key valid flag

This bit is set by hardware when the key of size defined by KEYSIZE is loaded in AES_KEYRx key registers.

0: Key not valid

1: Key valid

The EN bit can only be set when KEYVALID is set.

In normal mode when KMOD[1:0] is at zero, the key must be written in the key registers in the correct sequence, otherwise the KEIF flag is set and KEYVALID remains cleared.

When KMOD[1:0] is different from zero, the BUSY flag is automatically set by AES. When the key is loaded successfully, BUSY is cleared and KEYVALID set. Upon an error, KEIF is usually set, BUSY cleared and KEYVALID remains cleared.

If set, KEIF must be cleared through the AES_ICR register, otherwise KEYVALID cannot be set. See the KEIF flag description for more details.

For further information on key loading, refer to *Section 44.4.16: AES key registers*.

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **BUSY:** Busy

This flag indicates whether AES is idle or busy.
0: Idle
1: Busy
AES is flagged as idle when disabled (when EN is low) or when the last processing is completed.
AES is flagged as busy when processing a block data, preparing a key (ECB or CBC decryption only), or transferring a shared key from the SAES peripheral.
When GCM encryption payload phase is selected, this flag must be at zero before suspending current process to manage a higher-priority message.

Bit 2 **WRERRF**: Write error flag

This bit is set when an unexpected write to the AES_DINR register occurred. When set WRERRF bit has no impact on the AES operations.
0: No error
1: Unexpected write to AES_DINR register occurred during computation or data output phase.
The flag setting generates an interrupt if the RWEIE bit of the AES_IER register is set.
The flag is cleared by setting the RWEIF bit of the AES_ICR register.

Bit 1 **RDERRF**: Read error flag

This bit is set when an unexpected read to the AES_DOUTR register occurred. When set RDERRF bit has no impact on the AES operations.
0: No error
1: Unexpected read to AES_DOUTR register occurred during computation or data input phase.
The flag setting generates an interrupt if the RWEIE bit of the AES_IER register is set.
The flag is cleared by setting the RWEIF bit of the AES_ICR register.

Bit 0 Reserved, must be kept at reset value.

44.8.3 AES data input register (AES_DINR)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DIN[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIN[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **DIN[31:0]**: Data input

A four-fold sequential write to this bitfield during the Input phase results in writing a complete 16-bytes block of input data to the AES peripheral. From the first to the fourth write, the corresponding data weights are [127:96], [95:64], [63:32], and [31:0]. Upon each write, the data from the 32-bit input buffer are handled by the data swap block according to the DATATYPE[1:0] bitfield, then written into the AES core 16-bytes input buffer.
Reads return zero.

44.8.4 AES data output register (AES_DOUTR)

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DOUT[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DOUT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **DOUT[31:0]**: Data output

This read-only bitfield fetches a 32-bit output buffer. A four-fold sequential read of this bitfield, upon the computation completion (CCF flag set), virtually reads a complete 16-byte block of output data from the AES peripheral. Before reaching the output buffer, the data produced by the AES core are handled by the data swap block according to the DATATYPE[1:0] bitfield.

Data weights from the first to the fourth read operation are: [127:96], [95:64], [63:32], and [31:0].

44.8.5 AES key register 0 (AES_KEYR0)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[31:0]**: Cryptographic key, bits [31:0]

These are bits [31:0] of the write-only bitfield KEY[255:0] AES encryption or decryption key, depending on the MODE[1:0] bitfield of the AES_CR register.

Writes to AES_KEYRx registers are ignored when AES is enabled (EN bit set). When the key comes from the SAES peripheral (KMOD[1:0] at 0x2), writes to key registers are also ignored and they result in setting the KEIF bit of the AES_ISR register.

With KMOD[1:0] at 0x0, a special writing sequence is required. In this sequence, any valid write to AES_KEYRx register clears the KEYVALID flag except for the sequence-completing write that sets it. Also refer to the description of the KEYVALID flag in the AES_SR register.

44.8.6 AES key register 1 (AES_KEYR1)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[63:48]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[47:32]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[63:32]**: Cryptographic key, bits [63:32]

Refer to the AES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing AES_KEYRx registers.

44.8.7 AES key register 2 (AES_KEYR2)

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[95:80]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[79:64]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[95:64]**: Cryptographic key, bits [95:64]

Refer to the AES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing AES_KEYRx registers.

44.8.8 AES key register 3 (AES_KEYR3)

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[127:112]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[111:96]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[127:96]**: Cryptographic key, bits [127:96]

Refer to the AES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing AES_KEYRx registers.

44.8.9 AES initialization vector register 0 (AES_IVR0)

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IVI[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IVI[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IVI[31:0]**: Initialization vector input, bits [31:0]

AES_IVRx registers store the 128-bit initialization vector or the nonce, depending on the chaining mode selected. This value is updated by hardware after each computation round (when applicable). Write to this register is ignored when EN bit is set in AES_CR register

44.8.10 AES initialization vector register 1 (AES_IVR1)

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IVI[63:48]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IVI[47:32]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IVI[63:32]**: Initialization vector input, bits [63:32]

Refer to the AES_IVR0 register for description of the IVI[128:0] bitfield.

44.8.11 AES initialization vector register 2 (AES_IVR2)

Address offset: 0x028

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IVI[95:80]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IVI[79:64]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IVI[95:64]**: Initialization vector input, bits [95:64]

Refer to the AES_IVR0 register for description of the IVI[128:0] bitfield.

44.8.12 AES initialization vector register 3 (AES_IVR3)

Address offset: 0x02C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IVI[127:112]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IVI[111:96]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IVI[127:96]**: Initialization vector input, bits [127:96]
Refer to the AES_IVR0 register for description of the IVI[128:0] bitfield.

44.8.13 AES key register 4 (AES_KEYR4)

Address offset: 0x030

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[159:144]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[143:128]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[159:128]**: Cryptographic key, bits [159:128]
Refer to the AES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing AES_KEYRx registers.

44.8.14 AES key register 5 (AES_KEYR5)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[191:176]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[175:160]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[191:160]**: Cryptographic key, bits [191:160]
Refer to the AES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing AES_KEYRx registers.

44.8.15 AES key register 6 (AES_KEYR6)

Address offset: 0x038

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[223:208]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[207:192]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[223:192]**: Cryptographic key, bits [223:192]

Refer to the AES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing AES_KEYRx registers.

44.8.16 AES key register 7 (AES_KEYR7)

Address offset: 0x03C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[255:240]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[239:224]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[255:224]**: Cryptographic key, bits [255:224]

Refer to the AES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing AES_KEYRx registers.

44.8.17 AES suspend registers (AES_SUSPRx)

Address offset: 0x040 + 0x4 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SUSP[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SUSP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SUSP[31:0]**: Suspend data

AES_SUSPRx registers contain the complete internal register states of the AES when the GCM, GMAC or CCM processing of the current task is suspended to process a higher-priority task. Refer to *Section 44.4.8: AES suspend and resume operations* for more details.

Clearing EN bit of the AES_CR register clears this register to zero.

AES_SUSPRx registers are not used in other chaining modes than GCM, GMAC or CCM.

44.8.18 AES interrupt enable register (AES_IER)

Address offset: 0x300

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIE	RWEIE	CCFIE
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **KEIE:** Key error interrupt enable

This bit enables or disables (masks) the AES interrupt generation when KEIF (key error flag) is set.

0: Disabled (masked)

1: Enabled (not masked)

Bit 1 **RWEIE:** Read or write error interrupt enable

This bit enables or disables (masks) the AES interrupt generation when RWEIF (read and/or write error flag) is set.

0: Disabled (masked)

1: Enabled (not masked)

Bit 0 **CCFIE:** Computation complete flag interrupt enable

This bit enables or disables (masks) the AES interrupt generation when CCF (computation complete flag) is set.

0: Disabled (masked)

1: Enabled (not masked)

44.8.19 AES interrupt status register (AES_ISR)

Address offset: 0x304

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIF	RWEIF	CCF
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **KEIF:** Key error interrupt flag

This read-only bit is set by hardware when the key information fails to load into key registers.

0: No key error detected

1: Key information failed to load into key registers

The flag setting generates an interrupt if the KEIE bit of the AES_IER register is set. It also clears the key registers and the KEYVALID flag in the AES_SR register.

The flag is cleared by setting the corresponding bit of the AES_ICR register.

KEIF is raised upon any of the following events:

–AES_KEYRx register write does not respect the correct order. (For KEYSIZE cleared, AES_KEYR0 then AES_KEYR1 then AES_KEYR2 then AES_KEYR3 register, or reverse. For KEYSIZE set, AES_KEYR0 then AES_KEYR1 then AES_KEYR2 then AES_KEYR3 then AES_KEYR4 then AES_KEYR5 then AES_KEYR6 then AES_KEYR7, or reverse).

–AES fails to load the key shared by the SAES peripheral (KMOD[1:0] = 0x2).

KEIF must be cleared by the application software, otherwise KEYVALID cannot be set.

Bit 1 **RWEIF:** Read or write error interrupt flag

This read-only bit is set by hardware when a RDERRF or a WRERRF error flag is set in the AES_SR register.

0: No read or write error detected

1: Read or write error detected

The flag setting generates an interrupt if the RWEIE bit of the AES_IER register is set.

The flag is cleared by setting the corresponding bit of the AES_ICR register.

The flags has no meaning when key derivation mode is selected.

See the AES_SR register for details.

Bit 0 **CCF:** Computation complete flag

This flag indicates whether the computation is completed. It is significant only when the DMAOUTEN bit is cleared, and it may stay high when DMAOUTEN is set.

0: Not completed

1: Completed

The flag setting generates an interrupt if the CCFIE bit of the AES_IER register is set.

The flag is cleared by setting the corresponding bit of the AES_ICR register.

44.8.20 AES interrupt clear register (AES_ICR)

Address offset: 0x308

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIF	RWEIF	CCF
													w	w	w

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **KEIF:** Key error interrupt flag clear
Setting this bit clears the KEIF status bit of the AES_ISR register.

Bit 1 **RWEIF:** Read or write error interrupt flag clear
Setting this bit clears the RWEIF status bit of the AES_ISR register, and clears both RDERRF and WRERRF flags in the AES_SR register.

Bit 0 **CCF:** Computation complete flag clear
Setting this bit clears the CCF status bit of the AES_ISR register.

44.8.21 AES register map

Table 442. AES register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	AES_CR	IPRST	Res.	Res.	Res.	Res.	Res.	KMOD[1]	KMOD[0]	NPBLB[3:0]				Res.	KEYSIZE	Res.	CHMOD[2]	Res.	GCMPH[1:0]		DMAOUTEN	DMAINEN	Res.	Res.	Res.	Res.	CHMOD[1:0]		MODE[1:0]		DATATYPE[1:0]		EN
	Reset value	0						0	0	0	0	0	0		0		0		0	0	0	0					0	0	0	0	0	0	0
0x004	AES_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEYVALID	Res.	Res.	Res.	BUSY	WRERRF	RDERRF	Res.
	Reset value																									0				0	0	0	
0x008	AES_DINR	DIN[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C	AES_DOUTR	DOUT[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x010	AES_KEYR0	KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	AES_KEYR1	KEY[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 442. AES register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x018	AES_KEYR2	KEY[95:64]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x01C	AES_KEYR3	KEY[127:96]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	AES_IVR0	IVI[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	AES_IVR1	IVI[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x028	AES_IVR2	IVI[95:64]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x02C	AES_IVR3	IVI[127:96]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x030	AES_KEYR4	KEY[159:128]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x034	AES_KEYR5	KEY[191:160]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x038	AES_KEYR6	KEY[223:192]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x03C	AES_KEYR7	KEY[255:224]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x040	AES_SUSPR0	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x044	AES_SUSPR1	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x048	AES_SUSPR2	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04C	AES_SUSPR3	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x050	AES_SUSPR4	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x054	AES_SUSPR5	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x058	AES_SUSPR6	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x05C	AES_SUSPR7	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x060-0x2FF	Reserved	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res

Table 442. AES register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x300	AES_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIE	RWEIE	CCFIE
	Reset value																														0	0	0
0x304	AES_ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIF	RWEIF	CCF
	Reset value																														0	0	0
0x308	AES_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIF	RWEIF	CCF
	Reset value																														0	0	0
0x309-0x3FF	Reserved	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

45 Secure AES coprocessor (SAES)

45.1 SAES introduction

The secure AES coprocessor (SAES) encrypts or decrypts data in compliance with the advanced encryption standard (AES) defined by NIST. It incorporates a protection against side-channel attacks (SCA), including differential power analysis (DPA), required for SESIP and PSA security assurance level 3 target.

SAES supports ECB, CBC, CTR, GCM, GMAC, and CCM chaining modes for key sizes of 128 or 256 bits, as well as special modes such as hardware secret key encryption/ decryption (wrapped-key mode) and key sharing with faster AES peripheral (shared-key mode).

SAES has the possibility to load by hardware STM32 hardware secret master keys (boot hardware key BHK and derived hardware unique key DHUK), usable but not readable by the application.

The peripheral supports DMA single transfers for incoming and outgoing data (two DMA channels are required). It is hardware-linked with the true random number generator (TRNG) and with the AES peripheral.

45.2 SAES main features

- Compliant with NIST FIPS publication 197 *"Advanced encryption standard (AES)"* (November 2001)
- Encryption and decryption with multiple chaining modes:
  - Electronic codebook (ECB) mode
  - Cipher block chaining (CBC) mode
  - Counter (CTR) mode
  - Galois counter mode (GCM)
  - Galois message authentication code (GMAC) mode
  - Counter with CBC-MAC (CCM) mode
- Protection against side-channel attacks (SCA), incl. differential power analysis (DPA), required for SESIP and PSA security assurance level 3 target
- 128-bit data block processing, supporting cipher key lengths of 128-bit and 256-bit
  - 480 or 680 clock cycle latency in ECB mode for processing one 128-bit block with, respectively, 128-bit or 256-bit key
- Hardware secret key encryption/ decryption (Wrapped-key mode)
- Using dedicated key bus, optional key sharing with faster AES peripheral (shared-key mode), controlled by SAES
- Integrated key scheduler to compute the last round key for ECB/CBC decryption
- 256-bit of write-only registers for storing cryptographic keys (eight 32-bit registers)
  - Optional 128-bit or 256-bit hardware loading of two hardware secret keys (BHK, DHUK) that can be XOR-ed together
- Security context enforcement for keys
- 128-bit of registers for storing initialization vectors (four 32-bit registers)

- 32-bit buffer for data input and output
- Automatic data flow control supporting two direct memory access (DMA) channels, one for incoming data, one for processed data. Only single transfers are supported.
- Data-swapping logic to support 1-, 8-, 16-, or 32-bit data
- AMBA AHB slave peripheral, accessible through 32-bit word single accesses only. Other access types generate an AHB error, and other than 32-bit writes may corrupt the register content.
- Possibility for software (in CPU mode only, not in DMA mode) to suspend a message if SAES needs to process another message with a higher priority, then resume the original message

45.3 SAES implementation

The devices have one SAES peripheral, implemented as per the following table. It shares the key with the AES peripheral. For comparison, the AES peripheral is also included in the table.

Table 443. AES versus SAES features

Modes or features(1)	AES	SAES
ECB, CBC chaining	X	X
CTR, CCM, GCM chaining	X	X
AES 128-bit ECB encryption in cycles	51	480
DHUK and BHK key selection	-	X
Resistance to side-channel attacks	-	X
Shared key between SAES and AES	X	
Key sizes in bits	128, 256	128, 256

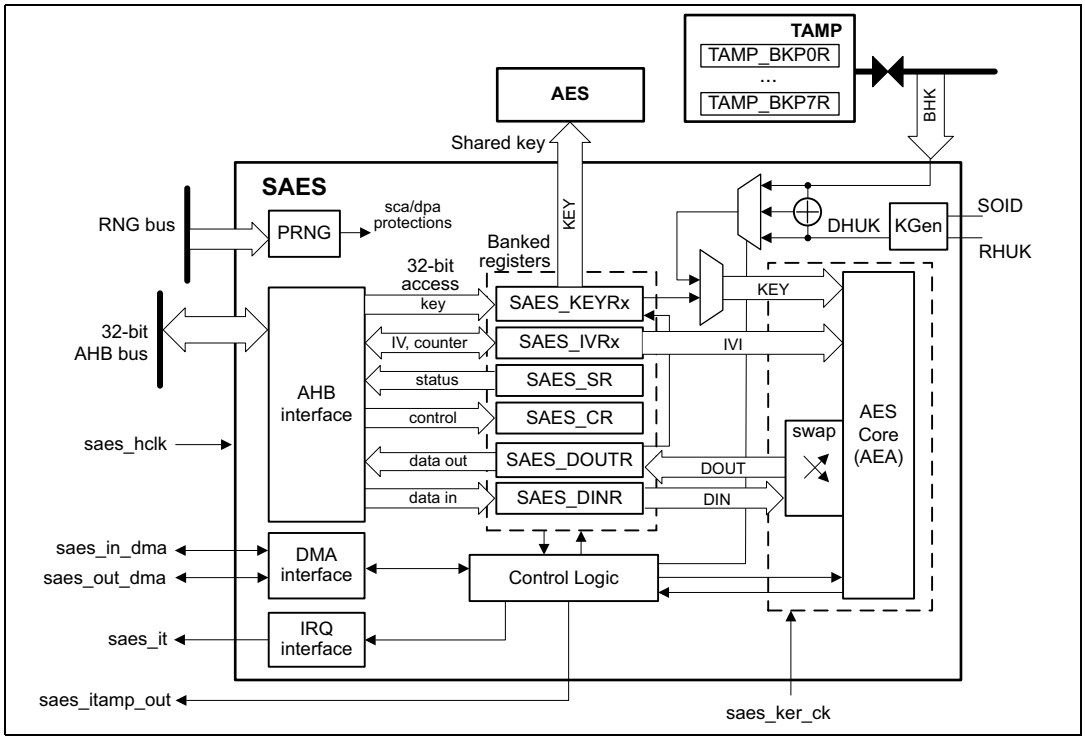
1. X = supported.

45.4 SAES functional description

45.4.1 SAES block diagram

Figure 453 shows the block diagram of SAES.

Figure 453. SAES block diagram



Note: AES represents the AES peripheral.

45.4.2 SAES internal signals

Table 444 describes the user relevant internal signals interfacing the SAES peripheral.

Table 444. SAES internal input/output signals

Signal name	Signal type	Description
saes_hclk	Input	AHB bus clock
saes_ker_ck	Input	SAES kernel clock.
saes_it	Output	SAES interrupt request
saes_in_dma	Input/Output	SAES incoming data DMA single request/acknowledge
saes_out_dma	Input/Output	SAES processed data DMA single request/acknowledge
saes_itamp_out	Output	Tamper event signal to TAMP (XOR-ed), triggered when an unexpected hardware fault occurs. When this signal is triggered, SAES automatically clears key registers. A reset is required for SAES to be usable again.
RHUK	Input	256-bit root hardware unique key (nonvolatile, unique per device and secret to software), used to internally compute the derived hardware unique key (DHUK)

Table 444. SAES internal input/output signals (continued)

Signal name	Signal type	Description
BHK(1)	Input	256-bit boot hardware key (BHK) stored in tamper-resistant secure backup registers and written by a secure code during boot. Once written, this key cannot be read nor written by any application until the next product reset.
SOID	Input	Static operating ID hardware input used during each DHUK computation. Its change causes the erasure of key registers and sets the KEIF flag.

1. Connected to a set of backup registers in TAMP peripheral that are written, then read/write locked, by the application software (see *Section 45.4.17* for details).

45.4.3 SAES reset and clocks

The SAES peripheral is clocked by the AHB bus clock. It has a dedicated reset bit and a dedicated kernel clock, controlled through the RCC.

The SAES reset in RCC is mandatory when a hardware tamper event occurs in SAES. Refer to *Managing tamper errors* in *Section 45.4.19* for details.

After clocking then releasing the reset of the SAES peripheral in the RCC, SAES automatically draws random numbers from the RNG, setting the BUSY bit of the SAES_SR register. Refer to the *RNG error interrupt flag (RNGEIF)* in *Section 45.4.19* for details.

This background task must be completed before the device enters a low-power mode.

45.4.4 SAES symmetric cipher implementation

The secure AES coprocessor (SAES) is a 32-bit AHB peripheral that encrypts or decrypts 16-byte blocks of data using the advanced encryption standard (AES). It also implements a set of approved AES symmetric key security functions summarized in *Table 445*. Those functions can be certified NIST PUB 140-3.

Table 445. SAES approved symmetric key functions

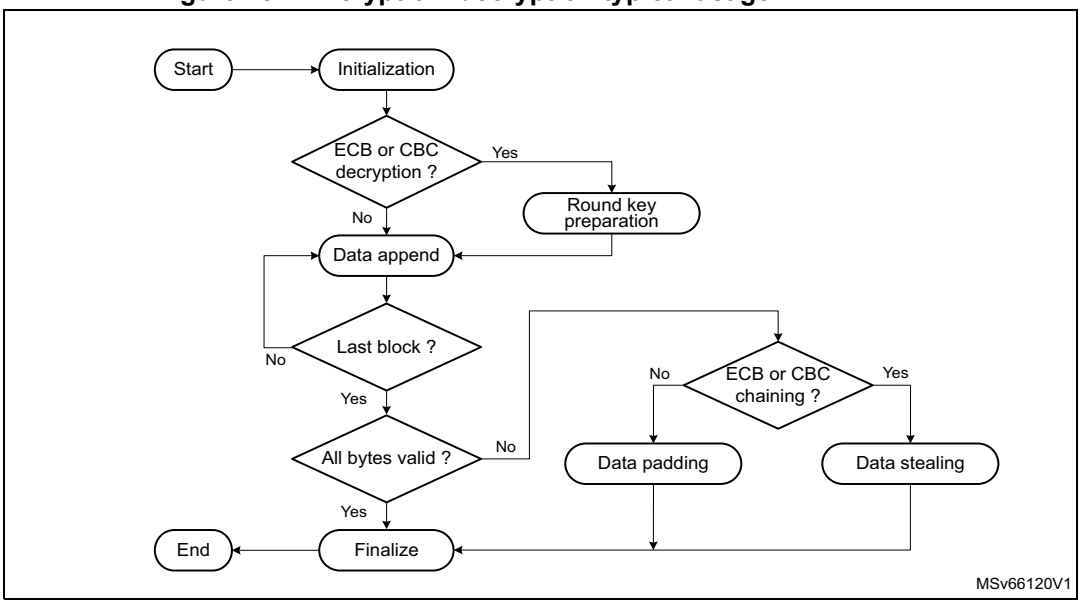
Operations	Algorithm	Specification	Key bit lengths	Chaining modes
Encryption, decryption	AES	FIPS PUB 197 NIST SP800-38A	128, 256	ECB, CBC, CTR
Authenticated encryption or decryption		NIST SP800-38C NIST SP800-38D		GCM, CCM
Cipher-based message authentication code		NIST SP800-38D		GMAC

SAES can be used directly by the CPU, or indirectly, using two DMA channels (one for the plaintext, one for the ciphertext).
It is possible to suspend then resume any SAES processing, following the sequence described in *Section 45.4.8*.

45.4.5 SAES encryption or decryption typical usage

The following figure shows a typical operation for encryption or decryption.

Figure 454. Encryption/ decryption typical usage



Initialization

The SAES peripheral is initialized according to the chaining mode. Refer to *Section 45.4.9: SAES basic chaining modes (ECB, CBC)* and *Section 45.4.10: SAES counter (CTR) mode* for details.

Data append

This section describes different ways of appending data for processing. For ECB or CBC chaining modes, refer to *Section 45.4.7: SAES ciphertext stealing and data padding* if the size of data to process is not a multiple of 16 bytes. The last block management in these cases is more complex than what is described in this section.

Appending data using the CPU in polling mode

This method uses flag polling to control the data append through the following sequence:

1. Enable the SAES peripheral when KEYVALID is set, by setting the EN bit of the SAES_CR register (if not already done).
2. Repeat the following sub-sequence until the payload is entirely processed:
   a) Write four input data words into the SAES_DINR register.
   b) Wait until the status flag CCF is set in the SAES_ISR register, then read the four data words from the SAES_DOUTR register.
   c) Clear the CCF flag, by setting the CCF bit of the SAES_ICR register.
   d) If the next processing block is the last block, pad (when applicable) the data with zeros to obtain a complete block, and specify the number of non-valid bytes (using

NPBLB[3:0]) in case of GCM payload encryption or CCM payload decryption (otherwise the tag computation is wrong).

3. As the data block just processed is the last block of the message, optionally discard the data that is not part of the message/payload, then disable the SAES peripheral by clearing EN.

Note: Up to three wait cycles are automatically inserted between two consecutive writes to the SAES_DINR register, to allow sending the key to the AES co-processor.

NPBLB[3:0] bitfield is not used in header phase of GCM, GMAC and CCM chaining modes.

Appending data using the CPU in interrupt mode

The method uses interrupt from the SAES peripheral to control the data append, through the following sequence:

1. Enable interrupts from SAES, by setting the CCFIE bit of the SAES_IER register.
2. Enable the SAES peripheral when KEYVALID is set, by setting EN (if not already done).
3. Write first four input data words into the SAES_DINR register.
4. Handle the data in the SAES interrupt service routine. Upon each interrupt:
   a) Read four output data words from the SAES_DOUTR register.
   b) Clear the CCF flag and thus the pending interrupt, by setting the CCF bit of the SAES_ICR register.
   c) If the next processing block is the last block of the message, pad (when applicable) the data with zeros to obtain a complete block, and specify the number of non-valid bytes (through NPBLB[3:0]) in case of GCM payload encryption or CCM payload decryption (otherwise the tag computation is wrong). Then proceed with point 4e).
   d) If the data block just processed is the last block of the message, optionally discard the data that are not part of the message/payload, then disable the SAES peripheral by clearing EN and quit the interrupt service routine.
   e) Write next four input data words into the SAES_DINR register and quit the interrupt service routine.

Note: SAES is tolerant of delays between consecutive read or write operations, which allows, for example, an interrupt from another peripheral to be served between two SAES computations.

The NPBLB[3:0] bitfield is not used in the header phase of GCM, GMAC, and CCM chaining modes.

Appending data using DMA

With this method, all the transfers and processing are managed by DMA and SAES. Proceed as follows:

1. If the last block of the message to process is shorter than 16 bytes, prepare the last four-word data block by padding the remainder of the block with zeros.
2. Configure the DMA controller so as to transfer the data to process from the memory to the SAES peripheral input and the processed data from the SAES peripheral output to the memory, as described in *Section 45.6: SAES DMA requests*. Configure the DMA controller so as to generate an interrupt on transfer completion. For GCM payload encryption or CCM payload decryption, the DMA transfer **must not** include the last four-word block if padded with zeros. The sequence described in *Appending data using the CPU in polling mode* must be used instead for this last block, because the

NPBLB[3:0] bitfield must be set up before processing the block, for SAES to compute a correct tag.

3. Enable the SAES peripheral when KEYVALID is set, by setting EN (if not already done).
4. Enable DMA requests, by setting DMAINEN and DMAOUTEN.
5. Upon DMA interrupt indicating the transfer completion, get the SAES-processed data from the memory.

When appending data using DMA, the suspend/resume operation as described in *Section 45.4.8* is not supported.

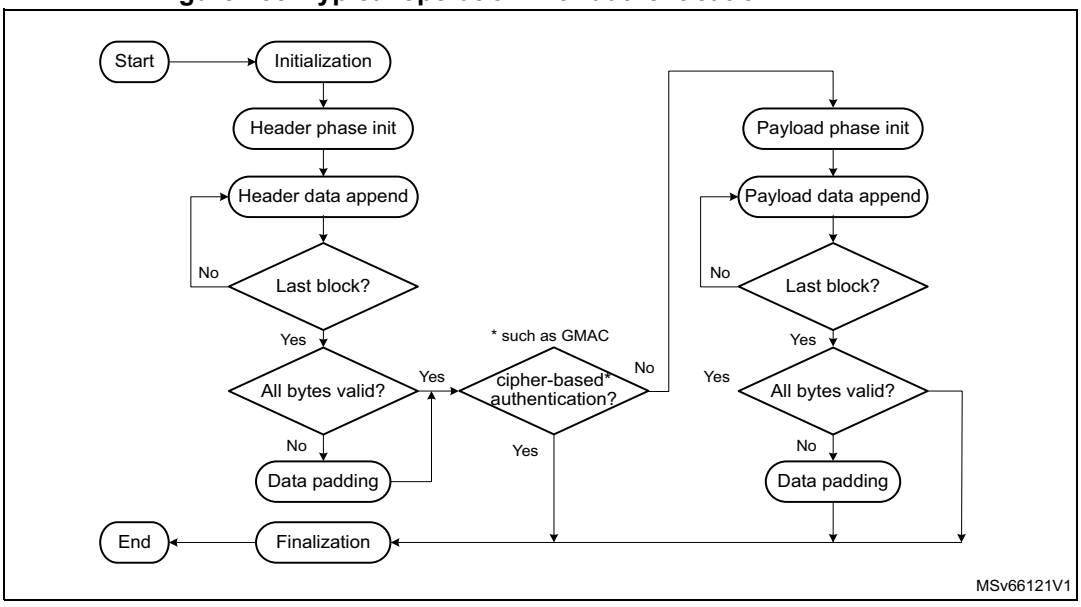
Note: The CCF flag has no use with this method because the reading of the SAES_DOUTR register is managed by DMA automatically, without any software action, at the end of the computation phase.

The NPBLB[3:0] bitfield is not used in the header phase of GCM, GMAC, and CCM chaining modes.

45.4.6 SAES authenticated encryption, decryption, and cipher-based message authentication

The following figure shows a typical operation for authenticated encryption or decryption, and for cipher-based message authentication.

Figure 455. Typical operation with authentication



Section 45.4.11: SAES Galois/counter mode (GCM) and *Section 45.4.13: SAES counter with CBC-MAC (CCM)* describe detailed sequences supported by SAES.

Cipher-based message authentication flow omits the payload phase, as shown in the figure. Detailed sequence supported by SAES is described in *Section 45.4.12: SAES Galois message authentication code (GMAC)*.

45.4.7 SAES ciphertext stealing and data padding

When using SAES in ECB or CBC modes to manage messages the size of which is not a multiple of the block size (16 bytes), the application must use ciphertext stealing techniques such as those described in NIST Special Publication 800-38A*, Recommendation for Block Cipher Modes of Operation: Three Variants of Ciphertext Stealing for CBC Mode*. Since SAES does not implement such techniques, the application must complete the *last block* of input data using data from the *second last* block.

Note: Ciphertext stealing techniques are not documented in this reference manual.

Similarly, in modes other than ECB or CBC, an incomplete input data block (that is, a block with input data shorter than 16 bytes) must be padded with zeros prior to encryption. That is, extra bits must be appended to the trailing end of the data string. After decryption, the extra bits must be discarded. Since SAES does not implement automatic data padding operation to the *last block*, the application must follow the recommendation given in this document to manage messages the size of which is not a multiple of 16 bytes.

45.4.8 SAES suspend and resume operations

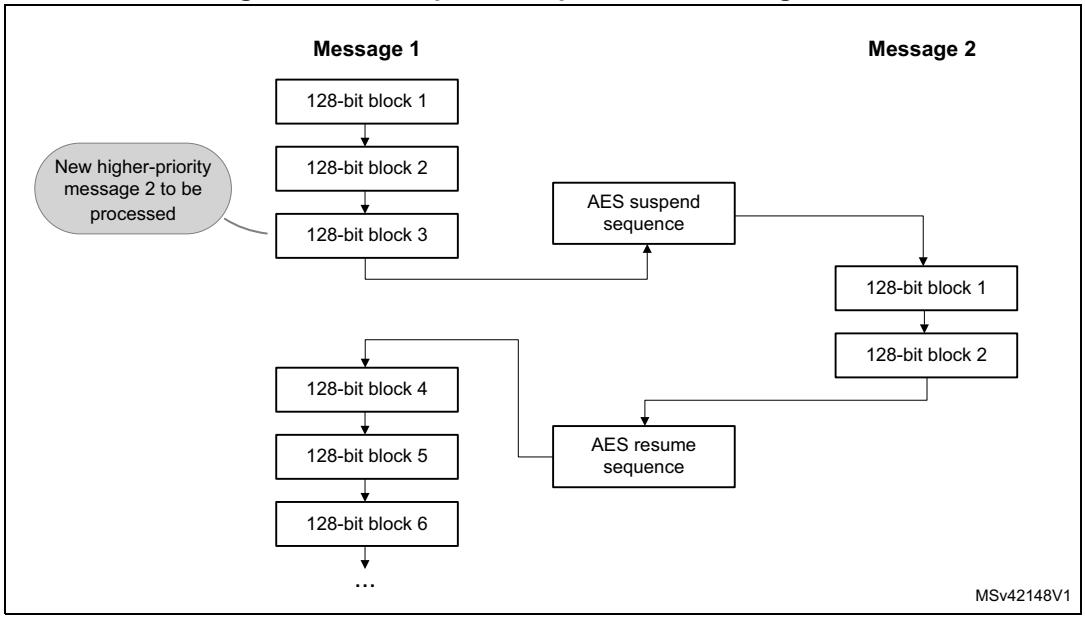
A message can be suspended to process another message with a higher priority. When the higher-priority message is sent, the suspended message can resume. This applies to both encryption and decryption mode.

Suspend and resume operations do not break the chaining operation. The message processing can resume as soon as SAES is enabled again, to receive a next data block.

The suspend and resume operations are only supported when SAES is used in CPU mode, not in DMA mode.

Figure 456 gives an example of suspend and resume operations: Message 1 is suspended in order to send a shorter and higher-priority Message 2.

Figure 456. Example of suspend mode management



A detailed description of suspend and resume operations is in the sections dedicated to each chaining mode.

45.4.9 SAES basic chaining modes (ECB, CBC)

ECB is the simplest mode of operation. There are no chaining operations, and no special initialization stage. The message is divided into blocks and each block is encrypted or decrypted separately. When decrypting in ECB, a special key scheduling is required before processing the first block.

Figure 457 and *Figure 458* describe the electronic codebook (ECB) chaining implementation in encryption and in decryption, respectively. To select ECB chaining mode, write CHMOD[2:0] with 0x0.

Figure 457. ECB encryption

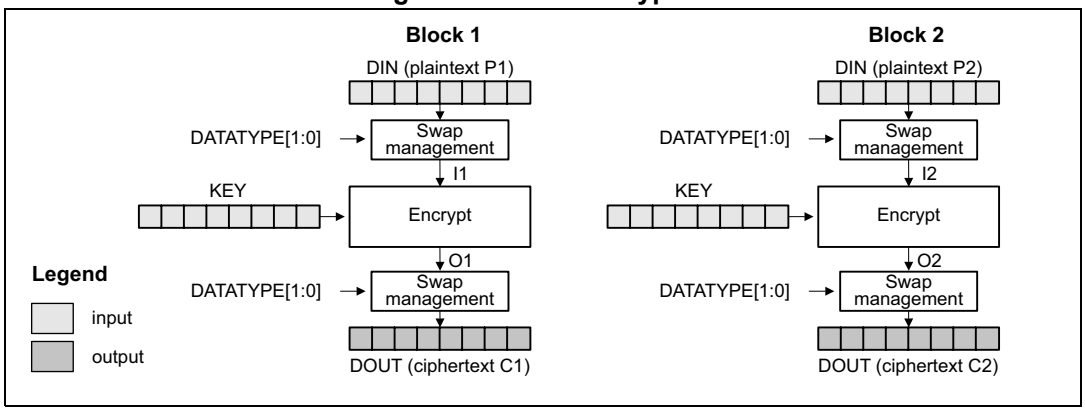
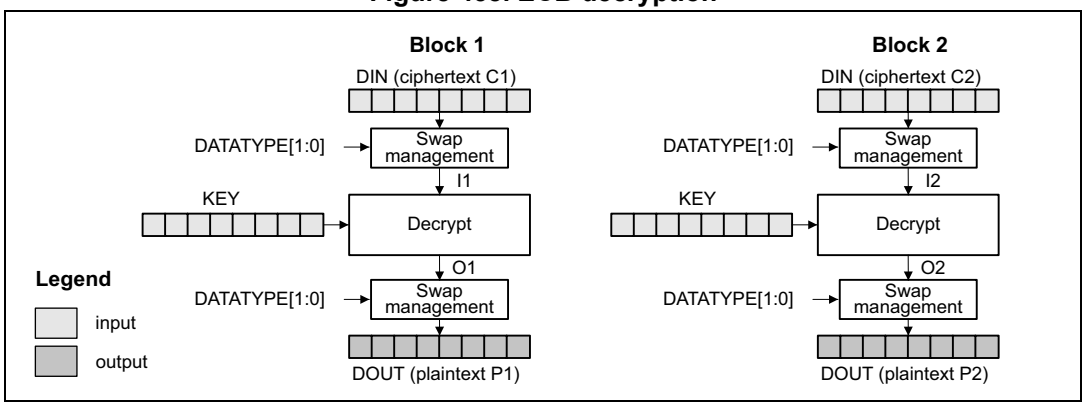


Figure 458. ECB decryption



In CBC encryption mode the output of each block chains with the input of the following block. To make each message unique, an initialization vector is used during the first block processing. When decrypting in CBC, a special key scheduling is required before processing the first block.

Figure 459 and *Figure 460* describe the cipher block chaining (CBC) implementation in encryption and in decryption, respectively. To select this chaining mode, write CHMOD[2:0] with 0x1.

Figure 459. CBC encryption

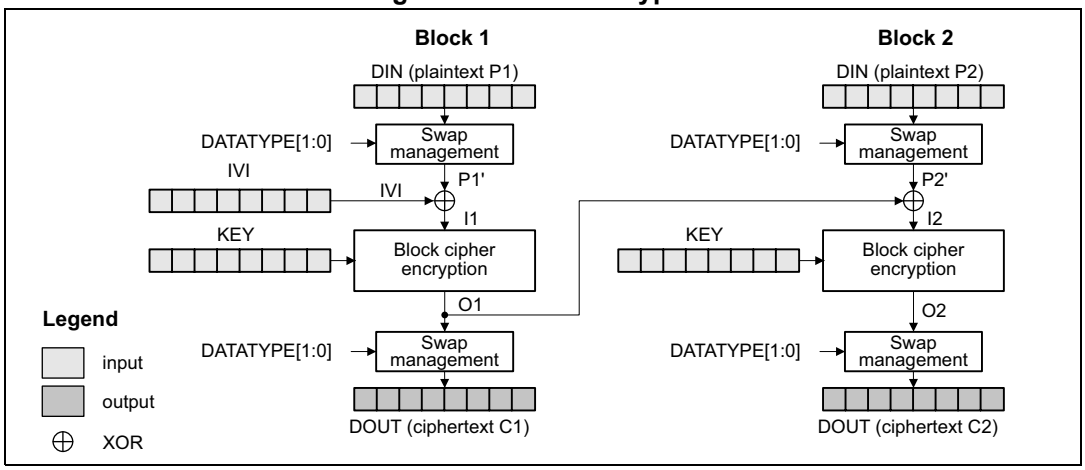
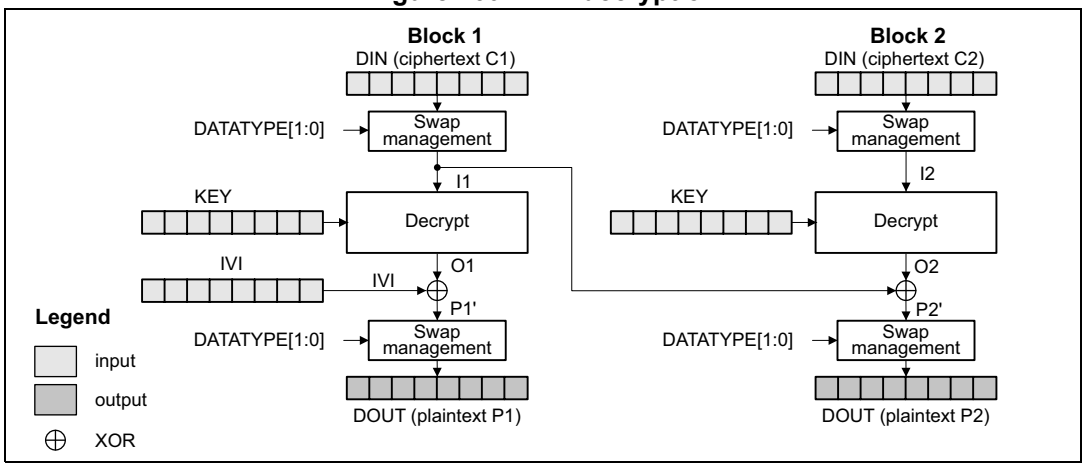


Figure 460. CBC decryption



For more details, refer to NIST Special Publication 800-38A, *Recommendation for Block Cipher Modes of Operation.*

ECB and CBC encryption process

This process is described in *Section 45.4.5*, with the following sequence of events:

1. Disable the SAES peripheral, by clearing EN.
2. Wait until BUSY is cleared (no RNG random number fetch in progress).
3. Initialize the SAES_CR register as follows:
   - Select ECB or CBC chaining mode (write CHMOD[2:0] with 0x0 or 0x1) in *encryption* mode (write MODE[1:0] with 0x0).
   - Configure the data type, through DATATYPE[1:0].
   - Configure the key size, through KEYSIZE. If the key must not be shared with a different security context (different secure attribute), the KEYPROT bit must also be set.
   - Select normal key mode by writing KMOD[1:0] with 0x0. For the other KMOD[1:0] values, refer to *Section 45.4.14* (wrapped keys) and *Section 45.4.15* (shared keys).
4. Write the initialization vector into the SAES_IVRx registers if CBC mode is selected in the previous step.
5. Write the key into the SAES_KEYRx registers. Alternatively, select a key source different from the key registers by writing KEYSEL[2:0] with a value different from 0x0. Refer to *Section 45.4.17: SAES key registers* for details.
6. Wait until KEYVALID is set (the key loading completed).
7. Enable the SAES peripheral, by setting EN.
8. Append cleartext data:
   a) If it is the second-last or the last block and the plaintext size of the message is not a multiple of 16 bytes, follow the guidance in *Section 45.4.7*.
   b) Append the cleartext block into SAES as described in *Section 45.4.5*, then read the SAES_DOUTR register four times to save the ciphertext block.
   c) Repeat the step *b)* until the third-last plaintext block is encrypted. For the last two blocks, follow the steps *a)* and *b)*.
9. Finalize the sequence: disable the SAES peripheral, by clearing EN.

ECB/CBC decryption process

This process is described in *Section 45.4.5*, with the following sequence of events:

1. Disable the SAES peripheral, by clearing EN.
2. Wait until BUSY is cleared (no RNG random number fetch in progress).
3. Initialize the SAES_CR register as follows:
   - Select the *key derivation* mode (write MODE[1:0] with 0x1). The CHMOD[2:0] bitfield is not significant during this operation.
   - Configure the data type, through DATATYPE[1:0].
   - Configure the key size, through KEYSIZE. If the key must not be shared with a different security context (different secure attribute), the KEYPROT bit must also be set.
   - Select normal key mode by writing KMOD[1:0] with 0x0. For the other KMOD[1:0] values, refer to *Section 45.4.14* (wrapped keys) and *Section 45.4.15* (shared keys).

4. Write the key into the SAES_KEYRx registers. Alternatively, select a key source different from the key registers by writing KEYSEL[2:0] with a value different from 0x0. Refer to *Section 45.4.17: SAES key registers* for details.
5. Wait until KEYVALID is set (the key loading completed).
6. Enable the SAES peripheral, by setting EN. The peripheral immediately starts an AES round for key preparation.
7. Wait until the CCF flag in the SAES_ISR register is set.
8. Clear the CCF flag, by setting the CCF bit of the SAES_ICR register. The decryption key is available in the AES core and SAES is disabled automatically.
9. Select ECB or CBC chaining mode (write CHMOD[2:0] with 0x0 or 0x1) in *decryption* mode (write MODE[1:0] with 0x2). Do not change other parameters.
10. Write the initialization vector into the SAES_IVRx registers if CBC mode is selected in the previous step.
11. Enable the SAES peripheral, by setting EN.
12. Append encrypted data:
    a) If it is the second-last or the last block and the ciphertext size of the message is not a multiple of 16 bytes, follow the guidance in *Section 45.4.7*.
    b) Append the ciphertext block into SAES as described in *Section 45.4.5*, then read the SAES_DOUTR register four times to save the cleartext block (MSB first).
    c) Repeat the step *b)* until the third-last ciphertext block is decrypted. For the last two blocks, follow the steps *a)* and *b)*.
13. Finalize the sequence: disable the SAES peripheral, by clearing EN.

Suspend/resume operations in ECB/CBC modes

The following sequences are valid for normal key mode (KMOD[1:0] at 0x0).

The suspend and resume operations are only supported when SAES is used in CPU mode, not in DMA mode.

To suspend the processing of a message, proceed as follows:

1. Wait until the CCF flag in the SAES_ISR register is set (computation completed).
2. Read four times the SAES_DOUTR register to save the last processed block.
3. Clear the CCF flag, by setting the CCF bit of the SAES_ICR register.
4. Save initialization vector registers (only required in CBC mode as the SAES_IVRx registers are altered during the data processing).
5. Disable the SAES peripheral, by clearing EN.
6. Save the SAES_CR register and clear the key registers if they are not needed, to process the higher-priority message.

To resume the processing of a message, proceed as follows:

1. Disable the SAES peripheral, by clearing EN.
2. Restore the SAES_CR register (with correct KEYSIZE) then restore the SAES_KEYRx registers. For KEYSEL[2:0] selecting a key source different from key registers, refer to *Section 45.4.17: SAES key registers* for details.
3. Prepare the decryption key, as described in *ECB/CBC decryption process* (only required for ECB or CBC decryption).

4. Restore the SAES_IVRx registers, using the saved configuration (only required in CBC mode).
5. Enable the SAES peripheral, by setting EN.

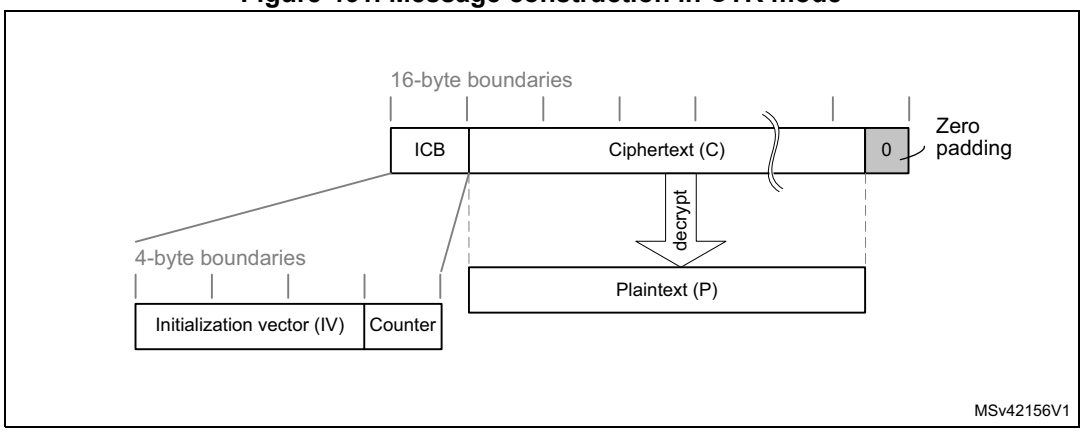
Note: It is not required to save the key registers as the application knows the original key.

45.4.10 SAES counter (CTR) mode

The CTR mode uses the AES core to generate a key stream. The keys are then XOR-ed with the plaintext to obtain the ciphertext. Unlike with ECB and CBC modes, no key scheduling is required for the CTR decryption since the AES core is always used in encryption mode.

A typical message construction in CTR mode is given in *Figure 461*.

Figure 461. Message construction in CTR mode



The structure of this message is:

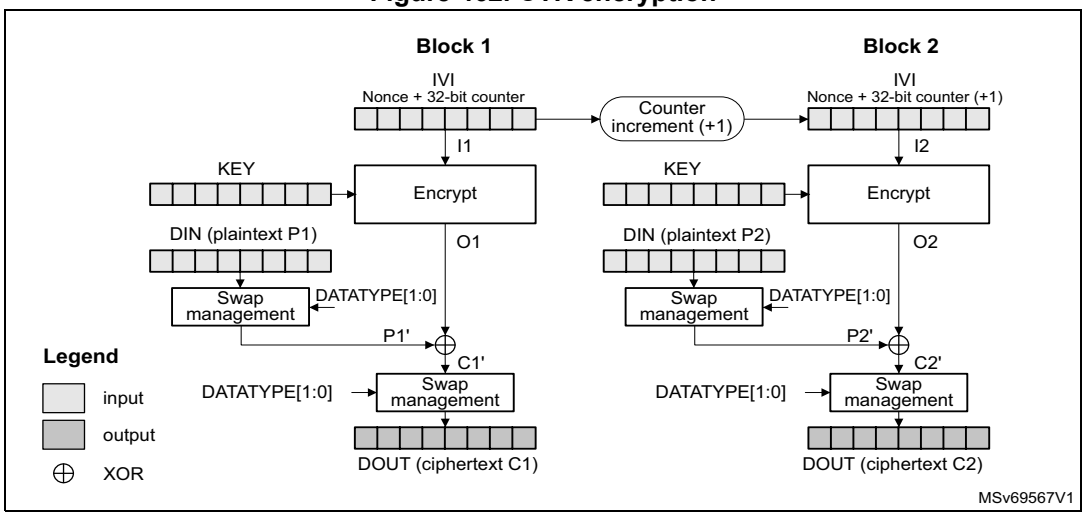
- A 16-byte initial counter block (ICB), composed of two distinct fields:
  - **Initialization vector** (IV): a 96-bit value that must be unique for each encryption cycle with a given key.
  - **Counter**: a 32-bit big-endian integer that is incremented each time a block processing is completed. The initial value of the counter must be set to 1.
- The plaintext P is encrypted as ciphertext C, with a known length. This length can be non-multiple of 16 bytes, in which case a plaintext padding is required.

For more details, refer to NIST *Special Publication 800-38A, Recommendation for Block Cipher Modes of Operation.*

CTR encryption and decryption

Figure 462 describes the counter (CTR) chaining implementation in the SAES peripheral (encryption). To select this chaining mode, write CHMOD[2:0] with 0x2.

Figure 462. CTR encryption



Initialization vectors in SAES must be initialized as shown in *Table 446*.

Table 446. Counter mode initialization vector definition

SAES_IVR3[31:0]	SAES_IVR2[31:0]	SAES_IVR1[31:0]	SAES_IVR0[31:0]
IVI[127:96]	IVI[95:64]	IVI[63:32]	IVI[31:0] 32-bit counter = 0x0001

CTR encryption and decryption process

This process is described in *Section 45.4.5*, with the following sequence of events:

1. Disable the SAES peripheral, by clearing EN.
2. Wait until BUSY is cleared (no RNG random number fetch in progress).
3. Initialize the SAES_CR register:
   - Select CTR chaining mode (write CHMOD[2:0] with 0x2) in encryption or decryption mode (write MODE[1:0] with 0x0 or 0x2).
   - Configure the data type, through DATATYPE[1:0].
   - Configure the key size, through KEYSIZE. If the key must not be shared with a different security context (different secure attribute), the KEYPROT bit must also be set.
   - Select normal key mode, by writing KMOD[1:0] with 0x0. For the other KMOD[1:0] values, refer to *Section 45.4.14* (wrapped keys) and *Section 45.4.15* (shared keys).
4. Write the initialization vector into the SAES_IVRx registers according to *Table 446*.
5. Write the key into the SAES_KEYRx registers. Alternatively, select a key source different from the key registers by writing KEYSEL[2:0] with a value different from 0x0. Refer to *Section 45.4.17: SAES key registers* for details.
6. Wait until KEYVALID is set (the key loading completed).

7. Enable the SAES peripheral, by setting EN.
8. Append data:
   a) If it is the last block and the plaintext (encryption) or ciphertext (decryption) size in the block is less than 16 bytes, pad the remainder of the block with zeros.
   b) Append the data block into SAES as described in *Section 45.4.5*, then read the SAES_DOUTR register four times to save the resulting block (MSB first).
   c) Repeat the step *b)* until the second-last block is processed. For the last block of plaintext (encryption only), follow the steps *a)* and *b)*. For the last block, discard the bits that are not part of the message when the last block is smaller than 16 bytes.
9. Finalize the sequence: disable the SAES peripheral, by clearing EN.

Suspend/resume operations in CTR mode

Like for the CBC mode, it is possible to interrupt a message to send a higher-priority message, then resume the interrupted message. Detailed CBC suspend and resume sequence is described in *Section 45.4.9: SAES basic chaining modes (ECB, CBC)*.

The suspend and resume operations are only supported when SAES is used in CPU mode, not in DMA mode.

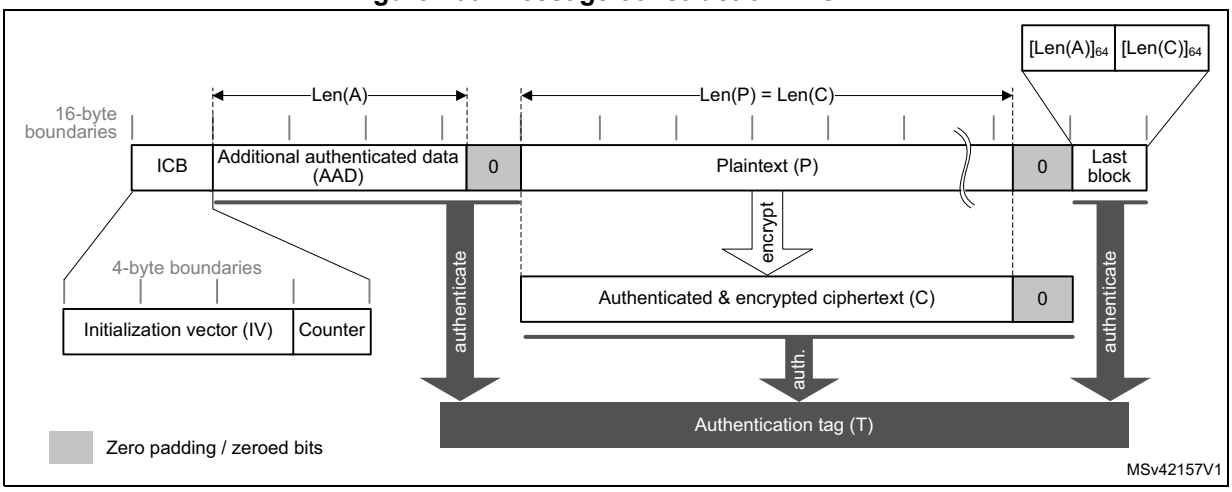
Note: Like for CBC mode, the IV registers must be reloaded during the resume operation.

45.4.11 SAES Galois/counter mode (GCM)

The AES Galois/counter mode (GCM) allows encrypting and authenticating a plaintext message into the corresponding ciphertext and tag (also known as message authentication code).

GCM mode is based on AES in counter mode for confidentiality. It uses a multiplier over a fixed finite field for computing the message authentication code. The following figure shows a typical message construction in GCM mode.

Figure 463. Message construction in GCM



The message has the following structure:

- **16-byte initial counter block (ICB)**, composed of two distinct fields:
  - **Initialization vector (IV):** a 96-bit value that must be unique for each encryption cycle with a given key. The GCM standard supports IVs with less than 96 bits, but in this case strict rules apply.
  - **Counter:** a 32-bit big-endian integer that is incremented each time a block processing is completed. According to NIST specification, the counter value is 0x2 when processing the first block of payload.
- **Authenticated header AAD** (also knows as additional authentication data) has a known length Len(A) that may be a non-multiple of 16 bytes, and must not exceed $2^{64} – 1$ bits. This part of the message is only authenticated, not encrypted.
- **Plaintext message P** is both authenticated and encrypted as ciphertext C, with a known length Len(P) that may be non-multiple of 16 bytes, and cannot exceed 2^{32} - 2 16-byte blocks.
- **Last block** contains the AAD header length (bits [32:63]) and the payload length (bits [96:127]) information, as shown in *Table 448*.

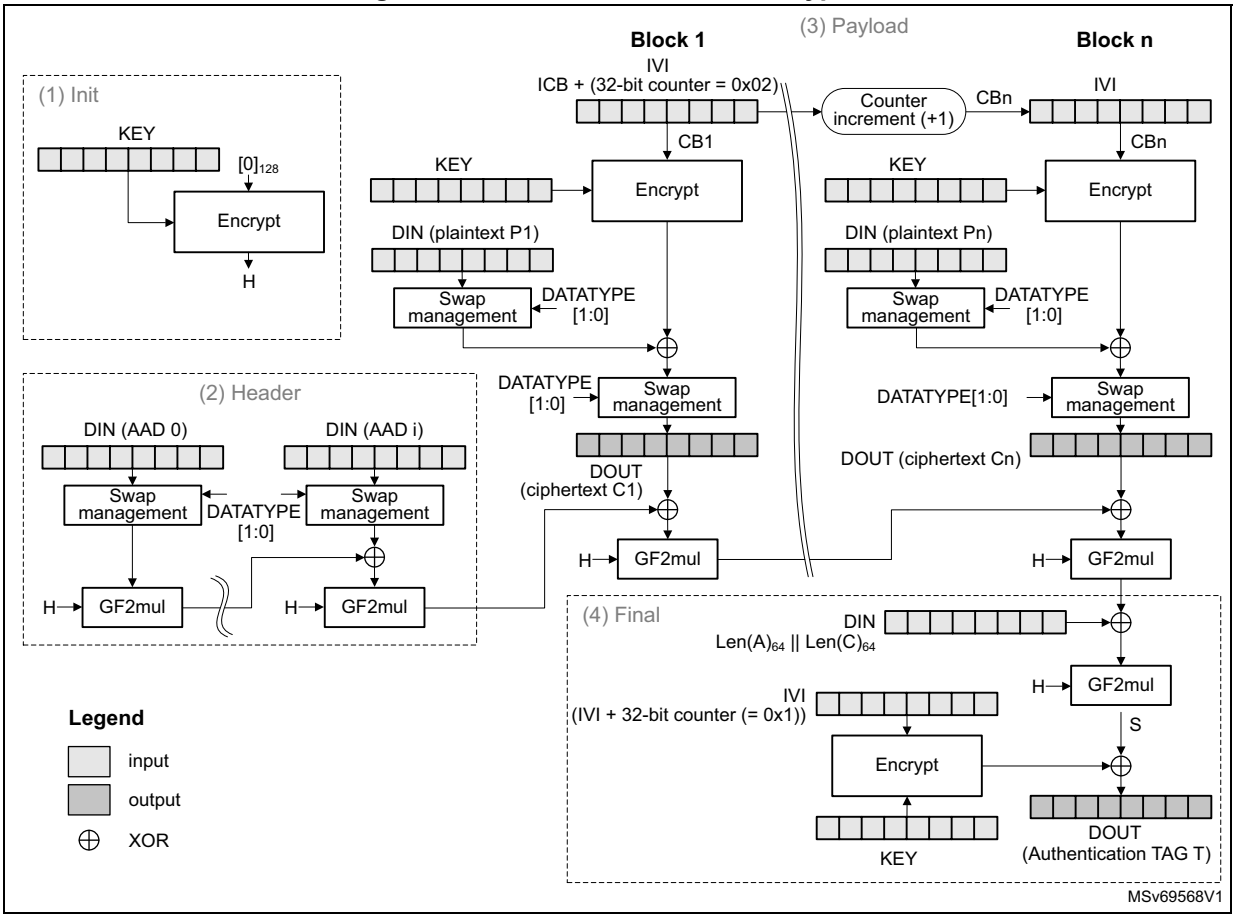
The GCM standard specifies that ciphertext C has the same bit length as the plaintext P.

When a part of the message (AAD or P) has a length that is a non-multiple of 16-bytes a special padding scheme is required.

For more details, refer to NIST Special Publication 800-38D*, Recommendation for Block Cipher Modes of Operation - Galois/Counter Mode (GCM) and GMAC.*

Figure 464 describes the GCM chaining implementation in the SAES peripheral (encryption). To select this chaining mode, write CHMOD[2:0] with 0x3.

Figure 464. GCM authenticated encryption



The first counter block (CB1) is derived from the initial counter block ICB by the application software, as defined in *Table 447*.

Table 447. Initialization of IV registers in GCM mode

SAES_IVR3[31:0]	SAES_IVR2[31:0]	SAES_IVR1[31:0]	SAES_IVR0[31:0]
ICB[127:96]	ICB[95:64]	ICB[63:32]	ICB[31:0] 32-bit counter = 0x0002

The last block of a GCM message contains the AAD header length and the payload length information, as shown in *Table 448*.

Table 448. GCM last block definition

Word order to SAES_DINR	First word	Second word	Third word	Fourth word
Input data	AAD length[63:32]	AAD length[31:0]	Payload length[63:32]	Payload length[31:0]

GCM encryption and decryption process

This process is described in *Section 45.4.6*, with the following sequence of events:

GCM initialize

1. Disable the SAES peripheral, by clearing EN.
2. Wait until BUSY is cleared (no RNG random number fetch in progress).
3. Initialize the SAES_CR register:
   - Select GCM chaining mode (write CHMOD[2:0] with 0x3) in encryption or decryption mode (write MODE[1:0] with 0x0 or 0x2). Do not write MODE[1:0] with 0x1.
   - Configure the data type, through DATATYPE[1:0]
   - Configure the key size, through KEYSIZE. If the key must not be shared with a different security context (such as secure, nonsecure, specific CPU), also set KEYPROT.
   - Select normal key mode, by writing KMOD[1:0] with 0x0. For the other KMOD[1:0] values, refer to *Section 45.4.14* (wrapped keys) and *Section 45.4.15* (shared keys).
   - Select the GCM initialization phase, by writing GCMPH[1:0] with 0x0.
4. Write the initialization vector in SAES_IVRx registers according to *Table 447*.
5. Write the key into the SAES_KEYRx registers. Alternatively, select a key source different from the key registers by writing KEYSEL[2:0] with a value different from 0x0. Refer to *Section 45.4.17: SAES key registers* for details.
6. Wait until KEYVALID is set (the key loading completed).
7. Set EN to start the calculation of the hash key. EN is automatically cleared when the calculation is completed.
8. Wait until the CCF flag is set in the SAES_ISR register, indicating that the GCM hash subkey (H) computation is completed.
9. Clear the CCF flag by setting the CCF bit of the SAES_ICR register.

GCM header phase

10. Initialize header phase:
    a) Select the GCM header phase, by writing 0x1 to GCMPH[1:0]. Do not change the other configurations written during GCM initialization.
    b) Enable the SAES peripheral, by setting EN.
11. Append header data:
    a) If it is the last block and the AAD in the block is smaller than 16 bytes, pad the remainder of the block with zeros.
    b) Append the data block into SAES as described in *Section 45.4.5*.
    c) Repeat the step *b)* until the second-last AAD data block is processed. For the last block, follow the steps *a)* and *b)*.

Note: This phase can be skipped if there is no AAD, that is, Len(A) = 0.

No data are read during header phase.

GCM payload phase

12. Initialize payload phase:
    a) Select the GCM payload phase, by writing GCMPH[1:0] with 0x2. Do not change the other configurations written during GCM initialization.
    b) If the header phase is skipped, enable the SAES peripheral by setting EN.
13. Append payload data:
    a) If it is the last block and the message in the block is smaller than 16 bytes, pad the remainder of the block with zeros.
    b) Append the data block into SAES as described in *Section 45.4.5*, then read the SAES_DOUTR register four times to save the resulting block
    c) Repeat the step *b)* until the second-last plaintext block is encrypted or until the last block of ciphertext is decrypted. For the last block of plaintext (encryption only), follow the steps *a)* and *b)*. For the last block, discard the bits that are not part of the payload when the last block is smaller than 16 bytes.

Note: This phase can be skipped if there is no payload, that is, Len(C)=0 (see GMAC mode).

GCM finalization

14. Encryption only: wait until the BUSY flag in the SAES_SR register is cleared.
15. Select the GCM final phase, by writing GCMPH[1:0] with 0x3. Do not change the other configurations written during GCM initialization.
16. Write the final GCM block into the SAES_DINR register. It is the concatenated AAD bit and payload bit lengths, as shown in *Table 448*.
17. Wait until the CCF flag in the SAES_ISR register is set.
18. Get the GCM authentication tag, by reading the SAES_DOUTR register four times.
19. Clear the CCF flag, by setting the CCF bit of the SAES_ICR register.
20. Disable the SAES peripheral, by clearing EN. If it is an authenticated decryption, compare the generated tag with the expected tag passed with the message.

Note: In the final phase, data are written to SAES_DINR normally (no swapping), while swapping is applied to tag data read from SAES_DOUTR.

When transiting from the header or the payload phase to the final phase, the SAES peripheral must not be disabled, otherwise the result is wrong.

Suspend/resume operations in GCM mode

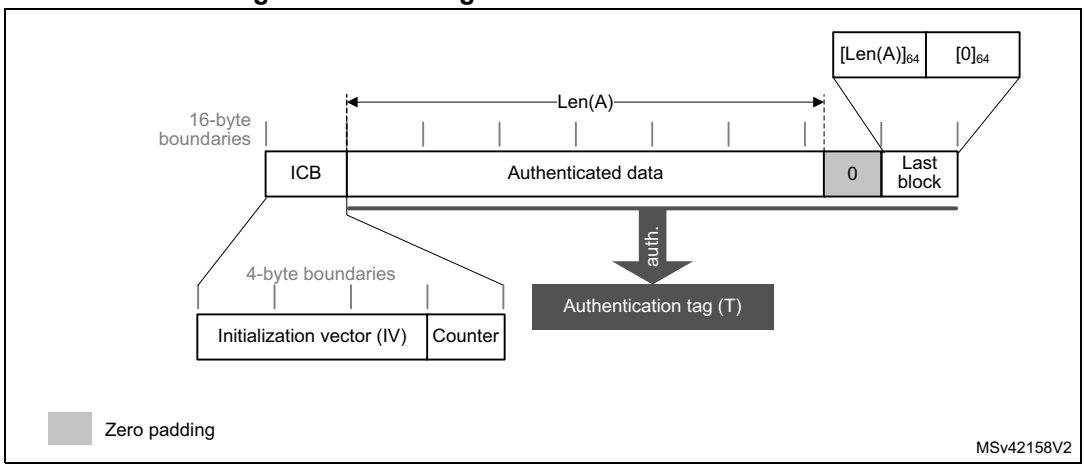
Suspend/resume operations are not supported in GCM mode.

45.4.12 SAES Galois message authentication code (GMAC)

The Galois message authentication code (GMAC) allows the authentication of a plaintext, generating the corresponding tag information (also known as message authentication code).

GMAC is similar to GCM, except that it is applied on a message composed only by plaintext authenticated data (that is, only header, no payload). The following figure shows typical message construction for GMAC.

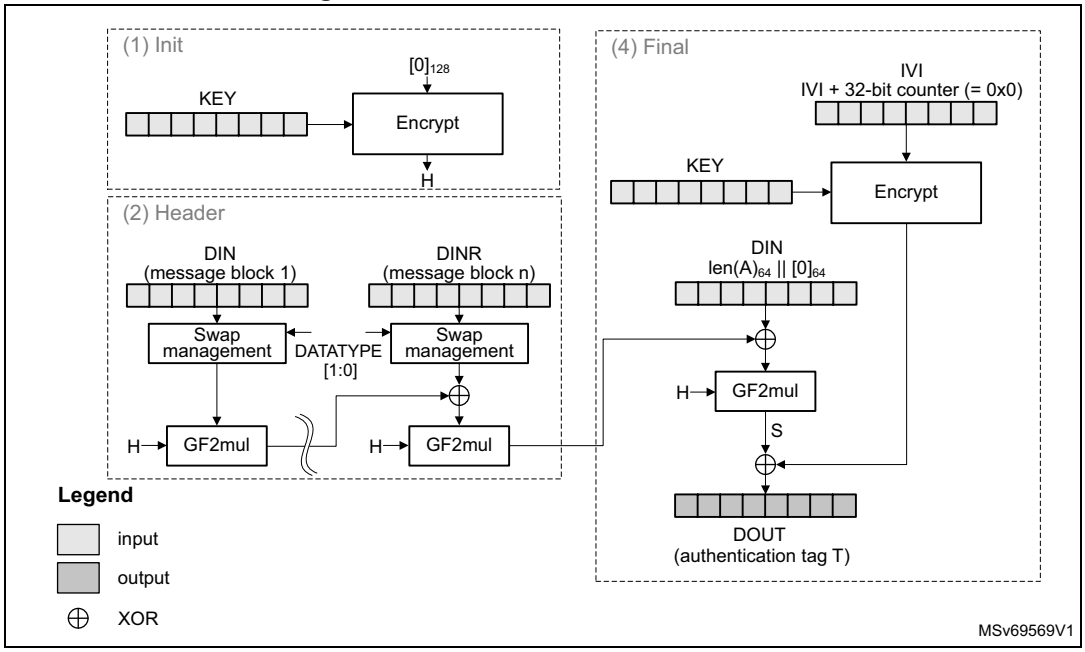
Figure 465. Message construction in GMAC mode



For more details, refer to NIST Special Publication 800-38D*, Recommendation for Block Cipher Modes of Operation - Galois/Counter Mode (GCM) and GMAC.*

Figure 466 describes the GMAC chaining implementation in the SAES peripheral. To select this chaining mode, write CHMOD[2:0] with 0x3.

Figure 466. GMAC authentication mode



The GMAC algorithm corresponds to the GCM algorithm applied on a message that only contains a header. As a consequence, all steps and settings are the same as with the GCM, except that the payload phase is omitted.

Suspend/resume operations in GMAC

Suspend/resume operations are not supported in GMAC mode.

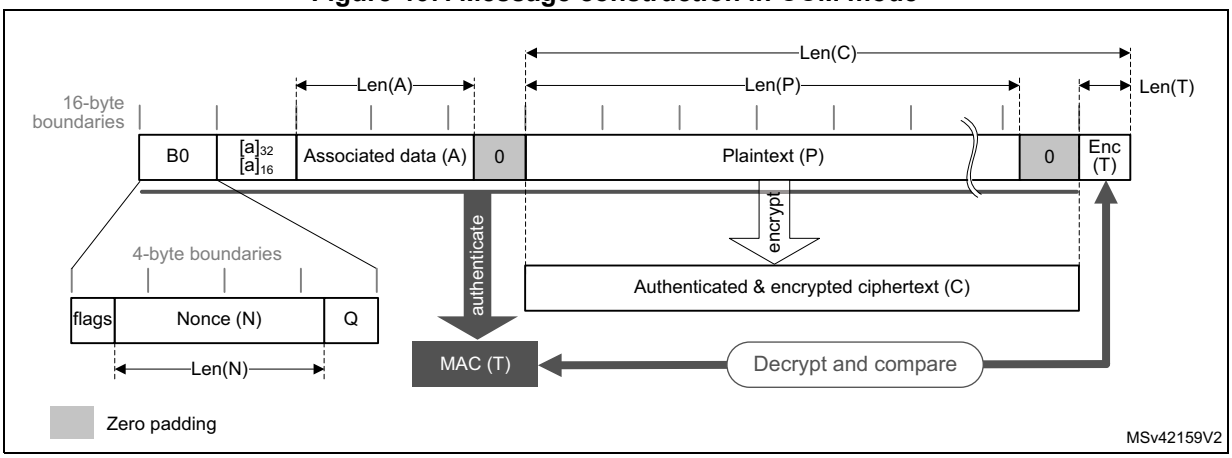
45.4.13 SAES counter with CBC-MAC (CCM)

The AES counter with cipher block chaining-message authentication code (CCM) algorithm allows encryption and authentication of plaintext, generating the corresponding ciphertext and tag (also known as message authentication code). To ensure confidentiality, the CCM algorithm is based on AES counter mode processing. It uses cipher block chaining technique to generate the message authentication code. This is commonly called CBC-MAC.

Note: NIST does not approve CBC-MAC as an authentication mode outside the context of the CCM specification.

The following figure shows typical message construction for CCM.

Figure 467. Message construction in CCM mode



The structure of the message is:

- **16-byte first authentication block (B0)**, composed of three distinct fields:
  - **Q:** a bit string representation of the octet length of P (Len(P))
  - **Nonce (N):** a single-use value (that is, a new nonce must be assigned to each new communication) of Len(N) size. The sum Len(N) + Len(P) must be equal to 15 bytes.
  - **Flags:** most significant octet containing four flags for control information, as specified by the standard. It contains two 3-bit strings to encode the values **t** (MAC length expressed in bytes) and **Q** (plaintext length such that Len(P) < 2^{8Q} bytes). The counter blocks range associated to **Q** is equal to 2^{8Q-4}, that is, if the maximum value of **Q** is 8, the counter blocks used in cipher must be on 60 bits.
- **16-byte blocks (B)** associated to the associated data (A).
  This part of the message is only authenticated, not encrypted. This section has a known length Len(A) that can be a non-multiple of 16 bytes (see *Figure 467*). The standard also states that, on MSB bits of the first message block (B1), the associated data length expressed in bytes (a) must be encoded as follows:
  - If $0 < a < 2^{16} - 2^8$, then it is encoded as $[a]_{16}$, that is, on two bytes.
  - If $2^{16} - 2^8 < a < 2^{32}$, then it is encoded as 0xff || 0xfe || $[a]_{32}$, that is, on six bytes.
  - If $2^{32} < a < 2^{64}$, then it is encoded as 0xff || 0xff || $[a]_{64}$, that is, on ten bytes.

- **16-byte blocks (B)** associated to the plaintext message P, which is both authenticated and encrypted as ciphertext C, with a known length Len(P). This length can be a non-multiple of 16 bytes (see *Figure 467*).
- **Encrypted MAC (T)** of length Len(T) appended to the ciphertext C of overall length Len(C).

When a part of the message (A or P) has a length that is a non-multiple of 16-bytes, a special padding scheme is required.

Note: CCM chaining mode can also be used with associated data only (that is, no payload).

As an example, the C.1 section in NIST Special Publication 800-38C gives the following values (hexadecimal numbers):

N: 10111213 141516 (Len(N) = 56 bits or 7 bytes)

A: 00010203 04050607 (Len(A) = 64 bits or 8 bytes)

P: 20212223 (Len(P) = 32 bits or 4 bytes)

T: 6084341B (Len(T) = 32 bits or t = 4)

B0: 4F101112 13141516 00000000 00000004
B1: 00080001 02030405 06070000 00000000
B2: 20212223 00000000 00000000 00000000

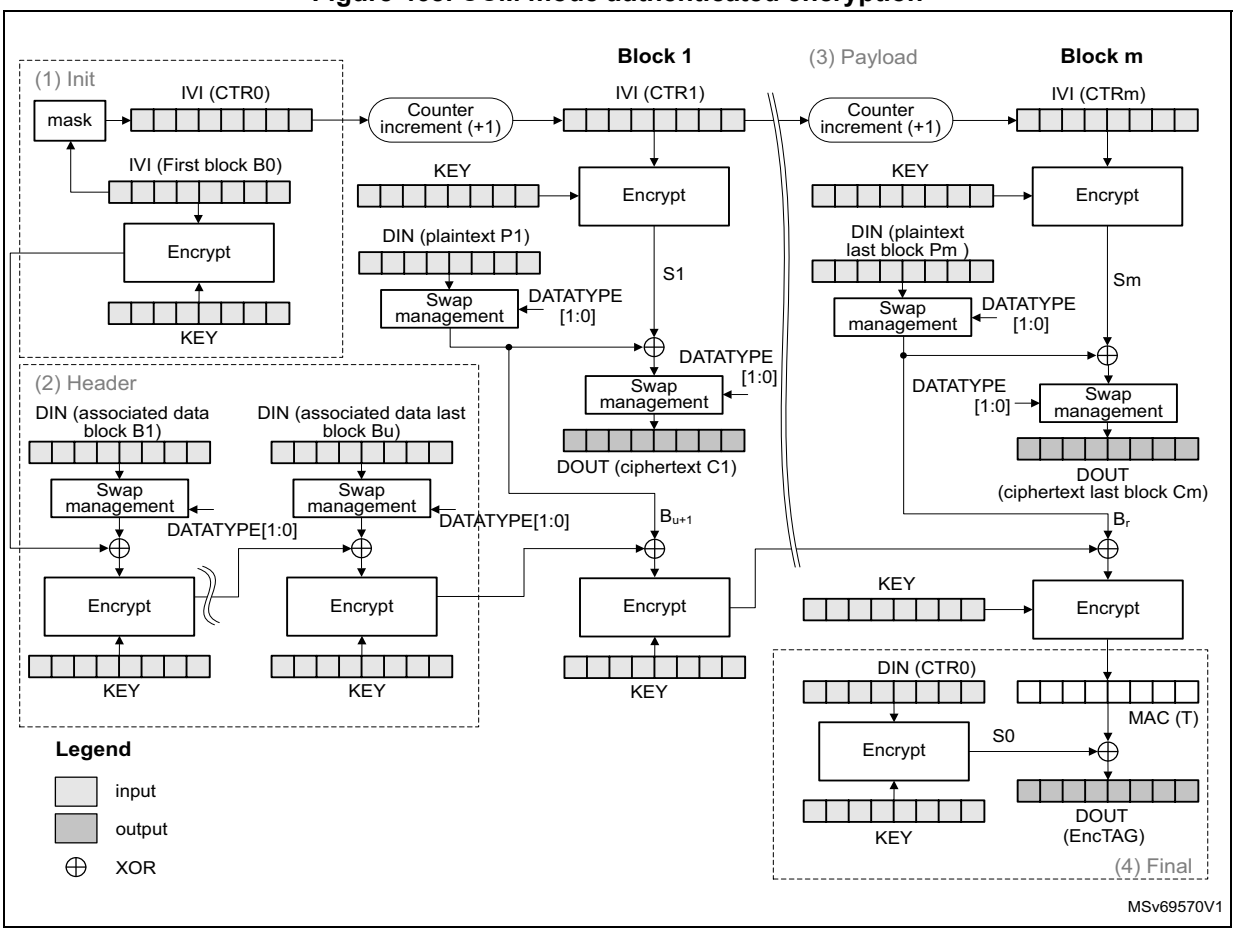
CTR0: 0710111213 141516 00000000 00000000

CTR1: 0710111213 141516 00000000 00000001

For more details, refer to NIST Special Publication 800-38C*, Recommendation for Block Cipher Modes of Operation - The CCM Mode for Authentication and Confidentiality*.

Figure 468 describes the CCM chaining implementation in the SAES peripheral (encryption). To select this chaining mode, write CHMOD[2:0] with 0x4.

Figure 468. CCM mode authenticated encryption



The first block of a CCM message (B0) must be prepared by the application as defined in *Table 449*.

Table 449. Initialization of IV registers in CCM mode

SAES_IVR3[31:0]	SAES_IVR2[31:0]	SAES_IVR1[31:0]	SAES_IVR0[31:0]
B0[127:96](1)	B0[95:64]	B0[63:32]	B0[31:0](2)

1. The five most significant bits are cleared (flag bits).
2. Q length bits are cleared, except for the bit 0 that is set.

SAES supports counters up to 64 bits, as specified by NIST.

CCM encryption and decryption process

This process is described in *Section 45.4.6*, with the following sequence of events:

CCM initialize

1. Disable the SAES peripheral, by clearing EN.
2. Wait until BUSY is cleared (no RNG random number fetch in progress).
3. Initialize the SAES_CR register:
   - Select CCM chaining mode (write CHMOD[2:0] with 0x4) in encryption or decryption mode (write MODE[1:0] with 0x0 or 0x2). Do not write MODE[1:0] with 0x1.
   - Configure the data type, through DATATYPE[1:0]
   - Configure the key size, through KEYSIZE. If the key must not be shared with a different security context, also set the KEYPROT bit.
   - Select normal key mode, by writing KMOD[1:0] with 0x0. For the other KMOD[1:0] values, refer to *Section 45.4.14* (wrapped keys) and *Section 45.4.15* (shared keys).
   - Select the CCM initialization phase, by writing GCMPH[1:0] with 0x0.
4. Write the B0 data in SAES_IVRx registers according to *Table 449*.
5. Write the key into the SAES_KEYRx registers. Alternatively, select a key source different from the key registers by writing KEYSEL[2:0] with a value different from 0x0. Refer to *Section 45.4.17: SAES key registers* for details.
6. Wait until KEYVALID is set (the key loading completed).
7. Set EN to start the first mask calculation. The EN bit is automatically cleared when the calculation is completed.
8. Wait until the CCF flag in the SAES_ISR register is set.
9. Clear the CCF flag, by setting the CCF bit of the SAES_ICR register.

CCM header phase

10. Initialize header phase:
    a) Prepare the first block of the (B1) data associated with the message, in accordance with CCM chaining rules.
    b) Select the CCM header phase, by writing GCMPH[1:0] with 0x1. Do not change the other configurations written during the CCM initialization.
    c) Enable the SAES peripheral, by setting EN.
11. Append header data:
    a) If it is the last block and the associated data in the block is smaller than 16 bytes, pad the remainder of the block with zeros.
    b) Append the data block into SAES as described in *Section 45.4.5*.
    c) Repeat the step *b)* until the second-last associated data block is processed. For the last block, follow the steps *a)* and *b)*.

Note: This phase can be skipped if there is no associated data, that is, Len(A) = 0

No data are read during the header phase.

CCM payload phase

12. Initialize payload phase:
    a) Select the CCM payload phase, by writing GCMPH[1:0] with 0x2. Do not change the other configurations written during the CCM initialization.
    b) If the header phase is skipped, enable the SAES peripheral, by setting EN.
13. Append payload data:
    a) In encryption only, if it is the last block and the plaintext in the block is smaller than 16 bytes, pad the remainder of the block with zeros.
    b) Append the data block into SAES as described in *Section 45.4.5*, then read the SAES_DOUTR register four times to save the resulting block.
    c) Repeat the step *b)* until the second-last plaintext block is encrypted or until the last block of ciphertext is decrypted. For the last block of plaintext (encryption only), follow the steps *a)* and *b)*. For the last block, discard the bits that are not part of the payload when the last block is smaller than 16 bytes.

Note: This phase can be skipped if there is no payload, that is, Len(P) = 0 or Len(C) = Len(T).

Remove $LSB_{Len(T)}(C)$ encrypted tag information when decrypting ciphertext C.

CCM finalization

14. Select the CCM final phase, by writing GCMPH[1:0] with 0x3. Do not change the other configurations written during the CCM initialization.
15. Wait until CCF flag in the SAES_ISR register is set.
16. Get the CCM authentication tag, by reading the SAES_DOUTR register four times.
17. Clear the CCF flag, by setting the CCF bit of the SAES_ICR register.
18. Disable the SAES peripheral, by clearing EN. If it is an authenticated decryption, compare the generated tag with the expected tag passed with the message. Mask the authentication tag output with tag length to obtain a valid tag.

Note: In the final phase, swapping is applied to tag data read from SAES_DOUTR register.

When transiting from the header or the payload phase to the final phase, the SAES peripheral must not be disabled, otherwise the result is wrong.

Suspend and resume operations in CCM mode

The suspend and resume operations are only supported when SAES is used in CPU mode, not in DMA mode.

To suspend the processing of a message in header or payload phase, proceed as follows:

1. Wait until the CCF flag of the SAES_ISR register is set (computation completed).
2. In the payload phase, read four times the SAES_DOUTR register to save the last-processed block.
3. Clear the CCF flag in the SAES_ISR register, by setting the CCF bit of the SAES_ICR register.
4. Save the SAES_SUSPRx registers in the memory.
5. Save the IV registers as they are altered during the data processing.
6. Disable the SAES peripheral, by clearing EN.
7. Save the current SAES_CR configuration in the memory. Key registers do not need to be saved as the original key value is known by the application.

To resume the processing of a message, proceed as follows:

1. Disable the SAES peripheral, by clearing EN.
2. Write the suspend register values, previously saved in the memory, back into their corresponding SAES_SUSPRx registers.
3. Restore SAES_IVRx registers using the saved configuration.
4. Restore the initial setting values in the SAES_CR and SAES_KEYRx registers. For KEYSEL[2:0] selecting a key source different from the key registers, refer to *Section 45.4.17: SAES key registers* for details.
5. Enable the SAES peripheral, by setting EN.

45.4.14 SAES operation with wrapped keys

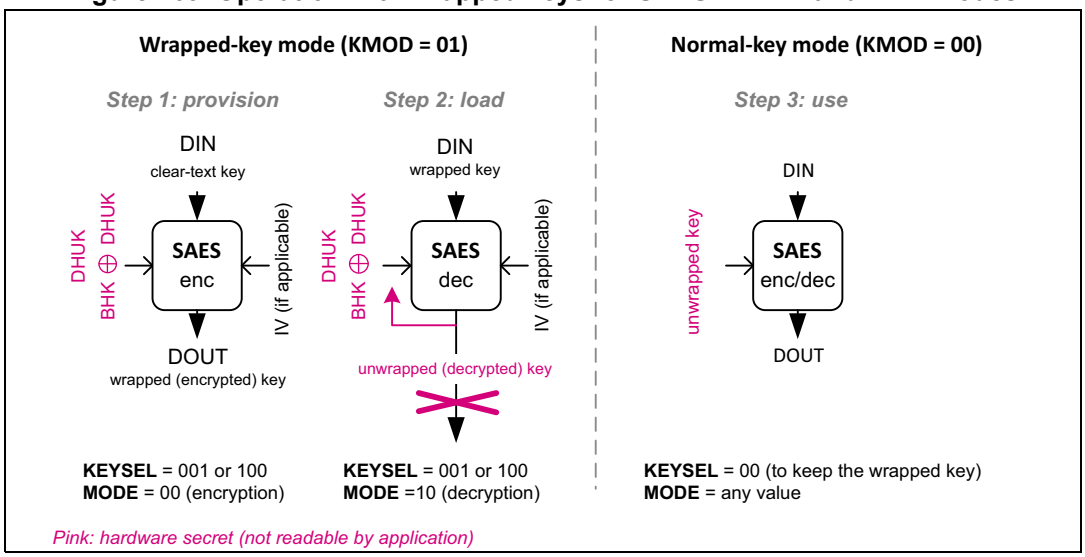
SAES peripheral can wrap (encrypt) and unwrap (decrypt) application keys using hardware-secret key DHUK, XOR-ed or not with application key BHK. With this feature, AES keys can be made usable by application software without being exposed in clear-text (unencrypted).

Wrapped key sequences are too small to be suspended/resumed. SAES cannot unwrap a key using an unwrapped key.

Operation with wrapped keys for SAES in ECB and CBC modes

Figure 469 summarizes how to wrap or unwrap keys for SAES in ECB and CBC modes. To protect the wrapped key, select DHUK by writing KEYSEL[2:0] with 0x1 or 0x4. Alternatively, select BHK by writing KEYSEL[2:0] with 0x2 if the corresponding registers are read/write-locked in the TAMP peripheral.

Figure 469. Operation with wrapped keys for SAES in ECB and CBC modes



Note: DHUK value depends on privilege, security, KMOD[1:0], KEYSEL[2:0], CHMOD[2:0], and KEYSIZE.

Key wrapping for SAES

The recommended sequence to wrap (that is, encrypt) a key is as follows:

1. Disable the SAES peripheral, by clearing EN.
2. Wait until BUSY is cleared (no RNG random number fetch in progress).
3. Initialize the SAES_CR register as follow:
   - Select ECB or CBC chaining mode (write CHMOD[2:0] with 0x0 or 0x1) in *encryption* mode (MODE[1:0] at 0x0)
   - Select 32-bit data type (DATATYPE[1:0] at 0x0)
   - Configure the key size with KEYSIZE. This information is used both for the encryption key and for the key to be encrypt.
   - Select wrapped key mode by writing KMOD[1:0] with 0x1
4. Write the initialization vector in SAES_IVRx registers if CBC mode has been selected in previous step.
5. Select the DHUK key source by writing KEYSEL[2:0] with 0x1 or 0x4. Optionally, select the BHK, by writing KEYSEL[2:0] with 0x2. Refer to *Section 45.4.17* for details on the use of KEYSEL[2:0].
6. Wait until KEYVALID is set (DHUK loading completed).
7. Enable the SAES peripheral, by setting EN.
8. Write the SAES_DINR register four times to input the key to encrypt (MSB first, see *Table 451*).
9. Wait until CCF flag is set in the SAES_ISR register.
10. Get the encrypted key (MSB first) by reading the SAES_DOUTR register four times. Then clear the CCF flag, by setting the CCF bit in SAES_ICR register.
11. Repeat steps *8.* to *10.* if KEYSIZE is set.
12. Disable the SAES peripheral, by clearing EN.

Note: Encryption in Wrapped-key mode is only supported when ECB or CBC is selected.

Key unwrapping for SAES

The recommended sequence to unwrap (or decrypt) a wrapped (encrypted) key using ECB/CBC is as follows:

1. Disable the SAES peripheral, by clearing EN.
2. Wait until BUSY is cleared (no RNG random number fetch in progress).
3. Initialize the SAES_CR register as follow:
   - Select the chaining mode used during the wrapping process (CHMOD[2:0] at 0x0 or 0x1) in *key derivation* mode (MODE[1:0] at 0x1)
   - Select 32-bit data type (DATATYPE[1:0] at 0x0)
   - Configure the key size used during the wrapping process, with KEYSIZE. This information is used both for the decryption key and for the key to decrypt.
   - Select wrapped key mode, by writing KMOD[1:0] with 0x1.
4. With KEYSEL[2:0], select the same key source as when the key was wrapped/encrypted.
5. Wait until KEYVALID is set (the key loading completed).
6. Set EN bit in SAES_CR to enable the peripheral
7. Wait until CCF flag is set in the SAES_ISR register.
8. Clear the CCF flag, by setting the CCF bit in SAES_ICR register. The decryption key is available in the AES core, and SAES is disabled automatically.
9. Select the *decryption* mode (MODE[1:0] at 0x2). Other parameters are unchanged.
10. Write the initialization vector in SAES_IVRx registers if CBC mode has been selected in previous step.
11. Enable the SAES peripheral, by setting EN.
12. Write the SAES_DINR register four times to input the key to decrypt (MSB first, see *Table 451*).
13. Wait until CCF flag is set in the SAES_ISR register. Then clear the CCF flag by setting the CCF bit in SAES_ICR register. Reading SAES_DOUTR returns zero and triggers a read error (RDERRF).
14. Repeat steps *12.* and *13.* if KEYSIZE is set.
15. Disable the SAES peripheral, by clearing EN.

At the end of this sequence, the decrypted wrapped key is immediately usable by the application for any AES operation (normal key mode, that is, with KMOD[1:0] = 0x0).

Decrypted wrapped key can be shared with an application running in a different security context (different security attribute) if KEYPROT bit was cleared during step 3.

Note: When KMOD[1:0] = 0x1 (wrapped key) and MODE[1:0] = 0x2 (decryption) a read access to SAES_DOUTR register triggers a read error (RDERRF).

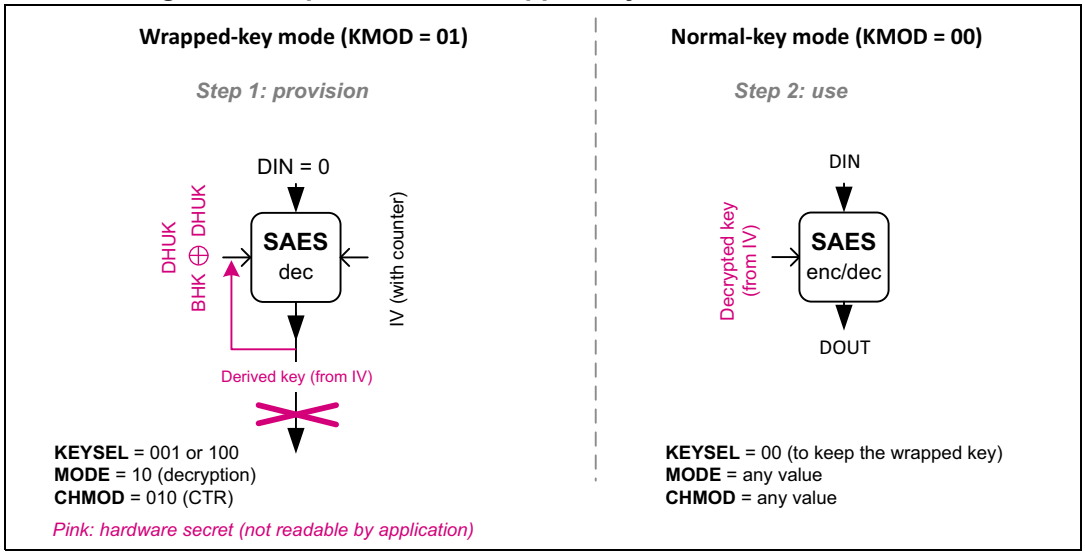
When KEYSEL[2:0] is at 0x1 (DHUK) or 0x4 (DHUK XOR BHK), the application software must use the same privilege, security, KMOD[1:0], CHMOD[2:0] and KEYSIZE context for encryption and decryption. Otherwise, the result is incorrect.

Operation with wrapped keys for SAES in CTR mode

Figure 470 summarizes how to unwrap keys for SAES in CTR mode. To protect the derived key, select DHUK by writing KEYSEL[2:0] with 0x1 or 0x4. Alternatively, select BHK by

writing KEYSEL[2:0] with 0x2 if the corresponding registers are read/write-locked in the TAMP peripheral.

Figure 470. Operation with wrapped keys for SAES in CTR mode



Note: DHUK value depends on privilege, security, KMOD[1:0], KEYSEL[2:0], CHMOD[2:0], and KEYSIZE.

The recommended sequence for SAES wrapped key mode using CTR is as follows:

1. Disable the SAES peripheral, by clearing EN.
2. Wait until BUSY is cleared (no RNG random number fetch in progress).
3. Initialize the SAES_CR register as follow:
   - Select the CTR chaining mode (CHMOD[2:0] at 0x2) in decryption mode (MODE[1:0] at 0x2). Other MODE[1:0] values are not supported.
   - Select 32-bit data type (DATATYPE[1:0] at 0x0)
   - Configure the key size with KEYSIZE. It is used for encryption key and for the key to share.
   - Select wrapped key mode, by writing KMOD[1:0] with 0x1.
4. Write the initialization vector in SAES_IVRx registers, keeping the two least significant bits of SAES_IVR0 at zero.
5. Select the DHUK key source by writing KEYSEL[2:0] with 0x1 or 0x4. Optionally, select the BHK, by writing KEYSEL[2:0] with 0x2. Refer to *Section 45.4.17* for details on the use of KEYSEL[2:0].
6. Wait until KEYVALID is set (the key loading completed).
7. Enable the SAES peripheral, by setting EN.
8. Wait until CCF flag is set in the SAES_ISR register.
9. Clear the CCF flag, by setting the CCF bit in SAES_ICR register. The derived hardware secret key is available in SAES_KEYRx registers.
10. Repeat steps *8.* and *9.* if KEYSIZE is set.
11. Disable the SAES peripheral, by clearing EN.

At the end of this sequence, the hardware secret key derived from the public data in the SAES_IVRx registers is then immediately usable by the application for any AES operation (normal key mode, that is, with KMOD[1:0] = 0x0).

Note: The configuration KMOD[1:0] at 0x1 (wrapped key), CHMOD[2:0] at 0x2 (CTR chaining), and MODE at 0x0 (encryption) disables the peripheral, by automatically clearing the EN bit of the SAES_*CR register.*

45.4.15 SAES operation with shared keys

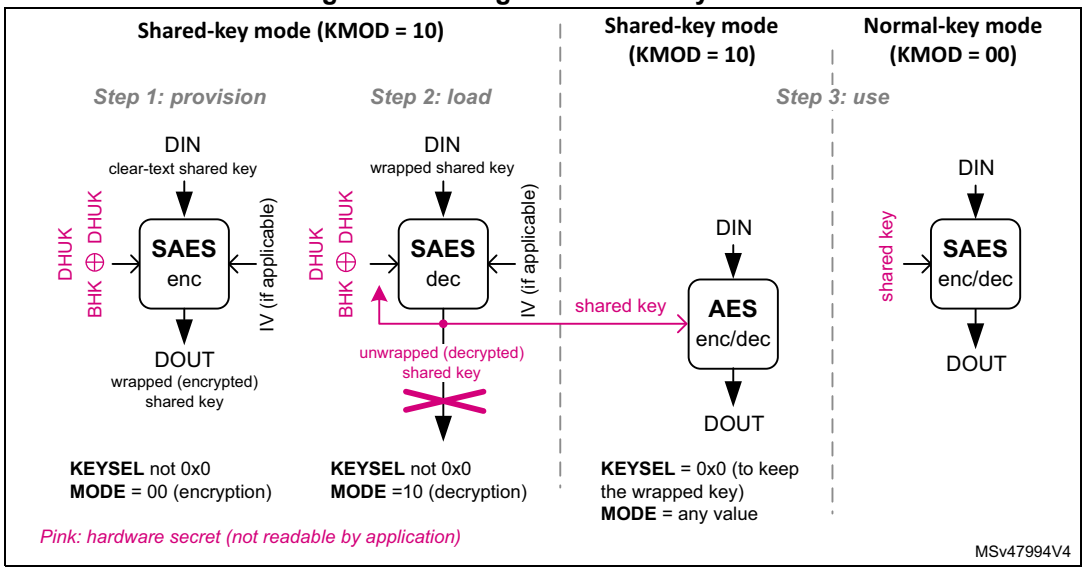
SAES peripheral can share application keys wrapped with hardware-secret key DHUK, XOR-ed or not with application key BHK. With this feature, the application software can make the AES keys available to the AES peripheral, without exposing them in clear-text (unencrypted).

Shared key sequences are too small to be suspended/resumed. SAES cannot unwrap a shared key using an unwrapped key.

Note: When a key stored in SAES is shared with AES, the protection given by KEYPROT bit is lost. The protection is detailed in Section 45.4.17: SAES key registers.

Figure 471 summarizes how to wrap or unwrap keys to share with *AES* peripheral. To protect the shared key, DHUK must be selected, by writing KEYSEL[2:0] with 0x1 or 0x4. Alternatively, select BHK by writing KEYSEL[2:0] with 0x2 if the corresponding registers are read/write-locked in the TAMP peripheral.

Figure 471. Usage of Shared-key mode



Note: DHUK value depends on privilege, security, KMOD[1:0], KSHAREID, KEYSEL[2:0], CHMOD[2:0], and KEYSIZE.

In the step 3, AES represents the AES peripheral.

Key wrapping for AES peripheral

Before SAES can share a key with the AES peripheral, the key must be encrypted (wrapped) once. The encryption sequence of a shared key is the same as for a wrapped

key, with KMOD[1:0] at 0x2 (shared key) and KSHAREID[1:0] kept at 0x0 in the step 3 in *Figure 471*. See *Key wrapping for SAES* for details.

Note: Encryption in Shared-key mode is only supported when ECB or CBC is selected.

Key unwrapping for AES peripheral (shared key)

Each time SAES needs to share a key with the AES peripheral, shared encrypted key must be decrypted (unwrapped) in SAES, then loaded by AES. The overall sequence is described next.

Sequence in the SAES peripheral

The decryption sequence of a shared key is the same as for a wrapped key, with KMOD[1:0] at 0x2 (shared key) and KSHAREID[1:0] kept at 0x0 in the step 3 in *Figure 471*. See *Key unwrapping for SAES* for details.

In shared key mode when decryption mode is selected (MODE[1:0] at 0x2), a read access to the SAES_DOUTR register triggers a read error (RDERRF).

Note: Instead of being shared, a decrypted shared key can be used directly in SAES as the KEYSEL[2:0] bitfield is automatically cleared. In this case, KMOD[1:0] must be written with 0x0 (normal key mode).

Sequence in the AES peripheral

Once the shared key is decrypted in SAES key registers, it can be shared with the AES peripheral, while SAES peripheral remains in key sharing state, that is, with KMOD[1:0] at 0x2 and KEYVALID set. The sequence in the AES key share target peripheral is described in *AES key sharing with secure AES co-processor* of the corresponding section in this document. It can be run multiple times (for example, to manage a suspend/resume situation) as long as SAES is unused and duly remains in key sharing state.

Note: When KMOD[1:0] is at 0x2 and BUSY set in the AES peripheral, and KEYSIZE value of AES and SAES differs, the key sharing fails and the KEIF flag is raised in both peripherals.

When KEYSEL[2:0] is at 0x1 (DHUK) or 0x4 (DHUK XOR BHK), the application software must use the same privilege, security, KMOD[1:0] / KSHAREID[1:0], CHMOD[2:0], and KEYSIZE context for encryption and decryption. Otherwise, the result is incorrect.

45.4.16 SAES data registers and data swapping

Data input and output

A 16-byte data block enters the SAES peripheral with four successive 32-bit word writes into the SAES_DINR register (bitfield DIN[31:0]), the most significant word (bits [127:96]) first, the least significant word (bits [31:0]) last.

A 16-byte data block is retrieved from the SAES peripheral with four successive 32-bit word reads of the SAES_DOUTR register (bitfield DOUT[31:0]), the most significant word (bits [127:96]) first, the least significant word (bits [31:0]) last.

The four 32-bit words of a 16-byte data block must be stored in the memory consecutively and in big-endian order, that is, with the most significant word on the lowest address. See *Table 450* “no swapping” option for details.

Data swapping

The SAES peripheral can be configured to perform a bit-, a byte-, a half-word-, or no swapping on the input data word in the SAES_DINR register, before loading it to the AES processing core, and on the data output from the AES processing core, before sending it to the SAES_DOUTR register. The choice depends on the type of data. For example, a byte swapping is used for an ASCII text stream.

The data swap type is selected through DATATYPE[1:0]. The selection applies to both SAES input and output.

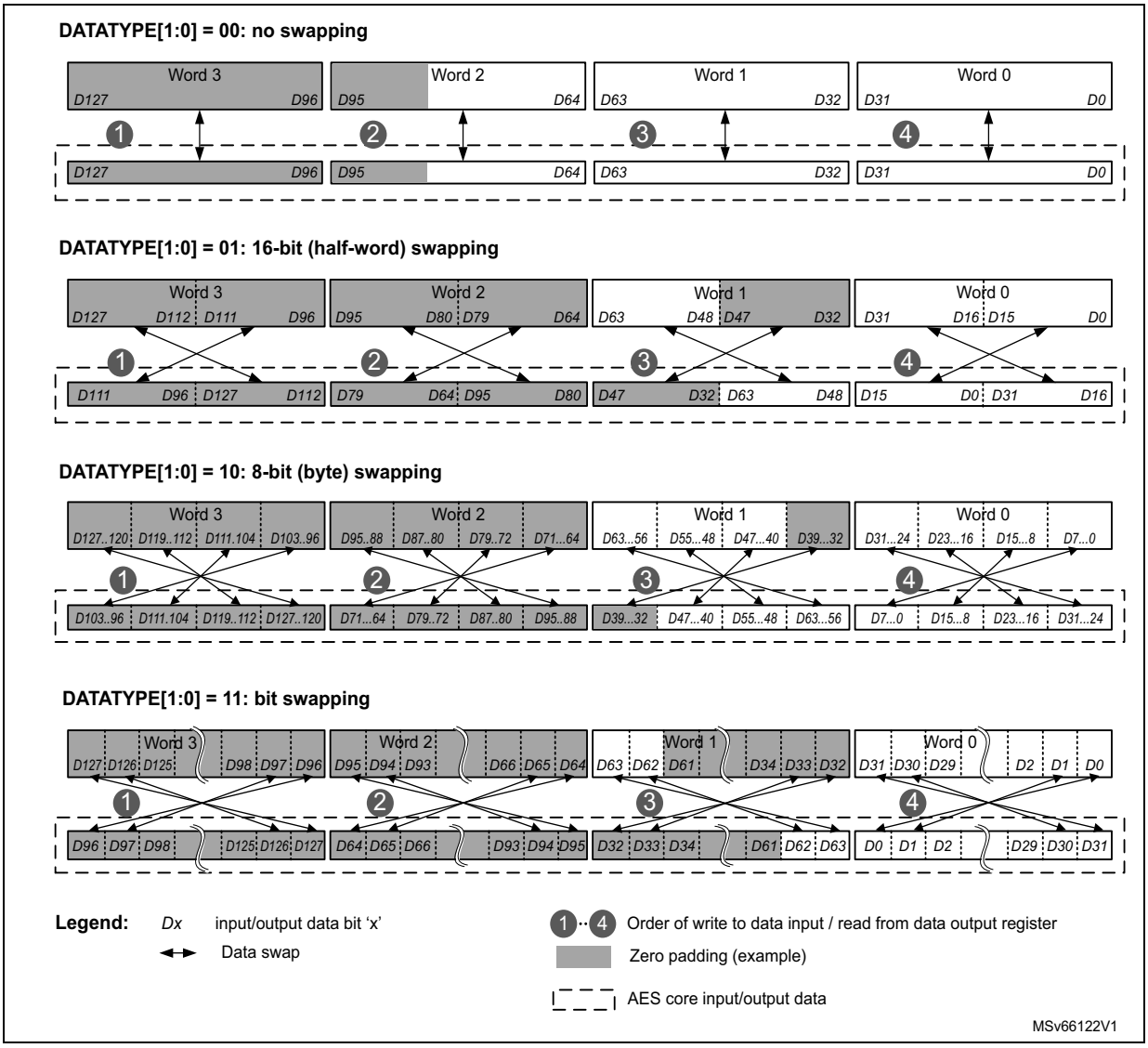
Note: The data in SAES key registers (SAES_KEYRx) and initialization vector registers (SAES_IVRx) are not sensitive to the swap mode selection.

The SAES data swapping feature is summarized in *Table 450* and *Figure 472*.

Table 450. AES data swapping example

DATATYPE[1:0]	Swapping performed	Data block
		System memory data (big-endian)
0x0	No swapping	Block[127..64]: 0x04EEF672 2E04CE96 Block[63..0]: 0x4E6F7720 69732074
		Address @, word[127..96]: 0x04EEF672 Address @ + 0x4, word[95..64]: 0x2E04CE96 Address @ + 0x8, word[63..32]: 0x4E6F7720 Address @ + 0xC, word[31..0]: 0x69732074
0x1	Half-word (16-bit) swapping	Block[63..0]: 0x**4E6F** 7720 **6973** 2074
		Address @, word[63..32]: 0x7720 **4E6F** Address @ + 0x4, word[31..0]: 0x2074 **6973**
0x2	Byte (8-bit) swapping	Block[63..0]: 0x**4E** 6F **77** 20 **69** 73 **20** 74
		Address @, word[63..32]: 0x20**77** 6F**4E** Address @ + 0x4, word[31..0]: 0x74**20** 73**69**
0x3	Bit swapping	Block[63..32]: 0x4E6F7720 0100 1110 0110 1111 0111 0111 0010 0000 Block[31..0]: 0x69732074 0110 1001 0111 0011 0010 0000 0111 0100
		Address @, word[63..32]: 0x04EE F672 0000 0100 1110 1110 1111 0110 0111 0010 Address @ + 0x4, word[31..0]: 0x2E04 CE96 0010 1110 0000 0100 1100 1110 1001 0110

Figure 472. 128-bit block construction according to the data type



Data padding

Figure 472 also gives an example of memory data block padding with zeros such that the zeroed bits after the data swap form a contiguous zone at the MSB end of the AES core input buffer. The example shows the padding of an input data block containing:

- 84 message bits, with DATATYPE[1:0] = 0x0
- 48 message bits, with DATATYPE[1:0] = 0x1
- 56 message bits, with DATATYPE[1:0] = 0x2
- 34 message bits, with DATATYPE[1:0] = 0x3

45.4.17 SAES key registers

The eight SAES_KEYRx write-only registers store the encryption or decryption key information, as shown on *Table 451*. Reads are not allowed for security reason.

Note: In memory and in SAES *key registers, keys are stored in little-endian format, with most significant byte on the highest address.*

Table 451. Key endianness in SAES_KEYRx registers (128/256-bit keys)

SAES_KEYR7 [31:0]	SAES_KEYR6 [31:0]	SAES_KEYR5 [31:0]	SAES_KEYR4 [31:0]	SAES_KEYR3 [31:0]	SAES_KEYR2 [31:0]	SAES_KEYR1 [31:0]	SAES_KEYR0 [31:0]
-	-	-	-	KEY[127:96]	KEY[95:64]	KEY[63:32]	KEY[31:0]
KEY[255:224]	KEY[223:192]	KEY[191:160]	KEY[159:128]	KEY[127:96]	KEY[95:64]	KEY[63:32]	KEY[31:0]
TAMP_BKP7R [31:0]	TAMP_BKP6R [31:0]	TAMP_BKP5R [31:0]	TAMP_BKP4R [31:0]	TAMP_BKP3R [31:0]	TAMP_BKP2R [31:0]	TAMP_BKP1R [31:0]	TAMP_BKP0R [31:0]

The key registers are not affected by the data swapping feature controlled by the DATATYPE[1:0] bitfield.

Write operations to the SAES_KEYRx registers are ignored when SAES peripheral is enabled (EN bit set) and KEYSEL[2:0] is different from zero. The application must check this before modifying key registers.

The entire key must be written before starting an AES computation.

In normal key mode (KMOD[1:0] at 0x0), with KEYSEL[2:0] at 0x0, the key registers must always be written in either ascending or descending order. The write sequence becomes:

- SAES_KEYRx (x = 0 to 3 or x=3 to 0) for KEYSIZE cleared
- SAES_KEYRx (x = 0 to 7 or x=7 to 0) for KEYSIZE set

Note: KEYSIZE must be written before the key.

As soon as the first key register is written, the KEYVALID flag is cleared. Once the key registers writing sequence is completed, KEYVALID is set and EN becomes writable. If an error occurs, KEYVALID is cleared and KEIF set (see *Section 45.4.19*).

Key selection

With KEYSEL[2:0] at 0x0, the application must write the key in the SAES_KEYRx registers.

With KEYSEL[2:0] at 0x1, a derived hardware unique key (DHUK), computed inside SAES from a nonvolatile and secret root hardware unique key, is loaded directly into key registers, based on KEYSIZE information. Thanks to the key derivation function, the computed DHUK depends on the SAES usage (privilege, security, KMOD[1:0] / KSHAREID[1:0], CHMOD[2:0], CPU, and KEYSIZE context).

With KEYSEL[2:0] at 0x2, the boot hardware key (BHK), stored in tamper-resistant secure backup registers, is entirely transferred into key registers upon a secure application performing a single read of all TAMP_BKPxR registers (x = 0 to 3 for KEYSIZE cleared, x = 0 to 7 for KEYSIZE set) in ascending order. Refer to *Table 451*.

With KEYSEL[2:0] at 0x4, the XOR combination of DHUK and BHK is entirely transferred into key registers upon a secure application performing a single read of all TAMP_BKPxR

registers (x = 0 to 3 for KEYSIZE cleared, x = 0 to 7 for KEYSIZE set) in ascending order. Refer to *Table 451*.

Repeated writing of KEYSEL[2:0] with the same non-zero value only triggers the loading of DHUK or BHK if KEYVALID is cleared. The recommended method to clear KEYVALID is to set IPRST. Such method is required for example when switching from ECB decryption to ECB encryption, selecting the same BHK (KEYSEL[2:0] at 0x2).

For all KEYSEL[2:0] values, initiating the key-loading sequence sets the BUSY flag and clears the KEYVALID flag. Once the amount of bits defined by KEYSIZE is transfered to the SAES_KEYRx registers, BUSY is cleared, KEYVALID set and the EN bit becomes writable. If an error occurs, BUSY and KEYVALID are cleared and KEIF set (see *Section 45.4.19*).

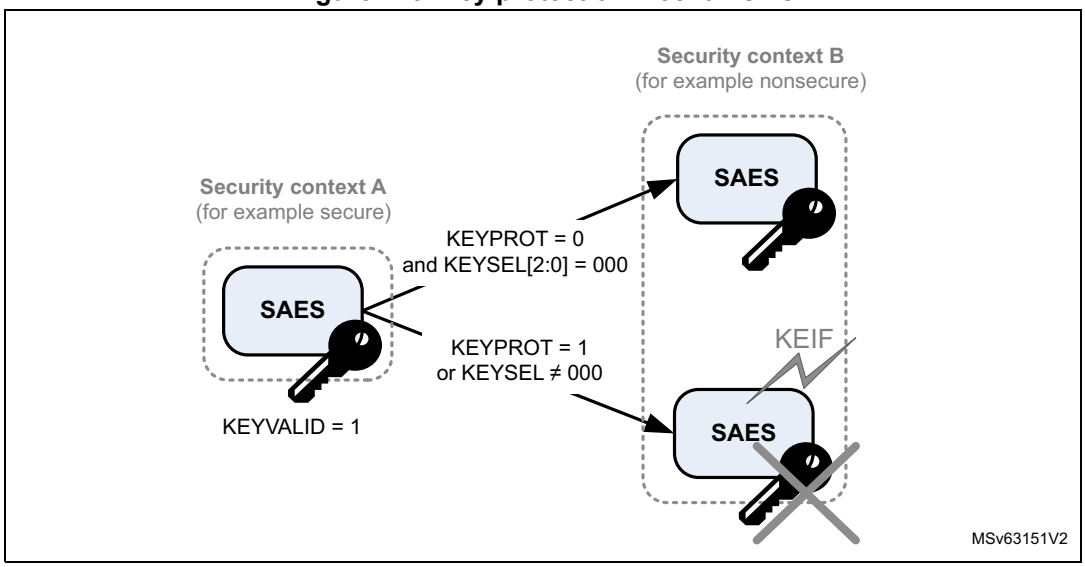
Note: DHUK, BHK and their XOR combination are not readable by any software (even secure).

Key protection

As depicted in *Figure 473*, when an application sets the KEYPROT bit before writing a key in SAES_KEYRx, any application executing in a different security context (that is, different security attribute) triggers a KEIF error flag upon access to any SAES register when KEYVALID is set.

Note: KEYSEL[2:0] values different from zero (normal key) automatically protect the key registers.

Figure 473. Key protection mechanisms



45.4.18 SAES initialization vector registers

The four SAES_IVRx registers store the initialization vector (IV) information, as shown in *Table 452*. They can only be written if the SAES peripheral is disabled (EN cleared).

Note: In memory and in SAES IV registers, initialization vectors are stored in little-endian format, with most significant byte on the highest address.

Table 452. IVI bitfield spread over SAES_IVRx registers

SAES_IVR3[31:0]	SAES_IVR2[31:0]	SAES_IVR1[31:0]	SAES_IVR0[31:0]
IVI[127:96]	IVI[95:64]	IVI[63:32]	IVI[31:0]

Initialization vector information depends on the chaining mode selected. When used, SAES_IVRx registers are updated upon each AES computation cycle (useful for managing suspend mode).

The initialization vector registers are not affected by the data swapping feature controlled through DATATYPE[1:0].

45.4.19 SAES error management

The SAES peripheral manages the errors described in this section.

Read error flag (RDERRF)

Unexpected read attempt of the SAES_DOUTR register returns zero, setting the RDERRF flag and the RWEIF flag. RDERRF is triggered during the computation phase or during the input phase.

Note: Unless otherwise indicated, SAES is not disabled when RDERRF rises and it continues processing.

An interrupt is generated if the RWEIE bit is set. For more details, refer to *Section 45.5: SAES interrupts*.

The RDERRF and RWEIF flags are cleared by setting the RWEIF bit of the SAES_ICR register.

Write error flag (WRERRF)

Unexpected write attempt of the SAES_DINR register is ignored, setting the WRERRF and the RWEIF flags. WRERRF is triggered during the computation phase or during the output phase.

Note: Unless otherwise indicated, SAES is not disabled when WRERRF rises and it continues processing.

An interrupt is generated if the RWEIE bit is set. For more details, refer to *Section 45.5: SAES interrupts*.

The WRERRF and RWEIF flags are cleared by setting the RWEIF bit of the SAES_ICR register.

Key error interrupt flag (KEIF)

There are multiple sources of errors that set the KEIF flag of the SAES_ISR register and clear the KEYVALID bit of the SAES_SR register:

- **Key protection error:** while KEYVALID is set, then if KEYPROT is set or KEYSEL[2:0] is different from zero, this error is triggered when an application executing in a security context different from the one used to load the key (that is, different security attribute) accesses SAES.

- **Key writing sequence error:** triggered upon detecting an incorrect sequence of writing key registers. See *Section 45.4.17: SAES key registers* for details.
- **Key sharing size mismatch error:** triggered when KMOD[1:0] is at 0x2 and KEYSIZE in AES peripheral does not match KEYSIZE in SAES peripheral.
- **Key sharing error:** triggered upon failing transfer of SAES shared key to AES peripheral. See *Section 45.4.15: SAES operation with shared keys* for details.
- **Hardware secret key loading error:** triggered upon failing load of DHUK or BHK into SAES. KEYSEL[2:0] at 0x1 (DHUK), 0x2 (BHK) or 0x4 (DHUK XOR BHK) is not functional.

The KEIF flag is cleared with corresponding bit of the SAES_ICR register. An interrupt is generated if the KEIE bit of the SAES_IER register is set. For more details, refer to *Section 45.5: SAES interrupts*.

Upon a key selection error, clearing the KEIF flag automatically restarts the key selection process. Persisting problems (for example, RHUK load failing) may require a power-on reset.

Upon a key sharing error, reset both AES and SAES peripherals through the IPRST bit of their corresponding control register, then restart the key sharing sequence.

Note: For any key error, clear KEIF flag prior to disabling and re-configuring SAES.

RNG error interrupt flag (RNGEIF)

SAES fetches random numbers from the RNG peripheral automatically after an IP reset triggered in the RCC. SAES cannot be used when RNGEIF is set.

An error detected while fetching a random number from RNG peripheral (due to, for example, bad entropy) sets the RNGEIF flag of the SAES_ISR register. The flag is cleared by setting the corresponding bit of the SAES_ICR register. An interrupt is generated if the RNGEIE bit of the SAES_IER register is set. For more details, refer to *Section 45.5: SAES interrupts*.

Upon an RNG error:

- Make sure that the RNG peripheral is properly configured.
- Verify that the RNG peripheral AHB clock is enabled and no noise source (or seed) error is pending in this peripheral.
- Clear RNGEIF or reset the peripheral by setting IPRST. The clearance of the BUSY flag then indicates the completion of the random number fetch from RNG.

Note: To avoid RNGEIF errors, it is recommended to activate the RNG AHB clock each time SAES AHB clock is activated.

Managing tamper errors

An unexpected error triggers an SAES internal tamper event in the TAMP peripheral, and stops any SAES co-processor processing.

To resume normal operation, reset the SAES peripheral through RCC or global reset.

45.5 SAES interrupts

There are multiple individual maskable interrupt sources generated by the SAES peripheral to signal the following events:

- computation completed (CCF)
- read error (RDERRF)
- write error (WRERRF)
- key error (KEIF)
- RNG error (RNGEIF)

See *Section 45.4.19: SAES error management* for details on SAES errors.

These sources are combined into a common interrupt signal from the SAES peripheral that connects to the Cortex® CPU interrupt controller. Application can enable or disable SAES interrupt sources individually by setting/clearing the corresponding enable bit of the SAES_IER register.

The status of the individual maskable interrupt sources can be read from the SAES_ISR register. They are cleared by setting the corresponding bit of the SAES_ICR register.

Table 453 gives a summary of the available features.

Table 453. SAES interrupt requests

Interrupt acronym	Interrupt event	Event flag	Enable bit	Interrupt clear method
SAES	computation completed flag	CCF	CCFIE	set CCF(1)
	read error flag	RDERRF(2)	RWEIE	set RWEIF(1)
	write error flag	WRERRF(2)		
	key error flag	KEIF	KEIE	set KEIF(1)
	RNG error flag	RNGEIF	RNGEIE	set RNGEIF(1)

1. Bit of the SAES_ICR register.
2. Flag of the SAES_SR register, mirrored by the flag RWEIF of the SAES_ISR register.

45.6 SAES DMA requests

The SAES peripheral provides an interface to connect to the DMA (direct memory access) controller. The DMA operation is controlled through the DMAINEN and DMAOUTEN bits of the SAES_CR register. When key derivation is selected (MODE[1:0] is at 0x1), setting those bits has no effect.

SAES only supports single DMA requests.

Suspend and resume operations are not supported in DMA mode.

Detailed usage of DMA with SAES can be found in *Appending data using DMA* subsection of *Section 45.4.5: SAES encryption or decryption typical usage*.

Data input using DMA

Setting DMAINEN enables DMA writing into SAES. SAES then initiates, during the input phase, a set of single DMA requests for each 16-byte data block to write to the SAES_DINR register (quadruple 32-bit word, MSB first).

Note: According to the algorithm and the mode selected, special padding / ciphertext stealing might be required (see Section 45.4.7).

Data output using DMA

Setting DMAOUTEN enables DMA reading from SAES. SAES then initiates, during the output phase, a set of single DMA requests for each 16-byte data block to read from the SAES_DOUTR register (quadruple 32-bit word, MSB first).

After the output phase, at the end of processing of a 16-byte data block, SAES switches automatically to a new input phase for the next data block, if any.

In DMA mode, the CCF flag has no use because the reading of the SAES_DOUTR register is managed by DMA automatically at the end of the computation phase. The CCF flag must only be cleared when transiting back to managing the data transfers by software.

Note: According to the message size, extra bytes might need to be discarded by application in the last block.

Stopping DMA transfers

All DMA request signals are de-asserted when SAES is disabled (EN cleared) or the DMA enable bit (DMAINEN for input data, DMAOUTEN for output data) is cleared.

45.7 SAES processing latency

The following tables provide the 16-byte data block processing latency per operating mode.

Table 454. Processing latency for ECB, CBC and CTR

Key size	Mode of operation	Chaining algorithm	Clock cycles(1)
128-bit	Encryption or decryption(2)	ECB, CBC, CTR	**480**
	Key preparation	-	**145**
256-bit	Encryption or decryption(2)	ECB, CBC, CTR	**680**
	Key preparation	-	**230**

1. SAES kernel clock
2. Excluding key preparation time (ECB and CBC only).

Table 455. Processing latency for GCM and CCM (in SAES kernel clock cycles)

Key size	Mode of operation	Chaining algorithm	Initialization phase	Header phase(1)	Payload phase(1)	Final phase(1)
128-bit	Mode 1: Encryption/ Mode 3: Decryption	GCM	490	72(2)	480(3)	490
		CCM	490	490	800	490
256-bit	Mode 1: Encryption/ Mode 3: Decryption	GCM	650	72(2)	690(3)	650
		CCM	650	680	1350	650

1. Data insertion can include wait states forced by SAES on the AHB bus (maximum 3 cycles, typical 1 cycle).
2. SAES AHB clock cycles instead of kernel clock cycle (Galois multiplier only).
3. As a worst case in encryption mode, add extra 72 AHB clock cycles for the last block computation.

45.8 SAES registers

The registers are accessible through 32-bit word single accesses only. Other access types generate an AHB error, and other than 32-bit writes may corrupt the register content.

45.8.1 SAES control register (SAES_CR)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IPRST	KEYSEL[2:0]			KSHAREID[1:0]		KMOD[1:0]		NPBLB[3:0]				KEYPROT	KEYSIZE	Res.	CHMOD[2]
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	GCMPH[1:0]		DMAOUTEN	DMAINEN	Res.	Res.	Res.	Res.	CHMOD[1:0]		MODE[1:0]		DATATYPE[1:0]		EN
	rw	rw	rw	rw					rw	rw	rw	rw	rw	rw	rw

Bit 31 **IPRST**: SAES peripheral software reset

Setting the bit resets the SAES peripheral, putting all registers to their default values, except the IPRST bit itself. Hence, any key-relative data are lost. For this reason, it is recommended to set the bit before handing over the SAES to a less secure application.

The bit must be kept low while writing any configuration registers.

Bits 30:28 **KEYSEL[2:0]**: Key selection

The bitfield defines the source of the key information to use in the AES cryptographic core.

0x0: Software key, loaded in key registers SAES_KEYx

0x1: Derived hardware unique key (DHUK)

0x2: Boot hardware key (BHK)

0x4: XOR of DHUK and BHK

Others: Reserved (if used, unfreeze SAES with IPRST)

When KEYSEL[2:0] is different from zero, selected key value is available in key registers when BUSY bit is cleared and KEYVALID is set in the SAES_SR register. Otherwise, the key error flag KEIF is set. Repeated writing of KEYSEL[2:0] with the same non-zero value only triggers the loading of DHUK or BHK when KEYVALID is cleared.

When the application software changes the key selection by writing the KEYSEL[2:0] bitfield, the key registers are immediately erased and the KEYVALID flag cleared.

At the end of the decryption process, if KMOD[1:0] is other than zero, KEYSEL[2:0] is cleared.

With the bitfield value other than zero and KEYVALID set, the application cannot transfer the ownership of SAES with a loaded key to an application running in another security context (such as secure, nonsecure). More specifically, when security of an access to any register does not match the information recorded by SAES, the KEIF flag is set.

Attempts to write the bitfield are ignored when the BUSY flag of SAES_SR register is set, as well as when the EN bit of the SAES_CR register is set before the write access and it is not cleared by that write access.

Bits 27:26 **KSHAREID[1:0]**: Key share identification

This bitfield defines, at the end of a decryption process with KMOD[1:0] at 0x2 (shared key), which target can read the SAES key registers using a dedicated hardware bus.

0x0: AES peripheral

Others: Reserved

Attempts to write the bitfield are ignored when BUSY is set, as well as when EN is set before the write access and it is not cleared by that write access.

Bits 25:24 **KMOD[1:0]**: Key mode selection

The bitfield defines how the SAES key can be used by the application. KEYSIZE must be correctly initialized when setting KMOD[1:0] different from zero.

0x0: Normal key mode. Key registers are freely usable and no specific use or protection applies to SAES_DINR and SAES_DOUTR registers.

0x1: Wrapped key for SAES mode. Key loaded in key registers can only be used to encrypt or decrypt AES keys. Hence, when a decryption is selected, read-as-zero SAES_DOUTR register is automatically loaded into SAES key registers after a successful decryption process.

0x2: Shared key mode. After a successful decryption process (unwrapping), SAES key registers are shared with the peripheral described in KSHAREID[1:0] bitfield. This sharing is valid only while KMOD[1:0] at 0x2 and KEYVALID=1. When a decryption is selected, read-as-zero SAES_DOUTR register is automatically loaded into SAES key registers after a successful decryption process.

Others: Reserved

With KMOD[1:0] other than zero, any attempt to configure the SAES peripheral for use by an application belonging to a different security context (such as secure or nonsecure) results in automatic key erasure and setting of the KEIF flag.

Attempts to write the bitfield are ignored when BUSY is set, as well as when EN is set before the write access and it is not cleared by that write access.

Bits 23:20 **NPBLB[3:0]:** Number of padding bytes in last block

This padding information must be filled by software before processing the last block of GCM payload encryption or CCM payload decryption, otherwise authentication tag computation is incorrect.

0x0: All bytes are valid (no padding)

0x1: Padding for the last LSB byte

...

0xF: Padding for the 15 LSB bytes of last block.

Bit 19 **KEYPROT**: Key protection

When set, hardware-based key protection is enabled.

0: When KEYVALID is set and KEYSEL[2:0] = 0 application can transfer the ownership of the SAES, with its loaded key, to an application running in another security context (such as nonsecure, secure).

1: When KEYVALID is set, key error flag (KEIF) is set when an access to any registers is detected, this access having a security context (for example, secure, nonsecure) that does not match the one of the application that loaded the key.

Attempts to write the bit are ignored when BUSY is set, as well as when EN is set before the write access and it is not cleared by that write access.

Bit 18 **KEYSIZE:** Key size selection

This bitfield defines the key length in bits of the key used by SAES.

0: 128-bit

1: 256-bit

When KMOD[1:0] is at 0x1 or 0x2, KEYSIZE also defines the length of the key to encrypt or decrypt.

Attempts to write the bit are ignored when BUSY is set, as well as when the EN is set before the write access and it is not cleared by that write access.

Bit 17 Reserved, must be kept at reset value.

Bit 15 Reserved, must be kept at reset value.

Bits 14:13 **GCMPH[1:0]:** GCM or CCM phase selection

This bitfield selects the phase, applicable only with GCM, GMAC or CCM chaining modes.
0x0: Initialization phase
0x1: Header phase
0x2: Payload phase
0x3: Final phase

Bit 12 **DMAOUTEN**: DMA output enable

This bit enables automatic generation of DMA requests during the data phase, for outgoing data transfers from SAES via DMA.
0: Disable
1: Enable
Setting this bit is ignored when MODE[1:0] is at 0x1 (key derivation).

Bit 11 **DMAINEN**: DMA input enable

This bit enables automatic generation of DMA requests during the data phase, for incoming data transfers to SAES via DMA.
0: Disable
1: Enable
Setting this bit is ignored when MODE[1:0] is at 0x1 (key derivation).

Bits 10:7 Reserved, must be kept at reset value.

Bits 16, 6:5 **CHMOD[2:0]**: Chaining mode

This bitfield selects the AES chaining mode:
0x0: Electronic codebook (ECB)
0x1: Cipher-block chaining (CBC)
0x2: Counter mode (CTR)
0x3: Galois counter mode (GCM) and Galois message authentication code (GMAC)
0x4: Counter with CBC-MAC (CCM)
others: Reserved
Attempts to write the bitfield are ignored when BUSY is set, as well as when EN is set before the write access and it is not cleared by that write access.

Bits 4:3 **MODE[1:0]**: Operating mode

This bitfield selects the SAES operating mode:
0x0: Encryption
0x1: Key derivation (or key preparation), for ECB/CBC decryption only
0x2: Decryption
0x3: Reserved
Attempts to write the bitfield are ignored when BUSY is set, as well as when EN is set before the write access and it is not cleared by that write access.

Bits 2:1 **DATATYPE[1:0]**: Data type

This bitfield defines the format of data written in the SAES_DINR register or read from the SAES_DOUTR register, through selecting the mode of data swapping. This swapping is defined in *Section 45.4.16: SAES data registers and data swapping*.
0x0: No swapping (32-bit data).
0x1: Half-word swapping (16-bit data)
0x2: Byte swapping (8-bit data)
0x3: Bit-level swapping
Attempts to write the bitfield are ignored when BUSY is set, as well as when EN is set before the write access and it is not cleared by that write access.

Bit 0 **EN**: Enable

This bit enables/disables the SAES peripheral.

0: Disable

1: Enable

At any moment, clearing then setting the bit re-initializes the SAES peripheral. When KMOD[1:0] is different from 0x0, using IPRST bit is recommended instead.

This bit is automatically cleared by hardware upon the completion of the key preparation (MODE[1:0] at 0x1) and upon the completion of GCM/GMAC/CCM initialization phase.

The bit cannot be set as long as KEYVALID is cleared, or when SAES is in one of the following configurations:

– KMOD[1:0] at 0x1 (wrap), CHMOD[2:0] at 0x3 (GCM)

– KMOD[1:0] at 0x1 (wrap), CHMOD[2:0] at 0x2 (CTR), MODE[1:0] at 0x0 (encryption).

45.8.2 SAES status register (SAES_SR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEYVALID	Res.	Res.	Res.	BUSY	WRERRF	RDERRF	Res.
								r				r	r	r	

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **KEYVALID**: Key valid flag

This bit is set by hardware when the key of size defined by KEYSIZE is loaded in SAES_KEYRx key registers.

0: Key not valid

1: Key valid

The EN bit can only be set when KEYVALID is set.

In normal mode when KEYSEL[2:0] is at zero, the key must be written in the key registers in the correct sequence, otherwise the KEIF flag is set and KEYVALID remains cleared.

When KEYSEL[2:0] is different from zero, the BUSY flag is automatically set by SAES. When the key is loaded successfully, BUSY is cleared and KEYVALID set. Upon an error, KEIF is set, BUSY cleared and KEYVALID remains cleared.

If set, KEIF must be cleared through the SAES_ICR register, otherwise KEYVALID cannot be set. See the KEIF flag description for more details.

For further information on key loading, refer to *Section 45.4.17: SAES key registers*.

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **BUSY:** Busy

This flag indicates whether SAES is idle or busy.

0: Idle

1: Busy

SAES is flagged as idle when disabled (when EN is low) or when the last processing is completed.

SAES is flagged as busy when processing a block data, preparing a key (ECB or CBC decryption only), fetching random number from the RNG, or transferring a shared key to the target peripheral.

When GCM encryption payload phase is selected, this flag must be at zero before suspending current process to manage a higher-priority message. BUSY must also be cleared before selecting the GCM final phase.

Bit 2 **WRERRF**: Write error flag

This bit is set when an unexpected write to the SAES_DINR register occurred. When set WRERRF bit has no impact on the SAES operations.

0: No error

1: Unexpected write to SAES_DINR register occurred during computation or data output phase.

The flag setting generates an interrupt if the RWEIE bit of the SAES_IER register is set.

The flag is cleared by setting the RWEIF bit of the SAES_ICR register.

Bit 1 **RDERRF**: Read error flag

This bit is set when an unexpected read to the SAES_DOUTR register occurred. When set RDERRF bit has no impact on the SAES operations.

0: No error

1: Unexpected read to SAES_DOUTR register occurred during computation or data input phase.

The flag setting generates an interrupt if the RWEIE bit of the SAES_IER register is set.

The flag is cleared by setting the RWEIF bit of the SAES_ICR register.

Bit 0 Reserved, must be kept at reset value.

45.8.3 SAES data input register (SAES_DINR)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DIN[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIN[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **DIN[31:0]**: Data input

A four-fold sequential write to this bitfield during the Input phase results in writing a complete 16-bytes block of input data to the SAES peripheral. From the first to the fourth write, the corresponding data weights are [127:96], [95:64], [63:32], and [31:0]. Upon each write, the data from the 32-bit input buffer are handled by the data swap block according to the DATATYPE[1:0] bitfield, then written into the AES core 16-bytes input buffer.

Reads return zero.

45.8.4 SAES data output register (SAES_DOUTR)

Address offset: 0x00C

Reset value: 0x0000 0000

Read when KMOD[1:0] is at 0x1 or 0x2 while MODE[1:0] is at 0x2 and EN is set triggers a read error.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DOUT[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DOUT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **DOUT[31:0]**: Data output

This read-only bitfield fetches a 32-bit output buffer. A four-fold sequential read of this bitfield, upon the computation completion (CCF flag set), virtually reads a complete 16-byte block of output data from the SAES peripheral. Before reaching the output buffer, the data produced by the AES core are handled by the data swap block according to the DATATYPE[1:0] bitfield.

Data weights from the first to the fourth read operation are: [127:96], [95:64], [63:32], and [31:0].

45.8.5 SAES key register 0 (SAES_KEYR0)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[31:0]**: Cryptographic key, bits [31:0]

These are bits [31:0] of the write-only bitfield KEY[255:0] AES encryption or decryption key, depending on the MODE[1:0] bitfield of the SAES_CR register.

Writes to SAES_KEYRx registers are ignored when SAES is enabled (EN bit set). When KEYSEL[2:0] is different from 0 and KEYVALID is 0, writes to key registers are also ignored and they result in setting the KEIF bit of the SAES_ISR register.

With KMOD[1:0] at 0x0, a special writing sequence is required. In this sequence, any valid write to AES_KEYRx register clears the KEYVALID flag except for the sequence-completing write that sets it. Also refer to the description of the KEYVALID flag in the AES_SR register.

45.8.6 SAES key register 1 (SAES_KEYR1)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[63:48]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[47:32]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[63:32]**: Cryptographic key, bits [63:32]

Refer to the SAES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing SAES_KEYRx registers.

45.8.7 SAES key register 2 (SAES_KEYR2)

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[95:80]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[79:64]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[95:64]**: Cryptographic key, bits [95:64]

Refer to the SAES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing SAES_KEYRx registers.

45.8.8 SAES key register 3 (SAES_KEYR3)

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[127:112]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[111:96]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[127:96]**: Cryptographic key, bits [127:96]

Refer to the SAES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing SAES_KEYRx registers.

45.8.9 SAES initialization vector register 0 (SAES_IVR0)

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IVI[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IVI[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IVI[31:0]**: Initialization vector input, bits [31:0]

SAES_IVRx registers store the 128-bit initialization vector or the nonce, depending on the chaining mode selected. This value is updated by hardware after each computation round (when applicable). Write to this register is ignored when EN bit is set in SAES_CR register

45.8.10 SAES initialization vector register 1 (SAES_IVR1)

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IVI[63:48]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IVI[47:32]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IVI[63:32]**: Initialization vector input, bits [63:32]

Refer to the SAES_IVR0 register for description of the IVI[128:0] bitfield.

45.8.11 SAES initialization vector register 2 (SAES_IVR2)

Address offset: 0x028

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IVI[95:80]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IVI[79:64]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IVI[95:64]**: Initialization vector input, bits [95:64]

Refer to the SAES_IVR0 register for description of the IVI[128:0] bitfield.

45.8.12 SAES initialization vector register 3 (SAES_IVR3)

Address offset: 0x02C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IVI[127:112]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IVI[111:96]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IVI[127:96]**: Initialization vector input, bits [127:96]
Refer to the SAES_IVR0 register for description of the IVI[128:0] bitfield.

45.8.13 SAES key register 4 (SAES_KEYR4)

Address offset: 0x030

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[159:144]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[143:128]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[159:128]**: Cryptographic key, bits [159:128]
Refer to the SAES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing SAES_KEYRx registers.

45.8.14 SAES key register 5 (SAES_KEYR5)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[191:176]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[175:160]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[191:160]**: Cryptographic key, bits [191:160]
Refer to the SAES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing SAES_KEYRx registers.

45.8.15 SAES key register 6 (SAES_KEYR6)

Address offset: 0x038

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[223:208]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[207:192]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[223:192]**: Cryptographic key, bits [223:192]

Refer to the SAES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing SAES_KEYRx registers.

45.8.16 SAES key register 7 (SAES_KEYR7)

Address offset: 0x03C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[255:240]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[239:224]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[255:224]**: Cryptographic key, bits [255:224]

Refer to the SAES_KEYR0 register for description of the KEY[255:0] bitfield and for information relative to writing SAES_KEYRx registers.

45.8.17 SAES suspend registers (SAES_SUSPRx)

Address offset: 0x040 + 0x4 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SUSP[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SUSP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SUSP[31:0]**: Suspend data

SAES_SUSPRx registers contain the complete internal register states of the SAES when the CCM processing of the current task is suspended to process a higher-priority task. Refer to *Section 45.4.8: SAES suspend and resume operations* for more details.

Clearing EN bit of the SAES_CR register clears this register to zero.

SAES_SUSPRx registers are not used in other chaining modes than CCM.

45.8.18 SAES interrupt enable register (SAES_IER)

Address offset: 0x300

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RNGEIE	KEIE	RWEIE	CCFIE
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **RNGEIE:** RNG error interrupt enable

This bit enables or disables (masks) the SAES interrupt generation when RNGEIF (RNG error flag) is set.

0: Disabled (masked)

1: Enabled (not masked)

Bit 2 **KEIE:** Key error interrupt enable

This bit enables or disables (masks) the SAES interrupt generation when KEIF (key error flag) is set.

0: Disabled (masked)

1: Enabled (not masked)

Bit 1 **RWEIE:** Read or write error interrupt enable

This bit enables or disables (masks) the SAES interrupt generation when RWEIF (read and/or write error flag) is set.

0: Disabled (masked)

1: Enabled (not masked)

Bit 0 **CCFIE:** Computation complete flag interrupt enable

This bit enables or disables (masks) the SAES interrupt generation when CCF (computation complete flag) is set.

0: Disabled (masked)

1: Enabled (not masked)

45.8.19 SAES interrupt status register (SAES_ISR)

Address offset: 0x304

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RNGEIF	KEIF	RWEIF	CCF
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **RNGEIF:** RNG error interrupt flag

This read-only bit is set by hardware when an error is detected on RNG bus interface (for example bad entropy).

0: RNG bus is functional

1: Error detected on RNG bus interface (random seed fetching error)

The flag setting generates an interrupt if the RNGEIE bit of the SAES_IER register is set.

The flag is cleared by setting the corresponding bit of the SAES_ICR register. The clear action triggers the reload of a new random number from the RNG peripheral.

Bit 2 **KEIF:** Key error interrupt flag

This read-only bit is set by hardware when the key information fails to load into key registers or when the key register use is forbidden.

0: No key error detected

1: Key information failed to load into key registers or the key register use is forbidden

The flag setting generates an interrupt if the KEIE bit of the SAES_IER register is set. It also clears the key registers and the KEYVALID flag in the SAES_SR register.

The flag is cleared by setting the corresponding bit of the SAES_ICR register.

KEIF is raised upon any of the following events:

–SAES fails to load the DHUK (KEYSEL[2:0] = 0x1 or 0x4).

–SAES fails to load the BHK (KEYSEL[2:0] = 0x2 or 0x4).

–AES fails to load the key shared by SAES peripheral (KMOD[1:0] = 0x2).

–KEYVALID is set and either KEYPROT is set or KEYSEL[2:0] is other than 0x0. The security context of the application that loads the key (secure or nonsecure) does not match the security attribute of the access to SAES_CR or SAES_DOUT. In this case, KEYVALID and EN bits are cleared.

–SAES_KEYRx register write does not respect the correct order. (For KEYSIZE cleared, SAES_KEYR0 then SAES_KEYR1 then SAES_KEYR2 then SAES_KEYR3 register, or reverse. For KEYSIZE set, SAES_KEYR0 then SAES_KEYR1 then SAES_KEYR2 then SAES_KEYR3 then SAES_KEYR4 then SAES_KEYR5 then SAES_KEYR6 then SAES_KEYR7, or reverse).

KEIF must be cleared by the application software, otherwise KEYVALID cannot be set.

Bit 1 **RWEIF:** Read or write error interrupt flag

This read-only bit is set by hardware when a RDERRF or a WRERRF error flag is set in the SAES_SR register.

0: No read or write error detected

1: Read or write error detected

The flag setting generates an interrupt if the RWEIE bit of the SAES_IER register is set.

The flag is cleared by setting the corresponding bit of the SAES_ICR register.

The flags has no meaning when key derivation mode is selected.

See the SAES_SR register for details.

Bit 0 **CCF:** Computation complete flag

This flag indicates whether the computation is completed. It is significant only when the DMAOUTEN bit is cleared, and it may stay high when DMAOUTEN is set.

0: Not completed

1: Completed

The flag setting generates an interrupt if the CCFIE bit of the SAES_IER register is set.

The flag is cleared by setting the corresponding bit of the SAES_ICR register.

45.8.20 SAES interrupt clear register (SAES_ICR)

Address offset: 0x308

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RNGEIF	KEIF	RWEIF	CCF
												w	w	w	w

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **RNGEIF:** RNG error interrupt flag clear

Application must set this bit to clear the RNGEIF status bit in SAES_ISR register.

Bit 2 **KEIF:** Key error interrupt flag clear

Setting this bit clears the KEIF status bit of the SAES_ISR register.

Bit 1 **RWEIF:** Read or write error interrupt flag clear

Setting this bit clears the RWEIF status bit of the SAES_ISR register, and clears both RDERRF and WRERRF flags in the SAES_SR register.

Bit 0 **CCF:** Computation complete flag clear

Setting this bit clears the CCF status bit of the SAES_ISR register.

45.8.21 SAES register map

Table 456. SAES register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	SAES_CR	IPRST	KEYSEL[2:0]			KSHAREID[1:0]		KMOD[1:0]		NPBLB[3:0]				KEYPROT	KEYSIZE	Res.	CHMOD[2]	Res.	GCMPH[1:0]		DMAOUTEN	DMAINEN	Res.	Res.	Res.	Res.	CHMOD[1]	CHMOD[0]	MODE[1:0]		DATATYPE[1:0]		EN
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0	0					0	0	0	0	0	0	0
0x004	SAES_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEYVALID	Res.	Res.	Res.	BUSY	WRERRF	RDERRF	Res.
	Reset value																									0				0	0	0	
0x008	SAES_DINR	DIN[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C	SAES_DOUTR	DOUT[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x010	SAES_KEYR0	KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	SAES_KEYR1	KEY[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x018	SAES_KEYR2	KEY[95:64]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x01C	SAES_KEYR3	KEY[127:96]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	SAES_IVR0	IVI[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	SAES_IVR1	IVI[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x028	SAES_IVR2	IVI[95:64]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x02C	SAES_IVR3	IVI[127:96]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x030	SAES_KEYR4	KEY[159:128]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x034	SAES_KEYR5	KEY[191:160]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x038	SAES_KEYR6	KEY[223:192]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x03C	SAES_KEYR7	KEY[255:224]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 456. SAES register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x040	SAES_SUSPR0	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x044	SAES_SUSPR1	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x048	SAES_SUSPR2	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04C	SAES_SUSPR3	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x050	SAES_SUSPR4	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x054	SAES_SUSPR5	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x058	SAES_SUSPR6	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x05C	SAES_SUSPR7	SUSP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x060-0x2FF	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x300	SAES_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RNGEIE	KEIE	RWEIE	CCFIE
	Reset value																													0	0	0	0
0x304	SAES_ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RNGEIF	KEIF	RWEIF	CCF
	Reset value																													0	0	0	0
0x308	SAES_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RNGEIF	KEIF	RWEIF	CCF
	Reset value																													0	0	0	0
0x309-0x3FF	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

46 Hash processor (HASH)

46.1 HASH introduction

The hash processor is a fully compliant implementation of the secure hash algorithm (SHA-1, SHA-2 family, SHA-3 family) and the HMAC (keyed-hash message authentication code) algorithm. HMAC is suitable for applications requiring message authentication.

The hash processor computes FIPS (Federal Information Processing Standards) approved digests of length of 160, 224, 256, 384 and 512 bits, for messages of any length less than 2^{64} bits (for SHA-1, SHA-224 and SHA-256) or less than 2^{128} bits (for SHA-384, SHA-512).

46.2 HASH main features

- Suitable for data authentication applications, compliant with:
  - Federal Information Processing Standards Publication FIPS PUB 180-4, *Secure Hash Standard* (SHA-1 and SHA-2 family)
  - Federal Information Processing Standards Publication FIPS PUB 186-4, *Digital Signature Standard (DSS)*
  - Internet Engineering Task Force (IETF) Request For Comments RFC 2104, *HMAC: Keyed-Hashing for Message Authentication* and Federal Information Processing Standards Publication FIPS PUB 198-1, *The Keyed-Hash Message Authentication Code (HMAC)*
  - Federal Information Processing Standards Publication FIPS PUB 202, *Secure Hash Standard* (SHA-3 family)
- Fast computation of SHA-1, SHA2-224, SHA2-256, SHA2-384, and SHA2-512
  - 82 (respectively 66) clock cycles for processing one 512-bit block of data using SHA-1 (respectively SHA-256) algorithm
  - 98 clock cycles for processing one 1024-bit block of data using either SHA2-384 or SHA2-512 algorithm
  - Support for SHA-2 truncated outputs (SHA2-512/224, SHA2-512/256)
- Support for the six Keccak-based functions defined in FIPS 202 standard
  - Fixed output length: SHA3-224, SHA3-256, SHA3-384 and SHA3-512
  - Extendable-output functions: SHAKE128 and SHAKE256
  - One cycle per Keccak round, hence 58 cycles per 1088-bit block for SHA3-256
- Support for HMAC mode with all supported algorithm
- Corresponding 32-bit words of the digest from consecutive message blocks are added to each other to form the digest of the whole message
  - Automatic 32-bit words swapping to comply with the internal little-endian representation of the input bit-string
  - Supported word swapping format: bits, bytes, half-words, and 32-bit words
- Single 32-bit, write-only, input register associated to an internal input FIFO that can receive a single data block of size depending on the selected algorithm
- Automatic padding to complete the input bit string to fit digest minimum block size
- AMBA AHB target peripheral, accessible through 32-bit word single accesses only (otherwise an AHB bus error is generated, and write accesses are ignored)

- 50 × 32-bit words (HR0 to HR41) for output message digest and general purpose SHA-3 outputs
- Automatic data flow control supporting direct memory access (DMA) using one channel.
- Support for both single and fixed DMA burst transfers of four words.
- Interruptible message digest computation, on a per-block basis
  - Reloadable digest registers
  - Hashing computation suspend/resume mechanism, including DMA

46.3 HASH implementation

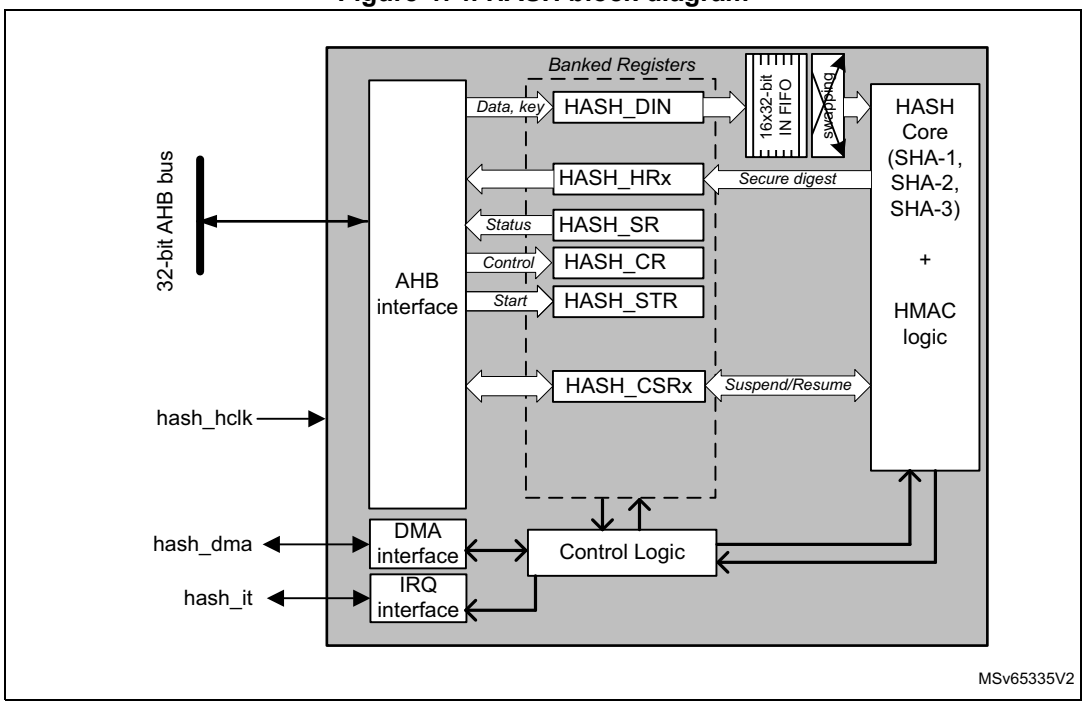
The devices have a single instance of HASH peripheral.

46.4 HASH functional description

46.4.1 HASH block diagram

Figure 474 shows the block diagram of the hash processor.

Figure 474. HASH block diagram



46.4.2 HASH internal signals

Table 457 describes a list of useful to know internal signals available at HASH level, not at product level (on pads).

Table 457. HASH internal input/output signals

Signal name	Signal type	Description
hash_hclk	digital input	AHB bus clock
hash_it	digital output	Hash processor global interrupt request
hash_dma	digital input/output	DMA burst request/ acknowledge

46.4.3 About secure hash algorithms

The hash processor is a fully compliant implementation of the secure hash algorithm defined by FIPS PUB 180-4 and FIPS PUB 202 standards.

With each algorithm, the HASH computes a condensed representation of a message or data file. More specifically, when a message is presented on the input, the HASH processing core produces a fixed-length output string called a message digest (see *Table 458*).

Table 458. Information on supported hash algorithms

Algorithm	Message digest size (in bits)	Block size (in bytes)(1)	Message length	Bit string message
SHA-1	160	64	$< 2^{64}$ bits	Yes
SHA2-224	224			
SHA2-256	256			
SHA2-384	384	128	$< 2^{128}$ bits	Yes
SHA2-512	512(2)			
SHA3-224	224	144	Any length	No(3)
SHA3-256	256	136		
SHA3-384	384	104		
SHA3-512	512	72		
SHAKE128	Variable output(4)	168		
SHAKE256		136		

1. Block size = (NBWE-1) * 4 bytes. NBWE[5:0] bitfield can be read from the HASH_SR register after ALGO and INIT bits are written in the HASH_CR register.
2. Digest size is 224 bits for SHA2-512/224 and 256 bits for SHA2-512/256 (truncated modes).
3. Data is fed as byte strings, not bit strings.
4. When the expected digest length is not reached (unbounded output), a new computation is required by setting DCAL in HASH_STR register. The number of computations equals the expected digest output length divided by the block size. The block size (or input rate) represents the maximum digest output that can be read after each computation.

The message digest can then be processed with a digital signature algorithm in order to generate or verify the signature for the message.

Signing the message digest rather than the message often improves the efficiency of the process since the message digest is usually much smaller in size than the message. The verifier of a digital signature has to use the same hash algorithm as the one used by the creator of the digital signature.

The SHA-2 and SHA-3 functions supported by the hash processor are qualified as “secure” by NIST because it is computationally infeasible to find a message that corresponds to a given message digest, or to find two different messages that produce the same message digest (SHA-1 does not qualify as secure since February 2017).

An extendable output function (XOF) SHAKE generates as many bits from its sponge as requested. For example, as per the NIST standard, for a message M and an output length d:

- SHAKE128(M,d = 256) can be used as a hash function delivering a 256-bit bit stream with 128-bit security strength. Arbitrarily large lengths can be used as pseudorandom number generators.
- SHAKE256(M, d = 128) can be used as a hash function with a 128-bit length and 128-bit resistance.

In compliance with FIPS PUB 202, SHAKE sponge functions provide different levels of preimage resistance (128 bits for SHAKE128, 256 bits for SHAKE256), provided the output size is no less than 128 bits for SHAKE128, and 256 bits for SHAKE256.

When the application selects a different output size, the security level is defined as follows (capacity_size = 256 for SHAKE128, 512 for SHAKE256):

- Security target against collisions = min (capacity_size / 2, output_size / 2)
- Security target against preimage attacks = min (capacity_size / 2, output_size)

46.4.4 Message data feeding

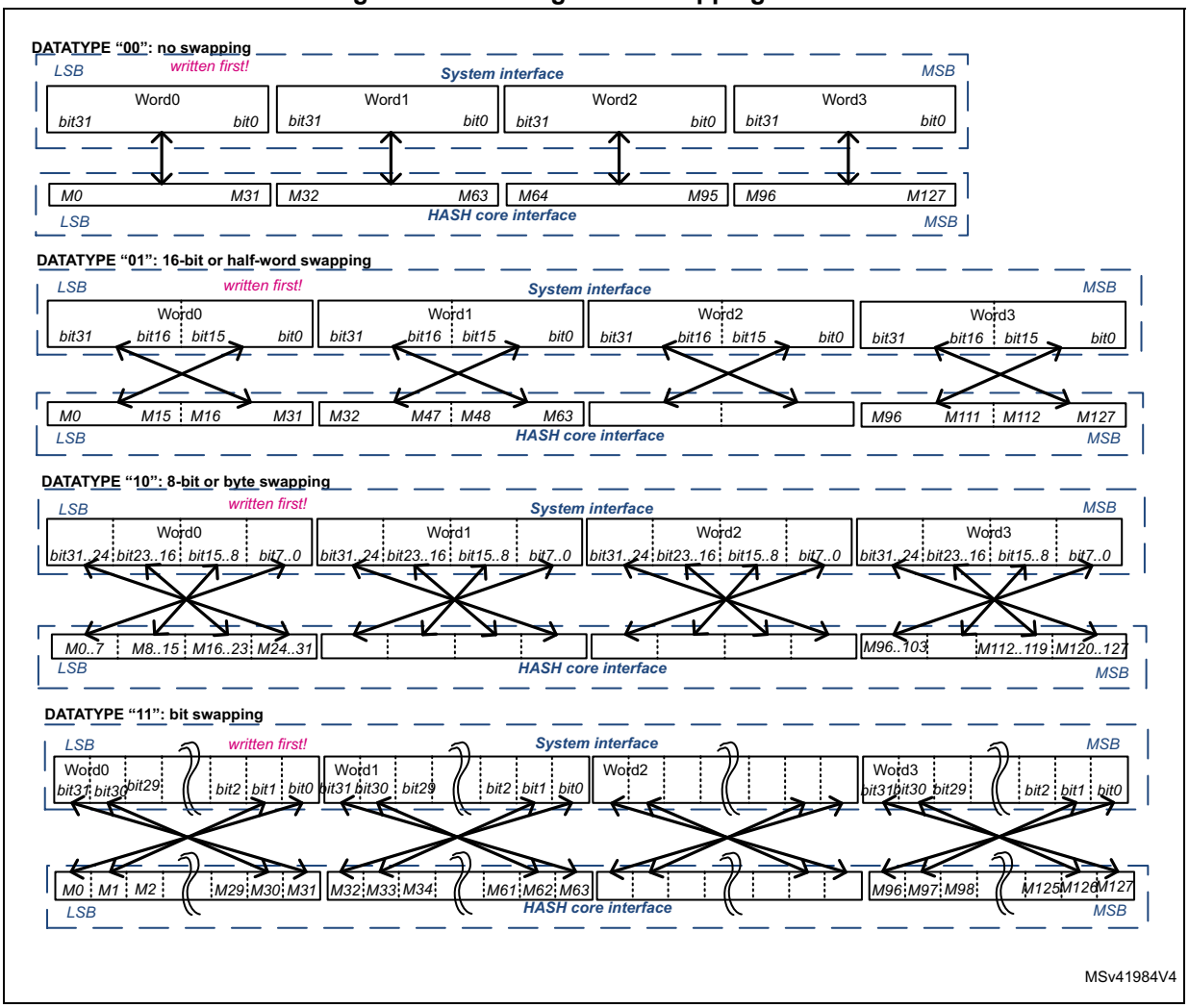
The message (or data file) to be processed by the HASH must be considered as a bit string, except for SHA-3 modes (see *Table 458*) where the message is a byte string. Per FIPS PUB 180-4 standard this message bit string grows from left to right, with hexadecimal words expressed in “big-endian” convention, so that within each word, the most significant bit is stored in the left-most bit position. For example message string “abc” with a bit string representation of “**01100001 01100010 01100011**” is represented by a 32-bit word **0x00636261**, and 8-bit words **0x61626300**.

Data are entered into the HASH one 32-bit word at a time, by writing them into the HASH_DIN register. The current contents of the HASH_DIN register are transferred to the 16 words input FIFO each time the register is written with new data. Hence, HASH_DIN and the FIFO form a seventeen 32-bit words length FIFO (named the IN buffer).

In accordance to the kind of data to be processed (for example byte swapping when data are ASCII text stream) there must be a bit, byte, half-word, or no swapping operation to be performed on data from the input FIFO before entering the little-endian hash processing core. *Figure 475* shows how the hash processing core 32-bit data block M0...31 is constructed from one 32-bit words popped into input FIFO by the driver, according to the DATATYPE bitfield in the HASH control register (HASH_CR)

HASH_DIN data endianness when bit swapping is disabled (DATATYPE = 00) can be described as following: the least significant bit of the message has to be at MSB position in the first word entered into the hash processor, the 32nd bit of the bit string has to be at MSB position in the second word entered into the hash processor and so on.

Figure 475. Message data swapping feature



46.4.5 Message digest computing

The hash processor sequentially processes several blocks when computing the message digest. Block sizes can be found in *Table 458: Information on supported hash algorithms*.

Each time the DMA or the CPU writes a block to the hash processor, the HASH automatically starts computing the message digest. This operation is known as partial digest computation.

As described in *Section 46.4.4: Message data feeding*, the message to be processed is entered into the HASH 32-bit word at a time, writing to the HASH_DIN register to fill the input FIFO. In order to perform the hash computation on this data the application must follow below sequence.

1. Initialize the hash processor using the HASH_CR register:
   - Write to the HASH_CR register to select the right algorithm using the ALGO bitfield, and set the INIT bit (other bits are kept at zero). Then read the NBWE bitfield from the HASH_SR register to deduce the algorithm block size, which equals **`(NBWE-1) * 4`**. This step is not required if the block size is already known (see *Table 458* for details).
   - Select the right algorithm using the ALGO[3:0] field. If needed, program the correct swapping operation on the message input words using the DATATYPE[1:0] bitfield.
   - When HMAC mode is required, set the MODE bit as well as the LKEY bit if the HMAC key size is greater than the known block size of the algorithm (otherwise keep LKEY cleared). Refer to *Section 46.4.7: HMAC operation* for details.
   - Update NBLW[4:0] in the HASH_STR register to define the number of valid bits in the last word of the message if it is different from 32 bits. NBLW information is used to correctly perform the automatic message padding before the final message digest computation.
2. Complete the initialization by setting the INIT bit in HASH_CR register. Also set the DMAE bit if data are transferred via DMA.

Caution: When programming step 2, it is important that the correct configuration values (ALGO, DATATYPE, HMAC mode, key length, NBLW) are set up before or at the same time.

3. Start filling data by writing to the HASH_DIN register, unless data are automatically transferred via DMA. Note that the processing of a block can start only once the last value of the block has entered the input FIFO. The way the partial or final digest computation is managed depends on the way data are fed into the processor:
   - Data are filled by software:

     Partial digest computations are triggered each time the application writes the first word of the next block, the block size being defined by NBWE bits in HASH_SR. Once the processor is ready again (DINIS = 1 in HASH_SR), the software can write new data to HASH_DIN. This mechanism avoids the introduction of wait states by the HASH.

     The final digest computation is triggered when the last block is entered and the software sets the DCAL bit. If the message length is not an exact multiple of the block size, the NBLW field in HASH_STR register must be written prior to writing DCAL bit (see *Section 46.4.6* for details).
   - Data are filled as a single DMA transfer (MDMAT = 0):

     Partial digest computations are triggered automatically each time the FIFO is full.

     The final digest computation is triggered automatically when the last block has been transferred to the HASH_DIN register by DMA (DCAL bit is set by hardware). If the message length is not an exact multiple of the block size, the NBLW field in HASH_STR register must be written prior to enabling the DMA (see *Section 46.4.6* for details).
   - Data are filled using multiple DMA transfers (MDMAT = 1):

     Partial digest computations are triggered as for single DMA transfers (refer to the above description). However, the final digest computation is not triggered automatically when the last block has been transferred by DMA to the HASH_DIN register (DCAL bit is not set by hardware). It enables the hash processor to receive a new DMA transfer as part of this digest computation. To launch the final digest computation, the software must clear MDMAT bit before the last DMA

transfer in order to trigger the final digest computation as it is done for single DMA transfers.

4. Once the digest calculation is completed (DCIS = 1), the resulting digest can be read from the output registers, as described in *Table 459*. When set, the DMAEN bit is automatically cleared by hardware.
5. For SHAKE128 or SHAKE256, a single computation may not be not sufficient (actual number of computation = expected output length divided by the block size). For each additional computation, execute the sequence below in CPU mode after step 4:
   a) Set DCAL in HASH_STR register.
   b) Wait for DCIS = 1, then read the new resulting digest from the same output registers. If an additional computation is required, go to step a.

Table 459. Hash processor outputs

Algorithm	Valid output registers(1)	Most significant bit	Digest size (in bits)
SHA-1	HASH_H0 to HASH_H4	HASH_H0[31]	160
SHA2-224	HASH_H0 to HASH_H6	HASH_H0[31]	224
SHA2-256	HASH_H0 to HASH_H7		256
SHA2-384	HASH_H0 to HASH_H11	HASH_H0[31]	384
SHA2-512	HASH_H0 to HASH_H15		512(2)
SHA3-224	HASH_H0 to HASH_H6	HASH_H0[31]	224
SHA3-256	HASH_H0 to HASH_H7		256
SHA3-384	HASH_H0 to HASH_H11		384
SHA3-512	HASH_H0 to HASH_H15		512
SHAKE128	HASH_H0 to HASH_H41		Variable output(3)
SHAKE256	HASH_H0 to HASH_H33		

1. Aliased HASH_HRAx registers are not used with SHA-3 or SHAKE algorithm (registers read as zero).
2. Digest size is 224 bits for SHA2-512/224 and 256 bits for SHA2-512/256 (truncated modes)
3. Unbounded in the upper limit (extendable output functions), see *Table 458*.

For more information about HMAC detailed instructions, refer to *Section 46.4.7: HMAC operation*.

Aborting HASH operation

HASH can be disabled at any time by writing 0x4 to HASH_CR, after stopping any running DMA transfer to HASH (if applicable).

46.4.6 Message padding

Overview

When computing a condensed representation of a message, the process of feeding data into the hash processor (with automatic partial digest computation every block size transfer) loops until the last bits of the original message are written to the HASH_DIN register.

As the length (number of bits) of a message can be any integer value, the last word written to the hash processor may have a valid number of bits between 1 and 32. This number of valid bits in the last word, NBLW, has to be written to the HASH_STR register, so that message padding is correctly performed before the final message digest computation.

Note: When a SHA-3 mode is selected in HASH_CR register, the message is defined as a number of bytes with the last word having a valid number of bytes between 1 and 4. Consequently NBLW bits 0 to 2 are read as zeros in HASH_STR register and writes to 1 are ignored.

Padding processing

Detailed hashing sequences with padding are described in *Section 46.4.5: Message digest computing*. As mentioned in these sequences, the padding is done automatically using the information provided in NBLW[4:0].

Hashing example

Below is an example of SHA-1 digest computation with HASH. Message processing and padding are defined in Federal Information Processing Standards PUB 180-4.

Let us assume that the original message is the ASCII binary-coded form of “abc”, of length L = 24 (‘**U**’ means don’t care):

```
byte 0    byte 1   byte 2   byte 3
01100001 01100010 01100011 UUUUUUUU
<-- 1st word written to HASH_DIN -->
```

NBLW has to be loaded with the value 24: a “**1**” is appended at bit location 24 in the bit string (starting counting from left to right in the above bit string), which corresponds to bit 31 in the HASH_DIN register (little-endian convention):

```
01100001 01100010 01100011 1UUUUUUU
```

Since L = 24, the number of bits in the above bit string is 25, and 423 “0” bits are automatically appended, making now 448 bits.

This gives in hexadecimal (byte words in big-endian format):

```
61626380 00000000 00000000 00000000
00000000 00000000 00000000 00000000
00000000 00000000 00000000 00000000
00000000 00000000
```

The message length value, **L**, in two-word format (that is 00000000 00000018) is appended. Hence, the final padded message in hexadecimal (byte words in big-endian format):

```
61626380 00000000 00000000 00000000
00000000 00000000 00000000 00000000
00000000 00000000 00000000 00000000
00000000 00000000 00000000 00000018
```

If the hash processor is programmed to swap byte within HASH_DIN input register (DATATYPE = 10 in HASH_CR), the above message has to be entered using following sequence:

1. **0xUU636261** is written to the HASH_DIN register (where '**U**' means don't care)
2. **0x18** is written to the HASH_STR register (the number of valid bits in the last word written to the HASH_DIN register is 24, as the original message length is 24 bits)
3. **0x100** is written to the HASH_STR register to run the final digest computation.
4. The hash computing is complete with the message digest available in the HASH_HRx registers (x = 0 to 4) for the SHA-1 algorithm. For this FIPS example, the expected value is as follows:

```
HASH_HR0 = 0xA9993E36
HASH_HR1 = 0x4706816A
HASH_HR2 = 0xBA3E2571
HASH_HR3 = 0x7850C26C
HASH_HR4 = 0x9CD0D89D
```

46.4.7 HMAC operation

Overview

As specified by Internet Engineering Task Force RFC2104 and NIST FIPS PUB 198-1, the HMAC algorithm is used for message authentication by irreversibly binding the message being processed to a key chosen by the user. The algorithm consists of two nested hash operations:

```
HMAC(message)= Hash((Key | pad) XOR opad |
               Hash((Key | pad) XOR ipad | message))
```

Where:

- **opad** = $[0x5C]_n$ (outer pad) and **ipad** = $[0x36]_n$ (inner pad)
- $[X]_n$ represents a repetition of X *n* times, where *n* equal to the byte size of the underlying hash function data block (n = 64 when block size is 512 bits).
- **pad** is a sequence of zeroes needed to extend the key to the length *n* defined above. If the key length is greater than *n*, the application must first hash the key using Hash() function and then use the resultant byte string as the actual key to HMAC.
- | represents the concatenation operator.

Note: HMAC mode of the hash processor can be used with all supported algorithms, except SHAKE.

HMAC processing

Four different steps are required to compute the HMAC:

1. The software sets the INIT bit, with the MODE bit set and the ALGO bits selecting the desired algorithm. The LKEY bit must also be set if the key being used is longer than the block size. In this case, as required by HMAC specifications, the hash processor uses the hash of the key instead of the real key.
2. The software provides the key to be used for the inner hash function, using the same mechanism as the message string loading that is by writing the key data into

HASH_DIN register and then completing the transfer by setting DCAL bit and the correct NBLW to HASH_STR register.

3. Once the processor is ready again (DINIS = 1 in HASH_SR), the software can write the message string to HASH_DIN. When the last word of the last block is entered and the software sets DCAL bit in HASH_STR register, the NBLW bitfield must be programmed at the same time to a value different from zero if the message length is not an exact multiple of the block size. Note that the DMA can also be used to feed the message string, as described in *Section 46.4.5: Message digest computing*.
4. Once the processor is ready again (DINIS = 1 in HASH_SR), the software provides the key to be used for the outer hash function, writing the key data into HASH_DIN register, and then completing the transfer by setting DCAL bit and programming the correct NBLW to HASH_STR register. The HMAC result can be found in the valid output registers (HASH_HRx) as soon as DCIS bit is set.

Note: The computation latency of the HMAC primitive depends on the lengths of the keys and message, as described in Section 46.4.11: HASH processing time.

Endianness management details can be found in Section 46.4.4: Message data feeding.

HMAC example

Below is an example of HMAC SHA-1 algorithm (ALGO = 00 and MODE = 1 in HASH_CR) as specified by NIST. SHA-1 block size is 64 bytes.

Let us assume that the original message is the ASCII binary-coded form of "**`Sample message for keylen = blocklen`**", of length L = 34 bytes. If the HASH is programmed in no swapping mode (DATATYPE = 00 in HASH_CR), the following data must be loaded sequentially into HASH_DIN register:

1. **Inner hash key** input (length = 64, that is, no padding), specified by NIST. As key length = 64, LKEY bit is cleared in HASH_CR register

   `00010203 04050607 08090A0B 0C0D0E0F 10111213 14151617`
   `18191A1B 1C1D1E1F 20212223 24252627 28292A2B 2C2D2E2F`
   `30313233 34353637 38393A3B 3C3D3E3F`
2. **Message** input (length = 34, that is, padding required). HASH_STR must be set to **`0x20`** to start message padding and inner hash computation (see **'U**' as don't care)

   `53616D70 6C65206D 65737361 67652066 6F72206B 65796C65`
   `6E3D626C 6F636B6C 656EUUUU`
3. **Outer hash key** input (length = 64, that is, no padding). A key identical to the inner hash key is entered here.
4. **Final outer hash computing** is then performed by the HASH. The HMAC-SHA1 digest result is available in the HASH_HRx registers, as shown below:

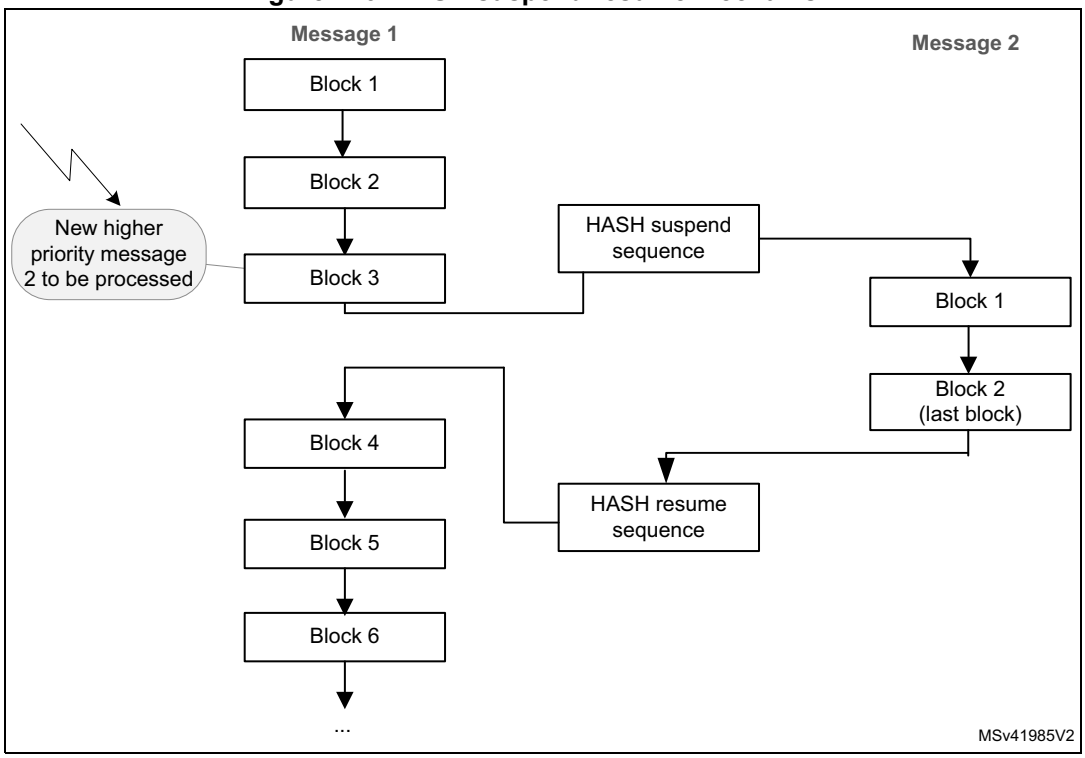
   `HASH_HR0 = 0x5FD596EE`
   `HASH_HR1 = 0x78D5553C`
   `HASH_HR2 = 0x8FF4E72D`
   `HASH_HR3 = 0x266DFD19`
   `HASH_HR4 = 0x2366DA29`

46.4.8 HASH suspend/resume operations

Overview

It is possible to interrupt a hash/HMAC operation to perform another processing with a higher priority. The interrupted process completes later when the higher-priority task has been processed, as shown in *Figure 476*.

Figure 476. HASH suspend/resume mechanism



To do so, the context of the interrupted task must be saved from the HASH registers to memory, and then be restored from memory to the HASH registers.

The procedures where the data flow is controlled by software or by DMA are described hereafter.

Data loaded by software

When the DMA is not used to load the message into the hash processor, the context can be saved only when no block processing is ongoing.

To suspend the processing of a message, proceed as follows after writing the number of words defined in NBWE:

1. In Polling mode, wait for BUSY = 0 then poll if the DINIS status bit is set.
   In Interrupt mode, implement the next step in DINIS interrupt handler (recommended).
2. Store the contents of the following registers into memory:
   - HASH_IMR
   - HASH_STR
   - HASH_CR
   - HASH_CSR0 to HASH_CSR37, when SHA-1 or SHA2-256 is selected, plus HASH_CSR38 to HASH_CSR53 if an HMAC operation was ongoing
   - HASH_CSR0 to HASH_CSR90, when SHA2-384 or SHA2-512 (truncated or not) is selected, plus HASH_CSR91 to HASH_CSR102 if an HMAC operation was ongoing.
   - HASH_CSR0 to HASH_CSR71, when SHA-3 is selected, plus HASH_CSR72 to HASH_CSR87 if a SHA3-384 or SHA3-512 HMAC operation was ongoing.

To resume the processing of a message, proceed as follows:

1. Write the following registers with the values saved in memory: HASH_IMR, HASH_STR, HASH_CR.
2. Initialize the hash processor by setting the INIT bit in the HASH_CR register
3. Write the HASH_CSRx registers with the values saved in memory.
4. Restart the processing from the point where it has been interrupted.

Data loaded by DMA

When the DMA is used to load the message into the hash processor, it is recommended to suspend and then restore a secure digest computing as described below.

In this sequence the DMA channel allocated to the hash peripheral remains allocated to the processing of message 1 (see *Figure 476*).

To suspend the processing of a message using DMA, proceed as follows:

1. Clear the DMAE bit to disable the DMA interface. The hash peripheral automatically fetches enough data via the DMA to complete the current burst transfer.
2. Wait until the last DMA transfer is complete (DMAS = 0 in HASH_SR).
3. Disable the DMA channel.
4. In Polling or Interrupt mode (recommended), wait until the hash processor is ready (no block is being processed), that is wait for DINIS = 1 in HASH_SR. If DCIS is also set in

HASH_SR, the hash result is available and the context swapping is useless. Else go to step 5.

5. Save HASH_IMR, HASH_STR and HASH_CR registers. Also save a number of HASH_CSRx registers depending on the SHA algorithm that is used:
   - When SHA-1 or SHA2-256 is selected, save HASH_CSR0 to HASH_CSR37, plus HASH_CSR38 to HASH_CSR53 if an HMAC operation was ongoing.
   - When SHA2-384 or SHA2-512 is selected, save HASH_CSR0 to HASH_CSR90, plus HASH_CSR91 to HASH_CSR102 if an HMAC operation was ongoing.
   - When a SHA-3 algorithm is selected, save HASH_CSR0 to HASH_CSR71, plus HASH_CSR72 to HASH_CSR87 if a SHA3-384 or SHA3-512 HMAC operation was ongoing.

To resume the processing of a message using DMA, proceed as follows:

1. Reconfigure the DMA controller so that it proceeds with the transfer of the message up to the end if it is not interrupted again.
2. Program the values saved in memory to HASH_IMR, HASH_STR and HASH_CR registers.
3. Initialize the hash processor by setting the INIT bit in the HASH_CR register.
4. Program the values saved in memory to the HASH_CSRx registers.
5. Restart the processing from the point where it was interrupted by setting the DMAE bit.

46.4.9 HASH DMA interface

The HASH supports both single and fixed DMA burst transfers of four words.

The hash processor provides an interface to connect to the DMA controller. This DMA can be used to write data to the HASH by setting the DMAE bit in the HASH_CR register. When this bit is set, the HASH initiates a DMA request each time a block has to be written to the HASH_DIN register.

Once four 32-bit words have been received, the HASH automatically triggers a new request to the DMA. For more information, refer to *Section 46.4.5: Message digest computing*.

Before starting the DMA transfer, the software must program the number of valid bits in the last word that is copied into HASH_DIN register. This is done by writing in HASH_STR register the following value:

`NBLW = Len(Message)% 32` where "**`x%32`**" gives the remainder of x divided by 32.

Note: While a SHA-3 algorithm is selected in HASH_CR register bits 0 to 2 of NBLW are always zero (processing of bytes, not bits).

The DMAS bit of the HASH_SR register provides information on the DMA interface activity. This bit is set with DMAE and cleared when DMAE is cleared and no DMA transfer is ongoing.

Note: No interrupt is associated to DMAS bit.

When MDMAT is set, the size of the transfer must be a multiple of four words.

46.4.10 HASH error management

No error flags are generated by the hash processor.

46.4.11 HASH processing time

Table 460 summarizes the time required to process an intermediate block for each mode of operation.

Table 460. Processing time (in clock cycle)

Mode of operation	Block size (in bytes)	FIFO load(1)	Computation phase	Total
SHA-1	64	16	66	**82**
SHA2-224		16	50	**66**
SHA2-256				
SHA2-384	128	32	66	**98**
SHA2-512(2)				
SHA3-224	144	36	24(3)	**60**
SHA3-256	136	34		**58**
SHA3-384	104	26		**50**
SHA3-512	72	18		**42**

1. Add the time required to load the block into the processor.
2. SHA2-512 includes SHA2-512/224 and SHA2-512/256 modes.
3. One cycle per round, 24 rounds required for these operations.

The time required to process the last block of a message (or of a key in HMAC) can be longer. This time depends on the length of the last block and the size of the key (in HMAC mode).

Compared to the processing of an intermediate block, it can be increased by the factor below:

- **1 to 2.5** for a hash message
- **~2.5** for an HMAC input-key
- **1 to 2.5** for an HMAC message
- **~2.5** for an HMAC output key in case of a short key
- **3.5 to 5** for an HMAC output key in case of a long key

46.5 HASH interrupts

Two individual maskable interrupt sources are generated by the hash processor to signal the following events:

- Digest calculation completion (DCIS)
- Data input buffer ready (DINIS)

Both interrupt sources are connected to the same global interrupt request signal (hash_it), which is in turn connected to the device interrupt controller. Each interrupt source can

individually be enabled or disabled by changing the mask bits in the HASH_IMR register. Setting the appropriate mask bit enables the interrupt.

The status of each maskable interrupt source can be read from the HASH_SR register. *Table 461* gives a summary of the available features.

Table 461. HASH interrupt requests

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method
HASH	Digest computation completed	DCIS	DCIE	Clear DCIS or set INIT
	Data input buffer ready to get a new block	DINIS	DINIE	Clear DINIS or write to HASH_DIN

46.6 HASH registers

The hash core is associated with several control and status registers and several message digest registers. All these registers are accessible through 32-bit word accesses only, else an AHB error is generated.

46.6.1 HASH control register (HASH_CR)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALGO[3:0]				LKEY
											rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	MDMAT	DINNE	NBW[3:0]				Res.	MODE	DATATYPE[1:0]		DMAE	INIT	Res.	Res.
		rw	r	r	r	r	r		rw	rw	rw	rw	w		

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:17 **ALGO[3:0]**: Algorithm selection

These bits select the hash algorithm. This selection is only taken into account when the INIT bit is set. Changing this bitfield during a computation has no effect

When the ALGO bitfield is updated and INIT bit is set, NBWE in HASH_SR is automatically updated to 0x11 when ALGO = 0x00XX.

0000: SHA-1
0001: reserved
0010: SHA2-224
0011: SHA2-256
1100: SHA2-384
1101: SHA2-512/224
1110: SHA2-512/256
1111: SHA2-512
0100: SHA3-224
0101: SHA3-256
0110: SHA3-384
0111: SHA3-512
1000: SHAKE128
1001: SHAKE256
Others: reserved, must not be used

Bit 16 **LKEY**: Long key selection

The application must set this bit if the HMAC key is greater than the block size corresponding to the hash algorithm (see *Table 458: Information on supported hash algorithms* for details). For example the block size is 64 bytes for SHA2-256.

This selection is only taken into account when the INIT and MODE bits are set (HMAC mode selected). Changing this bit during a computation has no effect.

0: HMAC key is shorter or equal to the block size (short key). The actual key value written in HASH_DIN is used during the HMAC computation.

1: HMAC key is longer than the block size (long key). The hash of the key is used instead of the real key during the HMAC computation.

Bit 15 Reserved, must be kept at reset value.

Bit 14 Reserved, must be kept at reset value.

Bit 13 **MDMAT**: Multiple DMA transfers

This bit is set when hashing large files when multiple DMA transfers are needed.

0: DCAL is automatically set at the end of a DMA transfer.

1: DCAL is not automatically set at the end of a DMA transfer.

Bit 12 **DINNE**: DIN not empty

Refer to DINNE bit of HASH_SR for a description of DINNE bit.

This bit is read-only.

Bits 11:8 **NBW[3:0]:** Number of words already pushed

Refer to NBWP[3:0] bitfield of HASH_SR for a description of NBW[3:0] bitfield.

This bitfield is read-only.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **MODE:** Mode selection

This bit selects the normal or the keyed HMAC mode for the selected algorithm. This selection is only taken into account when the INIT bit is set. Changing this bit during a computation has no effect.

0: Hash mode selected

1: HMAC mode selected. LKEY bit must be set if the key being used is longer than the algorithm block size.

Bits 5:4 **DATATYPE[1:0]:** Data type selection

This bitfield defines the format of the data entered into the HASH_DIN register:

00: 32-bit data. The data written into HASH_DIN are directly used by the HASH processing, without reordering.

01: 16-bit data or half-word. The data written into HASH_DIN are considered as two half-words, and are swapped before being used by the HASH processing.

10: 8-bit data or bytes. The data written into HASH_DIN are considered as four bytes, and are swapped before being used by the HASH processing.

11: bit data or bit string. The data written into HASH_DIN are considered as 32 bits (1st bit of the string at position 0), and are swapped before being used by the HASH processing (1st bit of the string at position 31).

Bit 3 **DMAE:** DMA enable

Setting this bit enables DMA transfers. After this bit is set, it is cleared by hardware while the last data of the message is written into the hash processor.

Clearing this bit while a DMA transfer is ongoing does not abort the current transfer. Instead, the DMA interface of the HASH remains internally enabled until the transfer is complete or INIT is set.

Setting INIT bit does not clear DMAE bit.

0: DMA transfers disabled

1: DMA transfers enabled. A DMA request is sent as soon as the hash core is ready to receive data.

Bit 2 **INIT:** Initialize message digest calculation

This is a write-only bit always returning zero upon reading. Setting this bit resets the hash processor core, so that HASH is ready to compute the message digest of a new message. Clearing this bit has no effect.

Bits 1:0 Reserved, must be kept at reset value.

46.6.2 HASH data input register (HASH_DIN)

Address offset: 0x004

Reset value: 0x0000 0000

HASH_DIN is the data input register. It is 32-bit wide. This register is used to enter the message by blocks defined by the hash algorithm (see *Table 458: Information on supported hash algorithms* for details). For example the block size is 64 bytes for SHA2-256.

When the HASH_DIN register is programmed, the value presented on the AHB bus is ‘pushed’ into the hash core and the register takes the new value presented on the AHB bus. To get a correct message format, the DATATYPE bits must have been previously configured in the HASH_CR register.

When a complete block has been written to the HASH_DIN register, an intermediate digest calculation is launched:

- by writing first data of the next block into the HASH_DIN register, if the DMA is not used
- automatically, if the DMA is used

When the last block has been written to the HASH_DIN register, the final digest calculation (including padding) is launched by setting the DCAL bit in the HASH_STR register (final digest calculation). This operation is automatic if the DMA is used and MDMAT bit is cleared.

Reading the HASH_DIN register returns zeros.

Note: When the HASH is busy, a write access to the HASH_DIN register might stall the AHB bus if the digest calculation (intermediate or final) is not complete.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATAIN[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATAIN[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **DATAIN[31:0]:** Data input

Writing this register pushes the current register content into the FIFO, and the register takes the new value presented on the AHB bus.
Do not write to this register when BUSY is set.
Reading this register returns zeros.

46.6.3 HASH start register (HASH_STR)

Address offset: 0x008

Reset value: 0x0000 0000

The HASH_STR register has two functions:

- It is used to define the number of valid bits in the last word of the message entered in the hash processor (that is the number of valid least significant bits in the last data written to the HASH_DIN register)
- It is used to start the processing of the last block in the message by setting the DCAL bit.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCAL	Res.	Res.	Res.	NBLW[4:0]				
							w				rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **DCAL:** Digest calculation

This is a write-only bit always returning zero upon reading. Setting this bit starts the message padding using the previously written value of NBLW, and starts the calculation of the final message digest with all the data words written to the input FIFO since the INIT bit was last set.

Do not set DCAL when BUSY is set.

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **NBLW[4:0]:** Number of valid bits in the last word

When the last word of the message bit string is written to HASH_DIN register, the hash processor takes only the valid bits, specified as below, after internal data swapping.

The above mechanism is valid only if DCAL = 0. If NBLW bits are written while DCAL is set, the NBLW bitfield remains unchanged. In other words it is not possible to configure NBLW and set DCAL at the same time.

Reading NBLW bits returns the last value written to NBLW.

0x00: All the 32 bits of the last data written are valid message bits, that is M[31:0]

0x01: Only one bit of the last data written (after swapping) is valid, that is M[0]

0x02: Only two bits of the last data written (after swapping) are valid, that is M[1:0]

0x03: Only three bits of the last data written (after swapping) are valid that is M[2:0]

...

0x1F: Only 31 bits of the last data written (after swapping) are valid that is M[30:0]

Note: When the SHA-3 family is selected, bits 0 to 2 are read as zeros and writes to 1 are ignored (byte oriented input).

46.6.4 HASH digest registers

These registers contain the message digest result defined as follows:

- HASH_HR0, HASH_HR1, HASH_HR2, HASH_HR3 and HASH_HR4 registers return the SHA-1 digest result.
- HASH_HR0 to HASH_HR6 registers return the SHA2-224, SHA2-512/224 or SHA3-224 digest result.
- HASH_HR0 to HASH_HR7 registers return the SHA2-256, SHA2-512/256 or SHA3-256 digest result.
- HASH_HR0 to HASH_HR11 registers return the SHA2-384, or SHA3-384 digest result.
- HASH_HR0 to HASH_HR15 registers return the SHA2-512, or SHA3-512 digest result.
- HASH_HR0 to HASH_HR41 registers return the SHAKE128, while HASH_HR0 to HASH_HR33 registers return the SHAKE256 digest result (see for *Table 459: Hash processor outputs* for details).

In all cases, the digest most significant bit is stored in HASH_HR0[31], and unused HASH_HRx registers reads as zero.

If a read access to one of these registers is performed while the hash core is calculating an intermediate digest or a final message digest (DCIS bit equals 0), then the read operation returns zeros.

Note: When starting a digest computation for a new message (by setting the INIT bit), HASH_HRx registers are forced to their reset values.

HASH_HR0 to HASH_HR4 registers can be accessed through two different addresses (register aliasing), except when the SHA-3 or SHAKE algorithm is selected (aliased registers read as zero).

HASH aliased digest register x (HASH_HRAx)

Address offset: 0x00C + 0x4 * x, (x = 0 to 4)

Reset value: 0x0000 0000

The content of the HASH_HRAx registers is identical to the one of the HASH_HRx registers located at address offset 0x310.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Hx[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Hx[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **Hx[31:0]:** Hash data x

Refer to *Section 46.6.4: HASH digest registers* introduction.

HASH digest register x (HASH_HRx)

Address offset: 0x310 + 0x4 * x, (x = 0 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Hx[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Hx[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **Hx[31:0]:** Hash data x

Refer to *Section 46.6.4: HASH digest registers* introduction.

HASH supplementary digest register x (HASH_HRx)

Address offset: 0x310 + 0x4 * x, (x = 5 to 41)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Hx[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Hx[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **Hx[31:0]:** Hash data x

Refer to *Section 46.6.4: HASH digest registers* introduction.

46.6.5 HASH interrupt enable register (HASH_IMR)

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCIE	DINIE
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **DCIE:** Digest calculation completion interrupt enable
- 0: Digest calculation completion interrupt disabled
- 1: Digest calculation completion interrupt enabled.

Bit 0 **DINIE:** Data input interrupt enable
- 0: Data input interrupt disabled
- 1: Data input interrupt enabled

46.6.6 HASH status register (HASH_SR)

Address offset: 0x024

Reset value: 0x0011 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NBWE[5:0]					
										r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DINNE	NBWP[5:0]						Res.	Res.	Res.	Res.	Res.	BUSY	DMAS	DCIS	DINIS
r	r	r	r	r	r	r						r	r	rc_w0	rc_w0

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:16 **NBWE[5:0]:** Number of words expected

This bitfield reflects the number of words in the message that must be pushed into the FIFO to trigger a partial computation. NBWE is decremented by 1 when a write access is performed to the HASH_DIN register.

NBWE is set to the expected block size +1 in words when INIT bit is set in HASH_CR. It is set to the expected block size when the partial digest calculation ends.

Bit 15 **DINNE:** DIN not empty

This bit is set when the HASH_DIN register holds valid data (that is after being written at least once). It is cleared when either the INIT bit (initialization) or the DCAL bit (completion of the previous message processing) is set.

0: No data are present in the data input buffer

1: The input buffer contains at least one word of data

Bits 14:9 **NBWP[5:0]:** Number of words already pushed

This bitfield is the exact number of words in the message that have already been pushed into the FIFO. NBWP is incremented by 1 when a write access is performed to the HASH_DIN register.

When a digest calculation starts, NBWP is updated to NBWP- block size (in words), and NBWP goes to zero when the INIT bit is set.

Bits 8:4 Reserved, must be kept at reset value.

Bit 3 **BUSY:** Busy bit

0: No block is currently being processed

1: The hash core is processing a block of data

Bit 2 **DMAS:** DMA Status

This bit provides information on the DMA interface activity. It is set with DMAE and cleared when DMAE = 0 and no DMA transfer is ongoing. No interrupt is associated with this bit.

0: DMA interface is disabled (DMAE = 0) and no transfer is ongoing

1: DMA interface is enabled (DMAE = 1) or a transfer is ongoing

Bit 1 **DCIS:** Digest calculation completion interrupt status

This bit is set by hardware when a digest becomes ready (the whole message has been processed). It is cleared by writing it to 0 or by setting the INIT bit in the HASH_CR register.

0: No digest available in the HASH_HRx registers (zeros are returned)

1: Digest calculation complete, a digest is available in the HASH_HRx registers. An interrupt is generated if the DCIE bit is set in the HASH_IMR register.

Bit 0 **DINIS:** Data input interrupt status

This bit is set by hardware when the FIFO is ready to get a new block (16 locations are free). It is cleared by writing it to 0 or by writing the HASH_DIN register.

When DINIS = 0, HASH_CSRx registers reads as zero.

0: Less than 16 locations are free in the input buffer

1: A new block can be entered into the input buffer. An interrupt is generated if the DINIE bit is set in the HASH_IMR register.

46.6.7 HASH context swap registers

These registers contain the complete internal register states of the hash processor. They are useful when a suspend/resume operation has to be performed because a high-priority task needs to use the hash processor while it is already used by another task.

When such an event occurs, the HASH_CSRx registers have to be read and the read values have to be saved in the system memory space. Then the hash processor can be used by the preemptive task. When the hash computation is complete, the saved context can be read from memory and written back into the HASH_CSRx registers.

HASH_CSRx registers can be read only when DINIS equals to 1, otherwise zeros are returned.

HASH context swap register x (HASH_CSRx)

Address offset: 0x0F8 + 0x4 * x, (x = 0 to 102)

Reset value: 0x0022 0002 (HASH_CSR0)

Reset value: 0x0000 0000 (others)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CSx[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CSx[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CSx[31:0]:** Context swap x
Refer to *Section 46.6.7: HASH context swap registers* introduction.

46.6.8 HASH register map

Table 462. HASH1 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	HASH_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALGO[3:2]		ALGO[1:0]		LKEY	Res.	Res.	MDMAT	DINNE	NBW[3:0]				Res.	MODE	DATATYPE[1:0]		DMAE	INIT	Res.	Res.
	Reset value												0	0	0	0	0			0	0	0	0	0	0		0	0	0	0	0		
0x004	HASH_DIN	DATAIN[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x008	HASH_STR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCAL	Res.	Res.	Res.	NBLW[4:0]				
	Reset value																								0				0	0	0	0	0
0x00C + 0x4 * x, (x = 0 to 4) Last address: 0x01C	HASH_HRAx	Hx[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 462. HASH1 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x020	HASH_IMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCIE	DINIE
	Reset value																															0	0
0x024	HASH_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NBWE[5]	NBWE[4:0]					DINNE	NBWP[5]	NBWP[4:0]					Res.	Res.	Res.	Res.	Res.	BUSY	DMAS	DCIS	DINIS
	Reset value											0	1	0	0	0	1	0	0	0	0	0	0	0						0	0	0	1
Reserved																																	
0x0F8	HASH_CSR0	CSR0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0x0FC	HASH_CSR1	CSR1[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x100	HASH_CSR2	CSR2[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
...																																	
0x1CC	HASH_CSR53	CSR53[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
...																																	
0x290	HASH_CSR102	CSR102[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reserved																																	
0x310 + 0x4 * x, (x = 0 to 41) Last address: 0x3B4	HASH_HRx	Hx[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

47 Public key accelerator (PKA)

47.1 PKA introduction

PKA (public key accelerator) is intended for the computation of cryptographic public key primitives, specifically those related to RSA, Diffie-Hellmann or ECC (elliptic curve cryptography) over GF(p) (Galois fields). To achieve high performance at a reasonable cost, these operations are executed in the Montgomery domain.

For a given operation, the accelerator performs all computations with no further hardware or software elaboration required to process the inputs or the outputs.

For manipulating secrets, the PKA incorporates a protection against side-channel attacks (SCA), including differential power analysis (DPA), required for SESIP and PSA security assurance level 3 target.

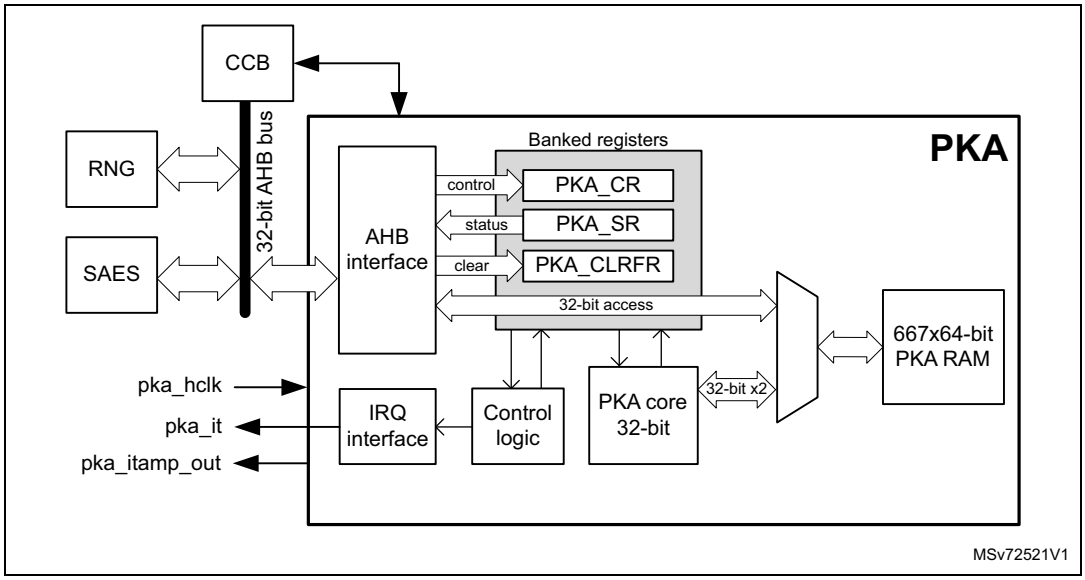
47.2 PKA main features

- Acceleration of RSA, DH and ECC over GF(p) operations, based on the Montgomery method for fast modular multiplications. More specifically:
  - RSA modular exponentiation, RSA chinese remainder theorem (CRT) exponentiation
  - ECC scalar multiplication, point on curve check, complete addition, double base ladder, projective to affine
  - ECDSA signature generation and verification
- Capability to handle operands up to 4160 bits for RSA/DH and 640 bits for ECC
- When manipulating secrets: protection against side-channel attacks (SCA), including differential power analysis (DPA), required for SESIP and PSA security assurance level 3 target.
  - Applicable to modular exponentiation, ECC scalar multiplication and ECDSA signature generation
- Arithmetic and modular operations such as addition, subtraction, multiplication, modular reduction, modular inversion, comparison, and Montgomery multiplication
- Built-in Montgomery domain inward and outward transformations
- AMBA AHB slave peripheral, accessible through 32-bit word single accesses only (otherwise an AHB bus error is generated, and write accesses are ignored)
- Support for CCB chaining operations required to protect private key used in PKA protected operations
- Hardware protections to monitor usage of private keys during protected operation initialization

47.3 PKA functional description

47.3.1 PKA block diagram

Figure 477. PKA block diagram



47.3.2 PKA internal signals

Table 463 lists the internal signals available at the PKA level, not necessarily available on product bonding pads.

Table 463. Internal input/output signals

Signal name	Signal type	Description
pka_hclk	Digital input	AHB bus clock
pka_it	Digital output	Public key accelerator IP global interrupt request
pka_itamp_out	Digital output	PKA internal tamper event signal to TAMP (XOR-ed), triggered when an unexpected fault occurs while PKA manipulates secrets, or when the programmed input point is not found on the input curve (ECDSA signature and ECC scalar multiplication only). A tamper is also generated if application does not respect the maximum supported size of operands, or when PKA finds a fault in critical configuration registers(1). This signal is asserted as soon as a fault is detected. When asserted, read access to PKA registers are reset to 0 and writes are ignored. The signal is de-asserted when PKA memory is cleared.

1. When tamper is active, the AHB interface is blocked: RAM and register reads are 0-ed and writes are ignored. There is no PKA RAM erase.

47.3.3 PKA reset and clocks

PKA is clocked on the AHB bus clock. When the PKA peripheral reset signal is released PKA_RAM is cleared automatically, taking 2000 clock cycles. During this time the setting of bit EN in PKA_CR register is ignored. Once EN bit is set, refer to *Section 47.3.6* for details about PKA initialization sequence.

According to the security policy applied to the device, PKA RAM can also be reset following a tamper event. Refer to *Tamper detection and response* in the System security section (if applicable to this product).

47.3.4 PKA public key acceleration

Overview

Public key accelerator (PKA) is used to accelerate Rivest, Shamir and Adleman (RSA), Diffie-Hellman (DH) as well as ECC over prime field operations. Supported operand sizes is up to 4160 bits for RSA and DH, and up to 640 bits for ECC.

The PKA supports all non-singular elliptic curves defined over prime fields, that can be described with a short Weierstrass equation $y^2 = x^3 + ax + b$ (mod p). More information can be found in *Section 47.5.1*.

Note: Binary curves, Edwards curves and Curve25519 are not supported by the PKA.

A memory of 5336 bytes (667 words of 64 bits) called PKA RAM is used to provide initial data to the PKA, and to hold the results after computation is completed. Access is done though the PKA AHB interface.

PKA operating modes

The list of operations the PKA can perform is detailed in *Table 464* and *Table 465*, respectively, for integer arithmetic functions and prime field (Fp) elliptic curve functions.

Table 464. PKA integer arithmetic functions list

PKA_CR.MODE[5:0]		Performed operation	Reference
Hex	Binary		
0x01	000001	Montgomery parameter computation R^2 mod *n*	*Section 47.4.2*
0x0E	001110	Modular addition (A+B) mod n	*Section 47.4.3*
0x0F	001111	Modular subtraction (A-B) mod n	*Section 47.4.4*
0x10	010000	Montgomery multiplication (AxB) mod n	*Section 47.4.5*
0x00	000000	Modular exponentiation A^e mod n	*Section 47.4.6*
0x02	000010	Modular exponentiation A^e mod n (fast mode)	
0x03	000011	Modular exponentiation A^e mod n (protected)	*Section 47.4.6*
0x08	001000	Modular inversion A^{-1} mod n	*Section 47.4.7*
0x0D	001101	Modular reduction A mod n	*Section 47.4.8*
0x09	001001	Arithmetic addition A+B	*Section 47.4.9*
0x0A	001010	Arithmetic subtraction A-B	*Section 47.4.10*
0x0B	001011	Arithmetic multiplication AxB	*Section 47.4.11*

Table 464. PKA integer arithmetic functions list (continued)

PKA_CR.MODE[5:0]		Performed operation	Reference
Hex	Binary		
0x0C	001100	Arithmetic comparison (A=B, A>B, A<B)	*Section 47.4.12*
0x07	000111	RSA CRT exponentiation	*Section 47.4.13*

Table 465. PKA prime field (Fp) elliptic curve functions list

PKA_CR.MODE[5:0]		Performed operation	Reference
Hex	Binary		
0x28	101000	Point on elliptic curve Fp check	*Section 47.4.14*
0x20	100000	ECC scalar multiplication kP (protected)	*Section 47.4.15*
0x23	100011	ECC complete addition	*Section 47.4.18*
0x24	100100	ECDSA sign (protected)	*Section 47.4.16*
0x26	100110	ECDSA verification	*Section 47.4.17*
0x27	100111	ECC double base ladder	*Section 47.4.19*
0x2F	101111	ECC projective to affine	*Section 47.4.20*

Each of these operating modes has an associated code that has to be written to the MODE[5:0] bitfield in the PKA_CR register. If the application selects any value that is not documented below the write to MODE[5:0] bitfield is ignored, and an operation error (OPERRF) is triggered. When this happens, a new operation must be selected after the error is cleared.

Some operations in *Table 464* and *Table 465* are indicated as protected. Those operations are used when manipulating secret keys (modular exponentiation for RSA decryption, scalar multiplication and signature for ECC). Those secrets (protected against side channel attacks) and any intermediate values are automatically erased when PKA RAM is cleared at the end of the protected operations (BUSY goes low). They are also protected against side channel attacks.

Caution: For security reason it is very important to select protected modular exponentiation (MODE[5:0] = 0x3) when performing RSA decryption.

Montgomery space and fast mode operations

For efficiency reasons, the PKA internally performs modular multiply operations in the Montgomery domain, automatically performing inward and outward transformations.

As Montgomery parameter computation is time consuming, the application can decide to use a faster mode of operation during which the precomputed Montgomery parameter is supplied before starting the operation. The performance improvement is detailed in *Section 47.5.2: Computation times*.

The only operation using fast mode is the modular exponentiation (MODE[5:0] = 0x02).

47.3.5 Typical applications for PKA

Introduction

The PKA can be used to accelerate a number of public key cryptographic functions such as:

- RSA encryption and decryption
- RSA key finalization
- CRT-RSA decryption
- DSA and ECDSA signature generation and verification
- DH and ECDH key agreement

The following publications specify the listed functions:

- FIPS PUB 186-4, Digital Signature Standard (DSS), July 2013 by NIST
- PKCS #1, RSA Cryptography Standard, v1.5, v2.1 and v2.2. by RSA Laboratories
- IEEE1363-2000, IEEE Standard Specifications for Public-Key Cryptography, January 2000
- ANSI X9.62-2005, Public Key Cryptography for the Financial Services Industry, The Elliptic Curve Digital Signature Algorithm (ECDSA), November 2005

Refer to these documents for full details. This document limits itself to describing principles.

RSA key pair

For the following RSA operations, a public key and a private key information are defined as follows:

- Alice transmits her public key (*n*, *e*) to Bob. Numbers *n* and *e* are very large positive integers.
- Alice keeps secret her private key d, also a very large positive integer. Alternatively, this private key can also be represented by a quintuple (p, q, dp, dq, qInv).

For more information, refer to the RSA specification.

RSA encryption/decryption principle

As recommended by the PKCS#1 specification, Bob, to encrypt message M using Alice's public key (*n*, *e*), must go through the following steps:

1. Compute the encoded message EM = ENCODE(M), where ENCODE is an encoding method.
2. Turn EM into an integer *m*, with $0 \leq m < n$ and (*m*, *n*) being coprimes.
3. Compute ciphertext $c = m^e \bmod n$.
4. Convert the integer c into a string ciphertext C.

Alice, to decrypt ciphertext c using her private key *d*, follows the steps indicated below:

1. Convert the ciphertext C to an integer ciphertext representative c.
2. If necessary, retrieve the prime factors (p, q) using (n, e, d) information, then compute phi = (p - 1) × (q - 1). Refer to NIST SP800-56B Appendix C for details.
3. Recover plaintext $m = c^d \bmod n = (m^e)^d \bmod n$. If the private key is the quintuple (p, q, dp, dq, qInv), then plaintext *m* is obtained by performing the operations:
   a) $m_1 = c^{dp} \bmod p$
   b) $m_2 = c^{dq} \bmod q$
   c) $h = qInv\,(m_1 - m_2) \bmod p$
   d) $m = m_2 + h\,q$
4. Convert the integer message representative *m* to an encoded message EM.
5. Recover message M = DECODE(EM), where DECODE is a decoding method.

To accelerate these operations with the PKA, use *Modular exponentiation* $A^e \bmod n$ if the private key is *d*, or *RSA CRT exponentiation* if the private key is the quintuple (p, q, dp, dq, qInv).

Note: The decoding operation and the conversion operations between message and integers are specified in PKCS#1 standard.

For the decryption process, the protected version of modular exponentiation (MODE[5:0] = 0x3) is strongly recommended for security reason. For the encryption process, the MODE[5:0] = 0x3 setting cannot be used as it requires the knowledge of the private key.

Elliptic curve selection

For the following ECC operations, the curve parameters are defined as follows:

- Curve corresponds to the elliptic curve field agreed among actors (Alice and Bob). Supported curves parameters are summarized in *Section 47.5.1: Supported elliptic curves*.
- G is the chosen elliptic curve base point (also known as generator), with a large prime order n (that is, $n \times G$ = identity element O).

ECDSA message signature generation

This section describes the ECDSA (elliptic curve digital signature algorithm) signature generation function principle.

Alice, to sign a message *m* using her private key integer d_A, goes through the following steps:

1. Calculate e = HASH(*m*), where HASH is a cryptographic hash function.
2. Let z be the L_n leftmost bits of e, where L_n is the bit length of the group order *n*.
3. Select a cryptographically secure random integer k where $0 < k < n$.
4. Calculate the curve point $(x_1, y_1) = k \times G$.
5. Calculate $r = x_1 \bmod n$. If $r = 0$ go back to step 3.
6. Calculate $s = k^{-1} (z + rd_A) \bmod n$. If $s = 0$ go back to step 3.
7. The signature is the pair (*r*, *s*).

The PKA accelerates the steps 4. to 7. by using:

- *ECDSA sign*, or
- All of the following operations:
  - *ECC Fp scalar multiplication* $k \times P$
  - *Modular reduction* A mod n
  - *Modular inversion* A^{-1} mod n
  - *Modular addition* and *Modular and Montgomery multiplication*

ECDSA signature verification

This section describes the ECDSA (elliptic curve digital signature algorithm) signature verification function principle.

Bob, to authenticate Alice's signature, must have a copy of her public key curve point Q_A. Bob can verify that Q_A is a valid curve point by going through the following steps:

1. Check that Q_A is not equal to the identity element O
2. Check that Q_A is on the agreed curve
3. Check that $n \times Q_A = O$.

Then Bob executes the following procedure:

1. Verify that r and s are integer in [1, n-1]
2. Calculate e = HASH(m), where HASH is the agreed cryptographic hash function
3. Let z be the L_n leftmost bits of e
4. Calculate $w = s^{-1}$ mod n
5. Calculate $u_1 = zw$ mod n and $u_2 = rw$ mod n
6. Calculate the curve point $(x_1, y_1) = u_1 \times G + u_2 \times Q_A$
7. The signature is valid if $r = x_1$ (mod n), it is invalid otherwise.

The PKA accelerates the steps 4. to 7. by using *ECDSA verification*.

47.3.6 PKA procedure to perform an operation

Enabling/disabling PKA

Setting the EN bit in the PKA_CR register enables the PKA peripheral. The PKA becomes available when the INITOK bit is set in the PKA_SR register. When EN = 0, the PKA peripheral is kept under reset, with its memory still accessible by the application through the AHB interface.

Note: When the PKA is in the process of clearing its memory, the EN bit cannot be set.

When setting the EN bit in PKA_CR, make sure that the MODE[5:0] bitfield value corresponds to an authorized PKA operation (see OPERRF in Section 47.3.8).

Clearing the EN bit while a calculation is in progress aborts the operation. In this case, the content of the PKA memory is not guaranteed, with the exception of the PKA modes 0x03, 0x20 and 0x24. For these operations, the PKA memory is cleared after abort, making the memory unavailable for 667 cycles. During this clearing time only the PKA registers can be accessed, with writes to EN bits ignored.

If the INITOK bit stays at 0, make sure that the RNG peripheral is clocked and properly initialized, then try to enable the PKA again.

Data formats

The format of the input data and the results in the PKA RAM are specified, for each operation, in *Section 47.4*.

Executing a PKA operation

To execute any of the supported PKA operations, proceed as follows:

1. Load initial data into the PKA internal RAM, which is located at address offset 0x400.
2. Write in the MODE[5:0] bitfield of PKA_CR register, specifying the operation which is to be executed and then assert the START bit, also in PKA_CR register.
3. Wait until the PROCENDF bit in the PKA_SR register is set, indicating that the computation is complete.
4. Read the result data from the PKA internal RAM, then clear PROCENDF bit by setting PROCENDFC bit in PKA_CLRFR.

Note: When PKA is busy (BUSY = 1), any access by the application to PKA RAM is ignored, and the RAMERRF flag is set in PKA_SR.

Selecting an illegal or unknown operation in step *2* triggers an OPERRF error and prevents the PROCENDF flag from being set and the procedure step *3* from being completed. See *Section 47.3.8* for details.

Using precomputed Montgomery parameters (PKA fast mode)

As explained in *Section 47.3.4*, when computing many operations with the same modulus, it can be beneficial for the application to compute the corresponding Montgomery parameter only once (see, for example, *Section 47.4.5*). This is referred to as *fast mode*.

To use the PKA peripheral in fast mode, follow this recommended procedure:

1. Load the modulus size and value information into the PKA RAM. Refer to *Section 47.5.1* for detail.
2. Configure the PKA_CR register to *Montgomery parameter computation* mode (MODE[5:0] = 0x1), then assert the START bit.
3. Wait until the PROCENDF bit in the PKA_SR register is set. Then, read the corresponding Montgomery parameter from the PKA memory and clear the PROCENDF bit by setting PROCENDFC in PKA_CLRFR.
4. Continue with the required PKA operation, loading the Montgomery information R2 mod *m* on top of the regular input data. Relevant addresses are provided in *Section 47.4*.

47.3.7 Private keys protection using CCB

Chaining modes

As shown in *Figure 478*, setting CCOP to a value different from 0 in the CCB peripheral automatically activates a chaining mechanism between PKA, RNG, and SAES, depending on the OPSTEP value (see *Table 466*), then sets the CCEN bit in the PKA_SR register.

For the effect of different OPSTEP values in each protected operation (ECDSA signature, scalar multiplication, modular exponentiation), refer to *Section 47.3.7: Private keys protection using CCB*.

Figure 478. Chaining of PKA with SAES or RNG

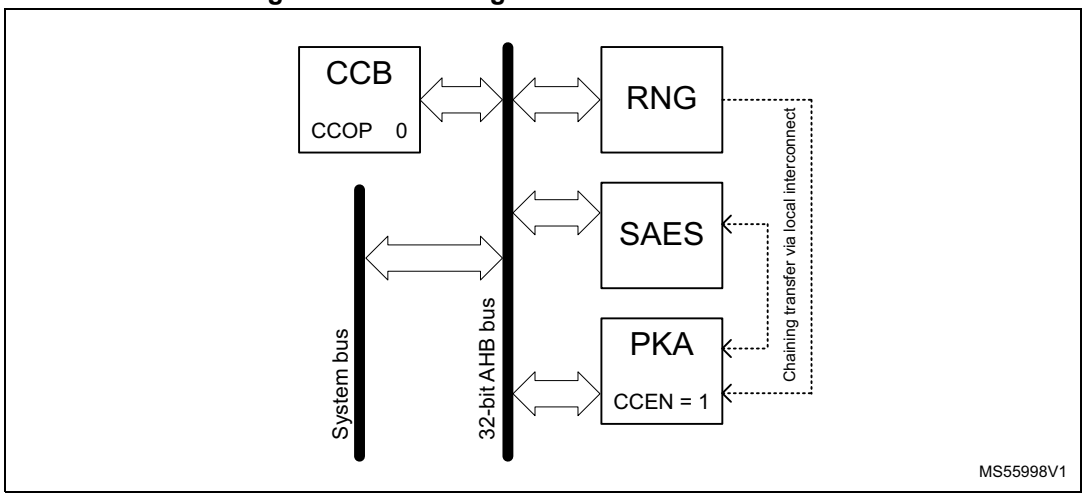


Table 466. Chaining mode to/from PKA

CCOP		OP STEP	Expected MODE[5:0] (1)	Chaining traffic(2)	Protected parameter written to PKA RAM	Expected flags(3)
x	0xC3	0x1	0x24	N/A	Hash (unprotected)	N/A
ECDSA signature	0xC0 or 0xC2	0x3	0x24	CPU → PKA + SAES(4)	Integrity protected parameters(5)	CMF error only
	0xC3	0x13				
		0x14		SAES → PKA	Decrypted private key d	DATAOKF or CMF error
		0x16		RNG → PKA	Random integer k	RNGOKF or CMF error
	0xC0	0x4		N/A	Clear text private key d	DATAOKF or CMF error
	0xC2	0x6		RNG → PKA	Random private key d	RNGOKF or CMF error
	0xC0 or 0xC2	0x8		PKA → SAES	Clear-text private key d	DATAOKF or CMF error
Scalar multiplication	0x80 or 0x82	0x3	0x20	CPU → PKA + SAES(4)	Integrity protected parameters(5)	CMF error only
	0x81	0x13				
		0x14		SAES → PKA	Decrypted k	DATAOKF or CMF error
	0x80	0x04		N/A	Clear text scalar mult k	
	0x82	0x6		RNG → PKA	Random scalar mult k	RNGOKF or CMF error
	0x80 or 0x82	0x8		PKA → SAES	Clear-text scalar mult k	DATAOKF or CMF error

Table 466. Chaining mode to/from PKA (continued)

CCOP		OP STEP	Expected MODE[5:0] (1)	Chaining traffic(2)	Protected parameter written to PKA RAM	Expected flags(3)
Modular exponentiation	0x44	0x3	0x3	CPU → PKA + SAES(4)	Integrity protected parameters(5)	CMF error only
	0x45	0x13				
		0x14		SAES → PKA	Decrypted exponent e	DATAOKF or CMF error
		0x15			Decrypted phi	
	0x44	0x4		N/A	Clear text exponent e	
		0x5			Clear text phi	
		0x8		PKA → SAES	Clear text exponent e	
		0x9			Clear text phi	

1. This mode must be written in PKA_CR before the START bit is set in PKA_CR.
2. Chaining traffic triggered by the CPU access to PKA RAM. “N/A” means no chaining traffic, only CPU traffic.
3. In PKA_SR bits 8 to 15 (“CMF error” refers to error flag bits 8 to 14).
4. In this mode chaining traffic includes the 32-bit data word plus the 32-bit physical address to PKA RAM.
5. Defined in *Table 467*.

When the application uses a PKA protected operation (with its private key), it must load the related blob information in the PKA RAM and in the SAES_DINR register. If the information exactly matches the conditions of the blob generation (the choice and order of writing protected parameters in PKA RAM, the selection of blob encryption key, and the usage of the original encrypted secrets), the CCB allows it to set the START bit in PKA_CR. When the PKA ignores the setting of the START bit, the application must reset the CCB using the IPRST bit in CCB_CR, then start the protected operation sequence again.

A protected application typically uses the PKA in the following sequence composed of three phases.

Step 1: Public phase

Before using a protected operation, the application may need to write unprotected parameters to the PKA RAM, as defined in *Table 466*.

Step 2: Integrity protected phase

To use a PKA operation, the application must load specific parameters in PKA RAM. When CCEN bit is set in PKA_SR, the integrity protected parameters defined in *Table 467* must always be written in the same way. Integrity protection is enforced in specific OPSTEPs, as defined in *Table 466*.

Typical issues with integrity of protected operation parameters are:

- The blob encryption key loaded in SAES registers is not correct.
- At least one confidentiality protected parameter defined in *Table 468* has an incorrect value, or was not properly written (DATAOKF = 0 or RNGOKF = 0, see *PKA status register (PKA_SR)*).
- At least one integrity protected parameter defined in *Table 467* has an incorrect value, is written at an incorrect address, or its write sequence to PKA RAM does not match

the sequence used during the blob creation. On this specific point, the application must follow the sequence detailed in *Table 467* when writing each item described in the column *Parameters*.

CCB feeds integrity protected parameters to SAES during the header phase of AES-GCM (GCMPH = 0x1).

Table 467. Integrity protected parameters list

Protected operation blob(1)	Parameters
ECC key blob	Curve prime order *n* length, curve modulus *p* length, curve coefficient *a* sign, curve coefficient |*a*|, curve coefficient *b*, curve modulus value *p*, curve prime order *n*
ECC signature blob	Same as scalar multiplication operation, adding curve base point G coordinates *x* and *y*
RSA key blob	Exponent *e* length, operand length, modulus value *n*

1. See *Table 468* for more details.

Step 3: Confidentiality phase

To use any PKA protected operation, the application must load confidentiality protected parameters in the PKA RAM. When the CCEN bit is set in PKA_SR, the parameters defined in *Table 468* are protected in confidentiality by:

- Making PKA RAM write-only
- Triggering a MODE[5:0] error (MDERRF) in PKA_SR when MODE[5:0] bitfiled in PKA_CR does not match the expected value when application sets START bit in PKA_CR
- Monitoring the correct management of protected parameters through DATAOKF and RNGOKF flags (see *PKA status register (PKA_SR)*)
- Optionally, generating ECC secrets from the on-chip TRNG when CCOP = 0xC2 or 0x82 and OPSTEP = 0x6, and when CCOP = 0xC3 and OPSTEP = 0x16. The PKA performs a sanity check before accepting this random value (see the RNGERRF flag).

Confidentiality protected parameters are described in *Table 468*. CCB feeds them to SAES during the payload phase of the AES-GCM (GCMPH = 0x2).

Table 468. Confidentiality protected parameter list

PKA operation	Secrets	Protected operation blob(1)	Start offset in PKA RAM	Size(2)
Modular exponentiation (protected, MODE[5:0] = 0x3)	Exponent e	RSA key blob	@0x14B8	ROS
	Phi value		@0xC68	
Scalar multiplication (MODE[5:0] = 0x20)	Scalar k	ECC key blob	@0x12A0	EOS
ECDSA signature (MODE[5:0] = 0x24)	Integer k	Not available	@0x12A0	EOS
	Private key d	ECC signature blob	@0xF28	

1. Information blob where confidentiality and integrity protected parameters are stored (see also *Table 467*)
2. See *Section 47.4.1* for details

Step 4: Running PKA protected operation

Set the START bit in PKA_CR. When the whole sequence executes correctly, the PKA RAM becomes inaccessible for reading and writing. Input parameters are automatically erased when the PROCENDF flag in PKA_SR is set, or if the application aborts the current operation by clearing the EN bit in PKA_CR.

47.3.8 PKA error management

The following error flags in the PKA_SR register are set to indicate errors that may occur when using the PKA:

- **ADDRERRF** flags that the access to PKA RAM falls outside the expected range.
- **RAMERRF** flags an AHB access to the PKA RAM occurring while the PKA core uses the PKA RAM. While the flag is set, reads form the PKA RAM return 0 and writes are ignored.
- **OPERRF** flags that the selected operating mode using MODE[5:0] bitfield is not listed in PKA operating modes (see the bitfield description), or PKA is running in limited mode (see LMF bit in PKA_SR). While the flag is set, writes to the MODE[5:0] bitfield are ignored.
- An ongoing chaining mode sequence error raises the chaining mode flag **CMF** and the corresponding error flag:
  - **INCRERRF** flags increment error
  - **DATAZF** flags data zeroed error
  - **TRZERRF** flags trailing zeros error
  - **MDERRF** flags mode error
  - **RNGERRF** flags RNG error

  For details on each flag and on enabling the chaining mode sequence, see *Section 47.7.2*.

For each error flag, the PKA generates an interrupt if enabled with the corresponding bit in the PKA_CR register (see *Section 47.6* for details).

The ADDRERRF, OPERRF, and RAMERRF error flags are cleared by setting the ADDRERRFC, OPERRFC, and RAMERRFC bit in PKA_CLRFR, respectively. The OPERRF error flag must be cleared before a new operation is initiated via the PKA_CR register.

Upon an ongoing chaining mode sequence error, the application must set the CMFC bit in the PKA_CLRFR register, then restart the ongoing protected operation sequence in the CCB peripheral.

Note: The PKA can be re-initialized at any moment by clearing the EN bit in the PKA_CR register.

47.4 PKA operating modes

47.4.1 Introduction

The operations supported by the PKA are detailed in the following subsections, which define the format of both input data and results stored in the PKA RAM.

Warning: Before starting any operation, ensure that all input parameters to the PKA are valid and consistent, as the PKA assumes their correctness. Additionally, input parameters must not exceed the operand sizes specified in the operation tables.

The following information applies to all PKA operations:

- The PKA core processes 64-bit words in its RAM. Accordingly, in the PKA section of this document, 'word' denotes a 64-bit unit.
- When writing an element as input in the PKA RAM, append an additional 64-bit word of zeros after the most significant word, except when the operand size is fixed at one word.
- All RAM storage addresses refer to the least significant word of the data. To obtain the actual address, the application must add the base address of the PKA to the indicated offset.
- Supported operand sizes are:
  - **ROS (RSA operand size)**: Data size is calculated as *(rsa_size / 64) + 1* words, where *rsa_size* is the modulus length in bits. For example, a 1024-bit RSA operand corresponds to 17 words (1088 bits).
  - **EOS (ECC operand size)**: Data size is *(ecc_size / 64) + 1* words, where *ecc_size* is the prime modulus length in bits. For example, a 192-bit ECC operand corresponds to four words (256 bits).

  Note: Both ROS and EOS include the additional zero word.
- Unless indicated otherwise, all operands in the tables are integers.

Note: Any fractional results in the formulas must be rounded to the nearest integer, as the PKA core processes data in 64-bit words.

Note: The maximum ROS is 66 words (4160-bit maximum exponent size), while the maximum EOS is 11 words (640-bit max operand size).

Example 1: Understanding endianness in PKA memory during ECC Fp scalar multiplication preparation

Write the *x*-coordinate of point P for an ECC P256 curve (EOS = 5 words) by placing the least significant bit at bit 0 of the word at address offset 0x578, and the most significant bit at bit 63 of the word at address offset 0x590. Then, write a zero word (0x0000000000000000) at address offset 0x598.

Example 2: Writing the curve coefficient '*a*' for ECC Fp scalar multiplication

To write the value *a* = -3 for a curve with a modulus length of 224 bits (rounded up to five 64-bit words), write the PKA memory with data as in the following table:

Table 469. Example of *'a'* curve coefficient for ECC Fp scalar

RAM offset	Value	Note
0x410	0x0000000000000001	Curve coefficient *a* sign without extra word
0x418	0x0000000000000011	Value of |*a*| LSB

Table 469. Example of *'a'* curve coefficient for ECC Fp scalar

RAM offset	Value	Note
0x420	0x0000000000000000	-
0x428	0x0000000000000000	-
0x430	0x0000000000000000	Value of |*a*| MSB
0x438	0x0000000000000000	Additional zero word

47.4.2 Montgomery parameter computation

This function is used to compute the Montgomery parameter (R^2 mod n) used by the PKA to convert operands into the Montgomery residue system representation. This operation can be very useful for fast mode operation because passing the Montgomery parameter as input saves the time for its computation.

Note: This operation also supports ECC curves when specifying the prime modulus length and EOS size.

The following table summarizes operation instructions for Montgomery parameter computation.

Table 470. Montgomery parameter computation

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x01	PKA_CR	6 bits
	Modulus length	(in bits, 0 ≤ value < 4160)	RAM@0x408	64 bits
	Modulus value *n*	(odd integer only, $n < 2^{4160}$)	RAM@0x1088	ROS
OUT	Result: R^2 mod *n*	-	RAM@0x620	

47.4.3 Modular addition

The following table summarizes operation instructions for modular addition operation that calculates *A* + *B* mod *n*.

Table 471. Modular addition

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x0E	PKA_CR	6 bits
	Operand length	(in bits, not null)	RAM@0x408	64 bits
	Operand *A*	(0 ≤ *A* < *n*)	RAM@0xA50	ROS
	Operand *B*	(0 ≤ *B* < *n*)	RAM@0xC68	
	Modulus value *n*	($n < 2^{4160}$)	RAM@0x1088	
OUT	Result: *A* + *B* mod *n*	(0 ≤ result < *n*)	RAM@0xE78	

47.4.4 Modular subtraction

Modular subtraction operation calculates:

- ***A* - *B* mod *n***, when $A \geq B$
- ***A* + *n* - *B* mod *n***, when $A < B$

The following table summarizes the operation instructions.

Table 472. Modular subtraction

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x0F	PKA_CR	6 bits
	Operand length	(in bits, not null)	RAM@0x408	64 bits
	Operand *A*	($0 \leq A < n$)	RAM@0xA50	ROS
	Operand *B*	($0 \leq B < n$)	RAM@0xC68	
	Modulus value *n*	($n < 2^{4160}$)	RAM@0x1088	
OUT	Result: *A* - *B* mod *n*	($0 \leq$ result $< n$)	RAM@0xE78	

47.4.5 Modular and Montgomery multiplication

To be more efficient when performing a sequence of multiplications, the PKA accelerates a multiplication that has at least one input in the Montgomery domain. The two main uses of this operation are:

- Map a value from natural domain to Montgomery domain and vice-versa
- Perform a modular multiplication $A \times B \bmod n$

The method to perform these operations is described next. The *x* function is this operation, and the *A*, *B*, and *C* operands are in the natural domain.

1. Inward or outward conversion to or from the Montgomery domain
   a) Assuming that *A* is an integer in the natural domain:
      – Compute *r2modn* using *Montgomery parameter computation*.
      – The result of $AR = A \times r2modn \bmod n$ is *A* in the Montgomery domain.
   b) Assuming that *BR* is an integer in the Montgomery domain:
      – The result of $B = BR \times 1 \bmod n$ is *B* in the natural domain.
      – Similarly, the *AR* value computed in *a)* can be converted into the natural domain by computing $A = AR \times 1 \bmod n$.
2. Simple modular multiplication $A \times B \bmod n$
   a) Compute *r2modn* using *Montgomery parameter computation*.
   b) Compute $AR = A \times r2modn \bmod n$. The output is in the Montgomery domain.
   c) Compute $AB = AR \times B \bmod n$. The output is in the natural domain.
3. Multiple modular multiplication $A \times B \times C \bmod n$
   a) Compute *r2modn* using *Montgomery parameter computation*.
   b) Compute $AR = A \times r2modn \bmod n$. The output is in the Montgomery domain.
   c) Compute $BR = B \times r2modn \bmod n$. The output is in the Montgomery domain.
   d) Compute $ABR = AR \times BR \bmod n$. The output is in the Montgomery domain.
   e) Compute $CR = C \times r2modn \bmod n$. The output is in the Montgomery domain.
   f) Compute $ABCR = ABR \times CR \bmod n$. The output is in the Montgomery domain.
   g) (optional) Repeat the two previous steps if multiplying with additional operands is required.
   h) Compute $ABC = ABCR \times 1 \bmod n$ to retrieve the result in the natural domain.

The following table summarizes the operation instructions.

Table 473. Montgomery multiplication

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x10	PKA_CR	6 bits
	Operand length	(in bits, not null)	RAM@0x408	64 bits
	Operand *A*	($0 \le A < n$)	RAM@0xA50	ROS
	Operand *B*	($0 \le B < n$)	RAM@0xC68	
	Modulus value *n*	(odd integer only, $n < 2^{4160}$)	RAM@0x1088	
OUT	Result: $A \times B \bmod n$(1)	-	RAM@0xE78	

1. Result in Montgomery domain or in natural domain, depending upon the inputs nature (see examples *2* and *3*).

47.4.6 Modular exponentiation

Modular exponentiation operation is commonly used to perform a single-step RSA operation. It calculates of $A^e \bmod n$.

RSA operation involving public information (RSA encryption) can use the normal or fast mode detailed on *Table 474* and *Table 475*. RSA operation involving secret information (RSA decryption) must use the protected mode detailed on *Table 476*, for security reason.

Note: Once this operation is started PKA control register and PKA memory is no more available. Access is restored once BUSY bit is set to 0 by the PKA.

When this operation completes with errors due to unexpected hardware events a PKA tamper event is triggered to TAMP peripheral, and access to PKA RAM becomes blocked until erased by hardware.

Note: When MODE[5:0] = 0x03, the error code is not affected when PKA automatically clears the PKA RAM at the end of this protected operation. When the error output equals 0xD60D, the result output is not affected either.

Operation instructions for modular exponentiation are summarized in *Table 474* (normal mode), *Table 475* (fast mode), and *Table 476* (protected mode). Fast mode usage is explained in *Section 47.3.6*.

Table 474. Modular exponentiation (normal mode)

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x00	PKA_CR	6 bits
IN	Exponent length	(in bits, not null)	RAM@0x400	64 bits
	Operand length	(in bits, not null)	RAM@0x408	
IN/OUT	Operand *A* (base of exponentiation)	($0 \le A < n$)	RAM@0xC68	ROS
IN	Exponent *e*	($0 \le e < n$)	RAM@0xE78	
	Modulus value *n*	(odd integer only, $n < 2^{4160}$)	RAM@0x1088	
OUT	Result: A^e mod *n*	($0 \le$ result $< n$)	RAM@0x838	

Table 475. Modular exponentiation (fast mode)

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x02	PKA_CR	6 bits
IN	Exponent length	(in bits, not null)	RAM@0x400	64 bits
	Operand length	(in bits, not null)	RAM@0x408	
IN/OUT	Operand *A* (base of exponentiation)	($0 \le A < n$)	RAM@0xC68	ROS
IN	Exponent *e*	($0 \le e < n$)	RAM@0xE78	
	Modulus value *n*	(odd integer only, $n < 2^{4160}$)	RAM@0x1088	
IN/OUT	Montgomery parameter R^2 mod *n*	(mandatory)	RAM@0x620	
OUT	Result: A^e mod *n*	($0 \le$ result $< n$)	RAM@0x838	

Table 476. Modular exponentiation (protected mode)

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x03	PKA_CR	6 bits
	Exponent *e* length	(in bits, not null)	RAM@0x400	64 bits
	Modulus or operand length	(in bits, not null)	RAM@0x408	
	Operand *A* (base of exponentiation)	($0 \le A < n$)	RAM@0x16C8	ROS
	Exponent *e*	($0 \le e < n$)	RAM@0x14B8	
	Modulus value *n*	(odd integer only, $n < 2^{4096}$)	RAM@0x0838	
	Phi value(1)	-	RAM@0x0C68	
OUT	Result: A^e mod *n*	($0 \le$ result $< n$)	RAM@0x838	
ERROR	Error A^e mod *n*	No errors: 0xD60D Errors: 0xCBC9	RAM@0x1298	64 bits

1. Euler totient function of n[1] with phi = (p - 1) × (q - 1), where p and q are prime factors of modulus n (see NIST SP800-56B Appendix C or *RSA encryption/decryption principle* for details). As optimization it is recommended to keep phi information as part of the key pair generation. Alternative is to store the key as (p, q, e, d) instead of (N, e, d, *phi*), in this case, to derive N and *phi* using PKA arithmetic multiplier: $N = p \times q$, and *phi* = (p - 1) × (q - 1).

47.4.7 Modular inversion

The modular inversion operation calculates multiplicative inverse A^{-1} mod n. If the modulus n is prime, for all values of A ($1 \le A < n$) modular inversion output is valid. If the modulus n is not prime, A has an inverse only if the greatest common divisor between A and n is 1.

If the operand A is a divisor of the modulus n the result is a multiple of a factor of n.

The following table summarizes the operation instructions.

Table 477. Modular inversion

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x08	PKA_CR	6 bits
	Operand length	(in bits, not null)	RAM@0x408	64 bits
	Operand *A*	($0 \le A < n$)	RAM@0xA50	ROS
	Modulus value *n*	(odd integer only, $n < 2^{4160}$)	RAM@0xC68	
OUT	Result: A^{-1} mod *n*	0 < result < *n*	RAM@0xE78	

47.4.8 Modular reduction

The modular reduction operation calculates the remainder of A divided by n.

The following table summarizes the operation instructions.

Table 478. Modular reduction

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x0D	PKA_CR	6 bits
	Operand length	(in bits, not null)	RAM@0x400	64 bits
	Modulus length	(in bits, 8 < value < 4160)	RAM@0x408	
	Operand *A*	($0 \le A < 2n < 2^{4160}$)	RAM@0xA50	ROS
	Modulus value *n*	(odd integer only, $n < 2^{4160}$)	RAM@0xC68	
OUT	Result *A* mod *n*	(0 < result < *n*)	RAM@0xE78	

47.4.9 Arithmetic addition

The arithmetic addition operation calculates *A* + *B*.

The following table summarizes the operation instructions.

Table 479. Arithmetic addition

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x09	PKA_CR	6 bits
	Operand length *M*	(in bits, not null)	RAM@0x408	64 bits
	Operand *A*	($0 \le A < 2^M$)	RAM@0xA50	ROS
	Operand *B*	($0 \le B < 2^M$)	RAM@0xC68	
OUT	Result: *A* + *B*	($0 \le$ result $< 2^{M+1}$)	RAM@0xE78	ROS + 1

47.4.10 Arithmetic subtraction

The arithmetic subtraction operation calculates:

- ***A* - *B***, when $A \ge B$
- $\boldsymbol{A + 2^{int(M / 32) \times 32 + 1} - B}$, when $A < B$ and the residue of $M / 32$ is greater than zero
- $\boldsymbol{A + 2^{int(M / 32) \times 32} - B}$, when $A < B$ and the residue of $M / 32$ is zero

For the last two list items, the 32-bit word following the most significant word of the output is 0xFFFF FFFF, as the result is negative.

The following table summarizes the operation instructions.

Table 480. Arithmetic subtraction

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x0A	PKA_CR	6 bits
	Operand length *M*	(in bits, not null)	RAM@0x408	64 bits
	Operand *A*	($0 \le < A < 2^M$)	RAM@0xA50	ROS
	Operand *B*	($0 \le < B < 2^M$)	RAM@0xC68	
OUT	Result: *A* - *B*	($0 \le$ result $< 2^M$)	RAM@0xE78	

47.4.11 Arithmetic multiplication

The arithmetic multiplication operation calculates A × B.

The following table summarizes the operation instructions.

Table 481. Arithmetic multiplication

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x0B	PKA_CR	6 bits
	Operand length *M*	(in bits, not null)	RAM@0x408	64 bits
	Operand *A*	($0 \le A < 2^M$)	RAM@0xA50	ROS
	Operand *B*	($0 \le B < 2^M$)	RAM@0xC68	
OUT	Result: *A* × *B*	($0 \le$ result $< 2^{2M}$)	RAM@0xE78	2xROS

47.4.12 Arithmetic comparison

The arithmetic comparison operation yields the following results:

- **0xED2C**, when *A* = *B*
- **0x7AF8**, when *A* > *B*
- **0x916A**, when *A* < *B*

The following table summarizes the operation instructions.

Table 482. Arithmetic comparison

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x0C	PKA_CR	6 bits
	Operand length *M*	(in bits, not null)	RAM@0x408	64 bits
	Operand *A*	($0 \le A < 2^M$)	RAM@0xA50	ROS
	Operand *B*	($0 \le B < 2^M$)	RAM@0xC68	
OUT	If result *A* = *B*	0xED2C, 0x7AF8, or 0x916A	RAM@0xE78	64 bits

47.4.13 RSA CRT exponentiation

For efficiency many popular crypto libraries such as OpenSSL RSA use the following optimization for decryption and signing based on the chinese remainder theorem (CRT):

- *p* and *q* are precomputed primes, stored as part of the private key
- $d_P = d \bmod (p - 1)$
- $d_Q = d \bmod (q - 1)$ and
- $q_{inv} = q^{-1} \bmod p$

These values allow the recipient to compute the exponentiation m = A^d (mod pq) more efficiently as follows:

- $m_1 = A^{dP} \bmod p$
- $m_2 = A^{dQ} \bmod q$
- $h = q_{inv} (m_1 - m_2) \bmod p$, with $m_1 > m_2$
- $m = m_2 + hq \bmod pq$

Operation instructions for computing CRT exponentiation A^d mod pq are summarized in *Table 483*.

Table 483. CRT exponentiation

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x07	PKA_CR	6 bits
IN	Operand length	(in bits, not null)	RAM@0x408	64 bits
IN	Operand d_P	$(0 < d_P < 2^{M/2})$	RAM@0x730	ROS / 2
	Operand d_Q	$(0 < d_Q < 2^{M/2})$	RAM@0xE78	
	Operand q_{inv}	$(0 < q_{inv} < 2^{M/2})$	RAM@0x948	
	Prime p(1)	$(0 < p < 2^{M/2})$	RAM@0xB60	
	Prime q(1)	$(0 < q < 2^{M/2})$	RAM@0x1088	
IN	Operand A	$(0 < A < 2^M)$	RAM@0x12A0	ROS
OUT	Result: A^d mod pq	(0 ≤ result < pq)	RAM@0x838	

1. Must be different from 2.

47.4.14 Point on elliptic curve Fp check

This operation checks whether a given point P (x, y) satisfies or not the curves over prime fields equation $y^2 = (x^3 + ax + b) \bmod p$, where a and b are elements of the curve.

The following table summarizes the operation instructions.

Table 484. Point on elliptic curve *Fp* check

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x28	PKA_CR	6 bits
	Modulus length	(in bits, not null, 8 < value < 640)	RAM@0x408	64 bits
	Curve coefficient *a* sign	0x0: positive 0x1: negative	RAM@0x410	
	Curve coefficient |*a*|	(absolute value, |*a*| < *p*)	RAM@0x418	EOS
	Curve coefficient *b*	(|*b*| < *p*)	RAM@0x520	
	Curve modulus value *p*	(odd integer prime, 0 < *p* < 2640)	RAM@0x470	
	Point P coordinate *x*	(*x* < p)	RAM@0x578	
	Point P coordinate *y*	(*y* < *p*)	RAM@0x5D0	
	Montgomery parameter R^2 mod *n*	-	RAM@0x4C8	
OUT	Result: point *P* on curve	0xD60D: point on curve 0xA3B7: point not on curve 0xF946: *x* or *y* coordinate is not smaller than modulus *p*	RAM@0x680	64 bits

47.4.15 ECC Fp scalar multiplication

This operation calculates $k \times P\,(x_P, y_P)$, where *P* is a point on a curve over prime fields and *x* is the elliptic curve scalar point multiplication. The result is a point that belongs to the same curve or a point at infinity.

Note: Once this operation is started PKA control register and PKA memory is no more available. Access is restored once BUSY bit is set to 0 by the PKA.

When this operation completes with errors due to unexpected hardware events, a PKA tamper event is triggered to TAMP peripheral, and access to PKA RAM becomes blocked until erased by hardware. PKA tamper is also triggered when the programmed input point is not found on the input ECC curve. PKA operation *point on elliptic curve* can be used to avoid this.

The following table summarizes the operation instructions.

Table 485. ECC Fp scalar multiplication

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x20	PKA_CR	6 bits
IN	Curve prime order *n* length	(in bits, not null,)	RAM@0x400	64 bits
	Curve modulus *p* length	(in bits, not null, 8 < value < 640)	RAM@0x408	
	Curve coefficient *a* sign	0x0: positive 0x1: negative	RAM@0x410	

Table 485. ECC Fp scalar multiplication (continued)

Parameters with direction		Value (note)	Storage	Size
IN	Curve coefficient |*a*|	(absolute value, |*a*| < *p*)	RAM@0x418	EOS
	Curve coefficient *b*	(positive integer)	RAM@0x520	
	Curve modulus value *p*	(odd integer prime, $0 < p < 2^{640}$)	RAM@0x1088	
	Scalar multiplier *k*	($0 \le k < n$)	RAM@0x12A0	
	Point P coordinate x_P	($x_P < p$)	RAM@0x578	
	Point P coordinate y_P	($y_P < p$)	RAM@0x470	
	Curve prime order *n*	(integer prime)	RAM@0xF88	
OUT	Result: *k* × *P* coordinate *x'*	(result < *p*)	RAM@0x578	EOS
	Result: *k* × *P* coordinate *y'*	(result < *p*)	RAM@0x5D0	
ERROR	Error *k* × *P*	No errors: 0xD60D Errors: 0xCBC9	RAM@0x680	64 bits

When performing this operation the following special cases must be noted:

- For *k* = 0 this function returns a point at infinity (0, 0) if curve parameter *b* is nonzero, (0, 1) otherwise. For *k* different from 0 it might happen that a point at infinity is returned. When the application detects this behavior, a new computation must be carried out.
- For *k* < 0 (that is, a negative scalar multiplication is required) the multiplier absolute value
  k = |-*k*| must be provided to the PKA. After the computation completion, the formula -*P* = (*x*, -*y*) can be used to compute the *y* coordinate of the effective final result (the *x* coordinate remains the same).

Note: The error code is not affected when PKA automatically clears the PKA RAM at the end of this protected operation. When the error output equals 0xD60D, the result output is not affected either.

47.4.16 ECDSA sign

Table 486 (input parameters) and *Table 487* (output parameters) summarize the ECDSA signing operation.

Upon an output error different from 0xD60D, the application must generate a new *k* and repeat the ECDSA sign operation.

Note: As long as this operation is ongoing (BUSY = 1), the PKA control register and the PKA memory are not accessible. The access is restored when the PKA clears the BUSY bit.

The operation completion with errors due to unexpected hardware events triggers a PKA tamper event in the TAMP peripheral and blocks access to the PKA RAM until the hardware erases the event. Missing programmed input point on the input ECC curve also triggers a PKA tamper event. The use of the *point on elliptic curve* PKA operation prevents this.

Table 486. ECDSA sign - Inputs

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x24	PKA_CR	6 bits
	Curve prime order *n* length (*nlen*)	(in bits, not null)	RAM@0x400	64 bits
	Curve modulus *p* length	(in bits, 8 < value < 640)	RAM@0x408	
	Curve coefficient *a* sign	0x0: positive 0x1: negative	RAM@0x410	
	Curve coefficient |*a*|	(absolute value, |*a*| < *p*)	RAM@0x418	EOS
	Curve coefficient *b*	(positive integer)	RAM@0x520	
	Curve modulus value *p*	(odd integer prime, $0 < p < 2^{640}$)	RAM@0x1088	
	Integer *k*(1)	($0 \leq k <$ n)	RAM@0x12A0	
	Curve base point *G* coordinate *x*	($x < p$)	RAM@0x578	
	Curve base point *G* coordinate *y*	($y < p$)	RAM@0x470	
	Hash of message *z*	(hash size equal to *nlen*)(2)	RAM@0xFE8	
	Private key *d*	($0 < d < n$)	RAM@0xF28	
	Curve prime order *n*	(integer prime)	RAM@0xF88	

1. This integer is usually a cryptographically secure random number, but in some cases *k* can be deterministically generated.
2. To match the hash parameter size to the length of the curve prime order *n,* pad the result with zeros or use the hash truncation.

Table 487. ECDSA sign - Outputs

Parameters with direction		Value (note)	Storage	Size
OUT	Signature part *r*	($0 < r < n$)	RAM@0x730	EOS
	Signature part *s*	($0 < s < n$)	RAM@0x788	
ERROR	Result of signature	0xD60D: successful computation, no error 0xCBC9: failed computation 0xA3B7: signature part r is equal to 0 0xF946: signature part s is equal to 0	RAM@0xFE0	64 bits

Note: The error code is not affected when the PKA automatically clears the PKA RAM at the end of this protected operation. The error output 0xD60D does not affect the result output either.

Extended ECDSA support

The PKA also supports the extended ECDSA signature, which accepts the same inputs as the standard ECDSA signature (see *Table 486*) and produces similar outputs (see *Table 487*), with the addition of the point *kG* coordinates. The following table defines these additional outputs.

Table 488. Extended ECDSA sign - additional outputs

Parameters with direction		Value (note)	Storage	Size
OUT	Curve point *kG* coordinate x_1	($0 \le x_1 < p$)	RAM@0x1400	EOS
	Curve point *kG* coordinate y_1	($0 \le y_1 < p$)	RAM@0x1458	

47.4.17 ECDSA verification

Table 489 (input parameters) and *Table 490* (output parameters) summarize the ECDSA verification operation.

Upon an output error different from 0xD60D, the signature is not verified.

Table 489. ECDSA verification - inputs

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x26	PKA_CR	6 bits
	Curve prime order *n* length (*nlen*)	(in bits, not null)	RAM@0x408	64 bits
	Curve modulus *p* length	(in bits, not null, 8 < value < 640)	RAM@0x4C8	
	Curve coefficient *a* sign	0x0: positive 0x1: negative	RAM@0x468	
	Curve coefficient |*a*|	(absolute value, $\|a\| < p$)	RAM@0x470	EOS
	Curve modulus value *p*	(odd integer prime, $0 < p < 2^{640}$)	RAM@0x4D0	
	Curve base point *G* coordinate *x*	($x < p$)	RAM@0x678	
	Curve base point *G* coordinate *y*	($y < p$)	RAM@0x6D0	
	Public-key curve point *Q* coordinate x_Q	($x_Q < p$)	RAM@0x12F8	
	Public-key curve point *Q* coordinate y_Q	($y_Q < p$)	RAM@0x1350	
	Signature part *r*	($0 < r < n$)	RAM@0x10E0	
	Signature part *s*	($0 < s < n$)	RAM@0xC68	
	Hash of message *z*	(hash size equal to *nlen*)(1)	RAM@0x13A8	
	Curve prime order *n*	(integer prime)	RAM@0x1088	

1. To match the hash parameter size to the length of the curve prime order *n,* pad the result with zeros or use the hash truncation.

Table 490. ECDSA verification - outputs

Parameters with direction		Value (note)	Storage	Size
OUT	Result: ECDSA verify	– 0xD60D: valid signature – 0xA3B7: invalid signature	RAM@0x5D0	64 bits
	Computed signature part *r*	– ($0 < r < n$)	RAM@0x578	EOS

47.4.18 ECC complete addition

The ECC complete addition operation calculates the sum of two points on an elliptic curve.

Operation instructions are summarized in *Table 491*.

Note: The two input points and the resulting point are represented in Jacobian coordinates (X,Y,Z). To input a point in affine coordinates (x, y) conversion (X, Y, Z) = (x, y, 1) can be used. To convert resulting point to Jacobian coordinates conversion (x, y)= (X / Z^2, Y / Z^3) can be used.

Table 491. ECC complete addition

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x23	PKA_CR	6 bits
	Curve modulus *p* length	(in bits, not null, 8 < value < 640)	RAM@0x408	64 bits
	Curve coefficient *a* sign	– 0x0: positive 0x1: negative	RAM@0x410	
	Curve modulus value *p*	(odd integer prime, $0 < p < 2^{640}$)	RAM@0x470	EOS
	Curve coefficient |*a*|	(absolute value, $\|a\| < p$)	RAM@0x418	
	First point P coordinate *X*	($x < p$)	RAM@0x628	
	First point P coordinate *Y*	($y < p$)	RAM@0x680	
	First point P coordinate *Z*	($z < p$)	RAM@0x6D8	
	Second point Q coordinate *X*	($x < p$)	RAM@0x730	
	Second point Q coordinate *Y*	($y < p$)	RAM@0x788	
	Second point Q coordinate *Z*	($z < p$)	RAM@0x7E0	
OUT	Result coordinate *X*	($x < p$)	RAM@0xD60	
	Result coordinate *Y*	($y < p$)	RAM@0xDB8	
	Result coordinate *Z*	($z < p$)	RAM@0xE10	

47.4.19 ECC double base ladder

ECC double base ladder operation consists in the computation of $k \times P + m \times Q$, where (P, Q) are two points on an elliptic curve and (k, m) are two scalars. Operation instructions are summarized in *Table 492*.

If the resulting point is the point at infinity (error code 0xA3B7), the resulting coordinate equals to (0, 0).

Note: The two input points are represented in Jacobian coordinates (X, Y , Z). To input a point in affine coordinates (x, y) conversion (X, Y, Z) = (x, y, 1) can be used. The result is represented in affine coordinates (x ,y)

This operation requires the input point Z coordinate to be equal to 1 (input point represented in affine coordinates).

Table 492. ECC double base ladder

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x27	PKA_CR	6 bits
	Curve prime order *n* length	(in bits, not null)	RAM@0x400	64 bits
	Curve modulus *p* length	(in bits, not null, 8 < value < 640)	RAM@0x408	
	Curve coefficient *a* sign	– 0x0: positive – 0x1: negative	RAM@0x410	EOS
	Curve coefficient |*a*|	(absolute value, |a| < p)	RAM@0x418	
	Curve modulus value *p*	(odd integer prime, $0 < p < 2^{640}$)	RAM@0x470	
	Integer *k*	($0 < k < 2^{640}$)	RAM@0x520	
	Integer *m*	($0 < m < 2^{640}$)	RAM@0x578	
	First point *P* coordinate *X*	($x < p$)	RAM@0x628	
	First point *P* coordinate *Y*	($y < p$)	RAM@0x680	
	First point *P* coordinate *Z*	($z < p$)	RAM@0x6D8	
	Second point *Q* coordinate *X*	($x < p$)	RAM@0x730	
	Second point *Q* coordinate *Y*	($y < p$)	RAM@0x788	
	Second point *Q* coordinate *Z*	($z < p$)	RAM@0x7E0	
OUT	Result coordinate *x*	($x < p$)	RAM@0x578	EOS
	Result coordinate *y*	(y < *p*)	RAM@0x5D0	
	Error code	– Point not at infinity: 0xD60D – Point at infinity: 0xA3B7	RAM@0x520	64 bits

47.4.20 ECC projective to affine

ECC projective to affine operation calculates the conversion between the representation of a point P in homogeneous projective coordinates and the representation of the point P in affine coordinates. Namely, if the point is represented by the triple (*X*, *Y*, *Z*), it calculates the affine coordinates (*x*, *y*) = (*X* / *Z*, *Y* / *Z*).

All the operations are performed modulo the modulus p of the curve, which the point belongs to. If the resulting point is the point at infinity (error code 0xA3B7), resulting coordinate equals (0,0).

Operation instructions are summarized in *Table 493*.

Table 493. ECC projective to affine

Parameters with direction		Value (note)	Storage	Size
IN	MODE[5:0]	0x2F	PKA_CR	6 bits
	Curve modulus *p* length	(in bits, 8 < value < 640)	RAM@0x408	64 bits
	Curve modulus value *p*	(odd integer prime, $0 < p < 2^{640}$)	RAM@0x470	EOS
	Point P coordinate *X* (projective)	($x < p$)	RAM@0xD60	
	Point P coordinate *Y* (projective)	($y < p$)	RAM@0xDB8	
	Point P coordinate *Z* (projective)	($z < p$)	RAM@0xE10	
	Montgomery parameter R^2 mod *n*	-	RAM@0x4C8	
OUT	Point P coordinate *x* (affine)	($x < p$)	RAM@0x578	
	Point P coordinate *y* (affine)	($y < p$)	RAM@0x5D0	
ERROR	Error code	Point not at infinity: 0xD60D Point at infinity: 0xA3B7	RAM@0x680	64 bits

47.5 Example of configurations and processing times

47.5.1 Supported elliptic curves

The PKA supports all non-singular elliptic curves defined over prime fields. Those curves can be described with a short Weierstrass equation, $y^2 = x^3 + ax + b$ (mod p).

Note: Binary curves, Edwards curves and Curve25519 are not supported by the PKA.
The maximum supported operand size for ECC operations is 640 bits.

When publishing the ECC domain parameters of those elliptic curves, standard bodies define the following parameters:

- the prime integer *p*, used as the modulus for all point arithmetic in the finite field *GF(p)*
- the (usually prime) integer *n*, the order of the group generated by *G*, defined below
- the base point of the curve *G*, defined by its coordinates (*Gx*, *Gy*)
- the integers *a* and *b*, coefficients of the short Weierstrass equation.

For the last bullet, when standard bodies define *a* as negative, PKA supports two representations:

1. ***a* defined as *p*-|*a*|** in the finite field *GF(p)*, for example ***p*-3**:
   Curve coefficient p = 0xFFFFFFFE FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF 00000000 FFFFFFFF FFFFFFF**F**
   Curve coefficient a sign= 0x0 (positive)
   Curve coefficient a = 0xFFFFFFFE FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF 00000000 FFFFFFFF FFFFFFF**C**
2. ***a* defined as negative**, for example **-3**:
   Curve coefficient p = 0xFFFFFFFE FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF 00000000 FFFFFFFF FFFFFFFF
   Curve coefficient a sign= 0x**1** (negative)
   Curve coefficient a = 0x00000000 00000000 00000000 00000000 00000000 00000000 00000000 0000000**3**

Table 494 summarizes the family of curves supported by PKA for ECC operations.

Table 494. Family of supported curves for ECC operations

Curve name	Standard	Reference	
P-192	NIST	*Digital Signature Standard (DSS)*, NIST FIPS 186-4	
P-224			
P-256			
P-384			
P-521			
brainpoolP224r1, brainpoolP224t1	IETF	– *Brainpool Elliptic Curves*, IETF RFC 5639 – *Brainpool Elliptic Curves for the Internet Key Exchange (IKE) Group Description Registry*, IETF RFC 6932	https://tools.ietf.org
brainpoolP256r1, brainpoolP256t1			
brainpoolP320r1, brainpoolP320t1			
brainpoolP384r1, brainpoolP384t1			
brainpoolP512r1, brainpoolP512t1			
secp192k1, secp192r1	SEC	*Standards for Efficient Cryptography SEC 2 curves*	https://www.secg.org
secp224k1, secp224r1			
secp256k1, secp256r1			
secp384r1			
secp521r1			
Recommended curve parameters for public key cryptographic algorithm SM2	OSCCA	– *Public key cryptographic algorithm SM2 based on elliptic curves*, Organization of State Commercial Administration of China OSCCA SM2, December 2010 – *Digital signatures - Part 3 Discrete logarithm based mechanisms*, ISO/IEC 14888-3, November 2018	

47.5.2 Computation times

The following tables summarize the PKA computation times, expressed in AHB clock cycles.

Table 495. Modular exponentiation

Exponent length (in bits)	Mode	Modulus length (in bits)			
		1024	2048	3072	4096
3	Normal	124600	491000	684000	1133200
	Fast	22700	82000	178000	311000
17	Normal	135700	531400	772400	1288000
	Fast	33800	122500	266500	465800
2^{16} + 1	Normal	180000	693700	1126200	1907200
	Fast	78200	284700	620400	1085000
1024	Protected	9958000	-	-	-
	Normal	5850000	-	-	-
	Fast	5748000	-	-	-
	CRT(1)	1775000	-	-	-
2048	Protected	-	63886000	-	-
	Normal	-	42240000	-	-
	Fast	-	41832000	-	-
	CRT(1)	-	11670000	-	-
3072	Protected	-	-	199403000	-
	Normal	-	-	136830000	-
	Fast	-	-	136325000	-
	CRT(1)	-	-	36886000	-
4096	Protected	-	-	-	454318000
	Normal	-	-	-	316000000
	Fast	-	-	-	315226000
	CRT(1)	-	-	-	84577000

1. CRT stands for chinese remainder theorem optimization (MODE[5:0] bitfield= 0x07).

Table 496. ECC scalar multiplication(1)

Modulus length (in bits)							
160	192	256	320	384	512	521	640
-	1590000	3083000	5339000	8518000	17818000	21053000	31826000

1. These times depend on the number of 1s included in the scalar parameter, and include the computation of Montgomery parameter R2.

Table 497. ECDSA signature average computation time(1) (2)

Modulus length (in bits)							
160	**192**	**256**	**320**	**384**	**512**	**521**	**640**
-	1500000	2744000	4579000	7184000	14455000	16685000	24965000

1. These values are average execution times of random moduli of given length, as they depend upon the length and the value of the modulus.
2. The execution time for the moduli that define the finite field of NIST elliptic curves is shorter than that needed for the moduli used for Brainpool elliptic curves or for random moduli of the same size.

Table 498. ECDSA verification average computation times

Modulus length (in bits)							
160	**192**	**256**	**320**	**384**	**512**	**521**	**640**
1011000	1495000	2938000	5014000	7979000	16804000	19254000	29582000

Table 499. ECC double base ladder average computation times

Modulus length (in bits)							
160	**192**	**256**	**320**	**384**	**512**	**521**	**640**
967000	1419000	2768000	4784000	7547000	15854000	18257000	28257000

Table 500. ECC projective to affine average computation times

Modulus length (in bits)						
160	**192**	**256**	**320**	**384**	**512**	**640**
47600	78000	148300	253000	419000	838400	1049300

Table 501. ECC complete addition average computation times

Modulus length (in bits)						
160	**192**	**256**	**320**	**384**	**512**	**640**
10000	12000	18000	26000	39000	63000	89000

Table 502. Point on elliptic curve Fp check average computation times

Modulus length (in bits)							
160	**192**	**256**	**320**	**384**	**512**	**521**	**640**
3400	4200	6100	8300	10900	17200	-	-

Table 503. Montgomery parameters average computation times(1)

Modulus length (in bits)							
192	**256**	**320**	**512**	**1024**	**2048**	**3072**	**4096**
8600	8710	11870	17000	102000	410000	506000	822000

1. The computation times depend upon the length and the value of the modulus, hence these values are average execution times of random moduli of given length.

47.6 PKA interrupts

There are five individual maskable interrupt sources generated by the public key accelerator, signaling the following events:

1. PKA unsupported operation error (OPERRF), see *Section 47.3.8*
2. Access to unmapped address (ADDRERRF), see *Section 47.3.8*
3. PKA RAM access while PKA operation is in progress (RAMERRF), see *Section 47.3.8*
4. PKA end of operation (PROCENDF)
5. Chaining mode flags (CMF)

The interrupt sources are connected to the same global interrupt request signal pka_it.

The user can enable or disable above interrupt sources individually by changing the mask bits in the *PKA control register (PKA_CR)*. Setting the appropriate mask bit to 1 enables the interrupt. The status of the individual interrupt events can be read from the PKA status register (PKA_SR), and it is cleared in PKA_CLRFR register.

CMF interrupt is triggered by the end of an operation (DATAOKF, RNGOKF) or by a chaining mode error (see *Section 47.3.8*). Chaining modes are described in *Section 47.3.7*.

Table 504 gives a summary of the available features.

Table 504. PKA interrupt requests

Acronym	Event	Event flag	Enable control bit	Clear method
PKA	Unsupported operation	OPERRF	OPERRIE	Set OPERRFC bit
	Access to unmapped address error	ADDRERRF	ADDRERRIE	Set ADDRERRFC bit
	PKA RAM access error	RAMERRF	RAMERRIE	Set RAMERRFC bit
	PKA end of operation	PROCENDF	PROCENDIE	Set PROCENDFC bit
	Chaining mode flag	CMF	CMFIE	Set CMFC bit

47.7 PKA registers

47.7.1 PKA control register (PKA_CR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMFIE	OPERRIE	ADDRERRIE	RAMERRIE	Res.	PROCENDIE	Res.
									rw	rw	rw	rw		rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	MODE[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	START	EN
		rw	rw	rw	rw	rw	rw							rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **CMFIE**: Chaining mode flags interrupt enable
0: No interrupt is generated when any flag in bits 8 to 15 is set in PKA_SR.
1: An interrupt is generated when any flag in bits 8 to 15 is set in PKA_SR.

Bit 21 **OPERRIE**: Operation error interrupt enable
0: No interrupt is generated when OPERRF flag is set in PKA_SR.
1: An interrupt is generated when OPERRF flag is set in PKA_SR.

Bit 20 **ADDRERRIE**: Address error interrupt enable
0: No interrupt is generated when ADDRERRF flag is set in PKA_SR.
1: An interrupt is generated when ADDRERRF flag is set in PKA_SR.

Bit 19 **RAMERRIE**: RAM error interrupt enable
0: No interrupt is generated when RAMERRF flag is set in PKA_SR.
1: An interrupt is generated when RAMERRF flag is set in PKA_SR.

Bit 18 Reserved, must be kept at reset value.

Bit 17 **PROCENDIE**: End of operation interrupt enable
0: No interrupt is generated when PROCENDF flag is set in PKA_SR.
1: An interrupt is generated when PROCENDF flag is set in PKA_SR.

Bits 16:14 Reserved, must be kept at reset value.

Bits 13:8 **MODE[5:0]**: PKA operation code

000000: Montgomery parameter computation then modular exponentiation
000001: Montgomery parameter computation only
000010: Modular exponentiation only (Montgomery parameter must be loaded first)
000011: Modular exponentiation (protected, used when manipulating secrets)
100000: Montgomery parameter computation then ECC scalar multiplication (protected)
100100: ECDSA sign (protected)
100110: ECDSA verification
101000: Point on elliptic curve Fp check
000111: RSA CRT exponentiation
001000: Modular inversion
001001: Arithmetic addition
001010: Arithmetic subtraction
001011: Arithmetic multiplication
001100: Arithmetic comparison
001101: Modular reduction
001110: Modular addition
001111: Modular subtraction
010000: Montgomery multiplication
100011: ECC complete addition
100111: ECC double base ladder
101111: ECC projective to affine

When an operation not listed here is written by the application with EN bit set, OPERRF bit is set in PKA_SR register, and the write to MODE[5:0] bitfield is ignored. When PKA is configured in limited mode (LMF = 1 in PKA_SR), writing a MODE[5:0] different from 0x26 with EN bit to 1 triggers OPERRF bit to be set and write to MODE[5:0] bit is ignored.

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **START**: start the operation

Set this bit to start the operation selected by the MODE[5:0] bitfield, using the operands and data already written to the PKA RAM. This bit is always read as 0.

When an illegal operation is selected while START bit is set no operation is started, and OPERRF bit is set in PKA_SR.

Note: START is ignored if PKA is busy.

Bit 0 **EN**: PKA enable

0: Disable PKA

1: Enable PKA; PKA becomes functional when INITOK is set by hardware in PKA_SR. When an illegal operation is selected while EN = 1, OPERRF bit is set in PKA_SR. See PKA_CR.MODE[5:0] bitfield for details.

Note: When EN = 0, PKA RAM can still be accessed by the application.

47.7.2 PKA status register (PKA_SR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMF	OPERRF	ADDRERRF	RAMERRF	Res.	PROCENDF	BUSY
									r	r	r	r		r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RNGERRF	MDERRF	TRZERRF	DATAZF	INCRERRF	DATAOKF	RNGOKF	Res.	Res.	Res.	Res.	Res.	CCEN	LMF	INITOK
	r	r	r	r	r	r	r						r	r	r

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **CMF**: Chaining mode flags

This status bit is only used when CCEN status bit is set in this register.

0: No chaining mode events.

1: Ongoing chaining mode sequence triggered at least one flag status in bits 8 to 14 of this register.

This bit is cleared using CMFC bit in PKA_CLRFR.

Bit 21 **OPERRF**: Operation error flag

0: No event error

1: An illegal or unknown operation has been selected in PKA_CR register

This bit is cleared using OPERRFC bit in PKA_CLRFR.

Bit 20 **ADDRERRF**: Address error flag

0: No address error

1: Address access is out of range (unmapped address)

This bit is cleared using ADDRERRFC bit in PKA_CLRFR.

Bit 19 **RAMERRF**: PKA RAM error flag

0: No PKA RAM access error

1: An AHB access to the PKA RAM occurred while the PKA core was computing and using its internal RAM (AHB PKA_RAM access are not allowed while PKA operation is in progress).

This bit is cleared using RAMERRFC bit in PKA_CLRFR.

Bit 18 Reserved, must be kept at reset value.

Bit 17 **PROCENDF**: PKA end of operation flag

0: Operation in progress

1: PKA operation is completed. This flag is set when the BUSY bit is deasserted.

Bit 16 **BUSY**: Busy flag

This bit is set whenever a PKA operation is in progress (START = 1 in PKA_CR). It is automatically cleared when the computation is complete, making PKA RAM accessible again.

0: No operation is in progress (default)

1: An operation is in progress

When CCEN = 1 PKA sets BUSY bit when it runs a sanity check on a random number that CCB wrote to the PKA RAM during a chaining sequence (see *Section 47.3.7*).

If PKA is started with a wrong opcode, it stays busy for a couple of cycles, then it aborts automatically the operation and goes back to ready (BUSY = 0).

Bit 15 Reserved, must be kept at reset value.

Bit 14 **RNGERRF**: RNG error flag

This read-only chaining mode error flag is active only when CCEN is set in this register.

0: No random number drawn from RNG, or generated ECC private key is NIST compliant.

1: Random number drawn from RNG did not pass NIST “key pair generation by testing candidates” equivalent algorithm (see FIPS 186-4 annex B.4.2). The last chaining operation must be restarted, otherwise the selected PKA operation remains unusable.

This bit is cleared when CMFC bit is set in PKA_CLRFR.

Bit 13 **MDERRF**: Mode error flag

This read-only chaining mode error flag is active only when CCEN is set in this register.

0: No mode error

1: The value written in MODE[5:0] of PKA_CR registers is different from the expected value corresponding to the CCOP mode selected in the CCB peripheral. Refer to *Section 47.3.7* for details.

This bit is cleared when CMFC bit is set in PKA_CLRFR.

Bit 12 **TRZERRF**: Trailing zeroes error flag

This read-only chaining mode error flag is active only when CCEN is set in this register.

0: No trailing 0s error

1: Clear-text coming from CPU, or decrypted data coming from SAES does not have the required trailing 0s.

This bit is cleared when CMFC bit is set in PKA_CLRFR.

Bit 11 **DATAZF**: Data zeroed error flag

This read-only chaining mode error flag is active only when CCEN is set in this register. DATAZF is set when PKA finds the complete data written to PKA RAM equal to 0, with all the expected 32-bit words null. This bit is cleared when CMFC bit is set in PKA_CLRFR.

Bit 10 **INCRERRF**: Increment error flag

This read-only chaining mode error flag is active only when CCEN is set in this register.

0: No increment error

1: During the reading or writing of protected parameters from or to the PKA RAM, the application did not properly incremented the address. Refer to *Section 47.3.7* for details.

During the read or write of an operand, and before DATAOKF or RNGOKF is set, the INCRERRF flag stays cleared if the application reads or writes again this operand (starting from the lowest address). This bit is cleared by setting the CMFC bit in PKA_CLRFR.

Bit 9 **DATAOKF**: Data OK flag

This read-only chaining mode status flag is active only when CCEN is set in this register.

0: Data not OK (if applicable), otherwise no event.

1: Sequential writes or reads to or from the PKA RAM successfully transfered the expected amount of data from or to SAES. Alternatively, the CPU wrote the correct amount of data in the PKA RAM. Refer to *Section 47.3.7* for details.

This bit is cleared when CMFC bit is set in PKA_CLRFR.

Bit 8 **RNGOKF**: RNG OK flag

This read-only chaining mode status flag is active only when CCEN is set in this register.

0: Random number not OK (if applicable). No event otherwise.

1: Sequential writes to PKA RAM successfully transfered the expected amount of random data from the RNG. Refer to *Section 47.3.7* for details.

This bit is cleared when CMFC bit is set in PKA_CLRFR.

Bits 7:3 Reserved, must be kept at reset value.

Bit 2 **CCEN**: Coupling and chaining mode enable

This bit is set when the application configures the CCB to run coupling and chaining sequences that perform protected PKA operation using the SAES and (optionally) RNG peripherals.

0: Access to PKA RAM and programming of PKA_CR has no extra limitation.

1: The PKA RAM is write-only until START is set (it is no access then), and the MODE[5:0] value written in PKA_CR must correspond to the CCOP mode selected in the CCB peripheral. The application must also follow the coupling and chaining sequences described in *Section 47.3.7*.

Bit 1 **LMF**: Limited mode flag

This bit is updated when EN bit in PKA_CR is set

0: All values documented in MODE[5:0] bitfield can be used.

1: Only ECDSA verification (MODE[5:0] = 0x26) is supported by the PKA.

Bit 0 **INITOK**: PKA initialization OK

This bit is asserted when PKA initialization is complete.

0: PKA is not initialized correctly. START bit cannot be set.

1: PKA is initialized correctly and can be used normally.

When RNG is not able to output proper random numbers or when SAES is using the RNG bus, INITOK remains at 0. If it happens, make sure the RNG peripheral is properly clocked and initialized, and the SAES peripheral is clocked with BUSY bit cleared in SAES_SR to release the RNG bus, then enable PKA again.

47.7.3 PKA clear flag register (PKA_CLRFR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMFC	OPERRFC	ADDRERRFC	RAMERRFC	Res.	PROCENDFC	Res.
									w	w	w	w		w	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **CMFC**: Clear chaining mode flag

0: No action

1: Clear the CMF flag and the chaining mode status bits in 8 to 15 in PKA_SR

Bit 21 **OPERRFC**: Clear operation error flag

0: No action

1: Clear the OPERRF flag in PKA_SR

Bit 20 **ADDRERRFC**: Clear address error flag

0: No action

1: Clear the ADDRERRF flag in PKA_SR

Bit 19 **RAMERRFC**: Clear PKA RAM error flag

0: No action

1: Clear the RAMERRF flag in PKA_SR

Bit 18 Reserved, must be kept at reset value.

Bit 17 **PROCENDFC**: Clear PKA end of operation flag
0: No action
1: Clear the PROCENDF flag in PKA_SR

Bits 16:0 Reserved, must be kept at reset value.

Note: Reading PKA_CLRFR returns all 0s.

47.7.4 PKA RAM

The PKA RAM is mapped at the offset address of 0x0400 compared to the PKA base address. Only 32-bit word single accesses are supported, through PKA.AHB interface.

RAM size is 5336 bytes (max word offset: 0x14D0)

Note: PKA RAM cannot be used just after a PKA reset or a product reset, as described in Section 47.3.3: PKA reset and clocks.

47.7.5 PKA register map

Table 505. PKA register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	PKA_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMFIE	OPERRIE	ADDRERRIE	RAMERRIE	Res.	PROCENDIE	Res.	Res.	Res.	MODE[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	START	EN
	Reset value										0	0	0	0		0				0	0	0	0	0	0							0	0
0x004	PKA_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMF	OPERRF	ADDRERRF	RAMERRF	Res.	PROCENDF	BUSY	Res.	RNGERRF	MDERRF	TRZERRF	DATAZF	INCRERRF	DATAOKF	RNGOKF		Res.	Res.	Res.	Res.	Res.	CCEN	LMF	INITOK
	Reset value										0	0	0	0		0	0		0	0	0	0	0	0	0						0	0	0
0x008	PKA_CLRFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMFC	OPERRFC	ADDRERRFC	RAMERRFC	Res.	PROCENDFC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value										0	0	0	0		0																	

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

48 On-the-fly decryption engine (OTFDEC)

48.1 OTFDEC introduction

OTFDEC allows on-the-fly decryption of the AHB traffic based on the read request address information. Four independent and non-overlapping encrypted regions can be defined in OTFDEC.

OTFDEC uses AES-128 in counter mode to achieve the lowest possible latency. As a consequence, each time the content of one encrypted region is changed, the entire region must be re-encrypted with a different cryptographic context (key or initialization vector). This constraint makes OTFDEC suitable to decrypt read-only data or code, stored in external NOR flash.

Note: When OTFDEC is used in conjunction with OCTOSPI, it is mandatory to access the flash memory using the memory-mapped mode of the flash memory controller.

When security is enabled in the product, OTFDEC can be programmed only by a secure host.

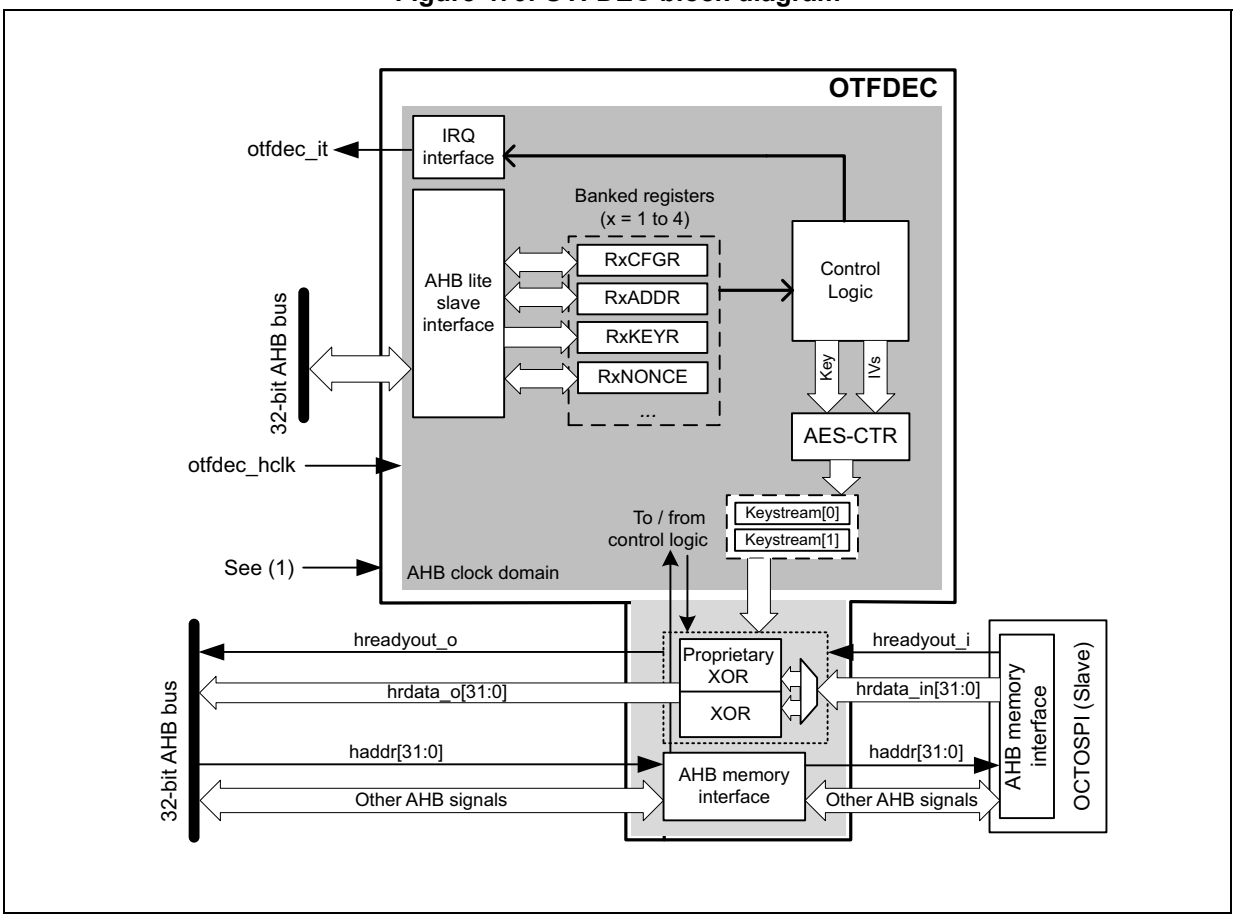
48.2 OTFDEC main features

- On-the-fly 128-bit decryption during the OCTOSPI Memory-mapped read operations (single or multiple).
  - Use of AES in counter (CTR) mode, with two 128-bit keystream buffers
  - Support for any read size
  - Physical address of the reads used for the encryption/decryption
- Up to four independent encrypted regions
  - Granularity of the region definition: 4096 bytes
  - Region configuration write-locking mechanism
  - Each region has its own 128-bit key, two bytes firmware version, and eight bytes application-defined nonce. At least one of those must be changed each time an encryption is performed by the application.
- Encryption keys confidentiality and integrity protection
  - Write-only registers, with software locking mechanism
  - Availability of 8-bit CRC as public key information
- Support for OCTOSPI pre-fetching mechanism
- Possibility to select an enhanced encryption mode to add a proprietary layer of protection on top of AES stream cipher (execute only)
- Privileged-aware AMBA AHB slave peripheral, accessible through 32-bit word single accesses only (otherwise an AHB bus error is generated, and write accesses are ignored)
- Secure only programming if TrustZone security is enabled in the product
- Encryption mode

48.3 OTFDEC functional description

48.3.1 OTFDEC block diagram

Figure 479. OTFDEC block diagram



1. otfdec_tzen

48.3.2 OTFDEC internal signals

Table 506 describes a list of useful to know internal signals available at OTFDEC level, not at the product level (on pads).

Table 506. OTFDEC internal input/output signals

Signal name	Signal type	Description
otfdec_hclk	Digital input	AHB bus clock
otfdec_it	Digital output	OTFDEC global interrupt request
otfdec_tzen	Digital input	OTFDEC TrustZone enable, controlling TrustZone features of the peripheral (TZEN)

The TZEN option bit in FLASH is used to activate TrustZone in the device.

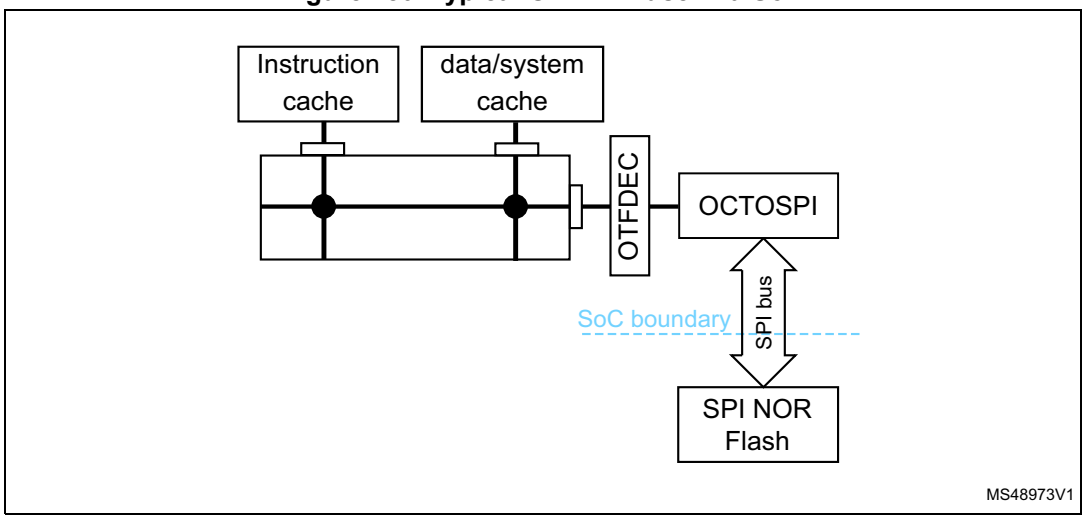
- TZEN = 1: TrustZone security is enabled in the product.
- TZEN = 0: TrustZone security is disabled in the product.

48.3.3 OTFDEC on-the-fly decryption

Introduction

Typical usage for OTFDEC is shown on *Figure 480*.

Figure 480. Typical OTFDEC use in a SoC



Original purpose of OTFDEC is to protect the confidentiality of read-only firmware libraries stored in external SPI NOR flash devices.

A special locking scheme is available in OTFDEC in order to protect the integrity of the decryption keys and also to protect the other configurations against software denial of services attacks. OTFDEC access to most registers can be made privileged-only by setting PRIV bit in OTFDEC_PRIVCFGR register. OTFDEC is only writeable by TrustZone CPU, when TrustZone security is activated.

When OTFDEC is used in conjunction with OCTOSPI, it is mandatory to read the flash memory using the Memory-mapped mode of the flash controller.

On top of decrypting on-the-fly, OTFDEC can also encrypt 32-bit word at a time (see *Section 48.5.3: Encrypting for OTFDEC* for more details).

OTFDEC architecture

OTFDEC analyzes all AHB read transfers on the associated AHB bus. If the read request is within one of the four regions programmed in OTFDEC, the control logic triggers a keystream computation based on AES algorithm in counter mode. This keystream is then used to decrypt on-the-fly the data present in the read transfer from the OCTOSPI AHB master, tying low the HREADYOUT signal of this master while the keystream information is being computed (this takes up to 11 cycles). Any accesses outside the enabled OTFDEC regions belong to a non-encrypted region.

Each OTFDEC region is programmed through OTFDEC_RxCFGR, OTFDEC_RxSTARTADDR, OTFDEC_RxENDADDR, OTFDEC_RxNONCER and

OTFDEC_RxKEYR registers, where x = 1 to 4. In OTFDEC_RxCFGR, the MODE bits define the OTFDEC operating mode (standard or enhanced encryption).

Granularity for the region determination is 4096 bytes.

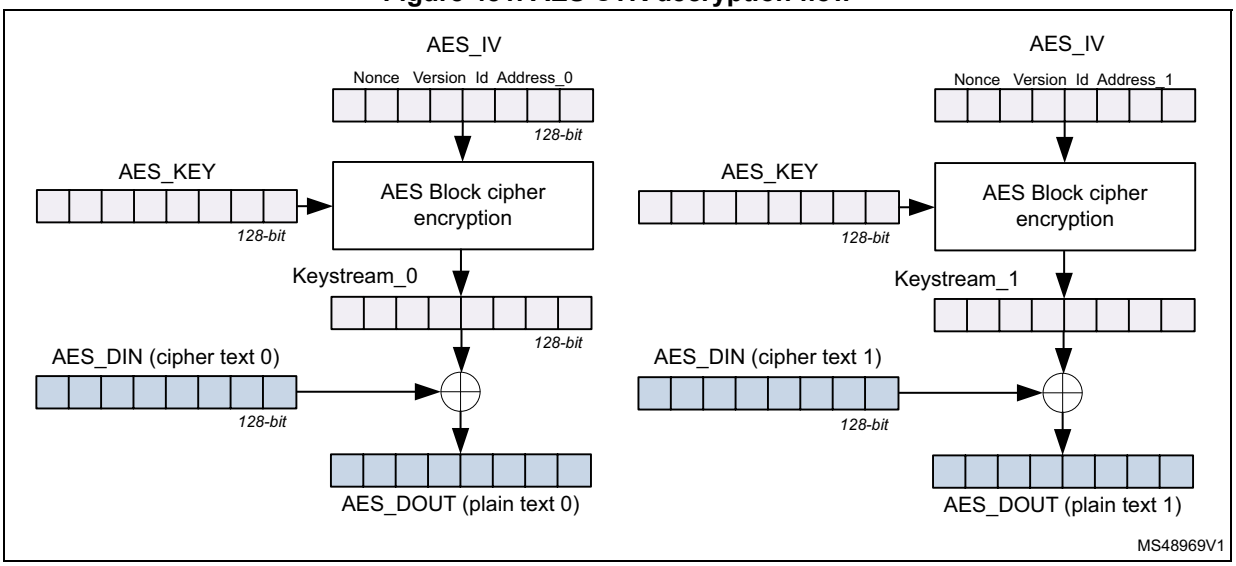
Note: Although OTFDEC does not prevent region overlapping, it is not a valid programming and it must be avoided by application software.

OTFDEC can decrypt incremental or wrap bursts only if they do not cross the 4096-byte aligned address boundaries.

48.3.4 OTFDEC usage of AES in counter mode decryption

Figure 481 shows how OTFDEC uses industry standard Advanced Encryption Standard (AES) algorithm in counter chaining mode. This mode is specified by NIST in *Special Publication 800-38A, Recommendation for Block Cipher Modes of Operation*.

Figure 481. AES CTR decryption flow



Every 128-bit data block, a special keystream information is computed using AES block cipher, as defined below:

- initialization vector AES_IV[127:0] = RxNONCER1[31:0] || RxNONCER0[31:0] || 0b0000 0000 0000 0000 || RxCFGR[31:16] || 0b00 || (x-1) || ReadAddress[31:4]
- key material AES_KEY[127:0] = R*x*KEYR3[31:0] || R*x*KEYR2[31:0] || R*x*KEYR1[31:0] || R*x*KEYR0[31:0]

Note: Above x is the RegionID of the selected encrypted region (x=1 to 4).
ReadAddress is the AHB address of the encrypted data block, modulo 128-bit.

Resulting 128-bit keystream is XORed with 128-bit cipher text data to produce the 128-bit clear text data.

- AES_DIN and AES_DOUT data blocks are constructed following the rule below (“|” represents a binary concatenation):
  AES_Dx[127:0]= AHB_word(@ | 0xC)[31:0] | AHB_word(@ | 0x8)[31:0] | AHB_word(@ | 0x4)[31:0] || AHB_word(@ | 0x0)[31:0], where @ is the hexadecimal address used to compute the keystream (ReadAddress[31:4] above).

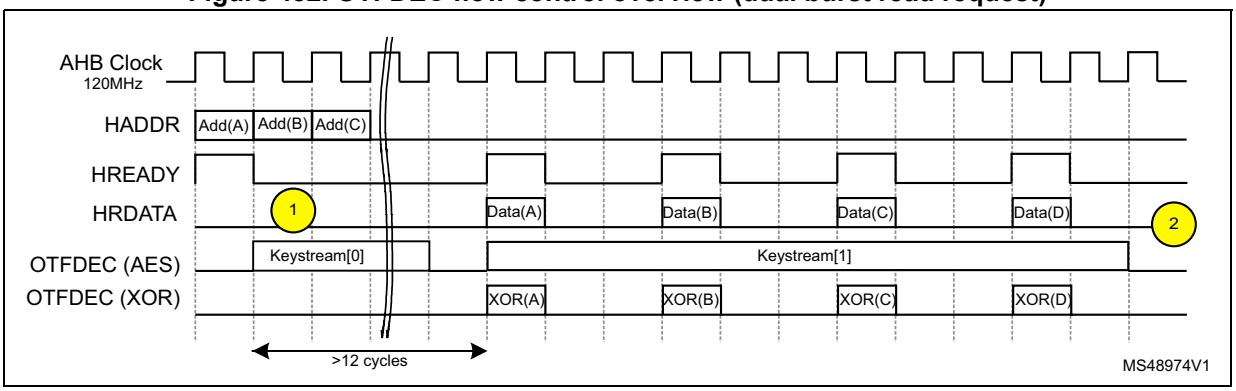
When the read request is not within an encrypted region, or the decryption is not enabled in this region, the AHB data is not changed.

Note: When the application sets the MODE bitfield to 11 in OTFDEC_RxCFGR, an additional layer of protection is added on top of the AES stream cipher. This enhanced encryption mode can only be used with instructions (execute-only region).

48.3.5 Flow control management

Figure 482 shows how OTFDEC manages one INCR4 AHB burst that corresponds to one 128-bit AES data block.

Figure 482. OTFDEC flow control overview (dual burst read request)



with the following notes:

1. OTFDEC enforces HREADY signal from the AHB master low as it is not ready to decrypt data (keystream computation).
2. Thanks to the keystream buffer, OTFDEC can be ready to process a new batch of data within 12 cycles in this configuration (120 MHz AHB clock, 104 MHz SPI bus delivering 2 bytes per SPI clock).

48.3.6 OTFDEC error management

OTFDEC automatically manages errors defined as below:

- Illegal read to OTFDEC_RxKEYR registers
- Illegal write to OTFDEC_RxKEYR registers while CONFIGLOCK or KEYLOCK = 1 in OTFDEC_RxCFGR, while the access is secure. If the security is disabled in the product, the same error occurs when the access is nonsecure.
- Illegal write to OTFDEC_RxCFGR, OTFDEC_RxSTARTADDR, OTFDEC_RxENDADDR or OTFDEC_RxNONCER registers while CONFIGLOCK = 1 in OTFDEC_RxCFGR (x = 1 to 4), while the access is secure. If the security is disabled in the product the same error occurs when the access is nonsecure.
- Illegal read to an execute-only region (MODE[1:0] = 11). Such illegal request returns 0x0, without bus error.
- Execution request to a region while encryption is enabled (ENC = 1). The request returns 0x0, without bus error.
- Key error: read request to an encrypted region while its key registers are null or not properly initialized (KEYCRC = 0x0). Source of the error can be an incorrect key loading sequence (see KEYCRC in OTFDEC_RxCFGR) or it can be an abort event

(tamper detection, unauthorized debug connection, untrusted boot, RDP level regression). Such read request returns 0x0, without bus error.

- Write to any registers while the access is nonsecure, if TrustZone security is enabled in the product.

  This last error is managed and cleared through TrustZone interrupt controller, as described in the GTZC section of the product reference manual.

For these errors (except the last one), an interrupt can be generated if the SEIE, XONEIE or KEIE bit is set in OTFDEC_IER register (see *Section 48.4*).

Note: After a key error, OTFDEC keys must be properly initialized again, and a reset of OTFDEC may be needed if registers are locked.

48.4 OTFDEC interrupts

There are three independent maskable interrupt sources generated by the OTFDEC, signaling following security events:

- Illegal read or write access to keys (SEIF flag), see *Section 48.3.6*
- Illegal write to a region configuration while CONFIGLOCK = 1 (SEIF flag), see *Section 48.3.6*
- Read access to an execute-only region (MODE[1:0] = 11), triggering the XONEIF flag
- Executing while encryption is enabled (XONEIF flag)
- Key error (encrypted regions read as zero) triggering the KEIF flag, see *Section 48.3.6*.

Interrupt sources are connected to the same global interrupt request signal.

OTFDEC interrupt sources can be enabled/disabled by setting the corresponding SEIE, XONEIE or KEIE bit in OTFDEC_IER, as described in *Table 507*. Status of the interrupt event is found in OTFDEC_ISR, and this event can be cleared using OTFDEC_ICR.

Table 507. OTFDEC interrupt requests

Interrupt acronym	Interrupt event	Event flag(1)	Enable control bit	Interrupt clear method
OTFDEC	Security error	SEIF	SEIE	Set SEIF in OTFDEC_ICR
	Execute-only Execute while encryption	XONEIF	XONEIE	Set XONEIF in OTFDEC_ICR
	Key error	KEIF	KEIE	Set KEIF in OTFDEC_ICR

1. The event flags are found in the OTFDEC_ISR register.

48.5 OTFDEC application information

48.5.1 OTFDEC initialization process

Introduction

One key aspect of OTFDEC is the trusted initialization of its registers, as it involves secret keys. Two trusted initialization schemes are recommended here below.

Note: Those sequences are for production code, as during firmware development, it is not always recommended to lock the key or the region configuration.

Writes to configuration registers are effective when the configuration locks allow it, even if the region is enabled.

Initialization scheme 1: one key for all regions

In this scheme, one entity owns the secret key used to decrypt the four protected regions. The recommended OTFDEC configuration sequence is described below:

1. For *x* = 1 to 4, write the correct MODE[1:0] value in OTFDEC_RxCFGR.
2. For *x* = 1 to 4, program OTFDEC_RxKEYR registers using the sequence described in KEYCRC (to have a valid CRC). Warning as key registers are write only.
3. For *x* = 1 to 4, check the key CRC. If OK, set KEYLOCK bit in OTFDEC_R*x*CFGR. This bit cannot be cleared (key registers in this region *x* are no more writable).
4. To do to decrypt a region x (task that does not necessarily have to be performed by the entity that owns the decryption keys):
   a) Verify if the key CRC corresponds to the encrypted binary stored in the region.
   b) Fill the detailed information corresponding to this binary (nonce, start address, end address, version number).
   c) Enable decryption of this region using REG_EN.
   d) Set CONFIGLOCK bit in OTFDEC_R*x*CFGR. This bit cannot be cleared (the region configuration is no more writable).

Caution: For a given region, when MODE bits are changed, the key registers and associated CRC are cleared by hardware. As a consequence, step 1 above must be done before step 2, and MODE bits must not be modified after step 2.

Initialization scheme 2: one key per region

In this scheme, one entity can own the secret used to decrypt one (or more) protected region. The recommended OTFDEC configuration sequence is described below:

1. To do to decrypt a region x (this task **must** be performed by the entity that owns the corresponding key):
   a) Write the correct MODE[1:0] value in OTFDEC_R*x*CFGR.
   b) Program OTFDEC_RxKEYR registers using the sequence described in KEYCRC (to have a valid CRC). Warning as key registers are write only.
   c) Check the key CRC. If OK, set KEYLOCK bit in OTFDEC_R*x*CFGR. This bit cannot be cleared (key registers are no more writable).
   d) Fill the detailed information corresponding to the protected firmware (nonce, start address, end address, version number).
   e) Enable decryption of this region using REG_EN.
   f) Set CONFIGLOCK bit in OTFDEC_R*x*CFGR. This bit cannot be cleared (the region configuration is no more writable).

Caution: For a given region, when MODE bits are changed, the key registers and associated CRC are cleared by hardware. As a consequence step a) above must be done before step b), and MODE bits must not be modified after step b).

48.5.2 OTFDEC and power management

Each time OTFDEC is reset, the correct key loading sequence described in *Section 48.5.1* must be performed (in this case KEYCRC = 0 in OTFDEC_RxCFGR).

It is recommended for application software to verify this point each time OTFDEC is reset by hardware.

48.5.3 Encrypting for OTFDEC

Code and data standard encryption

OTFDEC uses standard AES in counter mode when processing a binary stored in a protected region with MODE[1:0] = 10. When this mode is selected, any AES compatible hardware accelerator or library can be used to encrypt those protected libraries. OTFDEC can be used as well, as described in enhanced encryption section below (with MODE[1:0] = 10).

Definition and endianness of the AES inputs and outputs are defined in *Section 48.3.4: OTFDEC usage of AES in counter mode decryption*.

Enhanced encryption with OTFDEC

OTFDEC uses a proprietary layer of protection on top of the standard AES in counter mode when processing a code stored in a protected region with MODE[1:0] = 11.

Enhanced encryption mode can be used to increase the robustness against tampering.

Recommended sequence to encrypt using OTFDEC is described below:

1. The application in charge of the encryption sets the ENC bit in OTFDEC_CR. This application must run in TrustZone secure mode when TrustZone security is enabled in the product. If PRIV bit is set in OTFDEC_PRIVCFGR, this application must be privileged.
2. Encryption application initializes OTFDEC as described in *Section 48.5.1: OTFDEC initialization process*. OCTOSPI must also be properly clocked, so that OTFDEC is fully functional in encryption mode. This step can also be done before step 1.
3. Encryption application writes 32-bit of clear-text data at the expected protected address, then reads it back encrypted at the same address to store it in RAM. Note that this data stays inside the device, as it is intercepted by OTFDEC in encryption mode.
4. Encryption application goes back to previous step (changing the address) until the whole binary is processed.
5. Encryption application clears the ENC bit in OTFDEC_CR. Another application can then take the encrypted binary and flash it to the correct address in external flash.

There are few important notes about this procedure:

- Encryption granularity is 32-bit (single 32-bit access is mandatory).
- While ENC bit is set, reads to non-encrypted regions return normal data (such as no encryption nor decryption). While in encryption mode, no access to OCTOSPI (including registers) must be done. This is because the OTFDEC cuts the communication with OCTOPSI while ENC bit is set.
- OTFDEC does not support execution while ENC = 1 (only encrypted data reads). Upon illegal execution detection a XONEIF flag is raised and zero is returned.

48.5.4 OTFDEC key CRC source code

Below is the CRC source code that can be used to compare with the result of the computation provided by OTFDEC in KEYCRC bitfield after loading the keys in OTFDEC_RxKEYR registers.

```
uint8_t getCRC(uint32_t * keyin)
{
  const uint8_t CRC7_POLY = 0x7;
  const uint32_t key_strobe[4] = {0xAA55AA55, 0x3, 0x18, 0xC0};
  uint8_t  i, j, k, crc = 0x0;
  uint32_t  keyval;

  for (j = 0; j < 4; j++)
  {
    keyval = *(keyin+j);
    if (j == 0)
    {
      keyval ^= key_strobe[0];
    }
    else
    {
      keyval ^= (key_strobe[j] << 24) | (crc << 16) | (key_strobe[j] << 8)
| crc;
    }

    for (i = 0, crc = 0; i < 32; i++)
    {
      k = (((crc >> 7) ^ (keyval >> (31-i))&0xF)) & 1;
      crc <<= 1;
      if (k)
      {
        crc ^= CRC7_POLY;
       }
    }
    crc^=0x55;
  }
  return crc;
}
```

48.6 OTFDEC registers

48.6.1 OTFDEC control register (OTFDEC_CR)

Address offset: 0x0

Reset value: 0x0000 0000

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

Unprivileged reads return zero and unprivileged writes are ignored if PRIV bit is set in OTFDEC_PRIVCFGR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ENC
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **ENC**: Encryption mode bit

When this bit is set, OTFDEC is used in encryption mode, during which application can write clear text data then read back encrypted data. When this bit is cleared (default), OTFDEC is used in decryption mode, during which application only read back decrypted data. For both modes, cryptographic context (keys, nonces, firmware versions) must be properly initialized. When this bit is set, only data accesses are allowed (zeros are returned otherwise, and XONEIF is set). When MODE = 11, enhanced encryption mode is automatically selected.

0: OTFDEC working in decryption mode

1: OTFDEC working in encryption mode

Note: When ENC bit is set, no access to OCTOSPI must be done (registers and Memory-mapped region).

48.6.2 OTFDEC privileged access control configuration register (OTFDEC_PRIVCFGR)

Address offset: 0x10

Reset value: 0x0000 0000

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **PRIV:** Privileged access protection.

0: No additional protection is added on OTFDEC register accesses.

1: An additional protection is added when accessing all registers except OTFDEC_PRIVCFGR:

- Unprivileged read accesses to registers return zeros
- Unprivileged write accesses to registers are ignored.

Note: This bit can only be written in privileged mode. There is no limitations on reads.

48.6.3 OTFDEC region x configuration register (OTFDEC_RxCFGR)

Address offset: 0x20 + 0x30 * (x - 1), (x = 1 to 4)

Reset value: 0x0000 0000

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

Unprivileged reads return zero and unprivileged writes are ignored if PRIV bit is set in OTFDEC_PRIVCFGR.

Writes are ignored if CONFIGLOCK bit is set to 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REG_VERSION[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEYCRC[7:0]								Res.	Res.	MODE[1:0]		Res.	KEYLOCK	CONFIGLOCK	REG_EN
r	r	r	r	r	r	r	r			rw	rw		rs	rs	rw

Bits 31:16 **REG_VERSION[15:0]**: region firmware version

This 16-bit bitfield must be correctly initialized before the region corresponding REG_EN bit is set in OTFDEC_RxCFGR.

Bits 15:8 **KEYCRC[7:0]**: region key 8-bit CRC

When KEYLOCK = 0, KEYCRC bitfield is automatically computed by hardware while loading the key of this region in this exact sequence: KEYR0 then KEYR1 then KEYR2 then finally KEYR3 (all written once). A new computation starts as soon as a new valid sequence is initiated, and KEYCRC is read as zero until a valid sequence is completed.

When KEYLOCK = 1, KEYCRC remains unchanged until the next reset.

CRC computation is an 8-bit checksum using the standard CRC-8-CCITT algorithm $X^8 + X^2 + X + 1$ (according the convention). Source code is available in *Section 48.5.4*.

This field is read only.

Note: CRC information is updated only after the last bit of the key has been written.

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **MODE[1:0]**: operating mode

This bitfield selects the OTFDEC operating mode for this region:

10: All read accesses are decrypted (instruction or data).

11: Enhanced encryption mode is activated, and only instruction accesses are decrypted

Others: Reserved

When MODE ≠ 11, the standard AES encryption mode is activated.

When either of the MODE bits are changed, the region key and associated CRC are zeroed.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **KEYLOCK**: region key lock

0: Writes to this region KEYRx registers are allowed.

1: Writes to this region KEYRx registers are ignored until next OTFDEC reset. KEYCRC bitfield is locked.

Note: This bit is set once: if this bit is set, it can only be reset to 0 if the OTFDEC is reset.

Bit 1 **CONFIGLOCK**: region config lock

0: Writes to this region OTFDEC_RxCFGR, OTFDEC_RxSTARTADDR, OTFDEC_RxENDADDR and OTFDEC_RxNONCERy registers are allowed.

1: Writes to this region OTFDEC_RxCFGR, OTFDEC_RxSTARTADDR, OTFDEC_RxENDADDR and OTFDEC_RxNONCERy registers are ignored until next OTFDEC reset.

Note: This bit is set once. If this bit is set, it can only be reset to 0 if OTFDEC is reset. Setting this bit forces KEYLOCK bit to 1.

Bit 0 **REG_EN**: region on-the-fly decryption enable

0: On-the-fly decryption is disabled for this region.

1: On-the-fly decryption is enabled for this region. Data are XORed with the corresponding keystream.

Note: Garbage is decrypted if region context (version, key, nonce) is not valid when this bit is set.

48.6.4 OTFDEC region x start address register (OTFDEC_RxSTARTADDR)

Address offset: 0x24 + 0x30 * (x - 1), (x = 1 to 4)

Reset value: 0x0000 0000

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

Unprivileged reads return zero and unprivileged writes are ignored if PRIV bit is set in OTFDEC_PRIVCFGR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REG_START_ADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REG_START_ADDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **REG_START_ADDR[31:0]**: Region AHB start address

This register must be written before the region corresponding REG_EN bit in the OTFDEC_RxCFGR register is set.

Writing to this register is discarded if performed while the region CONFIGLOCK bit in the OTFDEC_RxCFGR register is set.

Note: When determining the region the first 12 bits (LSB) and the last 4 bits (MSB) are ignored.

When this register is accessed in read the 4 MSB bits and the 12 LSB bits return zeros .

48.6.5 OTFDEC region x end address register (OTFDEC_RxENDADDR)

Address offset: 0x28 + 0x30 * (x - 1), (x = 1 to 4)

Reset value: 0x0000 0FFF

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

Unprivileged reads return zero and unprivileged writes are ignored if PRIV bit is set in OTFDEC_PRIVCFGR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REG_END_ADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REG_END_ADDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **REG_END_ADDR[31:0]**: Region AHB end address

This register must be written before the region corresponding REG_EN bit in the OTFDEC_RxCFGR register is set, and OTFDEC_RxENDADDR must be strictly greater than OTFDEC_RxSTARTADDR to be valid.

Writing to this register is discarded if performed while the region CONFIGLOCK bit in OTFDEC_RxCFGR is set.

Note: When determining the region the first 12 bits (LSB) and the last 4 bits (MSB) are ignored.

When this register is accessed in read the 4 MSB bits return zeros and the 12 LSB bits return ones.

48.6.6 OTFDEC region x nonce register 0 (OTFDEC_RxNONCER0)

Address offset: 0x2C + 0x30 * (x - 1), (x = 1 to 4)

Reset value: 0x0000 0000

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

Unprivileged reads return zero and unprivileged writes are ignored if PRIV bit is set in OTFDEC_PRIVCFGR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REG_NONCE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REG_NONCE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **REG_NONCE[31:0]**: Region nonce, bits [31:0]

This register must be written before the region corresponding REG_EN bit in OTFDEC_RxCFGR is set.

Writing is discarded in this register if performed while the region CONFIGLOCK bit in the OTFDEC_RxCFGR is set.

48.6.7 OTFDEC region x nonce register 1 (OTFDEC_RxNONCER1)

Address offset: 0x30 + 0x30 * (x - 1), (x = 1 to 4)

Reset value: 0x0000 0000

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

Unprivileged reads return zero and unprivileged writes are ignored if PRIV bit is set in OTFDEC_PRIVCFGR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REG_NONCE[63:48]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REG_NONCE[47:32]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **REG_NONCE[63:32]**: Region nonce, bits [63:32]

Refer to the OTFDEC_RxNONCER0 register for description of the NONCE[63:0] bitfield.

48.6.8 OTFDEC region x key register 0 (OTFDEC_RxKEYR0)

Address offset: 0x34 + 0x30 * (x - 1), (x = 1 to 4)

Reset value: 0x0000 0000

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

Unprivileged writes are ignored if PRIV bit is set in OTFDEC_PRIVCFGR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REG_KEY[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REG_KEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **REG_KEY[31:0]**: Region key, bits [31:0]

This register must be written before the region corresponding REG_EN bit in OTFDEC_RxCFGR is set.

Reading this register returns a zero value. Writing to this register is discarded if performed while the region CONFIGLOCK or KEYLOCK bit is set in the OTFDEC_RxCFGR.

Note: When application successfully changes MODE bits in OTFDEC*_RxCFGR and* OTFDEC*_RxKEYR, and associated KEYCRC are erased.*

48.6.9 OTFDEC region x key register 1 (OTFDEC_RxKEYR1)

Address offset: 0x38 + 0x30 * (x - 1), (x = 1 to 4)

Reset value: 0x0000 0000

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

Unprivileged writes are ignored if PRIV bit is set in OTFDEC_PRIVCFGR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REG_KEY[63:48]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REG_KEY[47:32]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **REG_KEY[63:32]**: Region key, bits [63:32]
Refer to the OTFDEC_RxKEYR0 register for description of the KEY[127:0] bitfield.

48.6.10 OTFDEC region x key register 2 (OTFDEC_RxKEYR2)

Address offset: 0x3C + 0x30 * (x - 1), (x = 1 to 4)

Reset value: 0x0000 0000

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

Unprivileged writes are ignored if PRIV bit is set in OTFDEC_PRIVCFGR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REG_KEY[95:80]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REG_KEY[79:64]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **REG_KEY[95:64]**: Region key, bits [95:64]
Refer to the OTFDEC_RxKEYR0 register for description of the KEY[127:0] bitfield.

48.6.11 OTFDEC region x key register 3 (OTFDEC_RxKEYR3)

Address offset: 0x40 + 0x30 * (x - 1), (x = 1 to 4)

Reset value: 0x0000 0000

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

Unprivileged writes are ignored if PRIV bit is set in OTFDEC_PRIVCFGR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REG_KEY[127:112]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REG_KEY[111:96]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **REG_KEY[127:96]**: Region key, bits [127:96]

Refer to the OTFDEC_RxKEYR0 register for description of the KEY[127:0] bitfield.

48.6.12 OTFDEC interrupt status register (OTFDEC_ISR)

Address offset: 0x300

Reset value: 0x0000 0000

Unprivileged reads return zero if PRIV bit is set in OTFDEC_PRIVCFGR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIF	XONEIF	SEIF
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **KEIF:** Key error interrupt flag status

This bit is set by hardware and read only by application. The bit is set when a read access occurs on an encrypted region, while its key registers is null or not properly initialized (KEYCRC = 0x0).

This bit is cleared when the application sets in OTFDEC_ICR the corresponding bit to 1.

0: OTFDEC operates properly.

1: Read access detected on an enabled encrypted region with its key registers null or not properly initialized (KEYCRC = 0x0). OTFDEC returns a zeroed value for the read, and an optional interrupt is generated if bit KEIE is set to 1 in OTFDEC_IER.

After KEIF is set any subsequent read to the region with bad key registers returns a zeroed value. This state remains until those key registers are properly initialized (KEYCRC not zero).

Bit 1 **XONEIF:** Execute-only execute-never error interrupt flag status

This bit is set by hardware and read only by application. This bit is set when a read access and not an instruction fetch is detected on any encrypted region with MODE bits set to 11. Lastly, XONEIF is also set when an execute access is detected while encryption mode is enabled.

This bit is cleared when application sets in OTFDEC_ICR the corresponding bit to 1.

0: No execute-only error status. No interrupt pending.

1: Read access detected on one region with MODE bits set to 11 or execute access detected while ENC = 1. OTFDEC returns a zeroed value for the illegal access, and an optional interrupt is generated if bit XONEIE is set to 1 in OTFDEC_IER.

Bit 0 **SEIF:** Security error interrupt flag status

This bit is set by hardware and read only by application. This bit is set when at least one security error has been detected.

This bit is cleared when application sets in OTFDEC_ICR the corresponding bit to 1.

0: No security error status. No interrupt pending.

1: Security error flag status, with interrupt pending. Actual interrupt generation is dependent on OTFDEC_IER corresponding bit SEIE.

48.6.13 OTFDEC interrupt clear register (OTFDEC_ICR)

Address offset: 0x304

Reset value: 0x0000 0000

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

Unprivileged writes are ignored if PRIV bit is set in OTFDEC_PRIVCFGR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIF	XONEIF	SEIF
													w	w	w

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **KEIF:** Key error interrupt flag clear
This bit is written by application, and always read as 0.
0: KEIF flag status is not affected.
1: KEIF flag status is cleared in OTFDEC_ISR.
Note: Clearing KEIF does not solve the source of the problem (bad key registers). To be able to access again any encrypted region, OTFDEC key registers must be properly initialized again.

Bit 1 **XONEIF:** Execute-only execute-never error interrupt flag clear
This bit is written by application, and always read as 0.
0: XONEIF flag status is not affected.
1: XONEIF flag status is cleared in OTFDEC_ISR.

Bit 0 **SEIF:** Security error interrupt flag clear
This bit is written by application, and always read as 0.
0: SEIF flag status is not affected.
1: SEIF flag status is cleared in OTFDEC_ISR.

48.6.14 OTFDEC interrupt enable register (OTFDEC_IER)

Address offset: 0x308

Reset value: 0x0000 0000

Nonsecure AHB write access (HNONSEC = 1) is discarded if the TrustZone security is enabled in the product.

Unprivileged reads return zero and unprivileged writes are ignored if PRIV bit is set in OTFDEC_PRIVCFGR.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIE	XONEIE	SEIE
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **KEIE:** Key error interrupt enable

This bit is read and written by application. It controls the OTFDEC interrupt generation when KEIF flag status is set.

0: Interrupt generation on key error flag KEIF is disabled (masked).

1: Interrupt generation on key error flag KEIF is enabled (not masked).

Bit 1 **XONEIE:** Execute-only execute-never error interrupt enable

This bit is read and written by application. It controls the OTFDEC interrupt generation when XONEIF flag status is set.

0: Interrupt generation on execute-only error XONEIF is disabled (masked).

1: Interrupt generation on execute-only error XONEIF is enabled (not masked).

Bit 0 **SEIE:** Security error interrupt enable

This bit is read and written by application. It controls the OTFDEC interrupt generation when SEIF flag status is set.

0: Interrupt generation on security error SEIF is disabled (masked).

1: Interrupt generation on security error SEIF is enabled (not masked).

48.6.15 OTFDEC register map

Table 508. OTFDEC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	OTFDEC_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ENC
	Reset value																																0
0x04-0x0C	Reserved	Reserved																															
0x10	OTFDEC_PRIVCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV
	Reset value																																0
0x14-0x1C	Reserved	Reserved																															
0x20	OTFDEC_R1CFGR1	REG1_VERSION[15:0]																KEYCRC[7:0]								Res.	Res.	MODE[1:0]		KEYLOCK	CONFIGLOCK	REG_EN
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0
0x24	OTFDEC_R1STARTADDR	REG1_START_ADDR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	OTFDEC_R1ENDADDR	REG1_END_ADDR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	OTFDEC_R1NONCER0	REG1_NONCE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x30	OTFDEC_R1NONCER1	REG1_NONCE[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x34	OTFDEC_R1KEYR0	REG1_KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 508. OTFDEC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x38	OTFDEC_ R1KEYR1	REG1_KEY[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x3C	OTFDEC_ R1KEYR2	REG1_KEY[95:64]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x40	OTFDEC_ R1KEYR3	REG1_KEY[127:96]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x44 - 0x4C	Reserved	Reserved																															
0x50	OTFDEC_ R2CFGR	REG2_VERSION[15:0]																KEYCRC[7:0]									Res.	Res.	MODE[1:0]		KEYLOCK	CONFIGLOCK	REG_EN
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0
0x54	OTFDEC_ R2STARTADDR	REG2_START_ADDR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x58	OTFDEC_ R2ENDADDR	REG2_END_ADDR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x5C	OTFDEC_ R2NONCER0	REG2_NONCE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x60	OTFDEC_ R2NONCER1	REG2_NONCE[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x64	OTFDEC_ R2KEYR0	REG2_KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x68	OTFDEC_ R2KEYR1	REG2_KEY[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x6C	OTFDEC_ R2KEYR2	REG2_KEY[95:64]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x70	OTFDEC_ R2KEYR3	REG2_KEY[127:96]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x74 - 0x7C	Reserved	Reserved																															
0x80	OTFDEC_ R3CFGR	REG3_VERSION[15:0]																KEYCRC[7:0]									Res.	Res.	MODE[1:0]		KEYLOCK	CONFIGLOCK	REG_EN
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0
0x84	OTFDEC_ R3STARTADDR	REG3_START_ADDR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x88	OTFDEC_ R3ENDADDR	REG3_END_ADDR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 508. OTFDEC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x8C	OTFDEC_ R3NONCER0	REG3_NONCE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x90	OTFDEC_ R3NONCER1	REG3_NONCE[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x94	OTFDEC_ R3KEYR0	REG3_KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x98	OTFDEC_ R3KEYR1	REG3_KEY[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x9C	OTFDEC_ R3KEYR2	REG3_KEY[95:64]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xA0	OTFDEC_ R3KEYR3	REG3_KEY[127:96]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xA4 - 0xAC	Reserved	Reserved																															
0xB0	OTFDEC_ R4CFGR	REG4_VERSION[15:0]																KEYCRC[7:0]								Res.	Res.	MODE[1:0]		KEYLOCK	CONFIGLOCK	REG_EN
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0
0xB4	OTFDEC_ R4STARTADDR	REG4_START_ADDR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xB8	OTFDEC_ R4ENDADDR	REG4_END_ADDR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xBC	OTFDEC_ R4NONCER0	REG4_NONCE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xC0	OTFDEC_ R4NONCER1	REG4_NONCE[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xC4	OTFDEC_ R4KEYR0	REG4_KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xC8	OTFDEC_ R4KEYR1	REG4_KEY[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xCC	OTFDEC_ R4KEYR2	REG4_KEY[95:64]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xD0	OTFDEC_ R4KEYR3	REG4_KEY[127:96]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0D4- 0x2FC	Reserved	Reserved																															

Table 508. OTFDEC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x300	OTFDEC_ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.		KEIF	XONEIF	SEIF
	Reset value																														0	0	0
0x304	OTFDEC_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.		KEIF	XONEIF	SEIF
	Reset value																														0	0	0
0x308	OTFDEC_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.		KEIE	XONEIE	SEIE
	Reset value																														0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

49 Advanced-control timers (TIM1/TIM8)

49.1 TIM1/TIM8 introduction

The advanced-control timers (TIM1/TIM8) consist of a 16-bit autoreload counter driven by a programmable prescaler.

It may be used for a variety of purposes, including measuring the pulse lengths of input signals (input capture) or generating output waveforms (output compare, PWM, complementary PWM with dead-time insertion).

Pulse lengths and waveform periods can be modulated from a few microseconds to several milliseconds using the timer prescaler and the RCC clock controller prescalers.

The advanced-control (TIM1/TIM8) and general-purpose (TIMy) timers are completely independent, and do not share any resources. They can be synchronized together as described in *Section 49.3.30: Timer synchronization*.

49.2 TIM1/TIM8 main features

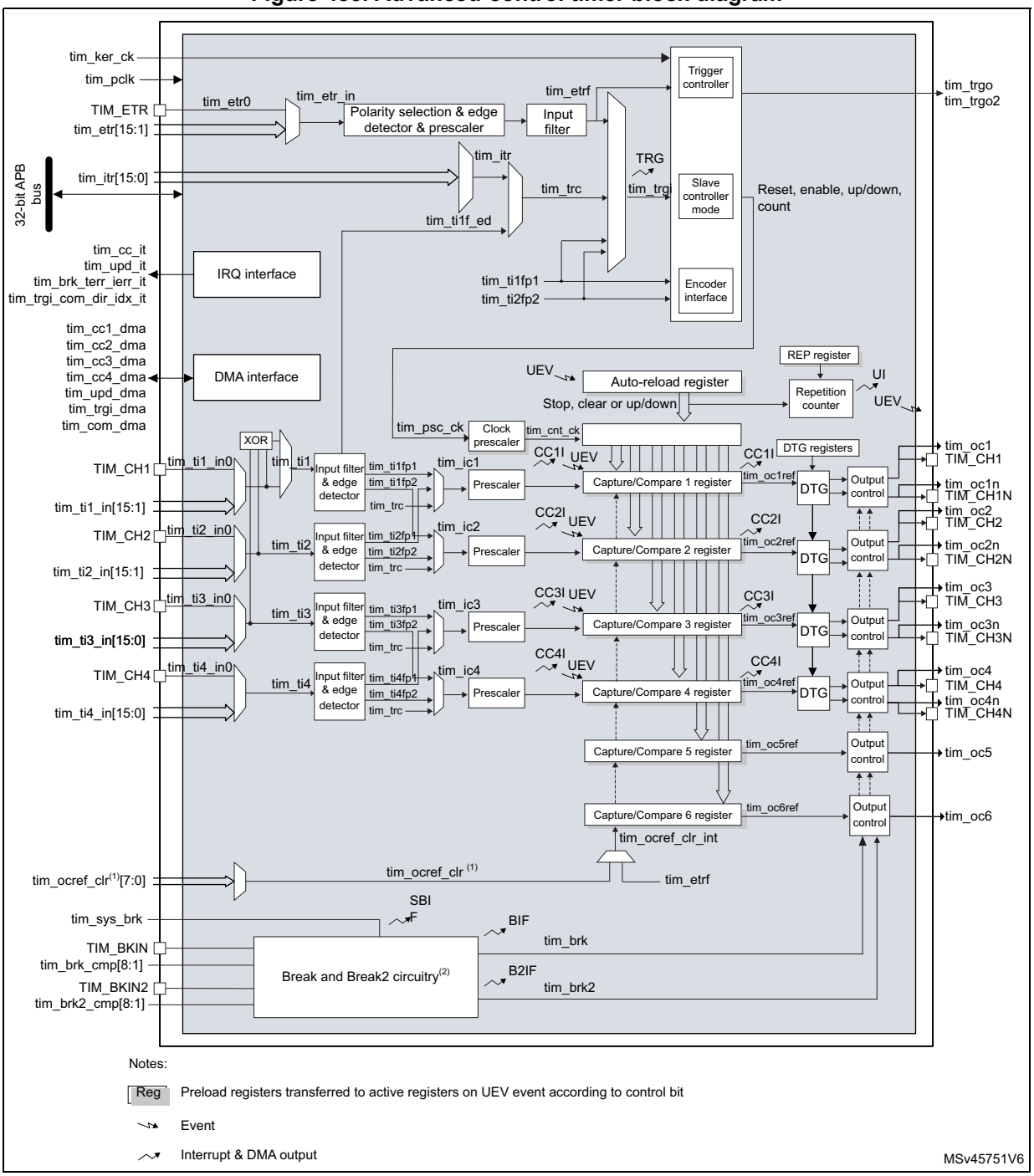
TIM1/TIM8 timer features include:

- 16-bit up, down, up/down autoreload counter.
- 16-bit programmable prescaler allowing dividing (also “on the fly”) the counter clock frequency by any factor from 1 to 65536.
- Up to six independent channels for:
  - Input capture (but channels 5 and 6)
  - Output compare
  - PWM generation (edge and center-aligned mode)
  - One-pulse mode output
- Complementary outputs with programmable dead-time
- Synchronization circuit to control the timer with external signals and to interconnect several timers together.
- Repetition counter to update the timer registers only after a given number of cycles of the counter.
- 2 break inputs to put the timer’s output signals in a safe user selectable configuration.
- Interrupt/DMA generation on the following events:
  - Update: counter overflow/underflow, counter initialization (by software or internal/external trigger)
  - Trigger event (counter start, stop, initialization, or count by internal/external trigger)
  - Input capture
  - Output compare
- Supports incremental (quadrature) encoder and hall-sensor circuitry for positioning purposes
- Trigger input for external clock or cycle-by-cycle current management

49.3 TIM1/TIM8 functional description

49.3.1 Block diagram

Figure 483. Advanced-control timer block diagram



1. This feature is not available on all timers, refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals*.
2. See *Figure 530: Break and Break2 circuitry overview* for details.

49.3.2 TIM1/TIM8 pins and internal signals

The tables in this section summarize the TIM inputs and outputs

Table 509. TIM input/output pins

Pin name	Signal type	Description
TIM_CH1 TIM_CH2 TIM_CH3 TIM_CH4	Input/output	Timer multi-purpose channels. Each channel can be used for capture, compare or PWM. TIM_CH1 and TIM_CH2 can also be used as external clock (below 1/4 of the tim_ker_ck clock), external trigger and quadrature encoder inputs. TIM_CH1, TIM_CH2 and TIM_CH3 can be used to interface with digital hall effect sensors.
TIM_CH1N TIM_CH2N TIM_CH3N TIM_CH4N	Output	Timer complementary outputs, derived from TIM_CHx outputs with the possibility to have deadtime insertion.
TIM_ETR	Input	External trigger input. This input can be used as external trigger or as external clock source. This input can receive a clock with a frequency higher than the tim_ker_ck if the tim_etr_in prescaler is used.
TIM_BKIN TIM_BKIN2	Input/output	Break and Break2 inputs. These inputs can also be configured in bidirectional mode.

Table 510. TIM internal input/output signals

Internal signal name	Signal type	Description
tim_ti1_in[15:0] tim_ti2_in[15:0] tim_ti3_in[15:0] tim_ti4_in[15:0]	Input	Internal timer inputs bus. The tim_ti1_in[15:0] and tim_ti2_in[15:0] inputs can be used for capture or as external clock (below 1/4 of the tim_ker_ck clock) and for quadrature encoder signals.
tim_etr[15:0]	Input	External trigger internal input bus. These inputs can be used as trigger, external clock or for hardware cycle-by-cycle pulsewidth control. These inputs can receive clock with a frequency higher than the tim_ker_ck if the tim_etr_in prescaler is used.
tim_itr[15:0]	Input	Internal trigger input bus. These inputs can be used for the slave mode controller or as a input clock (below 1/4 of the tim_ker_ck clock).
tim_trgo/tim_trgo2	Output	Internal trigger outputs. These triggers are used by other timers and /or other peripherals.

Table 510. TIM internal input/output signals (continued)

Internal signal name	Signal type	Description
tim_ocref_clr[7:0]	Input	Timer tim_ocref_clr input bus. These inputs can be used to clear the tim ocxref signals, typically for hardware cycle-by-cycle pulsewidth control.
tim_brk_cmp[8:1]	Input	Break input for internal signals
tim_brk2_cmp[8:1]	Input	Break2 input for internal signals
tim_sys_brk[n:0]	Input	System break input. This input gathers the MCU's system level errors.
tim_pclk	Input	Timer APB clock
tim_ker_ck	Input	Timer kernel clock
tim_cc_it	Output	Timer capture/compare interrupt
tim_upd_it	Output	Timer update event interrupt
tim_brk_terr_ierr_it	Output	Timer break, break2, transition error and index error interrupt
tim_trgi_com_dir_idx_it	Output	Timer trigger, commutation, direction and index interrupt
tim_cc1_dma tim_cc2_dma tim_cc3_dma tim_cc4_dma	Output	Timer capture / compare 1..4 dma requests
tim_upd_dma	Output	Timer update dma request
tim_trgi_dma	Output	Timer trigger dma request
tim_com_dma	Output	Timer commutation dma request

Table 511, *Table 512*, *Table 513* and *Table 514* list the sources connected to the tim_ti[4:1] input multiplexers.

Table 511. Interconnect to the tim_ti1 input multiplexer

tim_ti1 inputs	Sources	
	TIM1	TIM8
tim_ti1_in0	TIM1_CH1	TIM8_CH1
tim_ti1_in1	Reserved	Reserved
tim_ti1_in2	comp1_out	comp1_out
tim_ti1_in3	comp2_out	comp2_out
tim_ti1_in[15:4]	Reserved	Reserved

Table 512. Interconnect to the tim_ti2 input multiplexer

tim_ti2 inputs	Sources	
	TIM1	TIM8
tim_ti2_in0	TIM1_CH2	TIM8_CH2
tim_ti2_in[15:1]	Reserved	Reserved

Table 513. Interconnect to the tim_ti3 input multiplexer

tim_ti3 inputs	Sources	
	TIM1	TIM8
tim_ti3_in0	TIM1_CH3	TIM8_CH3
tim_ti3_in[15:1]	Reserved	Reserved

Table 514. Interconnect to the tim_ti4 input multiplexer

tim_ti4 inputs	Sources	
	TIM1	TIM8
tim_ti4_in0	TIM1_CH4	TIM8_CH4
tim_ti4_in[15:1]	Reserved	Reserved

Table 515 lists the internal sources connected to the tim_itr input multiplexer.

Table 515. Internal trigger connection

Timer internal trigger input signal	TIM1	TIM8
tim_itr0	Reserved	tim1_trgo
tim_itr1	tim2_trgo	tim2_trgo

Table 515. Internal trigger connection (continued)

Timer internal trigger input signal	TIM1	TIM8
tim_itr2	tim3_trgo	tim3_trgo
tim_itr3	tim4_trgo	tim4_trgo
tim_itr4	tim5_trgo	tim5_trgo
tim_itr5	tim8_trgo	Reserved
tim_itr6	tim12_trgo	tim12_trgo
tim_itr7	tim13_oc1	tim13_oc1
tim_itr8	tim14_oc1	tim14_oc1
tim_itr9	tim15_trgo	tim15_trgo
tim_itr10	tim16_oc1	tim16_oc1
tim_itr11	tim17_oc1	tim17_oc1
tim_itr[15:12]	Reserved	Reserved

Table 516 lists the internal sources connected to the tim_etr input multiplexer.

Table 516. Interconnect to the tim_etr input multiplexer

Timer external trigger input signal	Timer external trigger signals assignment	
	TIM1	TIM8
tim_etr0	TIM1_ETR	TIM8_ETR
tim_etr1	comp1_out	comp1_out
tim_etr2	comp2_out	comp2_out
tim_etr3	adc1_awd1	adc2_awd1
tim_etr4	adc1_awd2	adc2_awd2
tim_etr5	adc1_awd3	adc2_awd3
tim_etr6	Reserved	adc3_awd1
tim_etr7	Reserved	adc3_awd2
tim_etr8	Reserved	adc3_awd3
tim_etr[15:9]	Reserved	Reserved

Table 517, *Table 518* and *Table 519* list the sources connected to the tim_brk and tim_brk2inputs.

Table 517. Timer break interconnect

tim_brk inputs	TIM1	TIM8
TIM_BKIN	TIM1_BKIN pin	TIM8_BKIN pin
tim_brk_cmp1	comp1_out	comp1_out

Table 517. Timer break interconnect (continued)

tim_brk inputs	TIM1	TIM8
tim_brk_cmp2	comp2_out	comp2_out
tim_brk_cmp3	play1_out1	play1_out1
tim_brk_cmp[7:4]	Reserved	Reserved
tim_brk_cmp8	mdf1_brk0	mdf1_brk2

Table 518. Timer break2 interconnect

tim_brk2 inputs	TIM1	TIM8
TIM_BKIN2	TIM1_BKIN2 pin	TIM8_BKIN2 pin
tim_brk2_cmp1	comp1_out	comp1_out
tim_brk2_cmp2	comp2_out	comp2_out
tim_brk2_cmp3	play1_out2	play1_out2
tim_brk2_cmp[7:4]	Reserved	Reserved
tim_brk2_cmp8	mdf1_brk1	mdf1_br3

Table 519. System break interconnect

tim_sys_brk inputs	TIM1/TIM8	Enable bit in SBS_CFGR2 register
tim_sys_brk0	Flash memory double ECC error	ECCL
tim_sys_brk1	Programmable voltage detector (PVD)	PVDL
tim_sys_brk2	SRAM double ECC error	SEL
tim_sys_brk3	Cortex-M33 LOCKUP	CLL
CSS	Clock security system	None (always enabled)

Table 520. Interconnect to the tim_ocref_clr input multiplexer

Timer OCREF clear signal	Timer OCREF clear signal assignment	
	TIM1	TIM8
tim_ocref_clr0	comp1_out	comp1_out
im_ocref_clr1	comp2_out	comp2_out
tim_ocref_clr[7:2]	Reserved	Reserved

49.3.3 Time-base unit

The main block of the programmable advanced-control timer is a 16-bit counter with its related autoreload register. The counter can count up, down or both up and down. The counter clock can be divided by a prescaler.

The counter, the autoreload register and the prescaler register can be written or read by software, even when the counter is running.

The time-base unit includes:

- Counter register (TIMx_CNT)
- Prescaler register (TIMx_PSC)
- Autoreload register (TIMx_ARR)
- Repetition counter register (TIMx_RCR)

The autoreload register is preloaded. Writing to or reading from the autoreload register accesses the preload register. The content of the preload register are transferred into the shadow register permanently or at each update event (UEV), depending on the autoreload preload enable bit (ARPE) in TIMx_CR1 register. The update event is sent when the counter reaches the overflow (or underflow when downcounting) and if the UDIS bit equals 0 in the TIMx_CR1 register. It can also be generated by software. The generation of the update event is described in detailed for each configuration.

The counter is clocked by the prescaler output tim_cnt_ck, which is enabled only when the counter enable bit (CEN) in TIMx_CR1 register is set (refer also to the slave mode controller description to get more details on counter enabling).

Note: The counter starts counting 1 clock cycle after setting the CEN bit in the TIMx_CR1 register.

Prescaler description

The prescaler divides the counter clock frequency by any factor from 1 to 65536. It is based on a 16-bit counter controlled through a 16-bit register (in the TIMx_PSC register). It can be changed on the fly as this control register is buffered. The new prescaler ratio is taken into account at the next update event.

Figure 484 and *Figure 485* give some examples of the counter behavior when the prescaler ratio is changed on the fly.

Figure 484. Counter timing diagram with prescaler division change from 1 to 2

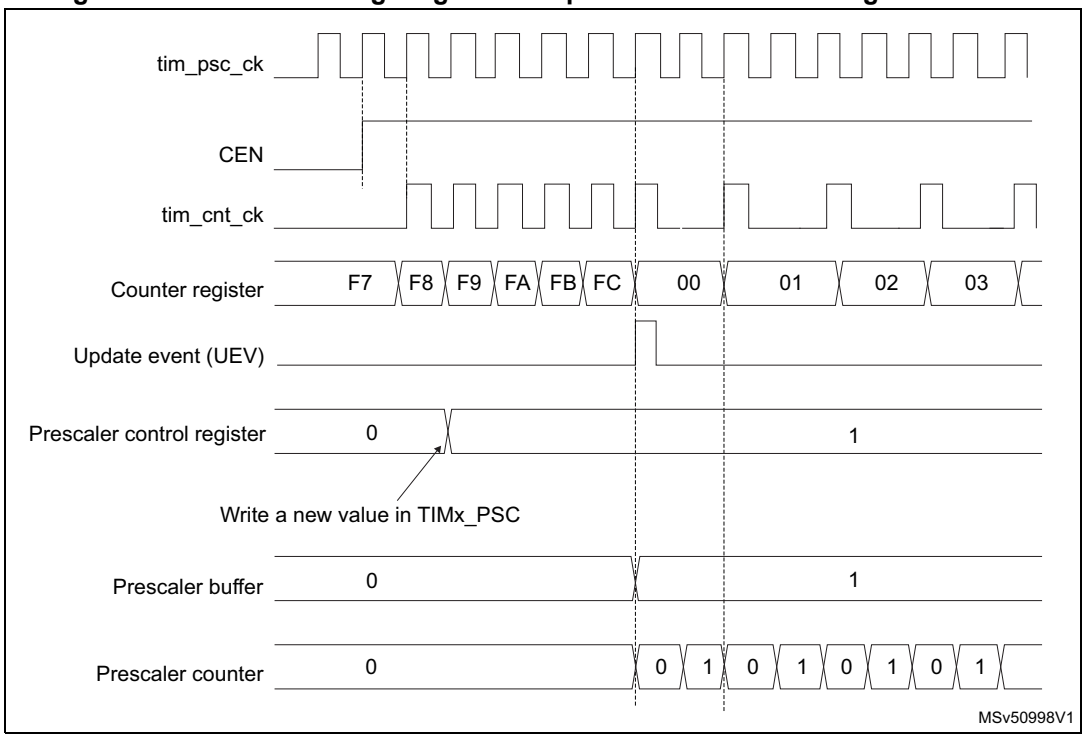
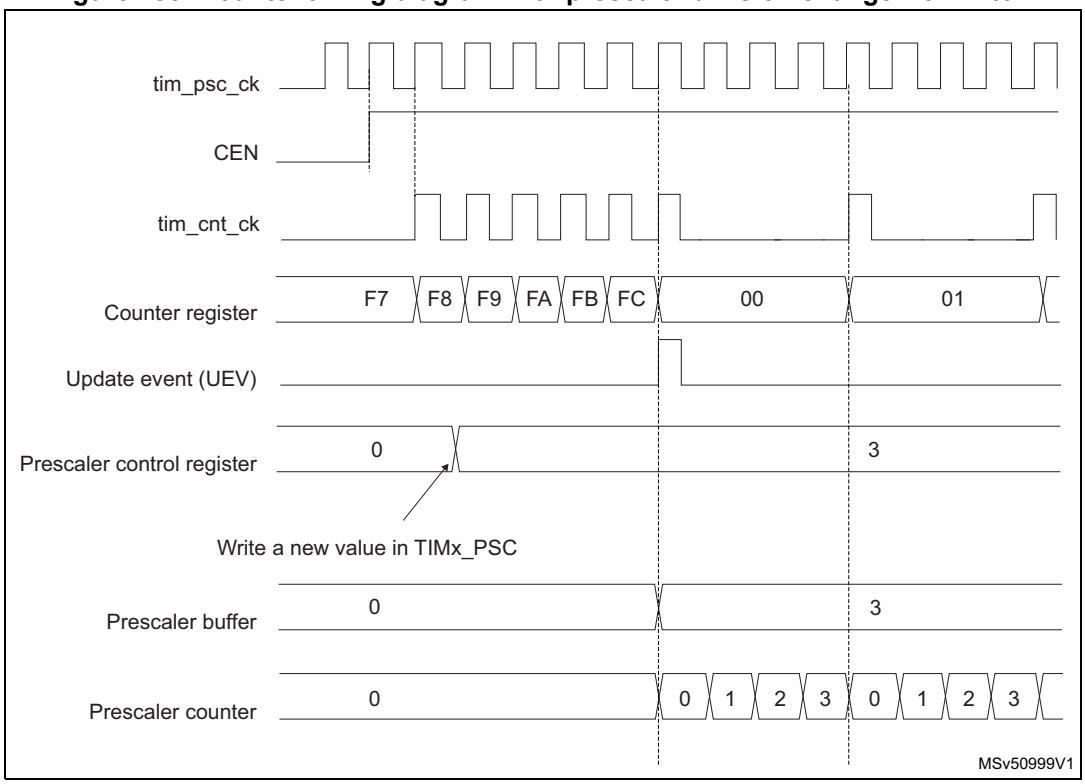


Figure 485. Counter timing diagram with prescaler division change from 1 to 4



49.3.4 Counter modes

Upcounting mode

In upcounting mode, the counter counts from 0 to the autoreload value (content of the TIMx_ARR register), then restarts from 0 and generates a counter overflow event.

If the repetition counter is used, the update event (UEV) is generated after upcounting is repeated for the number of times programmed in the repetition counter register (TIMx_RCR) + 1. Else the update event is generated at each counter overflow.

Setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller) also generates an update event.

The UEV event can be disabled by software by setting the UDIS bit in the TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter restarts from 0, as well as the counter of the prescaler (but the prescale rate does not change). In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The repetition counter is reloaded with the content of TIMx_RCR register,
- The autoreload shadow register is updated with the preload value (TIMx_ARR),
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR = 0x36.

Figure 486. Counter timing diagram, internal clock divided by 1

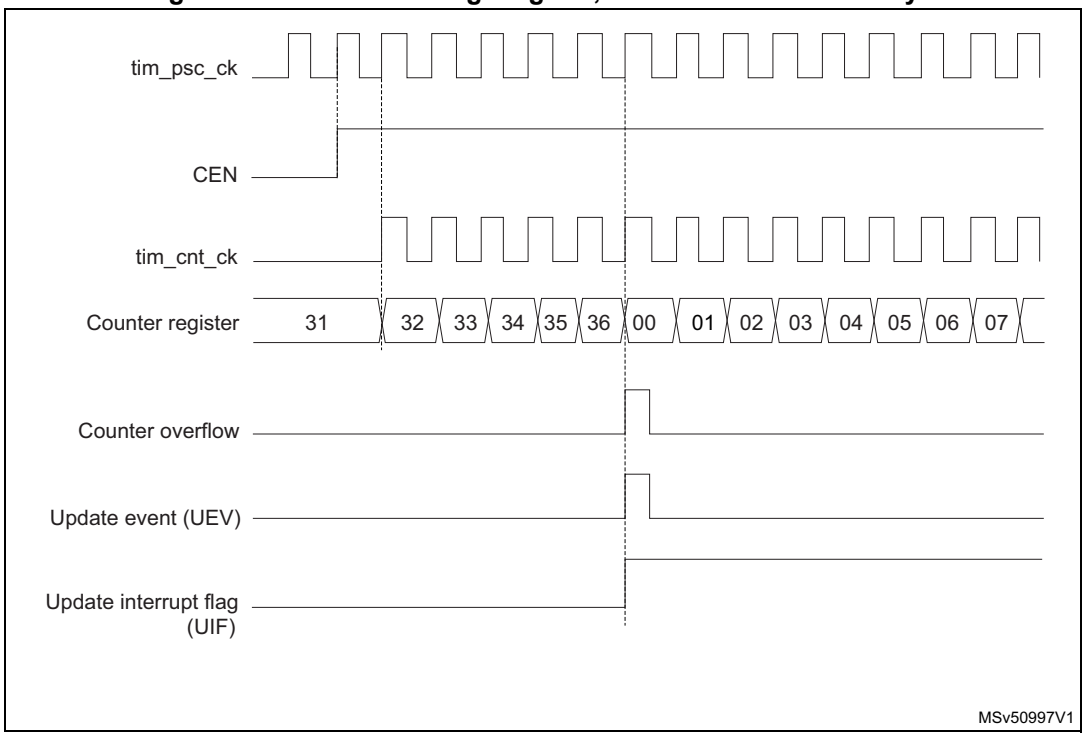


Figure 487. Counter timing diagram, internal clock divided by 2

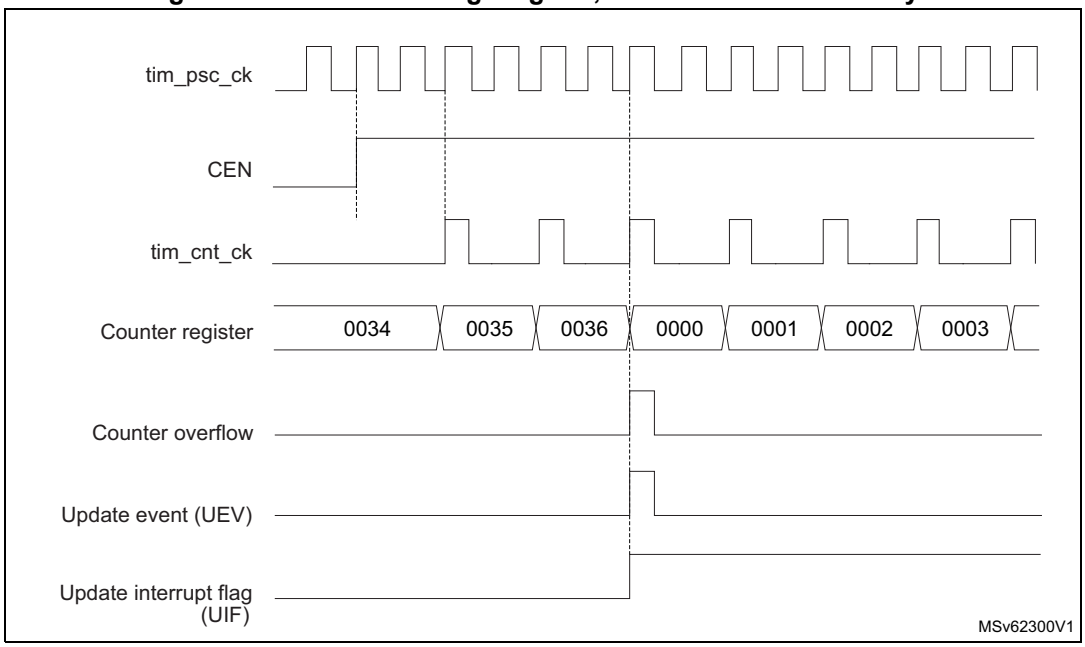


Figure 488. Counter timing diagram, internal clock divided by 4

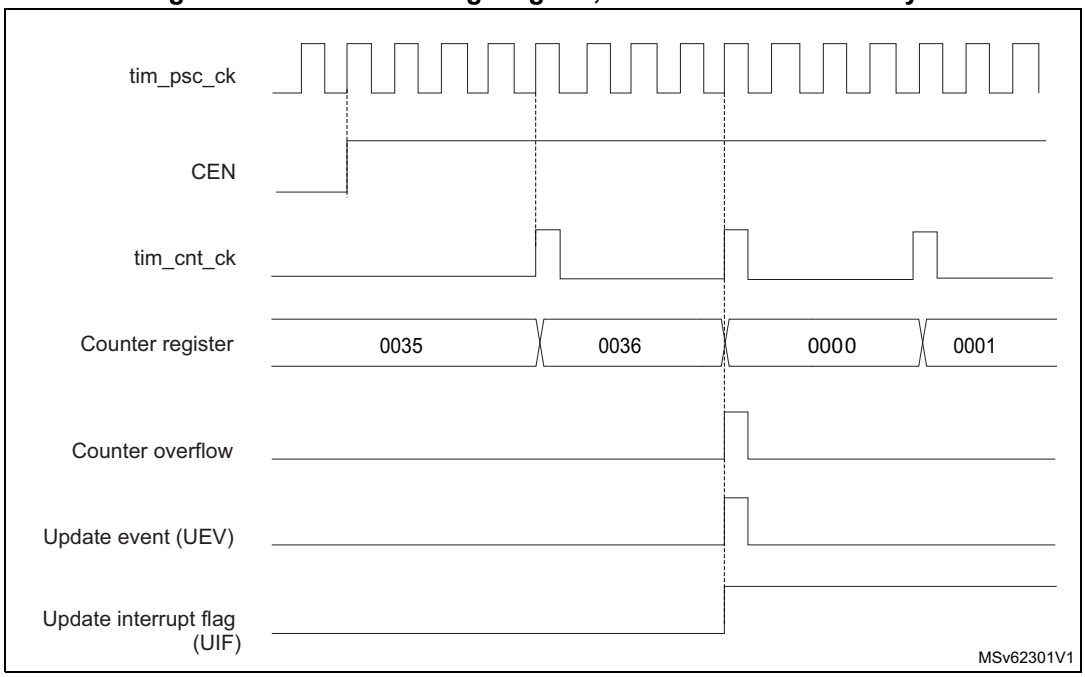


Figure 489. Counter timing diagram, internal clock divided by N

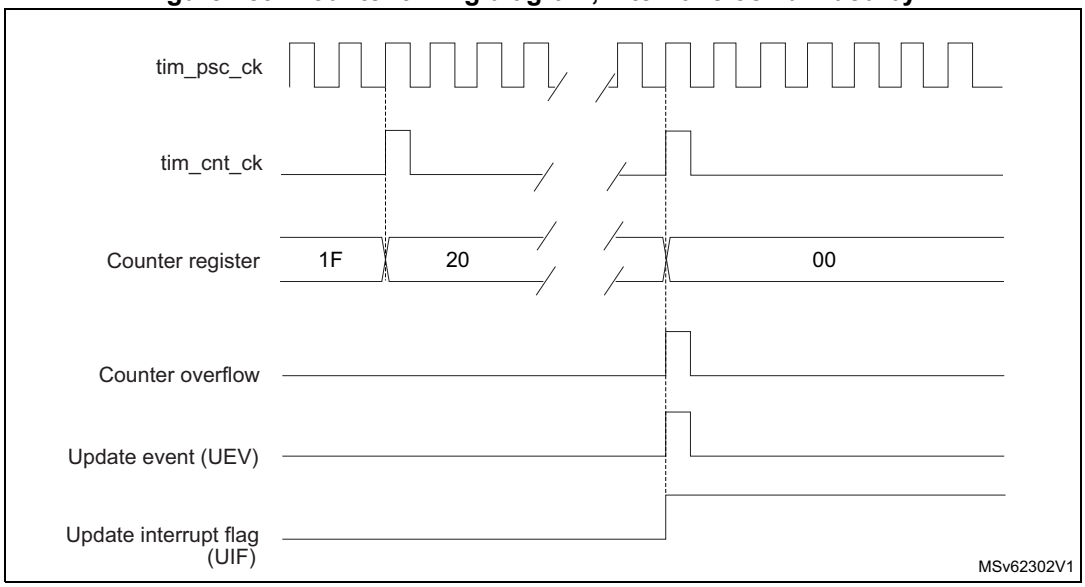


Figure 490. Counter timing diagram, update event when ARPE = 0 (TIMx_ARR not preloaded)

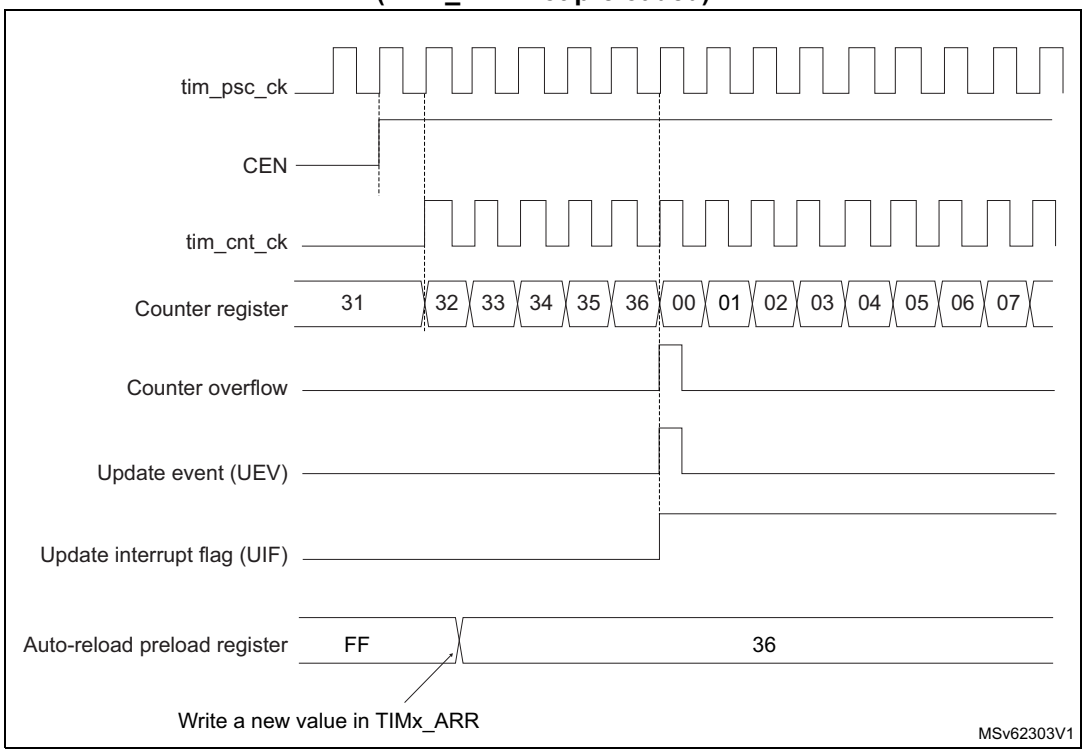
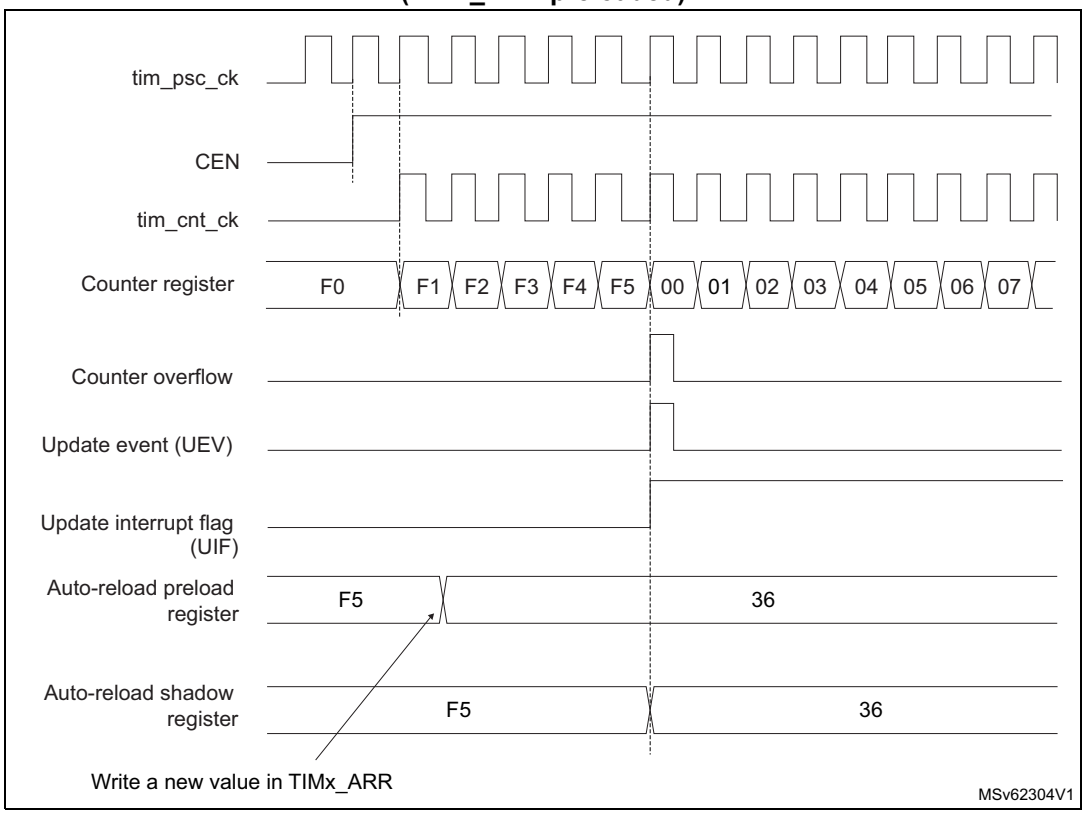


Figure 491. Counter timing diagram, update event when ARPE = 1 (TIMx_ARR preloaded)



Downcounting mode

In downcounting mode, the counter counts from the autoreload value (content of the TIMx_ARR register) down to 0, then restarts from the autoreload value and generates a counter underflow event.

If the repetition counter is used, the update event (UEV) is generated after downcounting is repeated for the number of times programmed in the repetition counter register (TIMx_RCR) + 1. Else the update event is generated at each counter underflow.

Setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller) also generates an update event.

The UEV update event can be disabled by software by setting the UDIS bit in TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until UDIS bit has been written to 0. However, the counter restarts from the current autoreload value, whereas the counter of the prescaler restarts from 0 (but the prescale rate doesn't change).

In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The repetition counter is reloaded with the content of TIMx_RCR register.
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).
- The autoreload active register is updated with the preload value (content of the TIMx_ARR register). Note that the autoreload is updated before the counter is reloaded, so that the next period is the expected one.

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR = 0x36.

Figure 492. Counter timing diagram, internal clock divided by 1

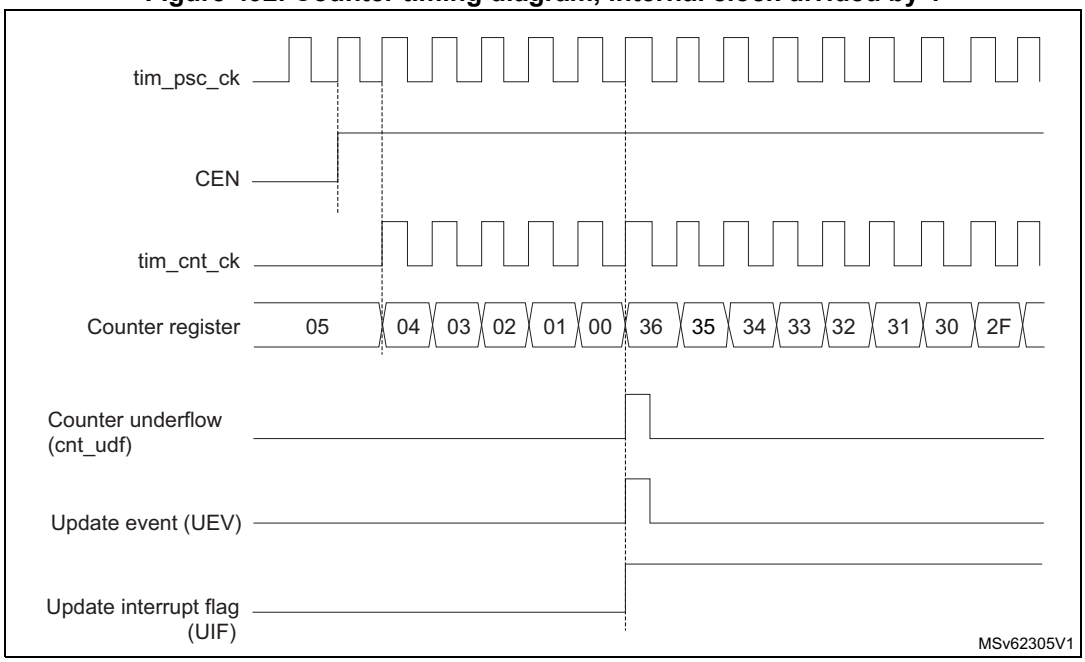


Figure 493. Counter timing diagram, internal clock divided by 2

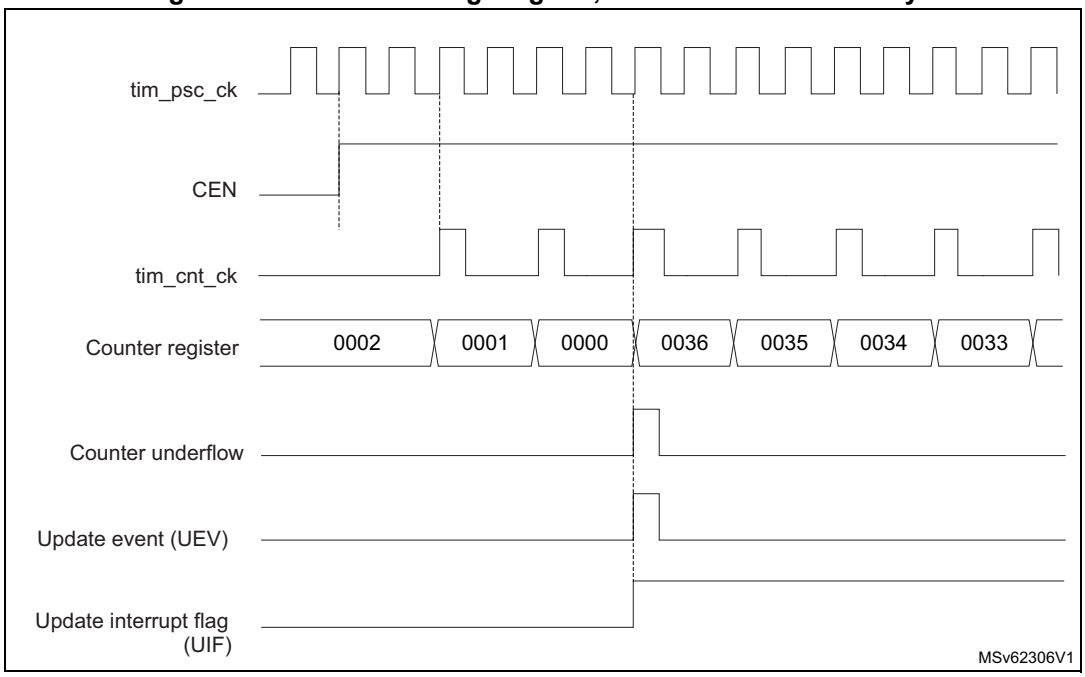


Figure 494. Counter timing diagram, internal clock divided by 4

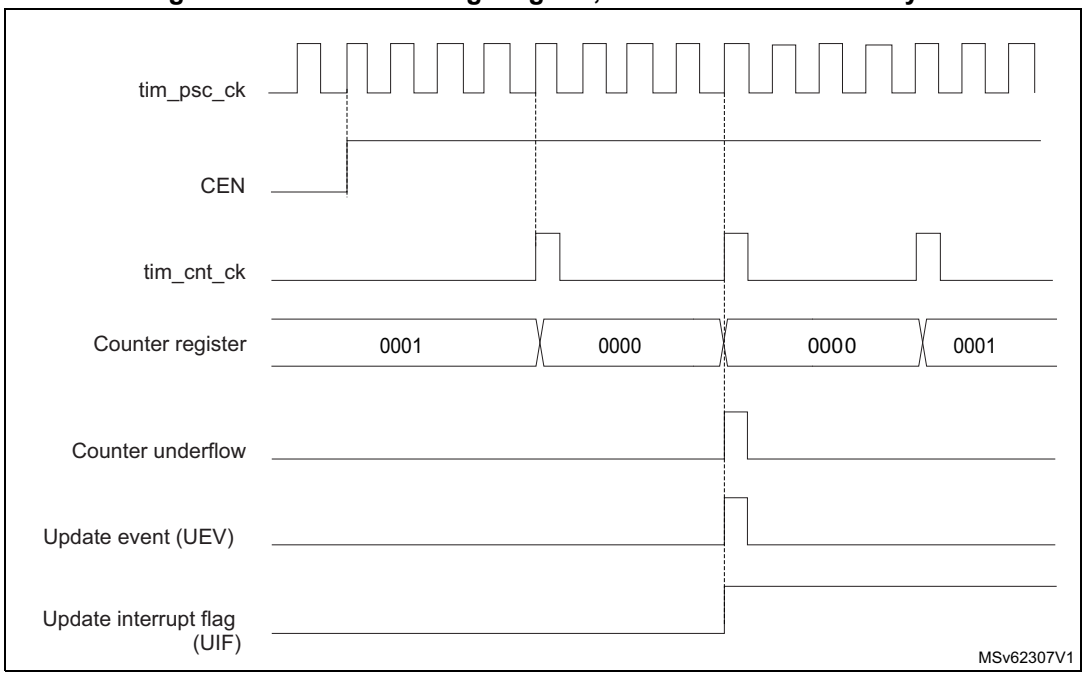


Figure 495. Counter timing diagram, internal clock divided by N

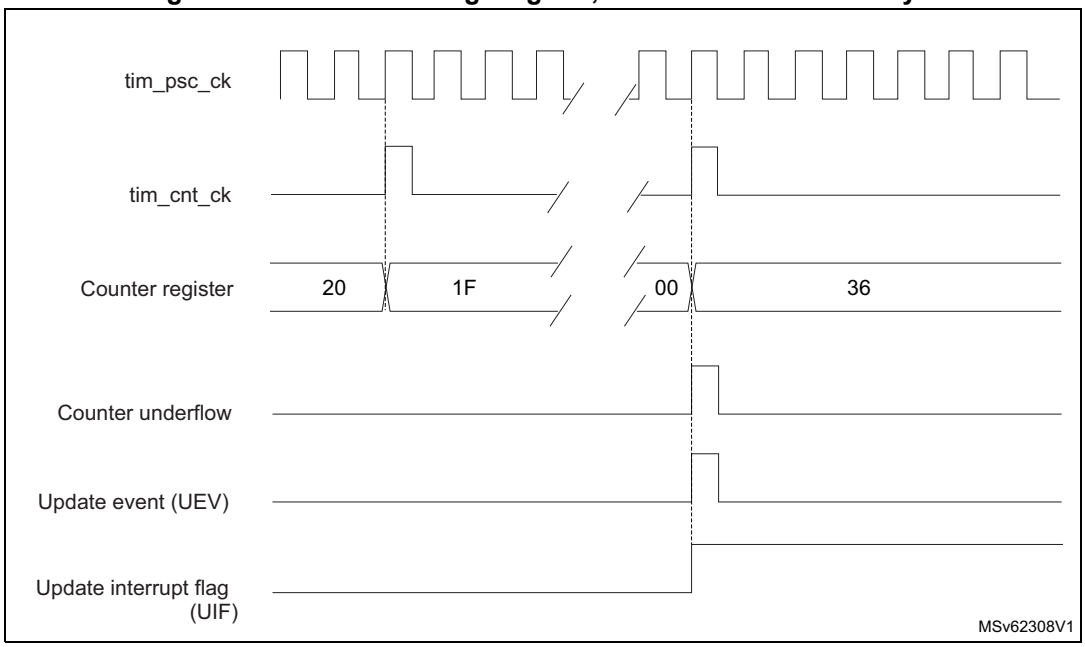
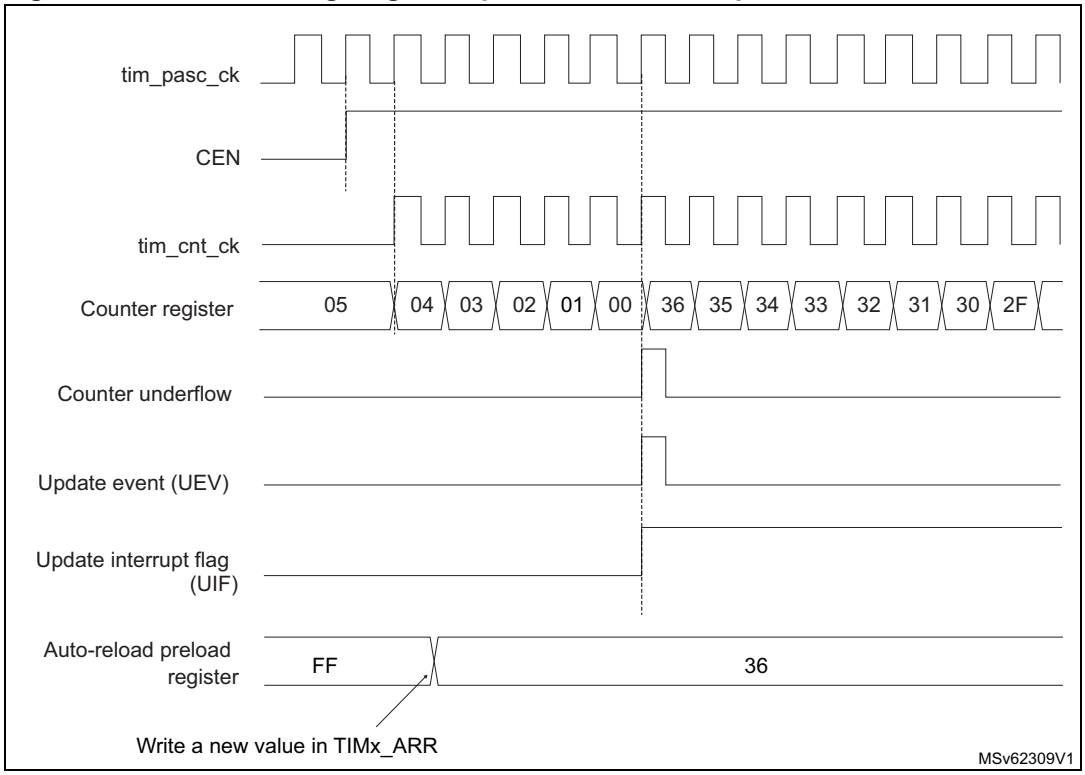


Figure 496. Counter timing diagram, update event when repetition counter is not used



Center-aligned mode (up/down counting)

In center-aligned mode, the counter counts from 0 to the autoreload value (content of the TIMx_ARR register) – 1, generates a counter overflow event, then counts from the

autoreload value down to 1 and generates a counter underflow event. Then it restarts counting from 0.

Center-aligned mode is active when the CMS bits in TIMx_CR1 register are not equal to 00. The Output compare interrupt flag of channels configured in output is set when: the counter counts down (Center aligned mode 1, CMS = 01), the counter counts up (Center aligned mode 2, CMS = 10) the counter counts up and down (Center aligned mode 3, CMS = 11).

In this mode, the DIR direction bit in the TIMx_CR1 register cannot be written. It is updated by hardware and gives the current direction of the counter.

The update event can be generated at each counter overflow and at each counter underflow or by setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller) also generates an update event. In this case, the counter restarts counting from 0, as well as the counter of the prescaler.

The UEV update event can be disabled by software by setting the UDIS bit in the TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until UDIS bit has been written to 0. However, the counter continues counting up and down, based on the current autoreload value.

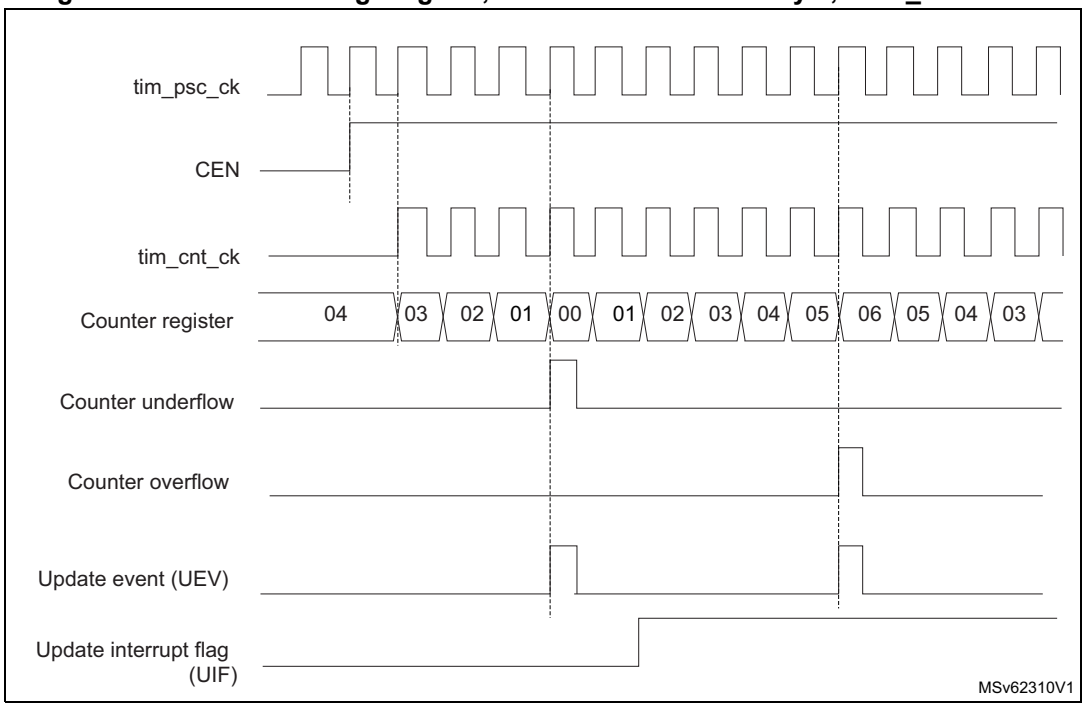
In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an UEV update event but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The repetition counter is reloaded with the content of TIMx_RCR register
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register)
- The autoreload active register is updated with the preload value (content of the TIMx_ARR register). Note that if the update source is a counter overflow, the autoreload is updated before the counter is reloaded, so that the next period is the expected one (the counter is loaded with the new value).

The following figures show some examples of the counter behavior for different clock frequencies.

Figure 497. Counter timing diagram, internal clock divided by 1, TIMx_ARR = 0x6



1. Here, center-aligned mode 1 is used (for more details refer to *Section 49.6: TIM1/TIM8 registers*).

Figure 498. Counter timing diagram, internal clock divided by 2

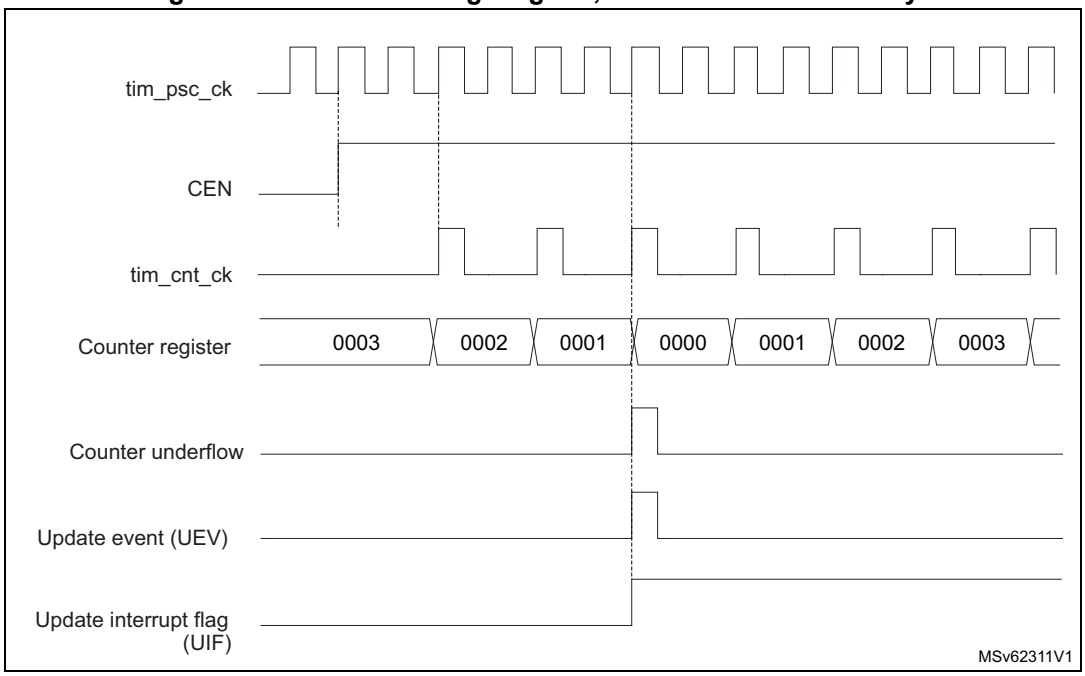


Figure 499. Counter timing diagram, internal clock divided by 4, TIMx_ARR = 0x36

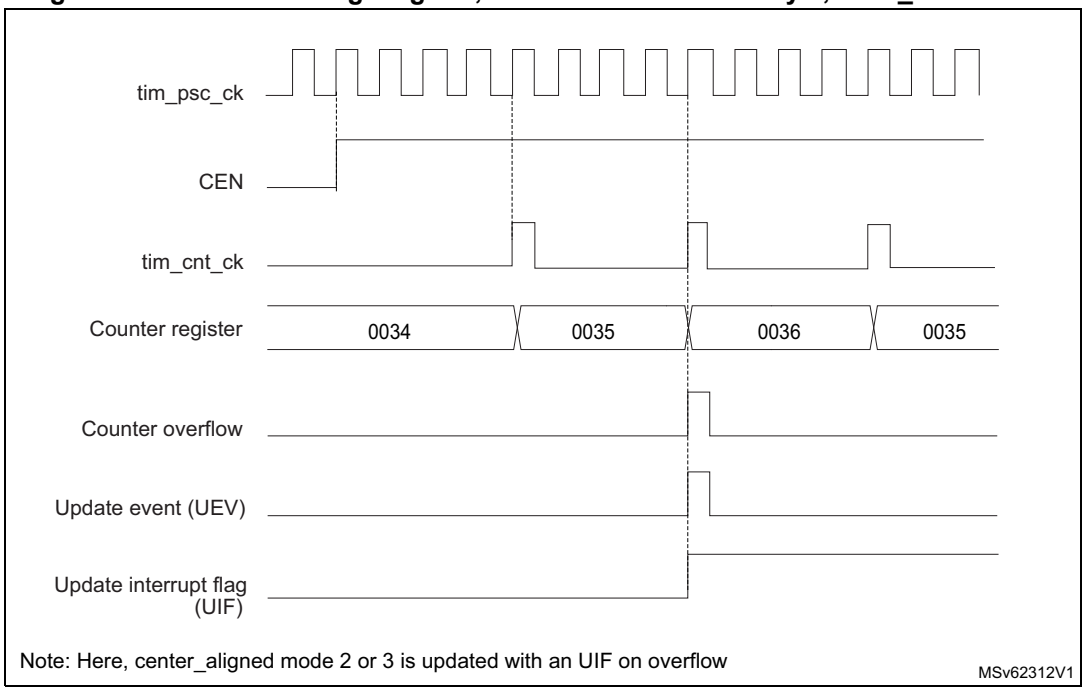


Figure 500. Counter timing diagram, internal clock divided by N

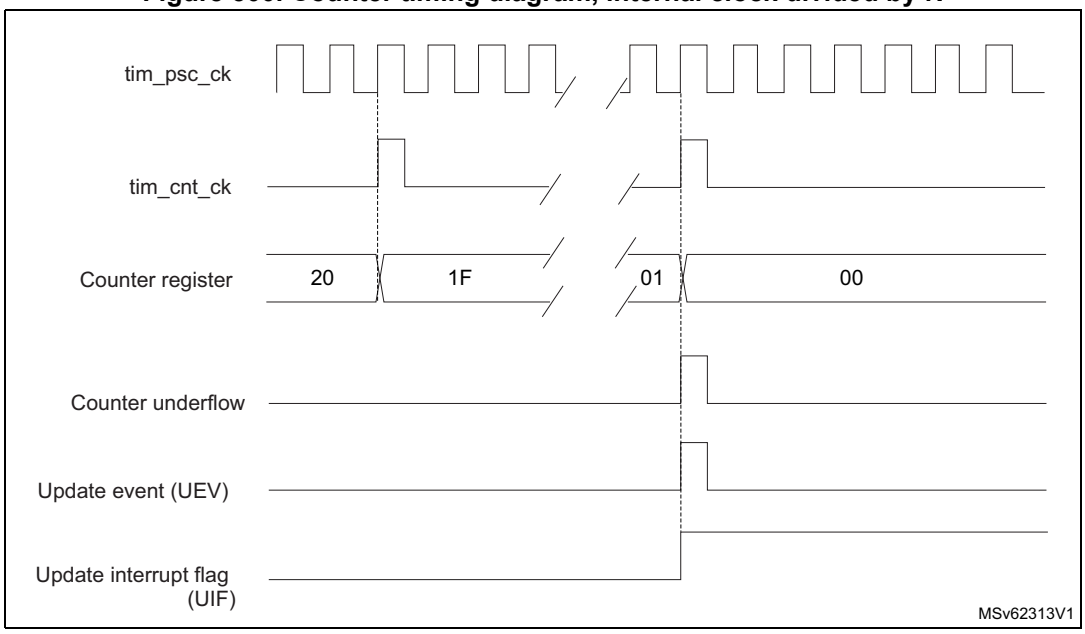


Figure 501. Counter timing diagram, update event with ARPE = 1 (counter underflow)

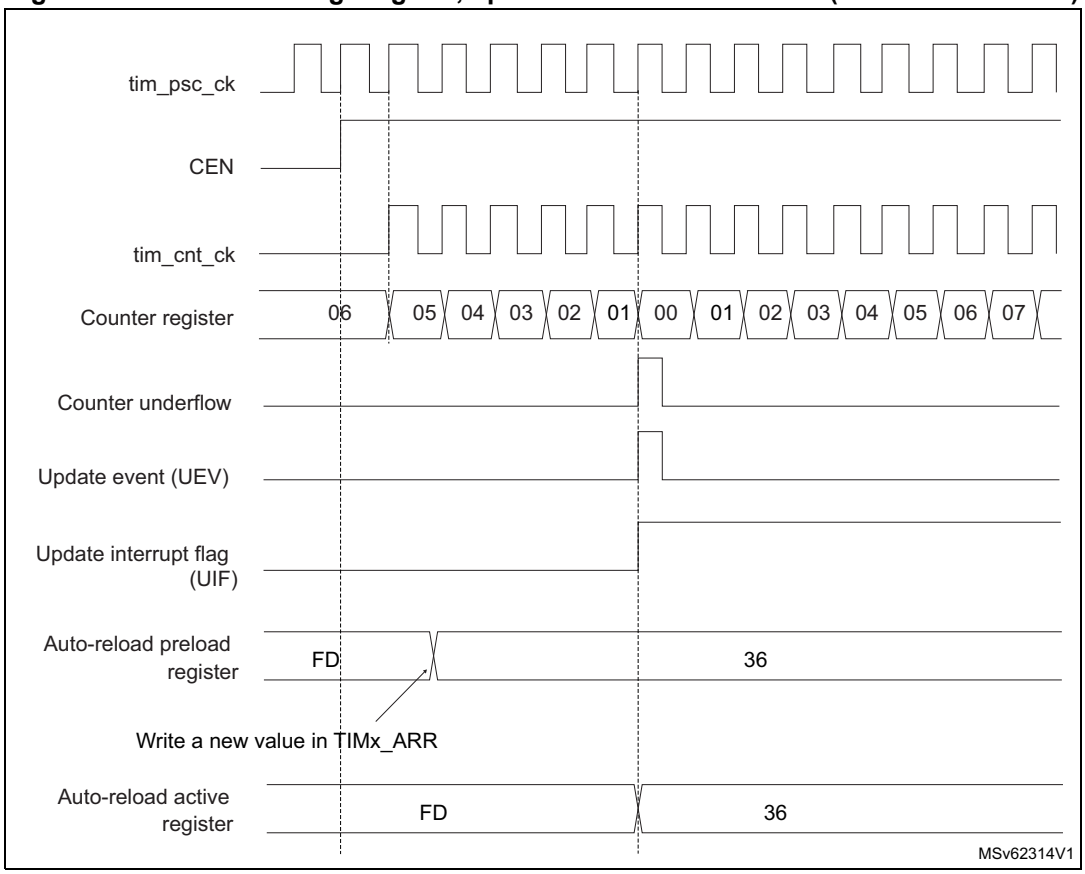
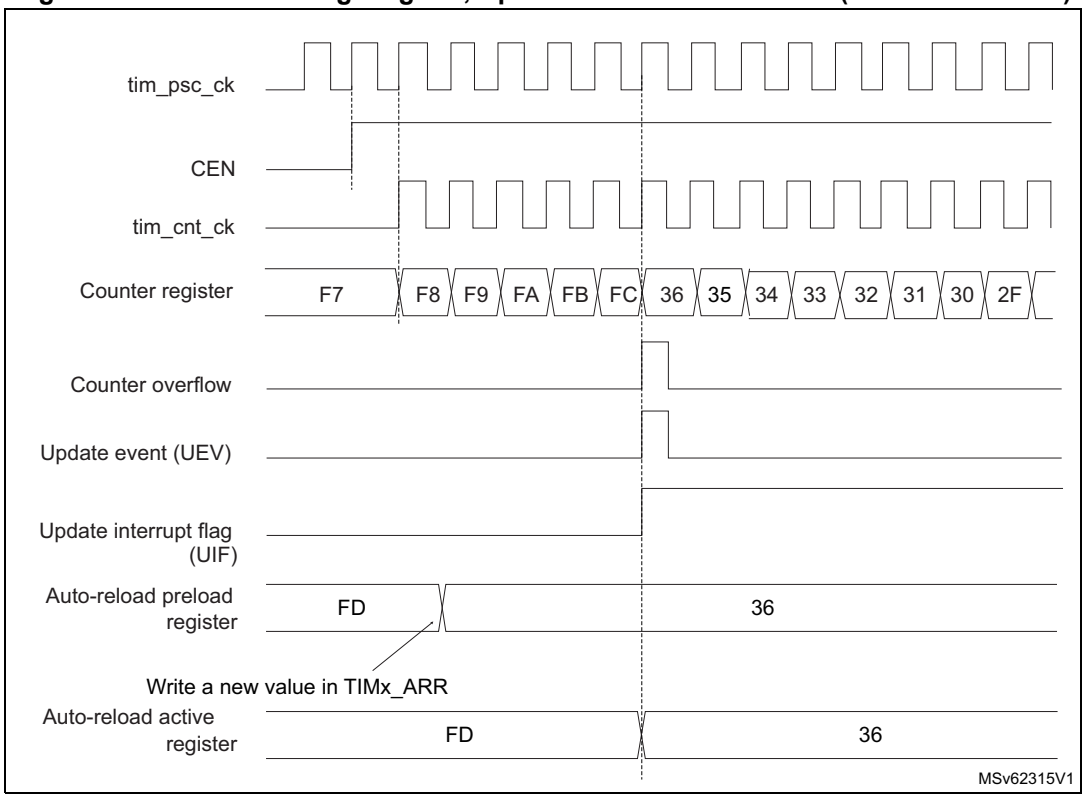


Figure 502. Counter timing diagram, Update event with ARPE = 1 (counter overflow)



49.3.5 Repetition counter

Section 49.3.3: Time-base unit describes how the update event (UEV) is generated with respect to the counter overflows/underflows. It is actually generated only when the repetition counter has reached zero. This can be useful when generating PWM signals.

This means that data are transferred from the preload registers to the shadow registers (TIMx_ARR autoreload register, TIMx_PSC prescaler register, but also TIMx_CCRx capture/compare registers in compare mode) every N+1 counter overflows or underflows, where N is the value in the TIMx_RCR repetition counter register.

The repetition counter is decremented:

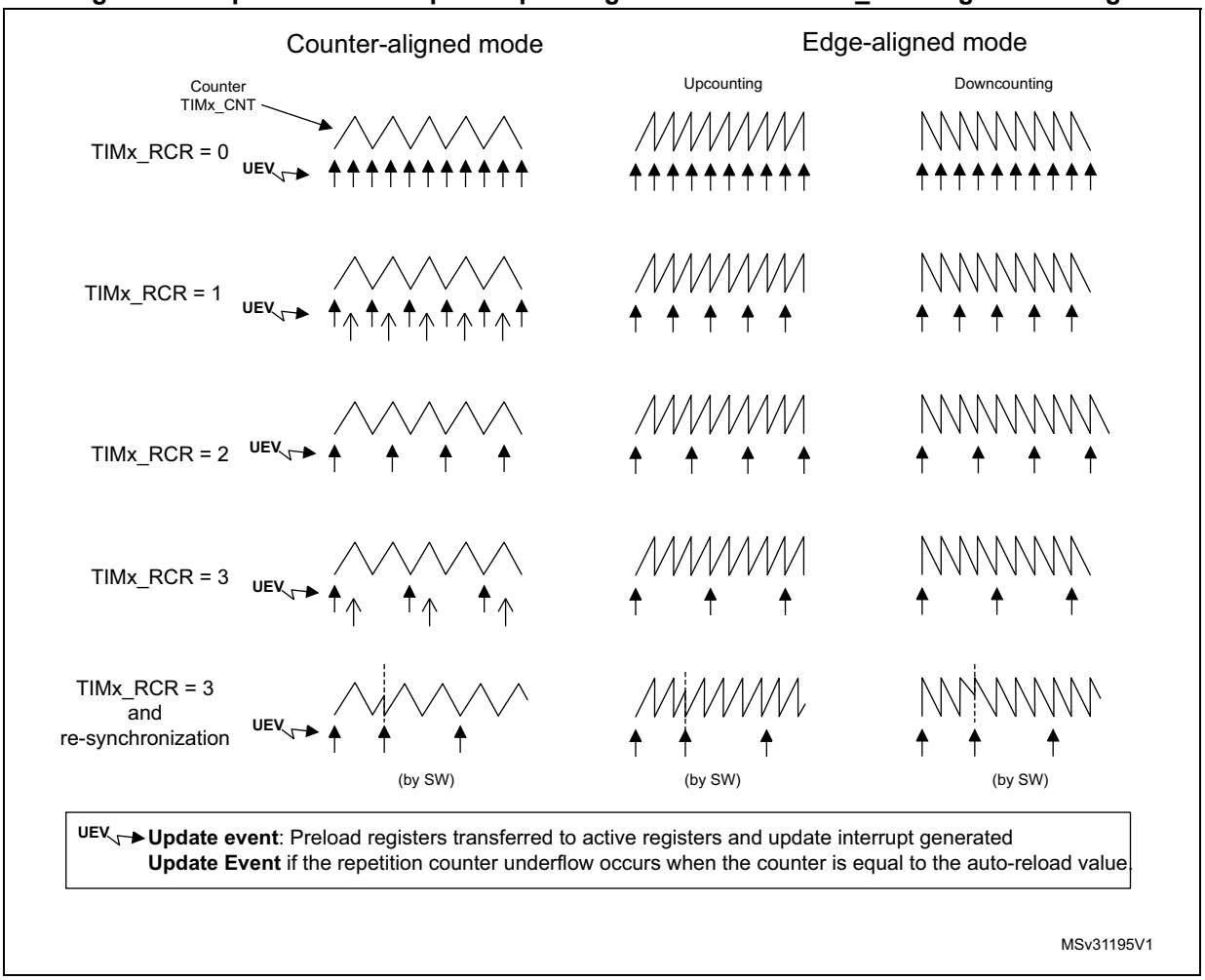
- At each counter overflow in upcounting mode,
- At each counter underflow in downcounting mode,
- At each counter overflow and at each counter underflow in center-aligned mode. Although this limits the maximum number of repetition to 32768 PWM cycles, it makes it possible to update the duty cycle twice per PWM period. When refreshing compare registers only once per PWM period in center-aligned mode, maximum resolution is $2xT_{ck}$, due to the symmetry of the pattern.

The repetition counter is an autoreload type; the repetition rate is maintained as defined by the TIMx_RCR register value (refer to *Figure 503*). When the update event is generated by software (by setting the UG bit in TIMx_EGR register) or by hardware through the slave mode controller, it occurs immediately whatever the value of the repetition counter is and the repetition counter is reloaded with the content of the TIMx_RCR register.

In Center aligned mode, for odd values of RCR, the update event occurs either on the overflow or on the underflow depending on when the RCR register was written and when the counter was launched: if the RCR was written before launching the counter, the UEV occurs on the underflow. If the RCR was written after launching the counter, the UEV occurs on the overflow.

For example, for RCR = 3, the UEV is generated each 4th overflow or underflow event depending on when the RCR was written.

Figure 503. Update rate examples depending on mode and TIMx_RCR register settings



49.3.6 External trigger input

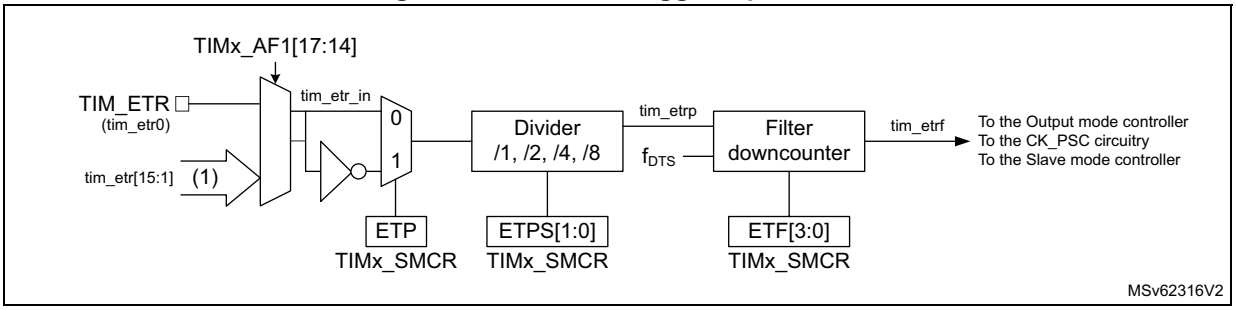
The timer features an external trigger input tim_etr_in. It can be used as:

- external clock (external clock mode 2, see *Section 49.3.7*)
- trigger for the slave mode (see *Section 49.3.30*)
- PWM reset input for cycle-by-cycle current regulation (see *Section 49.3.9*)

Figure 504 below describes the tim_etr_in input conditioning. The input polarity is defined with the ETP bit in TIMxSMCR register. The trigger can be prescaled with the divider programmed by the ETPS[1:0] bitfield and digitally filtered with the ETF[3:0] bitfield. The resulting signal (tim_etrf) is available for three purposes: as an external clock, to condition

the output (typically to reset a PWM output for a current limitation), and as a trigger for the Slave mode controller.

Figure 504. External trigger input block



The tim_etr_in input comes from multiple sources: input pins (default configuration), or internal sources. The selection is done with the ETRSEL[3:0] bitfield in the TIMx_AF1 register.

Refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals* for the list of sources connected to the etr_in input in the product.

49.3.7 Clock selection

The counter clock can be provided by the following clock sources:

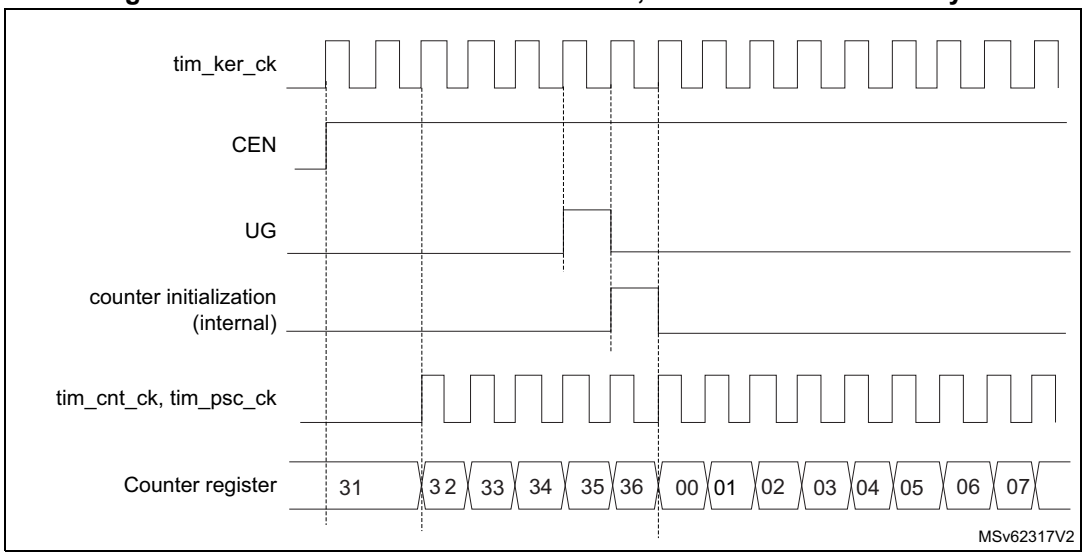
- Internal clock (tim_ker_ck)
- External clock mode1: external input pin (tim_ti1 or tim_ti2)
- External clock mode2: external trigger input (tim_etr_in)
- Encoder mode

Internal clock source (tim_ker_ck)

If the slave mode controller is disabled (SMS = 000), then the CEN, DIR (in the TIMx_CR1 register) and UG bits (in the TIMx_EGR register) are actual control bits and can be changed only by software (except UG which remains cleared automatically). As soon as the CEN bit is written to 1, the prescaler is clocked by the internal clock tim_ker_ck.

Figure 505 shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

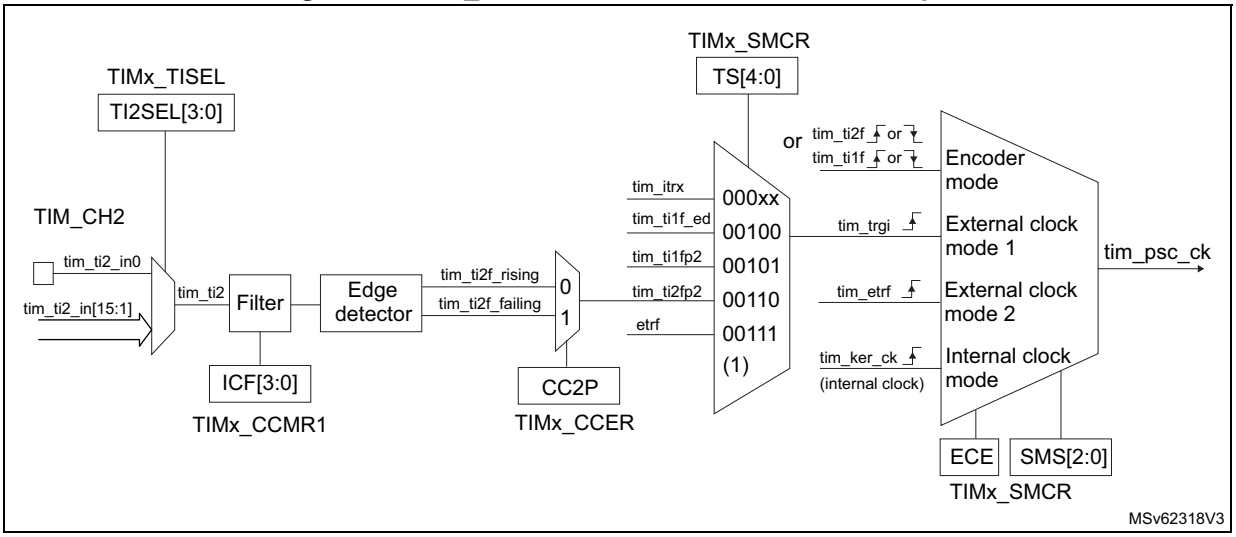
Figure 505. Control circuit in normal mode, internal clock divided by 1



External clock source mode 1

This mode is selected when SMS = 111 in the TIMx_SMCR register. The counter can count at each rising or falling edge on a selected input.

Figure 506. tim_ti2 external clock connection example



1. Codes ranging from 01000 to 11111 are reserved.

For example, to configure the upcounter to count in response to a rising edge on the tim_ti2 input, use the following procedure:

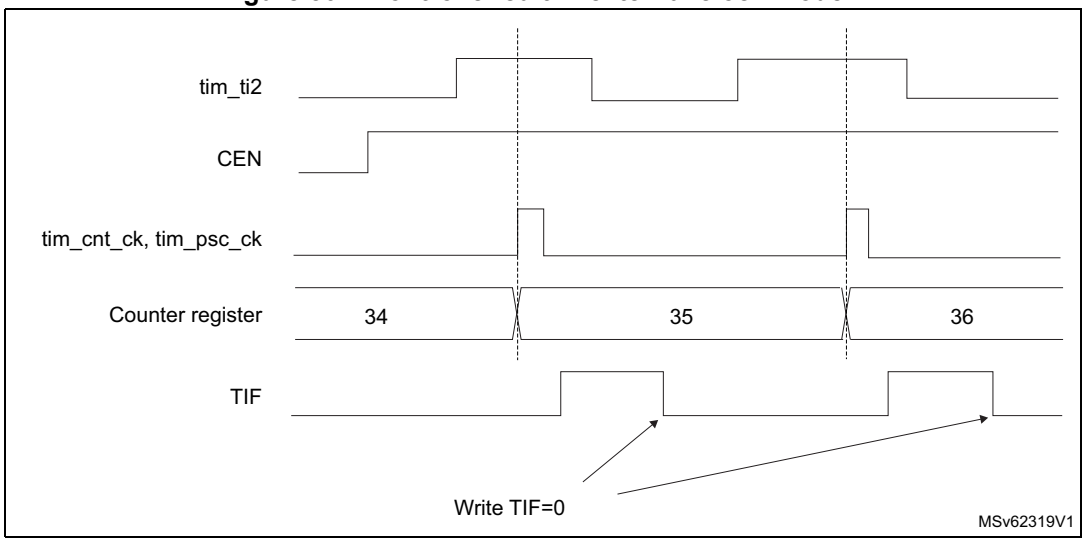
1. Configure channel 2 to detect rising edges on the tim_ti2 input by writing CC2S = 01 in the TIMx_CCMR1 register.
2. Configure the input filter duration by writing the IC2F[3:0] bits in the TIMx_CCMR1 register (if no filter is needed, keep IC2F = 0000).
3. Select rising edge polarity by writing CC2P = 0 and CC2NP = 0 in the TIMx_CCER register.
4. Configure the timer in external clock mode 1 by writing SMS = 111 in the TIMx_SMCR register.
5. Select tim_ti2 as the trigger input source by writing TS = 00110 in the TIMx_SMCR register.
6. Enable the counter by writing CEN = 1 in the TIMx_CR1 register.

Note: The capture prescaler is not used for triggering, it is not necessary to configure it.

When a rising edge occurs on tim_ti2, the counter counts once and the TIF flag is set.

The delay between the rising edge on tim_ti2 and the actual clock of the counter is due to the resynchronization circuit on tim_ti2 input.

Figure 507. Control circuit in external clock mode 1



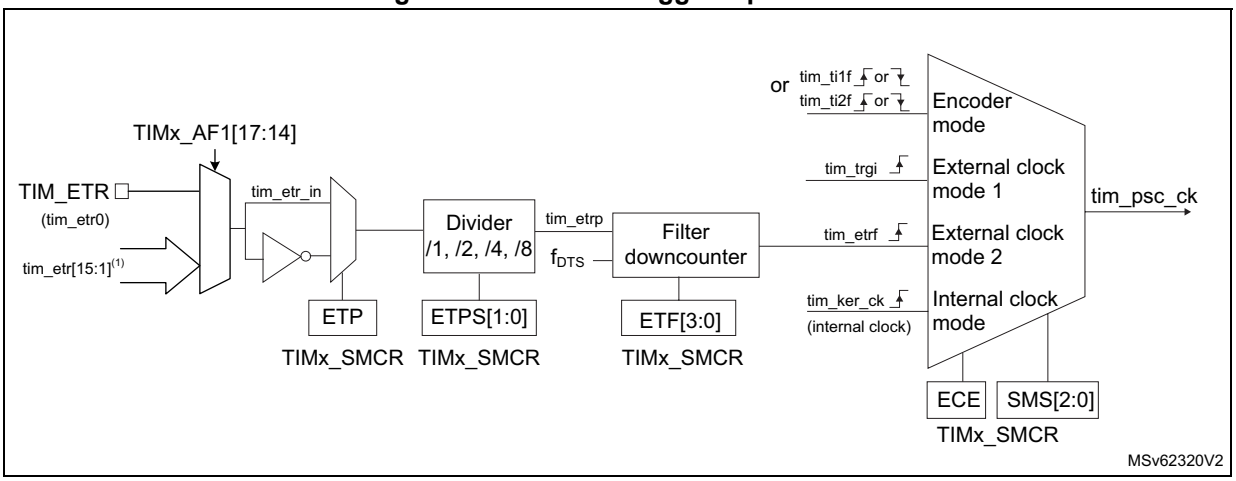
External clock source mode 2

This mode is selected by writing ECE = 1 in the TIMx_SMCR register.

The counter counts at each rising or falling edge on the external trigger input tim_etr_in.

The *Figure 508* gives an overview of the external trigger input block.

Figure 508. External trigger input block



1. Refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals*.

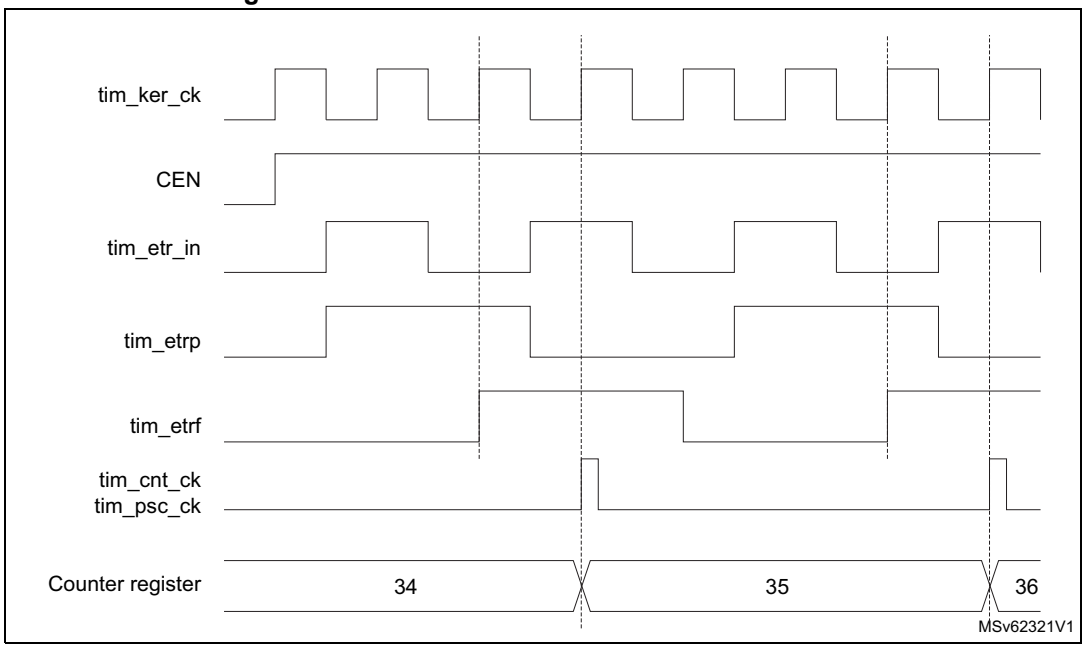
For example, to configure the upcounter to count each 2 rising edges on tim_etr_in, use the following procedure:

1. As no filter is needed in this example, write ETF[3:0] = 0000 in the TIMx_SMCR register.
2. Set the prescaler by writing ETPS[1:0] = 01 in the TIMx_SMCR register
3. Select rising edge detection on the tim_etr_in input by writing ETP = 0 in the TIMx_SMCR register
4. Enable external clock mode 2 by writing ECE = 1 in the TIMx_SMCR register.
5. Enable the counter by writing CEN = 1 in the TIMx_CR1 register.

The counter counts once each 2 tim_etr_in rising edges.

The delay between the rising edge on tim_etr_in and the actual clock of the counter is due to the resynchronization circuit on the tim_etrp signal. As a consequence, the maximum frequency which can be correctly captured by the counter is at most ¼ of tim_ker_ck frequency. When the ETRP signal is faster, the user must apply a division of the external signal by a proper ETPS prescaler setting.

Figure 509. Control circuit in external clock mode 2



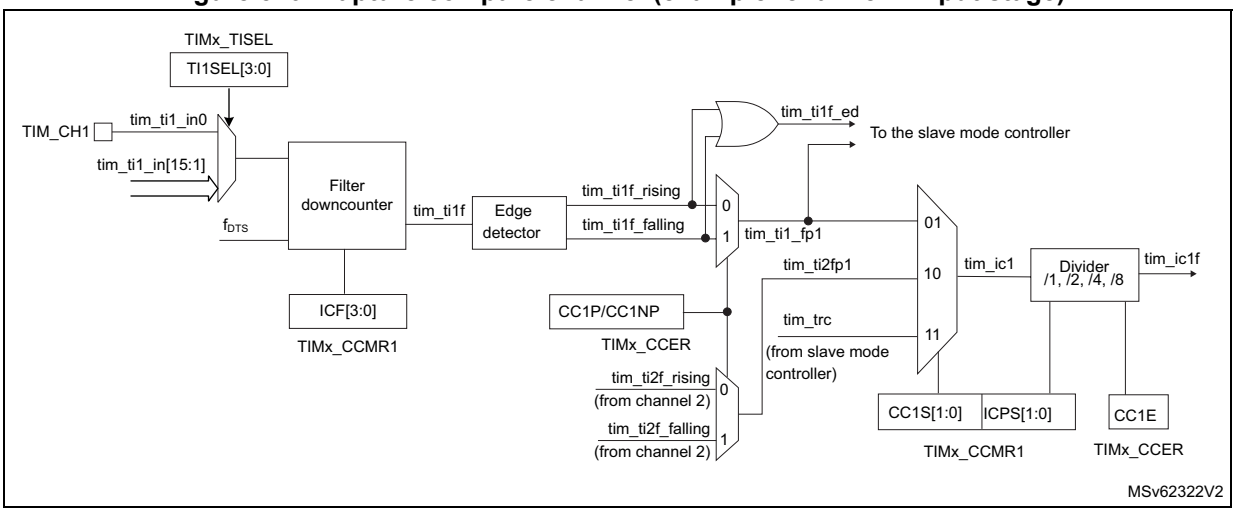
49.3.8 Capture/compare channels

Each capture/compare channel is built around a capture/compare register (including a shadow register), an input stage for capture (with digital filter, multiplexing, and prescaler, except for channels 5 and 6) and an output stage (with comparator and output control).

Figure 510 to *Figure 513* give an overview of one capture/compare channel.

The input stage samples the corresponding tim_tix input to generate a filtered signal tim_tixf. Then, an edge detector with polarity selection generates a signal (tim_tixfpy) which can be used as trigger input by the slave mode controller or as the capture command. It is prescaled before the capture register (ICxPS).

Figure 510. Capture/compare channel (example: channel 1 input stage)



The output stage generates an intermediate waveform which is then used for reference: tim_ocxref (active high). The polarity acts at the end of the chain.

Figure 511. Capture/compare channel 1 main circuit

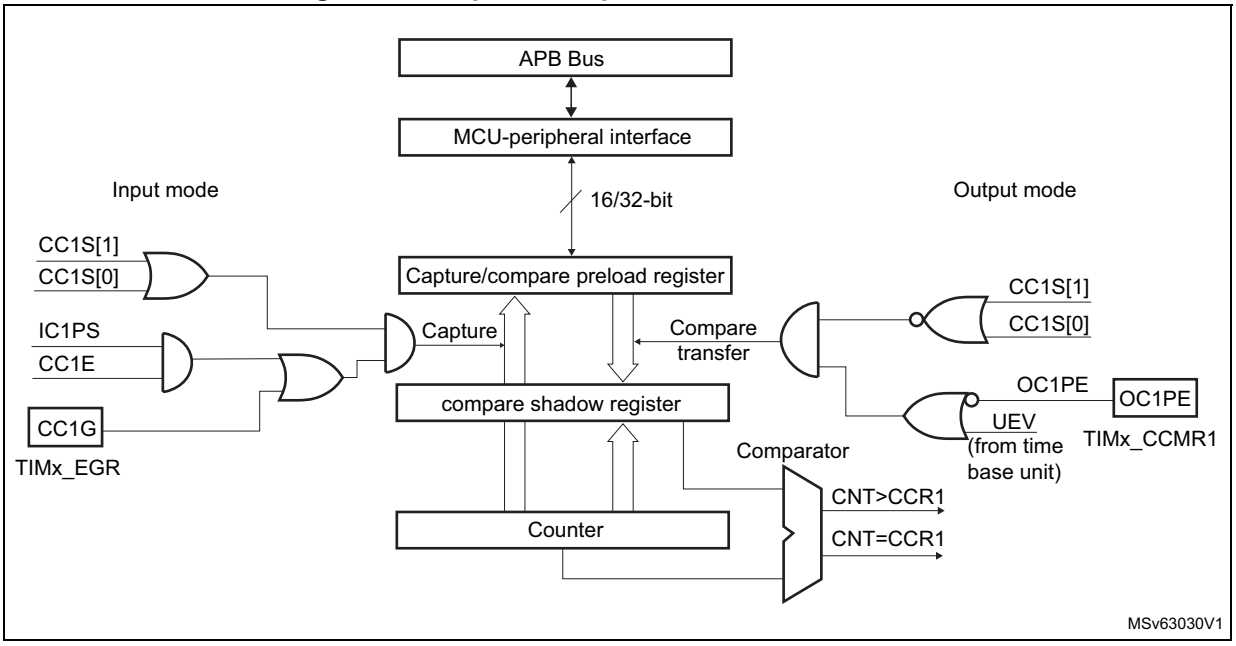
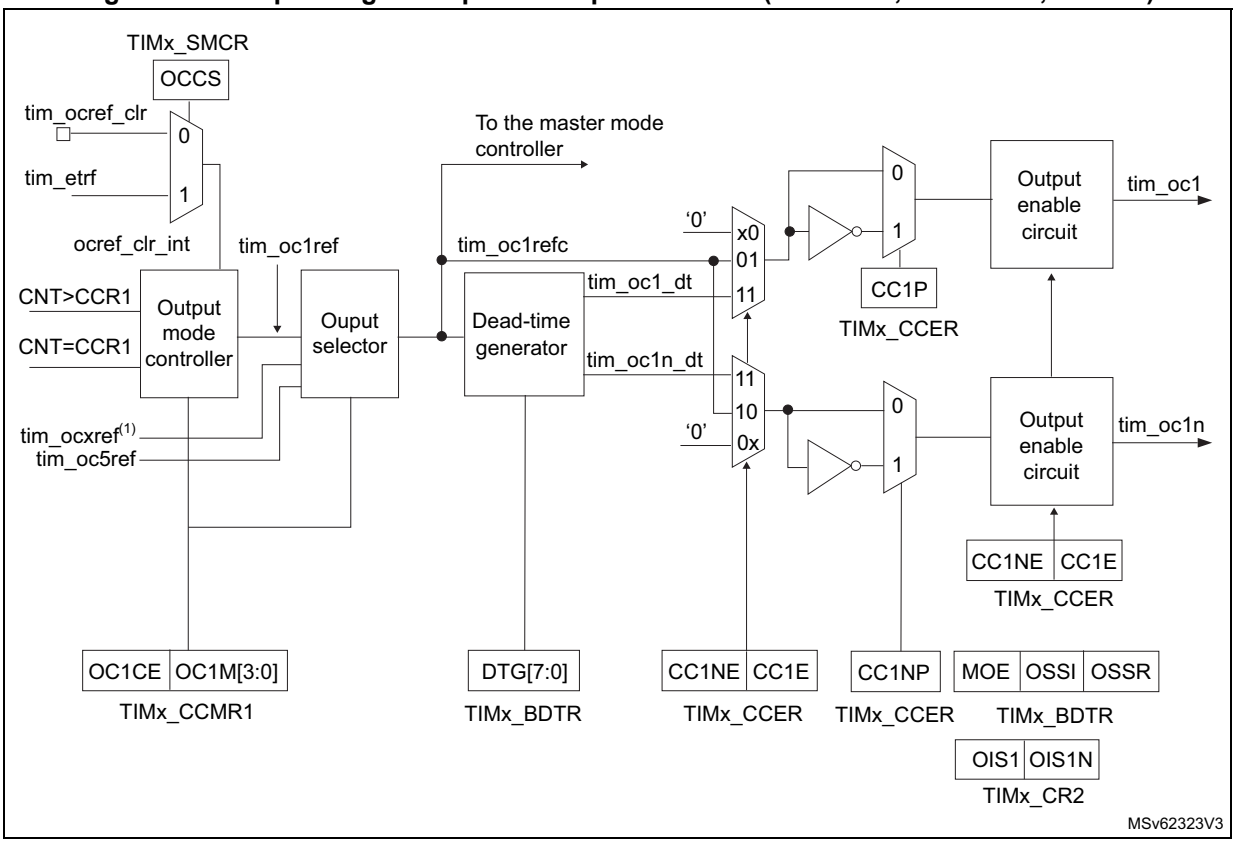
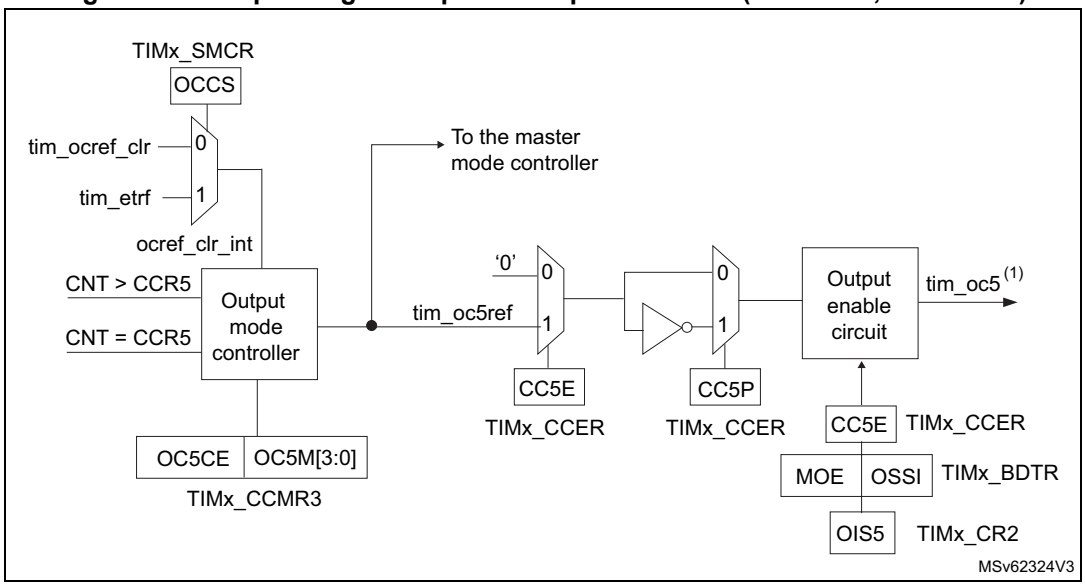


Figure 512. Output stage of capture/compare channel (channel 1, idem ch. 2, 3 and 4)



1. tim_ocxref, where x is the rank of the complementary channel

Figure 513. Output stage of capture/compare channel (channel 5, idem ch. 6)



1. Not available externally.

The capture/compare block is made of one preload register and one shadow register. Write and read always access the preload register.

In capture mode, captures are actually done in the shadow register, which is copied into the preload register.

In compare mode, the content of the preload register is copied into the shadow register which is compared to the counter.

49.3.9 Input capture mode

In Input capture mode, the capture/compare registers (TIMx_CCRx) are used to latch the value of the counter after a transition detected by the corresponding ICx signal. When a capture occurs, the corresponding CCXIF flag (TIMx_SR register) is set and an interrupt or a DMA request can be sent if they are enabled. If a capture occurs while the CCxIF flag was already high, then the overcapture flag CCxOF (TIMx_SR register) is set. CCxIF can be cleared by software by writing it to 0 or by reading the captured data stored in the TIMx_CCRx register. CCxOF is cleared when it is written with 0.

The following example shows how to capture the counter value in TIMx_CCR1 when tim_ti1 input rises. To do this, use the following procedure:

- Select the active input: TIMx_CCR1 must be linked to the tim_ti1 input, so write the CC1S bits to 01 in the TIMx_CCMR1 register. As soon as CC1S becomes different from 00, the channel is configured in input, and the TIMx_CCR1 register becomes read-only.
- Program the appropriate input filter duration in relation with the signal connected to the timer (when the input is one of the tim_tix (ICxF bits in the TIMx_CCMRx register). Let's imagine that, when toggling, the input signal is not stable during at must five internal clock cycles. We must program a filter duration longer than these five clock cycles. We can validate a transition on tim_ti1 when eight consecutive samples with the new level have been detected (sampled at f_{DTS} frequency). Then write IC1F bits to 0011 in the TIMx_CCMR1 register.
- Select the edge of the active transition on the tim_ti1 channel by writing CC1P and CC1NP bits to 0 in the TIMx_CCER register (rising edge in this case).
- Program the input prescaler. In our example, we wish the capture to be performed at each valid transition, so the prescaler is disabled (write IC1PS bits to 00 in the TIMx_CCMR1 register).
- Enable capture from the counter into the capture register by setting the CC1E bit in the TIMx_CCER register.
- If needed, enable the related interrupt request by setting the CC1IE bit in the TIMx_DIER register, and/or the DMA request by setting the CC1DE bit in the TIMx_DIER register.

When an input capture occurs:

- The TIMx_CCR1 register gets the value of the counter on the active transition.
- CC1IF flag is set (interrupt flag). CC1OF is also set if at least two consecutive captures occurred whereas the flag was not cleared.
- An interrupt is generated depending on the CC1IE bit.
- A DMA request is generated depending on the CC1DE bit.

In order to handle the overcapture, it is recommended to read the data before the overcapture flag. This is to avoid missing an overcapture which may happen after reading the flag and before reading the data.

Note: IC interrupt and/or DMA requests can be generated by software by setting the corresponding CCxG bit in the TIMx_EGR register.

49.3.10 PWM input mode

This mode is used to measure both the period and the duty cycle of a PWM signal connected to single tim_tix input:

- The TIMx_CCR1 register holds the period value (interval between two consecutive rising edges).
- The TIM_CCR2 register holds the pulsewidth (interval between two consecutive rising and falling edges.

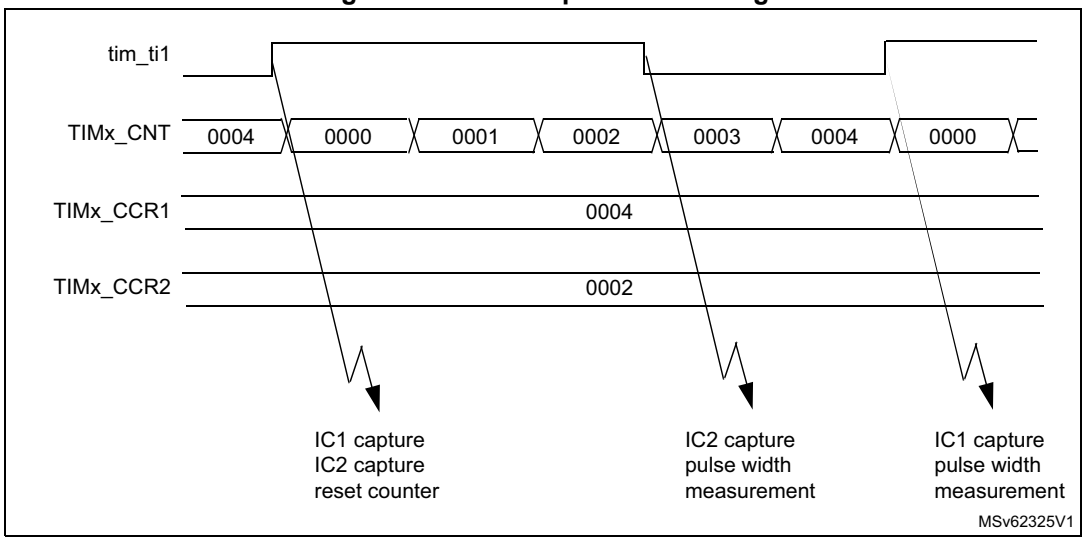
This mode is a particular case of input capture mode. The set-up procedure is similar with the following differences:

- Two ICx signals are mapped on the same tim_tixfp1 input.
- These two ICx signals are active on edges with opposite polarity.
- One of the two tim_tixfp signals is selected as trigger input and the slave mode controller is configured in reset mode.

The period and the pulsewidth of a PWM signal applied on tim_ti1 can be measured using the following procedure:

- Select the active input for TIMx_CCR1: write the CC1S bits to 01 in the TIMx_CCMR1 register (tim_ti1 selected).
- Select the active polarity for tim_ti1fp1 (used both for capture in TIMx_CCR1 and counter clear): write the CC1P and CC1NP bits to 0 (active on rising edge).
- Select the active input for TIMx_CCR2: write the CC2S bits to 10 in the TIMx_CCMR1 register (tim_ti1 selected).
- Select the active polarity for tim_ti1fp2 (used for capture in TIMx_CCR2): write the CC2P and CC2NP bits to CC2P/CC2NP = 10 (active on falling edge).
- Select the valid trigger input: write the TS bits to 00101 in the TIMx_SMCR register (tim_ti1fp1 selected).
- Configure the slave mode controller in reset mode: write the SMS bits to 0100 in the TIMx_SMCR register.
- Enable the captures: write the CC1E and CC2E bits to 1 in the TIMx_CCER register.

Figure 514. PWM input mode timing



49.3.11 Forced output mode

In output mode (CCxS bits = 00 in the TIMx_CCMRx register), each output compare signal (tim_ocxref and then tim_ocx/tim_ocxn) can be forced to active or inactive level directly by software, independently of any comparison between the output compare register and the counter.

To force an output compare signal (tim_ocxref/tim_ocx) to its active level, user just needs to write 0101 in the OCxM bits in the corresponding TIMx_CCMRx register. Thus tim_ocxref is forced high (tim_ocxref is always active high) and tim_ocx get opposite value to CCxP polarity bit.

For example: CCxP = 0 (tim_ocx active high) => tim_ocx is forced to high level.

The tim_ocxref signal can be forced low by writing the OCxM bits to 0100 in the TIMx_CCMRx register.

Anyway, the comparison between the TIMx_CCRx shadow register and the counter is still performed and allows the flag to be set. Interrupt and DMA requests can be sent accordingly. This is described in the output compare mode section below.

49.3.12 Output compare mode

This function is used to control an output waveform or indicate when a period of time has elapsed. Channels 1 to 4 can be output, while channel 5 and 6 are only available inside the microcontroller (for instance, for compound waveform generation or for ADC triggering).

When a match is found between the capture/compare register and the counter, the output compare function:

- Assigns the corresponding output pin to a programmable value defined by the output compare mode (OCxM bits in the TIMx_CCMRx register) and the output polarity (CCxP bit in the TIMx_CCER register). The output pin can keep its level (OCXM = 0000), be

set active (OCxM = 0001), be set inactive (OCxM = 0010) or can toggle (OCxM = 0011) on match.

- Sets a flag in the interrupt status register (CCxIF bit in the TIMx_SR register).
- Generates an interrupt if the corresponding interrupt mask is set (CCXIE bit in the TIMx_DIER register).
- Sends a DMA request if the corresponding enable bit is set (CCxDE bit in the TIMx_DIER register, CCDS bit in the TIMx_CR2 register for the DMA request selection).

The TIMx_CCRx registers can be programmed with or without preload registers using the OCxPE bit in the TIMx_CCMRx register.

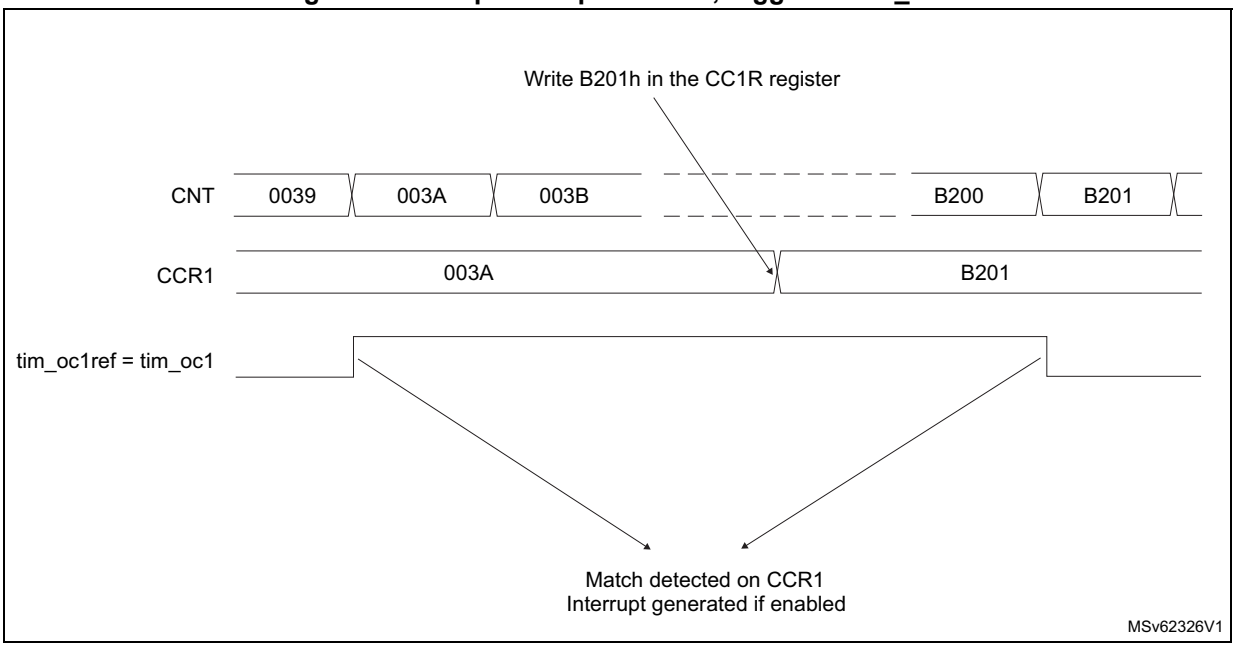
In output compare mode, the update event UEV has no effect on tim_ocxref and tim_ocx output. The timing resolution is one count of the counter. Output compare mode can also be used to output a single pulse (in One-pulse mode).

Procedure

1. Select the counter clock (internal, external, prescaler).
2. Write the desired data in the TIMx_ARR and TIMx_CCRx registers.
3. Set the CCxIE bit if an interrupt request is to be generated.
4. Select the output mode. For example:
   - Write OCxM = 0011 to toggle tim_ocx output pin when CNT matches CCRx
   - Write OCxPE = 0 to disable preload register
   - Write CCxP = 0 to select active high polarity
   - Write CCxE = 1 to enable the output
5. Enable the counter by setting the CEN bit in the TIMx_CR1 register.

The TIMx_CCRx register can be updated at any time by software to control the output waveform, provided that the preload register is not enabled (OCxPE = 0, else TIMx_CCRx shadow register is updated only at the next update event UEV). An example is given in *Figure 515*.

Figure 515. Output compare mode, toggle on tim_oc1



49.3.13 PWM mode

Pulse width modulation mode is used to generate a signal with a frequency determined by the value of the TIMx_ARR register and a duty cycle determined by the value of the TIMx_CCRx register.

The PWM mode can be selected independently on each channel (one PWM per tim_ocx output) by writing 0110 (PWM mode 1) or 0111 (PWM mode 2) in the OCxM bits in the TIMx_CCMRx register. The corresponding preload register must be enabled by setting the OCxPE bit in the TIMx_CCMRx register, and eventually the autoreload preload register (in upcounting or center-aligned modes) by setting the ARPE bit in the TIMx_CR1 register.

As the preload registers are transferred to the shadow registers only when an update event occurs, before starting the counter, all registers must be initialized by setting the UG bit in the TIMx_EGR register.

tim_ocx polarity is software programmable using the CCxP bit in the TIMx_CCER register. It can be programmed as active high or active low. tim_ocx output is enabled by a combination of the CCxE, CCxNE, MOE, OSSI, and OSSR bits (TIMx_CCER and TIMx_BDTR registers). Refer to the TIMx_CCER register description for more details.

In PWM mode (1 or 2), TIMx_CNT and TIMx_CCRx are always compared to determine whether TIMx_CCRx ≤ TIMx_CNT or TIMx_CNT ≤ TIMx_CCRx (depending on the direction of the counter).

The timer is able to generate PWM in edge-aligned mode or center-aligned mode depending on the CMS bits in the TIMx_CR1 register.

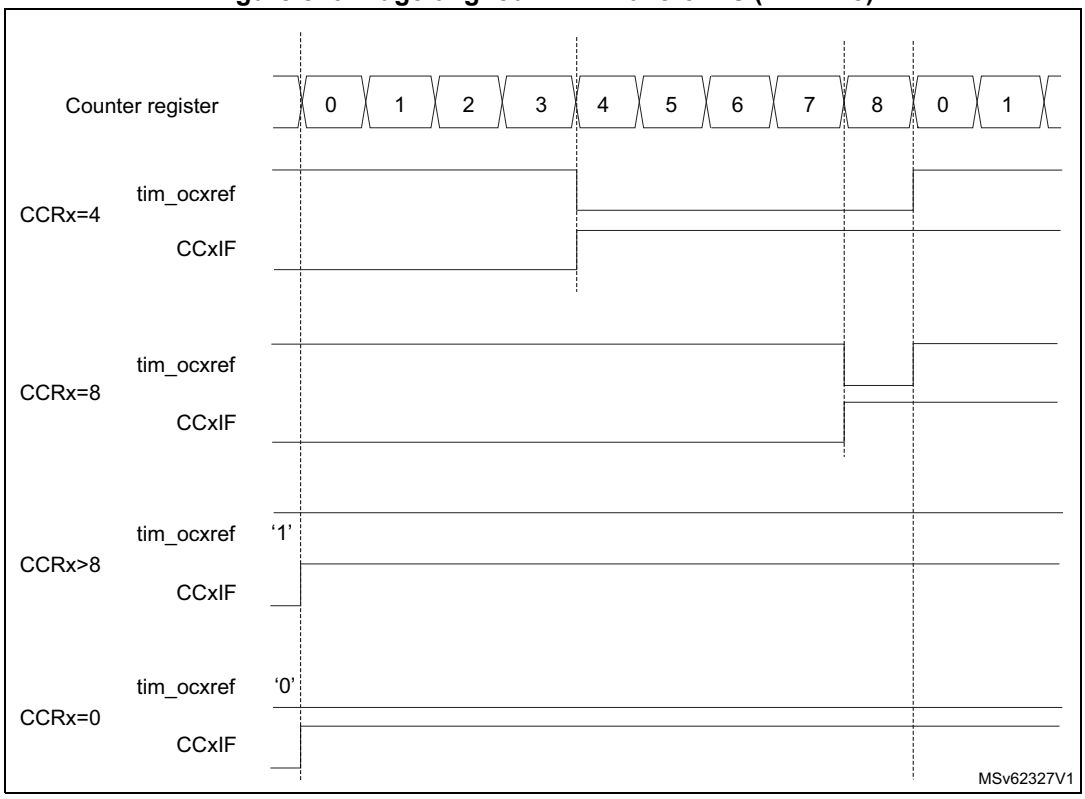
PWM edge-aligned mode

- Upcounting configuration

  Upcounting is active when the DIR bit in the TIMx_CR1 register is low. Refer to *Upcounting mode*.

  In the following example, the mode is PWM mode 1. The reference PWM signal tim_ocxref is high as long as TIMx_CNT < TIMx_CCRx else it becomes low. If the compare value in TIMx_CCRx is greater than the autoreload value (in TIMx_ARR) then tim_ocxref is held at 1. If the compare value is zero then tim_ocxref is held at 0. *Figure 516* shows some edge-aligned PWM waveforms in an example where TIMx_ARR = 8.

Figure 516. Edge-aligned PWM waveforms (ARR = 8)



- Downcounting configuration

  Downcounting is active when DIR bit in TIMx_CR1 register is high. Refer to the *Downcounting mode*

  In PWM mode 1, the reference signal tim_ocxref is low as long as TIMx_CNT > TIMx_CCRx else it becomes high. If the compare value in TIMx_CCRx is greater than the autoreload value in TIMx_ARR, then tim_ocxref is held at 1. 0% PWM is not possible in this mode.

PWM center-aligned mode

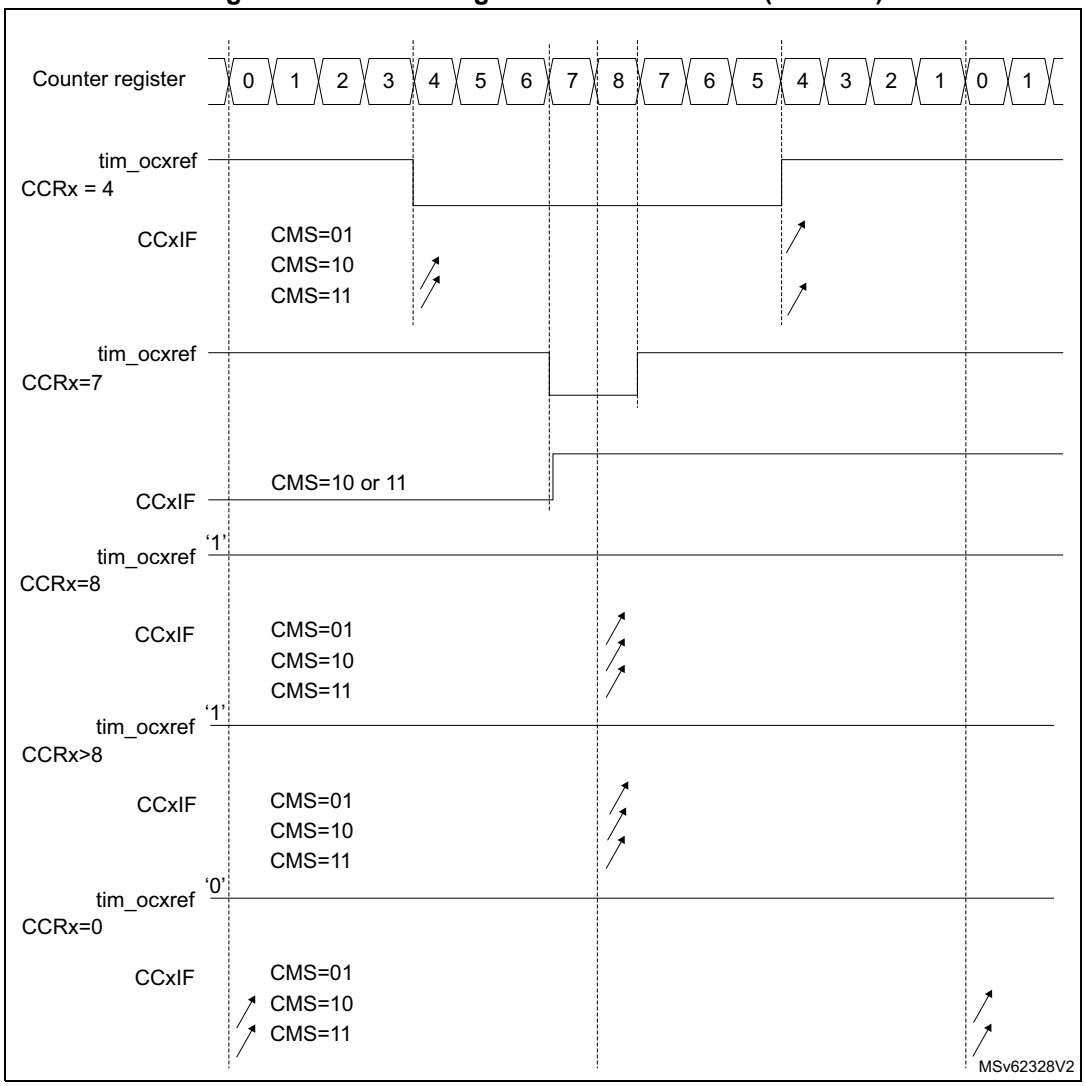
Center-aligned mode is active when the CMS bits in TIMx_CR1 register are different from 00 (all the remaining configurations having the same effect on the tim_ocxref/tim_ocx signals). The compare flag is set when the counter counts up, when it counts down or both when it counts up and down depending on the CMS bits configuration. The direction bit

(DIR) in the TIMx_CR1 register is updated by hardware and must not be changed by software. Refer to *Center-aligned mode (up/down counting)*.

Figure 517 shows some center-aligned PWM waveforms in an example where:

- TIMx_ARR = 8
- PWM mode is the PWM mode 1
- The flag is set when the counter counts down corresponding to the center-aligned mode 1 selected for CMS = 01 in TIMx_CR1 register.

Figure 517. Center-aligned PWM waveforms (ARR = 8)



Hints on using center-aligned mode:

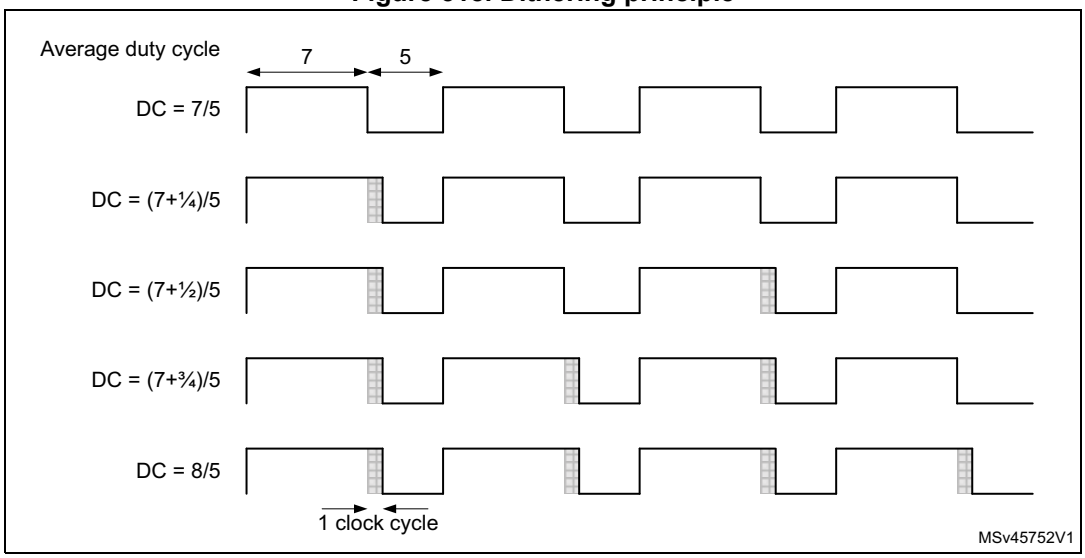
- When starting in center-aligned mode, the current up-down configuration is used. It means that the counter counts up or down depending on the value written in the DIR bit in the TIMx_CR1 register. Moreover, the DIR and CMS bits must not be changed at the same time by the software.
- Writing to the counter while running in center-aligned mode is not recommended as it can lead to unexpected results. In particular:
  - The direction is not updated if a value greater than the autoreload value is written in the counter (TIMx_CNT > TIMx_ARR). For example, if the counter was counting up, it continues to count up.
  - The direction is updated if 0 or the TIMx_ARR value is written in the counter but no update event UEV is generated.
- The safest way to use center-aligned mode is to generate an update by software (setting the UG bit in the TIMx_EGR register) just before starting the counter and not to write the counter while it is running.

Dithering mode

The PWM mode effective resolution can be increased by enabling the dithering mode, using the DITHEN bit in the TIMx_CR1 register. This applies to both the CCR (for duty cycle resolution increase) and ARR (for PWM frequency resolution increase).

The operating principle is to have the actual CCR (or ARR) value slightly changed (adding or not one timer clock period) over 16 consecutive PWM periods, with predefined patterns. This allows a 16-fold resolution increase, considering the average duty cycle or PWM period. *Figure 518* presents the dithering principle applied to four consecutive PWM cycles.

Figure 518. Dithering principle

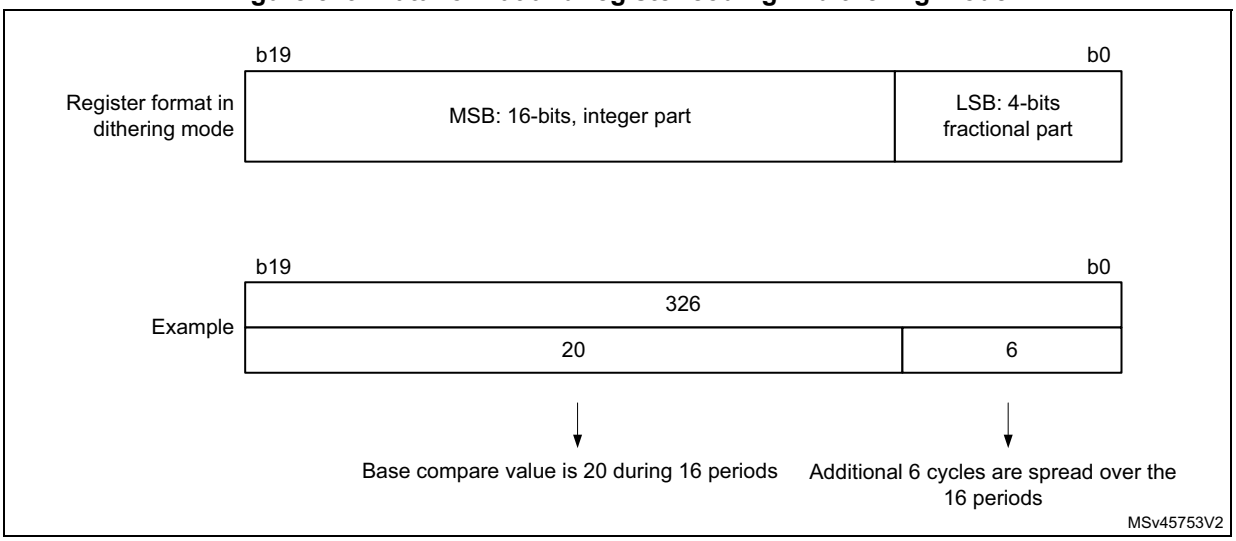


When the dithering mode is enabled, the register coding is changed as follows (see *Figure 519* for example):

- The four LSBs are coding for the enhanced resolution part (fractional part).
- The MSBs are left-shifted to the bits 19:4 and are coding for the base value.

Note: The following sequence must be followed when resetting the DITHEN bit:
1. CEN and ARPE bits must be reset.
2. The DITHEN bit must be reset.
3. The CCIF flags must be cleared.
4. The CEN bit can be set (eventually with ARPE = 1).

Figure 519. Data format and register coding in dithering mode



The minimum frequency is given by the following formula:

$$\text{Resolution} = \frac{F_{Tim}}{F_{pwm}} \Rightarrow F_{pwmMin} = \frac{F_{Tim}}{Max_{Resolution}}$$

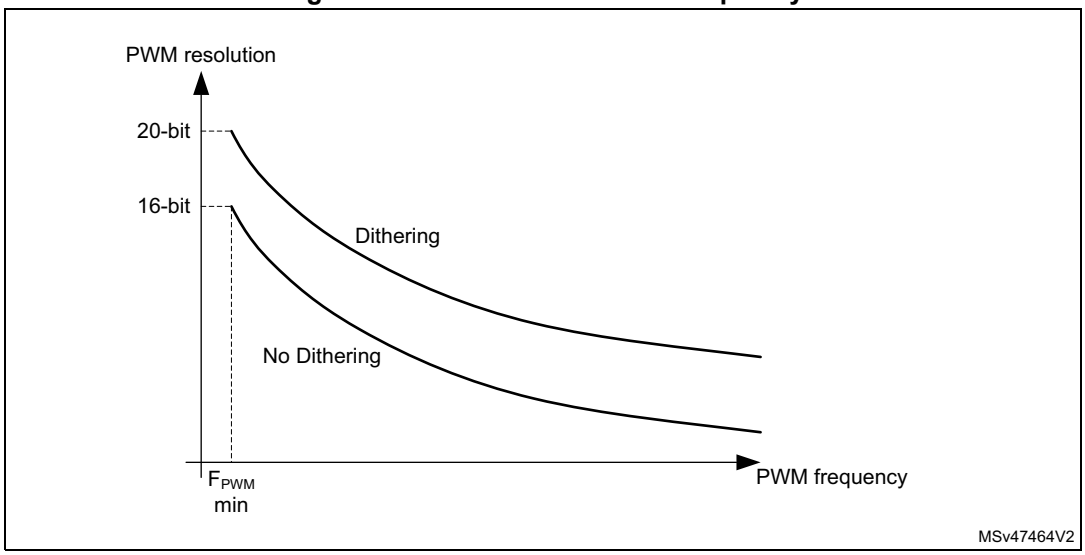
$$\text{Dithering mode disabled: } F_{pwmMin} = \frac{F_{Tim}}{65536}$$

$$\text{Dithering mode enabled: } F_{pwmMin} = \frac{F_{Tim}}{65535 + \frac{15}{16}}$$

Note: The maximum TIMx_ARR and TIMxCCRy values are limited to 0xFFFEF in dithering mode (corresponds to 65534 for the integer part and 15 for the dithered part).

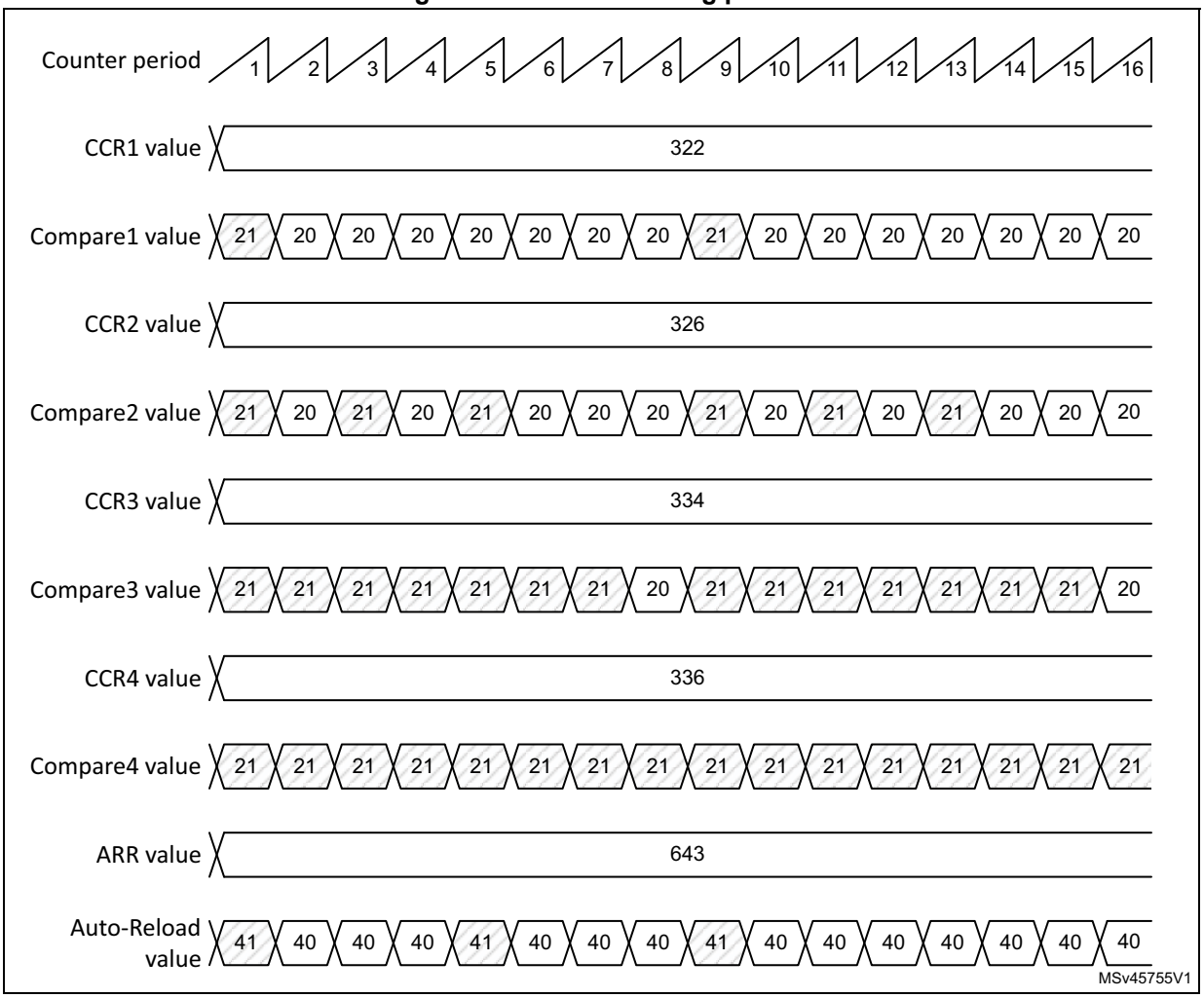
As shown on *Figure 520*, the dithering mode is used to increase the PWM resolution whatever the PWM frequency.

Figure 520. PWM resolution vs frequency



The duty cycle and/or period changes are spread over 16 consecutive periods, as described in *Figure 521*.

Figure 521. PWM dithering pattern



The autoreload and compare values increments are spread following specific patterns described in *Table 521*. The dithering sequence is done to have increments distributed as evenly as possible and minimize the overall ripple.

Table 521. CCR and ARR register change dithering pattern

LSB value	PWM period															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0001	+1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0010	+1	-	-	-	-	-	-	-	+1	-	-	-	-	-	-	-
0011	+1	-	-	-	+1	-	-	-	+1	-	-	-	-	-	-	-
0100	+1	-	-	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0101	+1	-	+1	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0110	+1	-	+1	-	+1	-	-	-	+1	-	+1	-	+1	-	-	-

Table 521. CCR and ARR register change dithering pattern (continued)

LSB value	PWM period															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0111	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	-	-
1000	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1001	+1	+1	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1010	+1	+1	+1	-	+1	-	+1	-	+1	+1	+1	-	+1	-	+1	-
1011	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	-	+1	-
1100	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-
1101	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-
1110	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	+1	+1	+1	+1	-
1111	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	-

The dithering mode is also available in center-aligned PWM mode (CMS bits in TIMx_CR1 register are not equal to 00). In this case, the dithering pattern is applied over eight consecutive PWM periods, considering the up and down counting phases as shown in *Figure 522*.

Figure 522. Dithering effect on duty cycle in center-aligned PWM mode

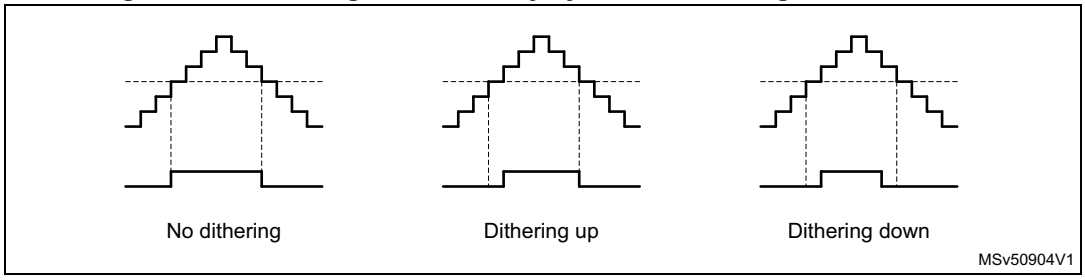


Table 522 shows how the dithering pattern is added in center-aligned PWM mode.

Table 522. CCR register change dithering pattern in center-aligned PWM mode

LSB value	PWM period															
	1		2		3		4		5		6		7		8	
	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn
0000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0001	+1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0010	+1	-	-	-	-	-	-	-	+1	-	-	-	-	-	-	-
0011	+1	-	-	-	+1	-	-	-	+1	-	-	-	-	-	-	-
0100	+1	-	-	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0101	+1	-	+1	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0110	+1	-	+1	-	+1	-	-	-	+1	-	+1	-	+1	-	-	-

Table 522. CCR register change dithering pattern in center-aligned PWM mode (continued)

LSB value	PWM period															
	1		2		3		4		5		6		7		8	
	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn
0111	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	-	-
1000	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1001	+1	+1	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1010	+1	+1	+1	-	+1	-	+1	-	+1	+1	+1	-	+1	-	+1	-
1011	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	-	+1	-
1100	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-
1101	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-
1110	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	+1	+1	+1	+1	-
1111	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	-

49.3.14 Asymmetric PWM mode

Asymmetric mode allows two center-aligned PWM signals to be generated with a programmable phase shift. While the frequency is determined by the value of the TIMx_ARR register, the duty cycle and the phase-shift are determined by a pair of TIMx_CCRx register. One register controls the PWM during up-counting, the second during down counting, so that PWM is adjusted every half PWM cycle:

- tim_oc1refc (or tim_oc2refc) is controlled by TIMx_CCR1 and TIMx_CCR2
- tim_oc3refc (or tim_oc4refc) is controlled by TIMx_CCR3 and TIMx_CCR4

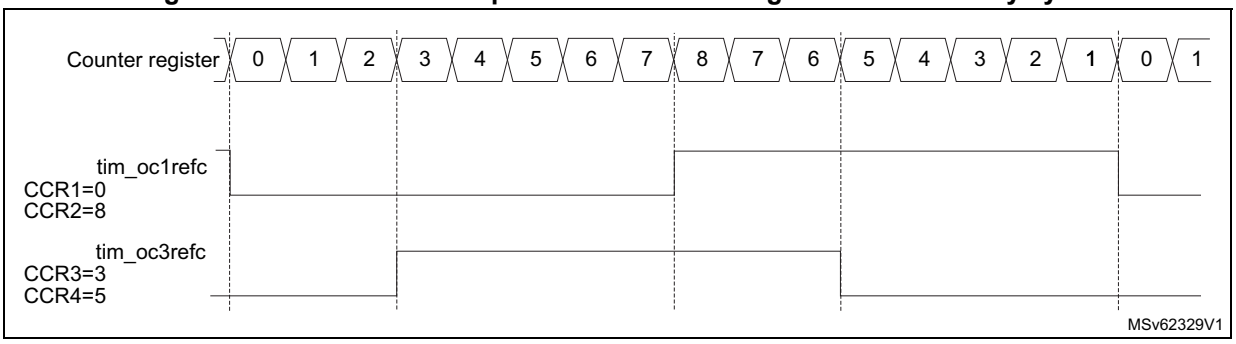
Asymmetric PWM mode can be selected independently on two channel (one tim_ocx output per pair of CCR registers) by writing 1110 (Asymmetric PWM mode 1) or 1111 (Asymmetric PWM mode 2) in the OCxM bits in the TIMx_CCMRx register.

Note: The OCxM[3:0] bitfield is split into two parts for compatibility reasons, the most significant bit is not contiguous with the three least significant ones.

When a given channel is used as asymmetric PWM channel, its complementary channel can also be used. For instance, if an tim_oc1refc signal is generated on channel 1 (Asymmetric PWM mode 1), it is possible to output either the tim_oc2ref signal on channel 2, or an tim_oc2refc signal resulting from asymmetric PWM mode 1.

Figure 523 represents an example of signals that can be generated using asymmetric PWM mode (channels 1 to 4 are configured in asymmetric PWM mode 2). Together with the deadtime generator, this allows a full-bridge phase-shifted DC to DC converter to be controlled.

Figure 523. Generation of 2 phase-shifted PWM signals with 50% duty cycle



49.3.15 Combined PWM mode

Combined PWM mode allows two edge or center-aligned PWM signals to be generated with programmable delay and phase shift between respective pulses. While the frequency is determined by the value of the TIMx_ARR register, the duty cycle and delay are determined by the two TIMx_CCRx registers. The resulting signals, tim_ocxrefc, are made of an OR or AND logical combination of two reference PWMs:

- tim_oc1refc (or tim_oc2refc) is controlled by TIMx_CCR1 and TIMx_CCR2
- tim_oc3refc (or tim_oc4refc) is controlled by TIMx_CCR3 and TIMx_CCR4

Combined PWM mode can be selected independently on two channels (one tim_ocx output per pair of CCR registers) by writing 1100 (Combined PWM mode 1) or 1101 (Combined PWM mode 2) in the OCxM bits in the TIMx_CCMRx register.

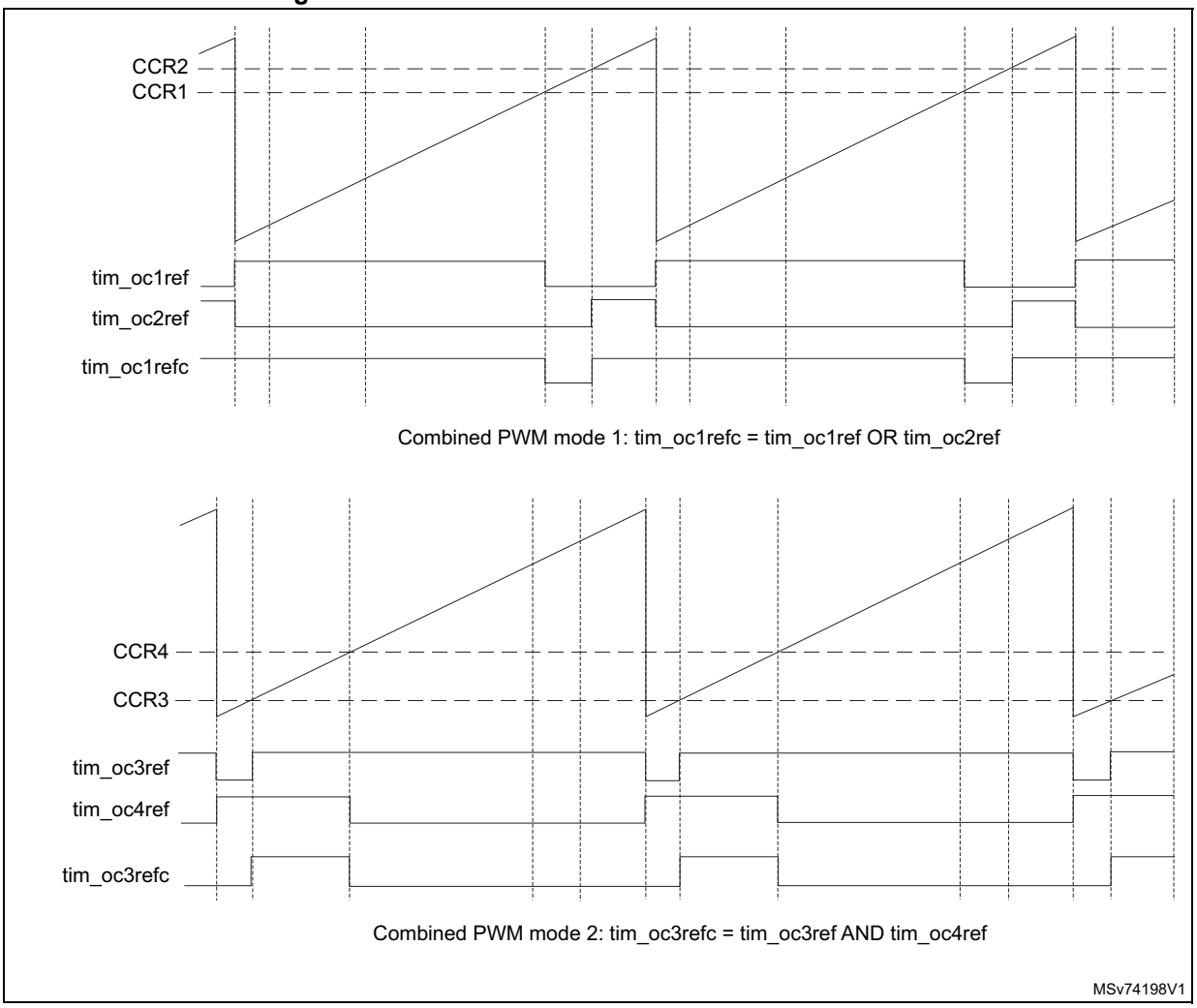
When a given channel is used as combined PWM channel, its complementary channel must be configured in the opposite PWM mode (for instance, one in Combined PWM mode 1 and the other in Combined PWM mode 2).

Note: The OCxM[3:0] bitfield is split into two parts for compatibility reasons, the most significant bit is not contiguous with the three least significant ones.

Figure 524 represents an example of signals that can be generated using combined PWM mode, obtained with the following configuration:

- Channel 1 is configured in Combined PWM mode 2.
- Channel 2 is configured in PWM mode 1.
- Channel 3 is configured in Combined PWM mode 2.
- Channel 4 is configured in PWM mode 1.

Figure 524. Combined PWM mode on channel 1 and 3



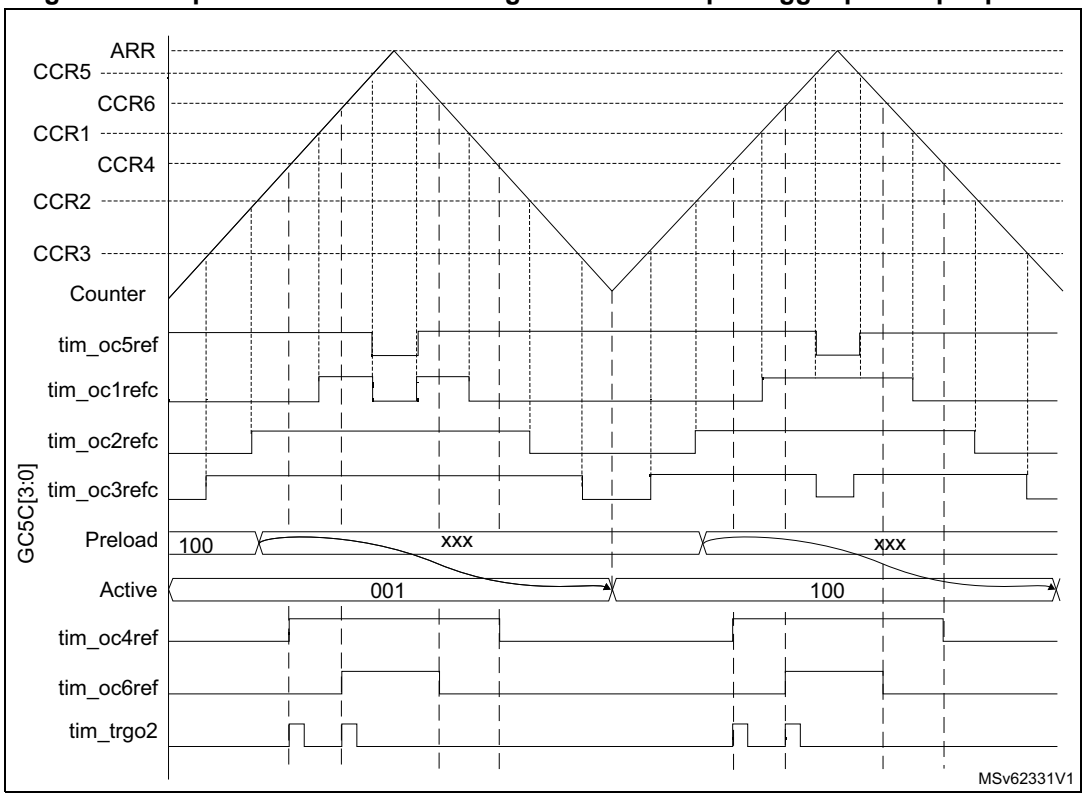
49.3.16 Combined 3-phase PWM mode

Combined 3-phase PWM mode allows one to three center-aligned PWM signals to be generated with a single programmable signal ANDed in the middle of the pulses. The tim_oc5ref signal is used to define the resulting combined signal. The 3-bits GC5C[3:1] in the TIMx_CCR5 allow selection on which reference signal the tim_oc5ref is combined. The resulting signals, tim_ocxrefc, are made of an AND logical combination of two reference PWMs:

- If GC5C1 is set, tim_oc1refc is controlled by TIMx_CCR1 and TIMx_CCR5.
- If GC5C2 is set, tim_oc2refc is controlled by TIMx_CCR2 and TIMx_CCR5.
- If GC5C3 is set, tim_oc3refc is controlled by TIMx_CCR3 and TIMx_CCR5.

Combined 3-phase PWM mode can be selected independently on channels 1 to 3 by setting at least one of the 3-bits GC5C[3:1].

Figure 525. 3-phase combined PWM signals with multiple trigger pulses per period



The tim_trgo2 waveform shows how the ADC can be synchronized on given 3-phase PWM signals. Refer to *Section 49.3.31: ADC triggers* for more details.

49.3.17 Complementary outputs and dead-time insertion

The advanced-control timers (TIM1/TIM8) can output two complementary signals and manage the switching-off and the switching-on instants of the outputs.

This time is generally known as dead-time and it has to be adjusted depending on the devices that are connected to the outputs and their characteristics (such as intrinsic delays of level-shifters, or delays due to power switches).

The polarity of the outputs (main output tim_ocx or complementary tim_ocxn) can be selected independently for each output. This is done by writing to the CCxP and CCxNP bits in the TIMx_CCER register.

The complementary signals tim_ocx and tim_ocxn are activated by a combination of several control bits: the CCxE and CCxNE bits in the TIMx_CCER register and the MOE, OISx, OISxN, OSSI, and OSSR bits in the TIMx_BDTR and TIMx_CR2 registers. Refer to *Table 530: Output control bits for complementary tim_ocx and tim_ocxn channels with break feature* for more details. In particular, the dead-time is activated when switching to the idle state (MOE falling down to 0).

Dead-time insertion is enabled by setting both CCxE and CCxNE bits, and the MOE bit if the break circuit is present. There is one 10-bit dead-time generator for each channel. From a

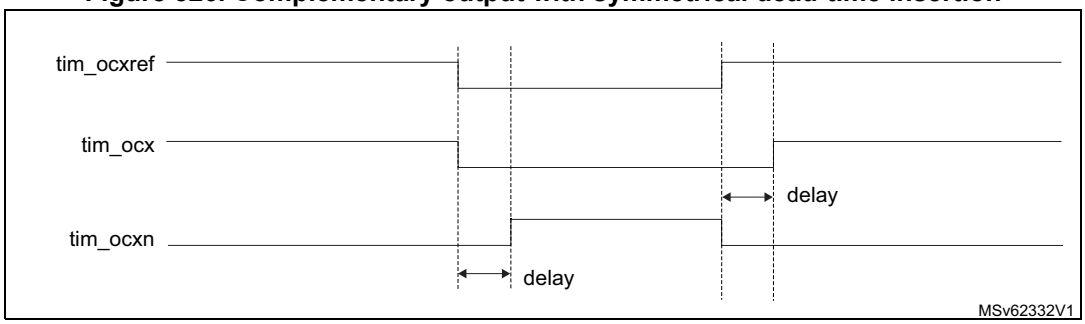
reference waveform tim_ocxref, it generates two outputs tim_ocx and tim_ocxn. If tim_ocx and tim_ocxn are active high:

- The tim_ocx output signal is the same as the reference signal except for the rising edge, which is delayed relative to the reference rising edge.
- The tim_ocxn output signal is the opposite of the reference signal except for the rising edge, which is delayed relative to the reference falling edge.

If the delay is greater than the width of the active output (tim_ocx or tim_ocxn) then the corresponding pulse is not generated.

The following figures show the relationships between the output signals of the dead-time generator and the reference signal tim_ocxref considering CCxP = 0, CCxNP = 0, MOE = 1, CCxE = 1 and CCxNE = 1 in these examples.

Figure 526. Complementary output with symmetrical dead-time insertion



The DTAE bit in the TIMx_DTR2 is used to differentiate the deadtime values for rising and falling edges of the reference signal, as shown on *Figure 527*.

In asymmetrical mode (DTAE = 1), the rising edge-referred deadtime is defined by the DTG[7:0] bitfield in the TIMx_BDTR register, while the falling edge-referred is defined by the DTGF[7:0] bitfield in the TIMx_DTR2 register. The DTAE bit must be written before enabling the counter and must not be modified while CEN = 1.

It is possible to have the deadtime value updated on-the-fly during pwm operation, using a preload mechanism. The deadtime bitfield DTG[7:0] and DTGF[7:0] are preloaded when the DTPE bit is set, in the TIMX_DTR2 register. The preload value is loaded in the active register on the next update event.

Note: If the DTPE bit is enabled while the counter is enabled, any new value written since last update is discarded and previous value is used.

Figure 527. Asymmetrical deadtime

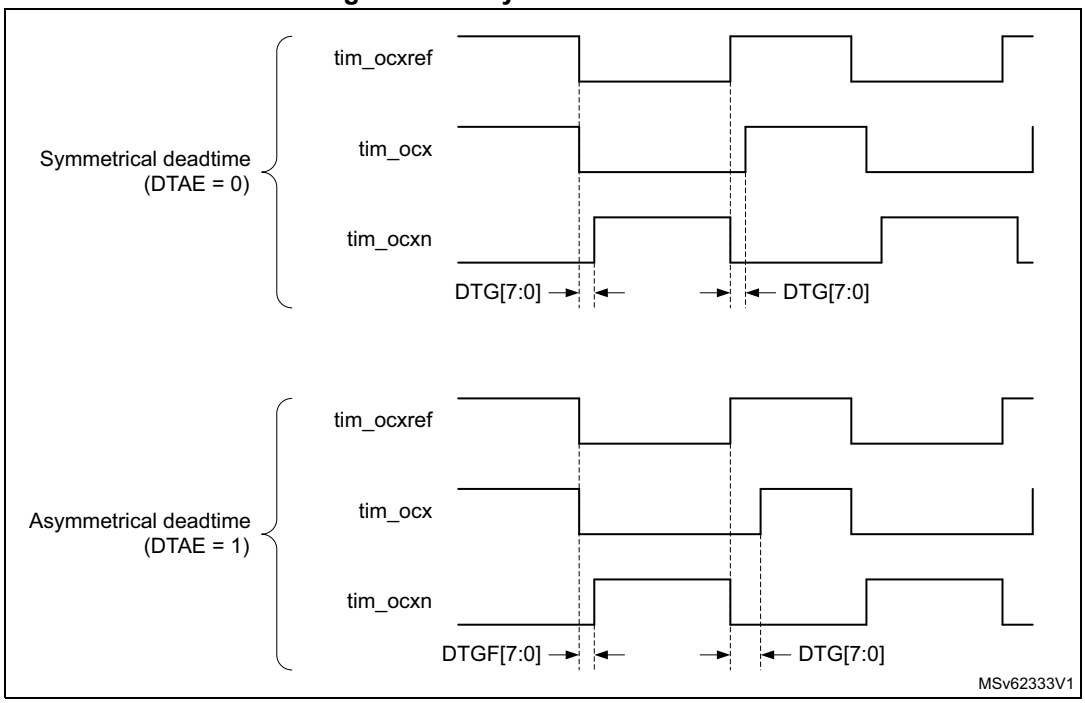


Figure 528. Dead-time waveforms with delay greater than the negative pulse

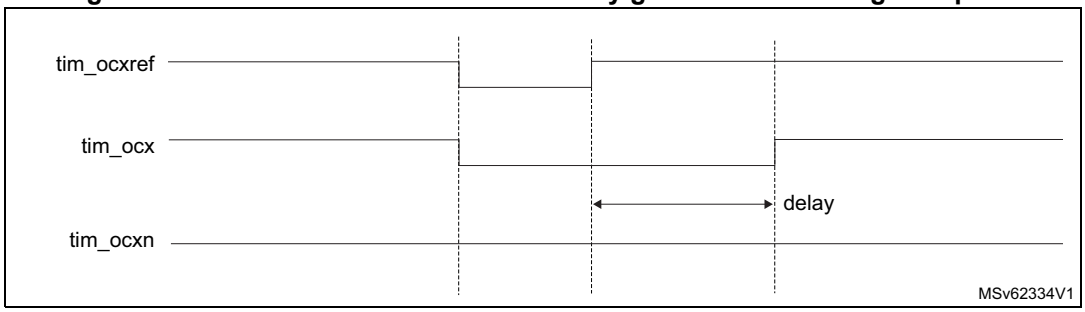
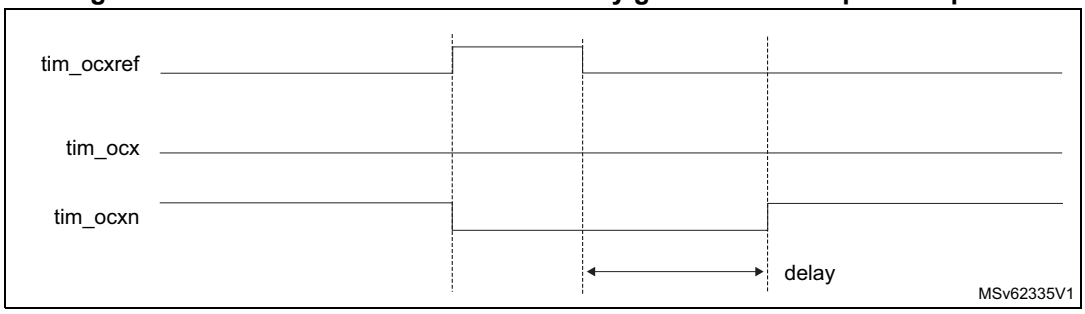


Figure 529. Dead-time waveforms with delay greater than the positive pulse



The dead-time delay is the same for each of the channels and is programmable with the DTG bits in the TIMx_BDTR register. Refer to *Section 49.6.20: TIMx break and dead-time register (TIMx_BDTR)(x = 1, 8)* for delay calculation.

Redirecting tim_ocxref to tim_ocx or tim_ocxn

In output mode (forced, output compare or PWM), tim_ocxref can be redirected to the tim_ocx output or to tim_ocxn output by configuring the CCxE and CCxNE bits in the TIMx_CCER register.

This is used to send a specific waveform (such as PWM or static active level) on one output while the complementary remains at its inactive level. Other alternative possibilities are to have both outputs at inactive level or both outputs active and complementary with dead-time.

Note: When only tim_ocxn is enabled (CCxE = 0, CCxNE = 1), it is not complemented and becomes active as soon as tim_ocxref is high. For example, if CCxNP = 0 then tim_ocxn = tim_ocxref. On the other hand, when both tim_ocx and tim_ocxn are enabled (CCxE = CCxNE = 1) tim_ocx becomes active when tim_ocxref is high whereas tim_ocxn is complemented and becomes active when tim_ocxref is low.

49.3.18 Using the break function

The purpose of the break function is to protect power switches driven by PWM signals generated with the timers. The two break inputs are usually connected to fault outputs of power stages and 3-phase inverters. When activated, the break circuitry shuts down the PWM outputs and forces them to a predefined safe state. A number of internal MCU events can also be selected to trigger an output shut-down.

The break features two channels. A break channel which gathers both system-level fault (clock failure, ECC/parity errors,...) and application fault (from input pins and built-in comparator), and can force the outputs to a predefined level (either active or inactive) after a deadtime duration. A break2 channel which only includes application faults and is able to force the outputs to an inactive state.

The output enable signal and output levels during break are depending on several control bits:

- The MOE bit in TIMx_BDTR register is used to enable/disable the outputs by software and is reset in case of break or break2 event.
- The OSSI bit in the TIMx_BDTR register defines whether the timer controls the output in inactive state or releases the control to the GPIO controller (typically to have it in Hi-Z mode)
- The OISx and OISxN bits in the TIMx_CR2 register which are setting the output shut-down level, either active or inactive. The tim_ocx and tim_ocxn outputs cannot be set both to active level at a given time, whatever the OISx and OISxN values. Refer to *Table 530: Output control bits for complementary tim_ocx and tim_ocxn channels with break feature* for more details.

When exiting from reset, the break circuit is disabled and the MOE bit is low. The break functions can be enabled by setting the BKE and BK2E bits in the TIMx_BDTR register. The break input polarities can be selected by configuring the BKP and BK2P bits in the same register. BKEx and BKPx can be modified at the same time. When the BKEx and BKPx bits are written, a delay of one APB clock cycle is applied before the writing is effective. Consequently, it is necessary to wait one APB clock period to correctly read back the bit after the write operation.

Because MOE falling edge can be asynchronous, a resynchronization circuit has been inserted between the actual signal (acting on the outputs) and the synchronous control bit (accessed in the TIMx_BDTR register). It results in some delays between the asynchronous

and the synchronous signals. In particular, if MOE is set to 1 whereas it was low, a delay must be inserted (dummy instruction) before reading it correctly. This is because the write acts on the asynchronous signal whereas the read reflects the synchronous signal.

The sources for break (tim_brk) channel are:

- External sources connected to one of the TIMx_BKIN pin (as per selection done in the GPIO alternate function selection registers), with polarity selection and optional digital filtering
- Internal sources:
  - coming from a tim_brk_cmpx input (refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals* for product specific implementation)
  - coming from a system break request (refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals* for product specific implementation)

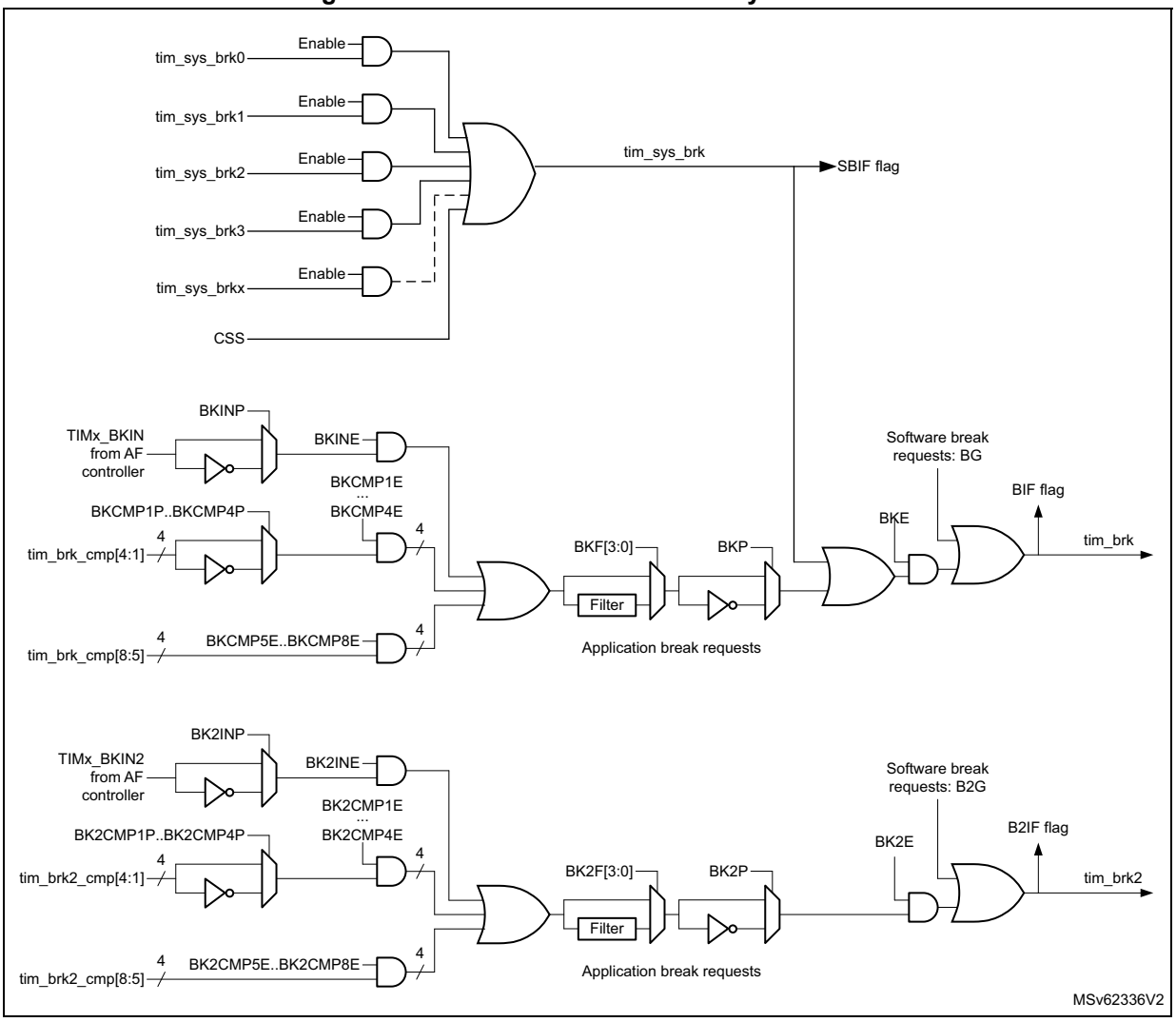
The sources for break2 (tim_brk2) are:

- External sources connected to one of the TIMx_BKIN2 pin (as per selection done in the GPIO alternate function selection registers), with polarity selection and optional digital filtering
- Internal sources coming from a tim_brk2_cmpx input (refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals* for product specific implementation)

Break events can also be generated by software using BG and B2G bits in the TIMx_EGR register.

All sources are ORed before entering the timer tim_brk or tim_brk2 inputs, as per *Figure 530* below.

Figure 530. Break and Break2 circuitry overview



Note: An asynchronous (clockless) operation is only guaranteed when the programmable filter is disabled. If it is enabled, a fail safe clock mode (for example by using the internal PLL and/or the CSS) must be used to guarantee that break events are handled.

When one of the breaks occurs (selected level on one of the break inputs):

- The MOE bit is cleared asynchronously, putting the outputs in inactive state, idle state, or even releasing the control to the GPIO controller (selected by the OSSI bit). This feature is enabled even if the MCU oscillator is off.
- Each output channel is driven with the level programmed in the OISx bit in the TIMx_CR2 register as soon as MOE = 0. If OSSI = 0, the timer releases the output control (taken over by the GPIO controller), otherwise the enable output remains high.
- When complementary outputs are used:
  - The outputs are first put in inactive state (depending on the polarity). This is done asynchronously so that it works even if no clock is provided to the timer.
  - If the timer clock is still present, then the dead-time generator is reactivated in order to drive the outputs with the level programmed in the OISx and OISxN bits after a dead-time. Even in this case, tim_ocx and tim_ocxn cannot be driven to

their active level together. Note that because of the resynchronization on MOE, the dead-time duration is slightly longer than usual (around 2 tim_ker_ck clock cycles).

  - If OSSI = 0, the timer releases the output control (taken over by the GPIO controller which forces a Hi-Z state), otherwise the enable outputs remain or become high as soon as one of the CCxE or CCxNE bits is high.

- The break status flag (SBIF, BIF, and B2IF bits in the TIMx_SR register) is set. An interrupt is generated if the BIE bit in the TIMx_DIER register is set. A DMA request can be sent if the BDE bit in the TIMx_DIER register is set.
- If the AOE bit in the TIMx_BDTR register is set, the MOE bit is automatically set again at the next update event (UEV). As an example, this can be used to perform a regulation. Otherwise, MOE remains low until the application sets it to 1 again. In this case, it can be used for security and the break input can be connected to an alarm from power drivers, thermal sensors, or any security components.

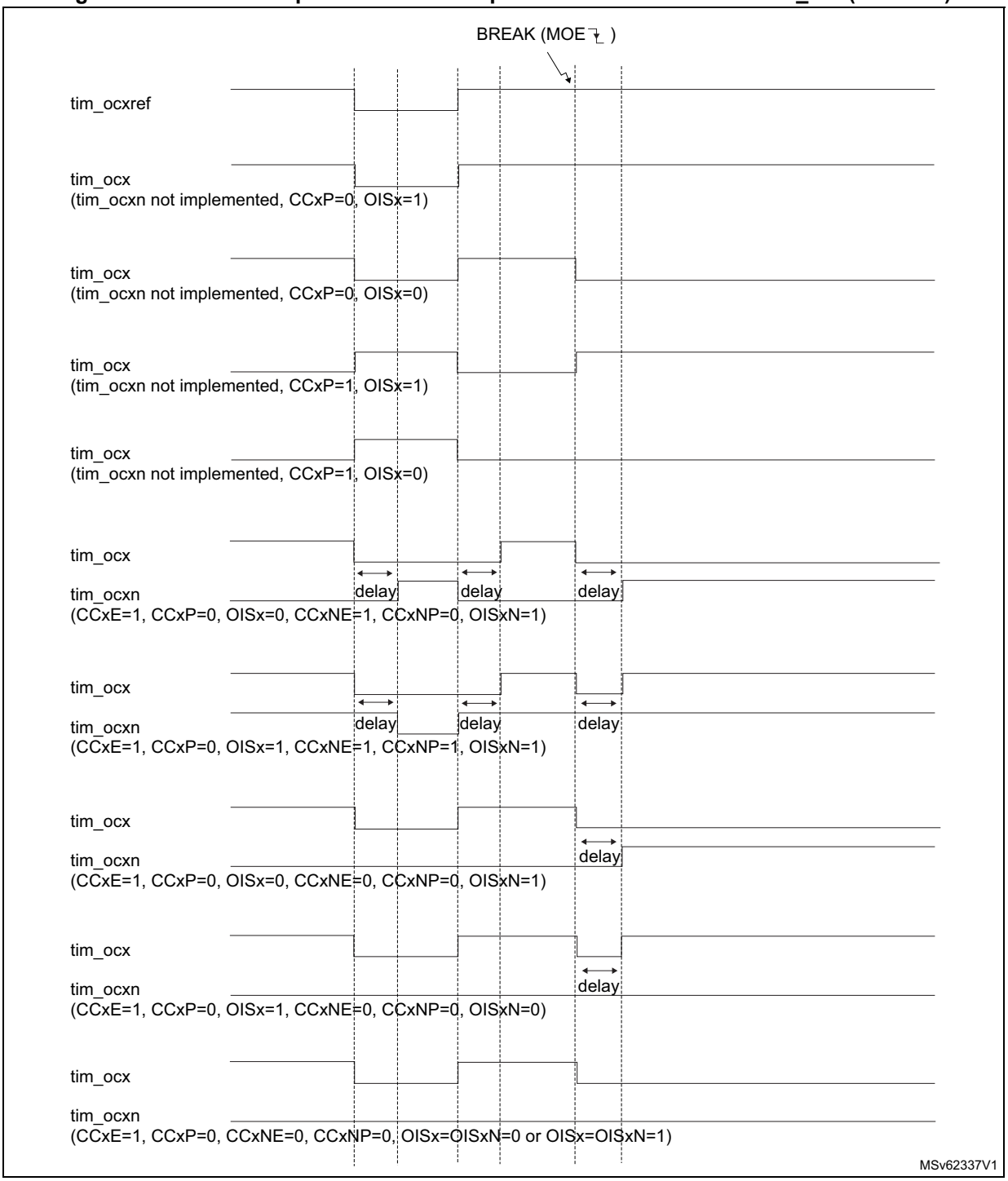
Note: If the MOE is reset by the CPU while the AOE bit is set, the outputs are in idle state and forced to inactive level or Hi-Z depending on OSSI value. If both the MOE and AOE bits are reset by the CPU, the outputs are in disabled state and driven with the level programmed in the OISx bit in the TIMx_CR2 register.

The break inputs are active on level. Thus, the MOE cannot be set while the break input is active (neither automatically nor by software). In the meantime, the status flag BIF and B2IF cannot be cleared.

In addition to the break input and the output management, a write protection has been implemented inside the break circuit to safeguard the application. It is used to freeze the configuration of several parameters (dead-time duration, tim_ocx/tim_ocxn polarities and state when disabled, OCxM configurations, break enable, and polarity). The application can choose from three levels of protection selected by the LOCK bits in the TIMx_BDTR register. Refer to *Section 49.6.20*. The LOCK bits can be written only once after an MCU reset.

Figure 531 shows an example of behavior of the outputs in response to a break.

Figure 531. Various output behavior in response to a break event on tim_brk (OSSI = 1)



The two break inputs have different behaviors on timer outputs:

- The tim_brk input can either disable (inactive state) or force the PWM outputs to a predefined safe state.
- tim_brk2 can only disable (inactive state) the PWM outputs.

The tim_brk has a higher priority than tim_brk2 input, as described in *Table 523*.

Note: tim_brk2 must only be used with OSSR = OSSI = 1.

Table 523. Behavior of timer outputs versus tim_brk/tim_brk2 inputs

tim_brk	tim_brk2	Timer outputs state	Typical use case	
			tim_ocxn output (low side switches)	tim_ocx output (high side switches)
Active	X	– Inactive then forced output state (after a deadtime) – Outputs disabled if OSSI = 0 (control taken over by GPIO logic)	ON after deadtime insertion	OFF
Inactive	Active	Inactive	OFF	OFF

Figure 532 gives an example of tim_ocx and tim_ocxn output behavior in case of active signals on tim_brk and tim_brk2 inputs. In this case, both outputs have active high polarities (CCxP = CCxNP = 0 in TIMx_CCER register).

Figure 532. PWM output state following tim_brk and tim_brk2 assertion (OSSI = 1)

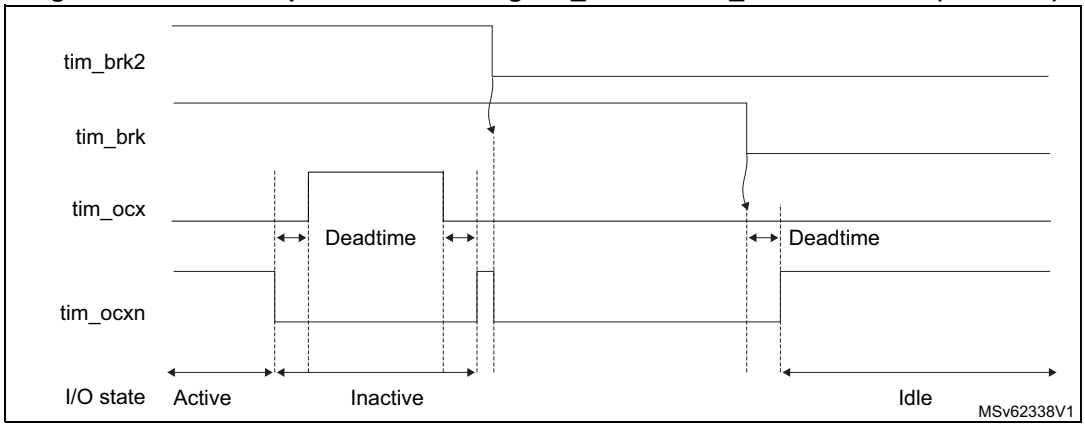
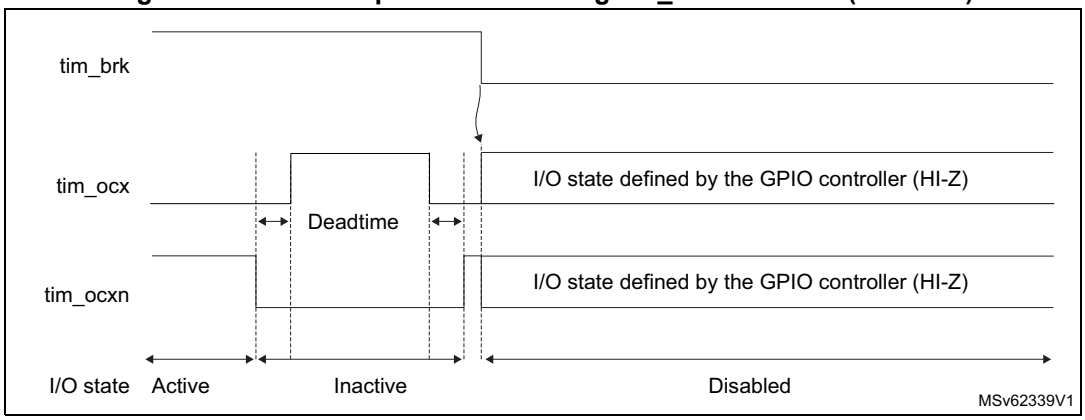


Figure 533. PWM output state following tim_brk assertion (OSSI = 0)



49.3.19 Bidirectional break inputs

The TIM1/TIM8 feature bidirectional break I/Os, as represented on *Figure 534*.

This provides support for:

- A board-level global break signal available for signaling faults to external MCUs or gate drivers, with a unique pin being both an input and an output status pin.
- Internal break sources and multiple external open drain sources ORed together to trigger a unique break event, when multiple internal and external break sources must be merged.

The tim_brk and tim_brk2 inputs are configured in bidirectional mode using the BKBID and BK2BID bits in the TIMxBDTR register. The BKBID programming bits can be locked in read-only mode using the LOCK bits in the TIMxBDTR register (in LOCK level 1 or above).

The bidirectional mode is available for both the tim_brk and tim_brk2 inputs, and require the I/O to be configured in open-drain mode with active low polarity (using BKINP, BKP, BK2INP and BK2P bits). Any break request coming either from system (for example CSS), from on-chip peripherals, or from break inputs forces a low level on the break input to signal the fault event. The bidirectional mode is inhibited if the polarity bits are not correctly set (active high polarity), for safety purposes.

The break software events (BG and B2G) also cause the break I/O to be forced to 0 to indicate to the external components that the timer is entered in break state. However, this is valid only if the break is enabled (BKE or B2KE = 1). When a software break event is generated with BKE or B2KE = 0), the outputs are put in safe state and the break flag is set, but there is no effect on the TIMx_BKIN and TIMx_BKIN2 I/Os.

A safe disarming mechanism prevents the system to be definitively locked-up (a low level on the break input triggers a break which enforces a low level on the same input).

When the BKDSRM (BK2DSRM) bit is set to 1, this releases the break output to clear a fault signal and to give the possibility to re-arm the system.

At no point the break protection circuitry can be disabled:

- The break input path is always active: a break event is active even if the BKDSRM (BK2DSRM) bit is set and the open drain control is released. This prevents the PWM output to be restarted as long as the break condition is present.
- The BKDSRM (BK2DSRM) bit cannot disarm the break protection as long as the outputs are enabled (MOE bit is set) (see *Table 524*).

Table 524. Break protection disarming conditions

MOE	BKBID (BK2BID)	BKDSRM (BK2DSRM)	Break protection state
0	0	X	Armed
0	1	0	Armed
0	1	1	Disarmed
1	X	X	Armed

Arming and rearming break circuitry

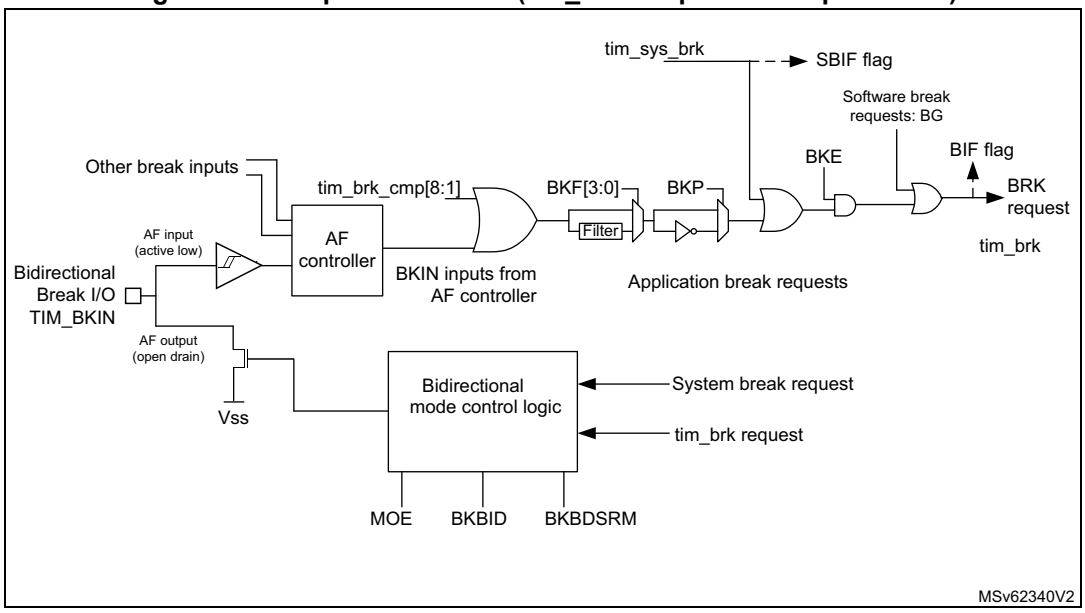
The break circuitry (in input or bidirectional mode) is armed by default (peripheral reset configuration).

The following procedure must be followed to re-arm the protection after a break (break2) event:

- The BKDSRM (BK2DSRM) bit must be set to release the output control.
- The software must wait until the system break condition disappears (if any) and clear the SBIF status flag (or clear it systematically before rearming).
- The software must poll the BKDSRM (BK2DSRM) bit until it is cleared by hardware (when the application break condition disappears).

From this point, the break circuitry is armed and active, and the MOE bit can be set to re-enable the PWM outputs.

Figure 534. Output redirection (tim_brk2 request not represented)



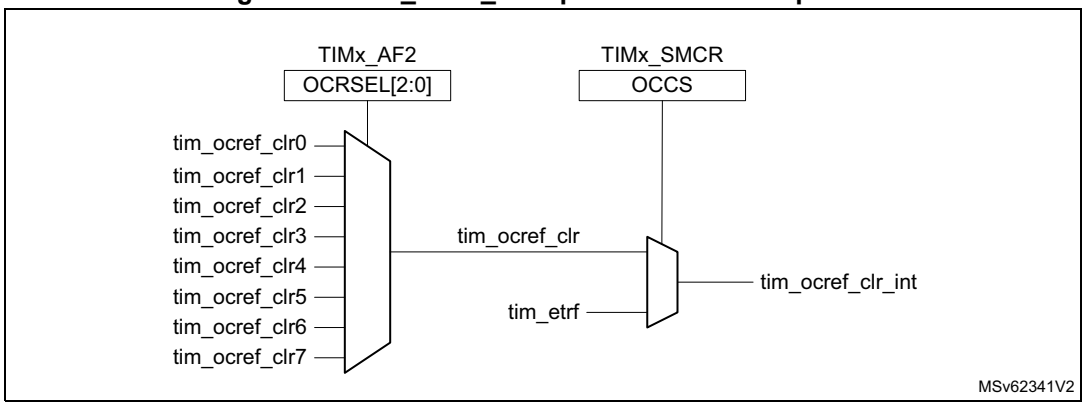
49.3.20 Clearing the tim_ocxref signal on an external event

The tim_ocxref signal of a given channel can be cleared when a high level is applied on the tim_ocref_clr_int input (OCxCE enable bit in the corresponding TIMx_CCMRx register set to 1). tim_ocxref remains low until the next transition to the active state, on the following PWM

cycle. This function can only be used in Output compare and PWM modes. It does not work in Forced mode. tim_ocref_clr_int input can be selected between the tim_ocref_clr input and tim_etrf (tim_etr_in after the filter) by configuring the OCCS bit in the TIMx_SMCR register.

The tim_ocref_clr input can be selected among several inputs, using the OCRSEL[2:0] bitfield in the TIMx_AF2 register, as shown on the *Figure 535* below. Refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals* for a list of sources available in the product.

Figure 535. tim_ocref_clr input selection multiplexer

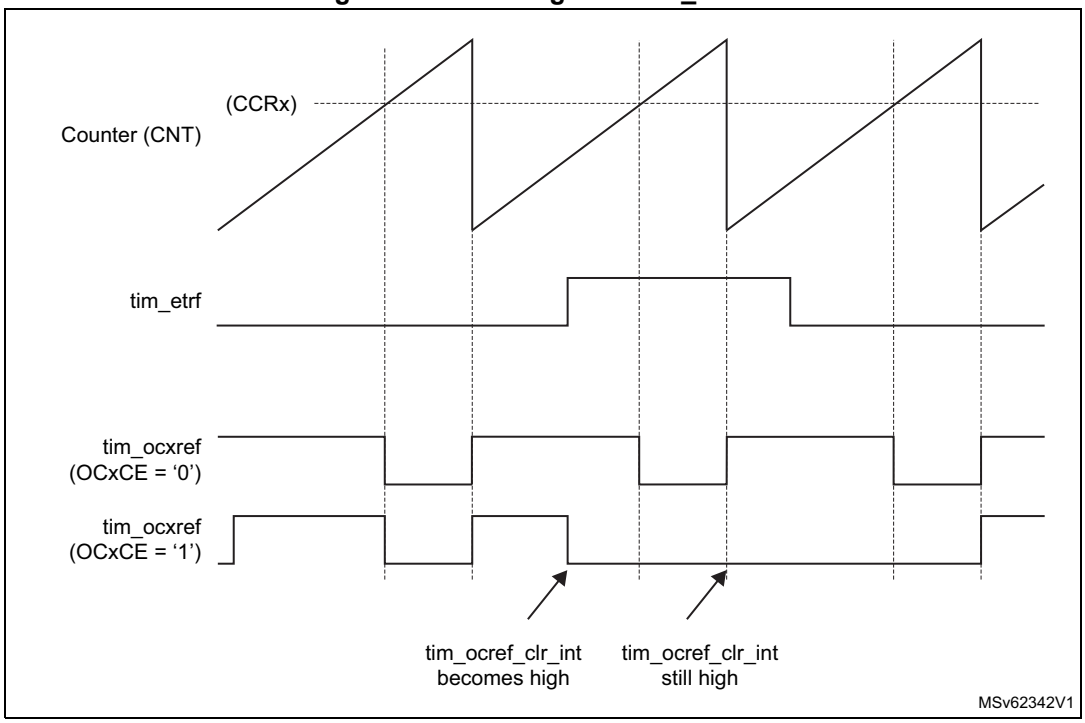


When tim_etrf is chosen, tim_etr_in must be configured as follows:

1. The external trigger prescaler must be kept off: bits ETPS[1:0] of the TIMx_SMCR register set to 00.
2. The external clock mode 2 must be disabled: bit ECE of the TIMx_SMCR register set to 0.
3. The external trigger polarity (ETP) and the external trigger filter (ETF) can be configured according to application needs (as per polarity of the source connected to the trigger and eventual need to remove noise using the filter).

Figure 536 shows the behavior of the tim_ocxref signal when the tim_etrf input becomes high, for both values of the enable bit OCxCE. In this example, the timer TIMx is programmed in PWM mode.

Figure 536. Clearing TIMx tim_ocxref



Note: In case of a PWM with a 100% duty cycle (if CCRx>ARR), then tim_ocxref is enabled again at the next counter overflow.

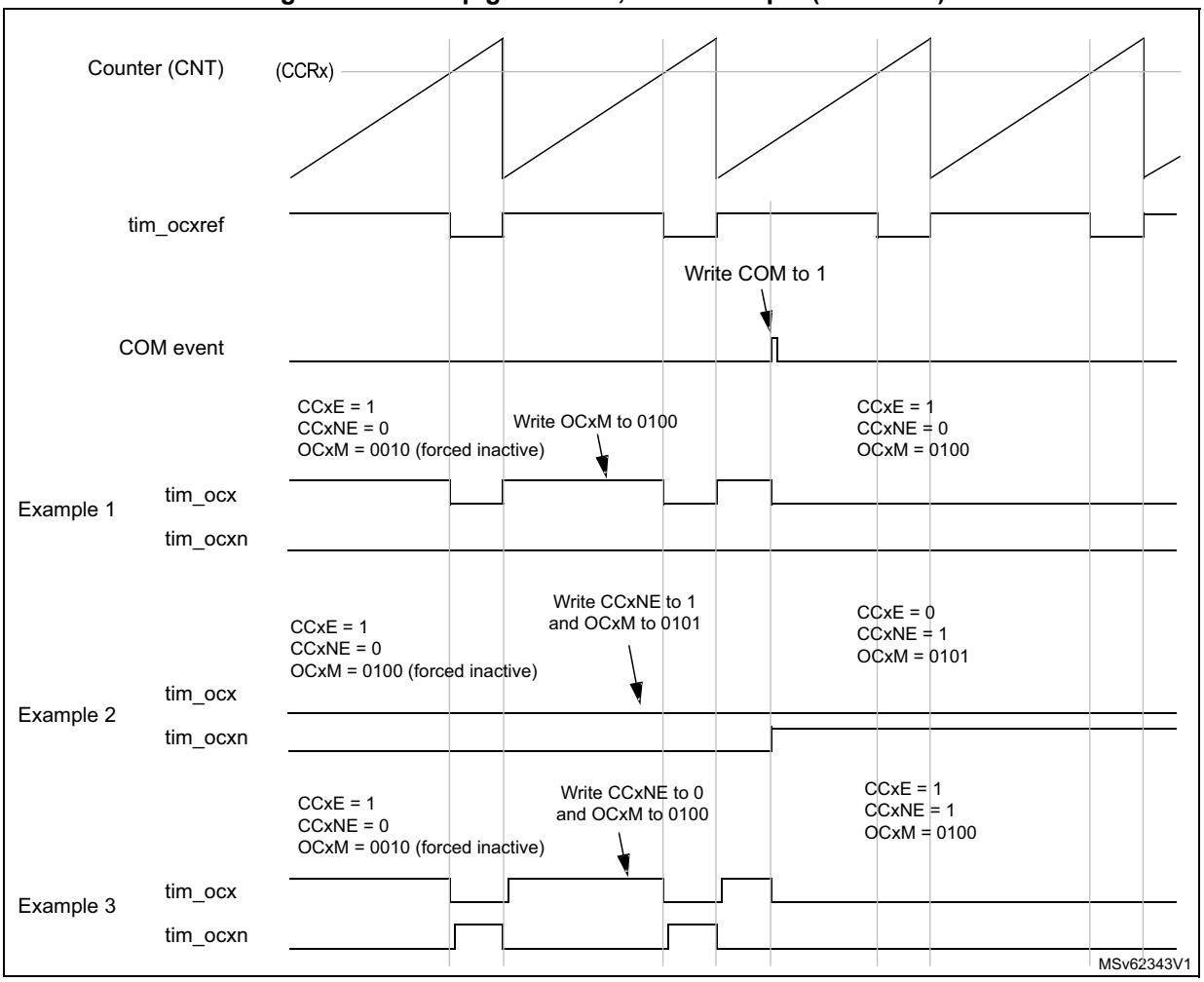
49.3.21 6-step PWM generation

When complementary outputs are used on a channel, preload bits are available on the OCxM, CCxE, and CCxNE bits. The preload bits are transferred to the shadow bits at the COM commutation event. Thus one can program in advance the configuration for the next step and change the configuration of all the channels at the same time. COM can be generated by software by setting the COM bit in the TIMx_EGR register or by hardware (on tim_trgi rising edge).

A flag is set when the COM event occurs (COMIF bit in the TIMx_SR register), which can generate an interrupt (if the COMIE bit is set in the TIMx_DIER register) or a DMA request (if the COMDE bit is set in the TIMx_DIER register).

Figure 537 describes the behavior of the tim_ocx and tim_ocxn outputs when a COM event occurs, in three different examples of programmed configurations.

Figure 537. 6-step generation, COM example (OSSR = 1)



49.3.22 One-pulse mode

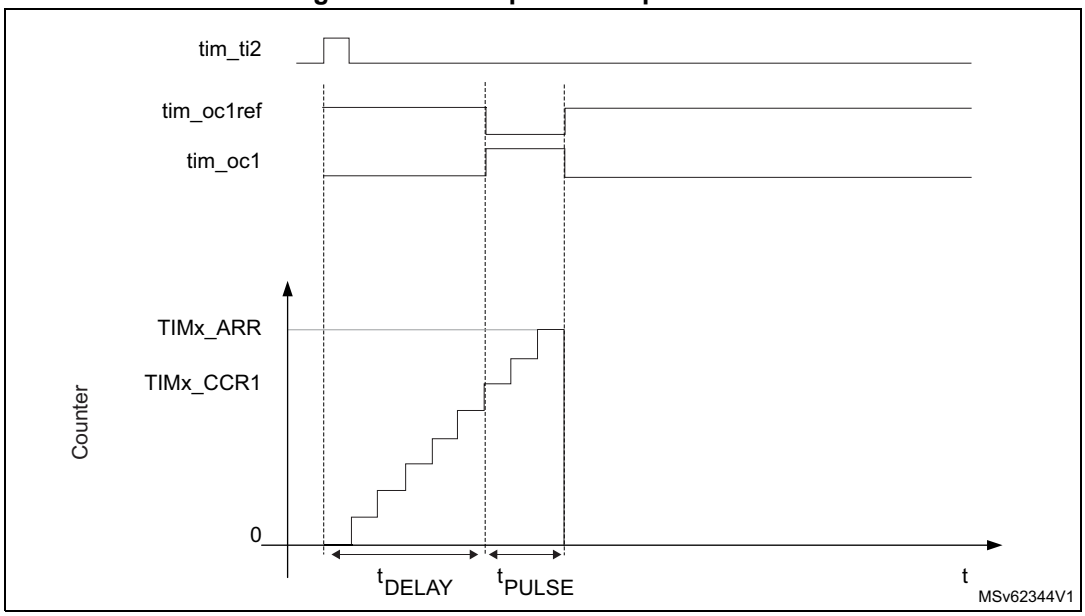
One-pulse mode (OPM) is a particular case of the previous modes. It allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length after a programmable delay.

Starting the counter can be controlled through the slave mode controller. Generating the waveform can be done in output compare mode or PWM mode. One-pulse mode is selected by setting the OPM bit in the TIMx_CR1 register. This makes the counter stop automatically at the next update event UEV.

A pulse can be correctly generated only if the compare value is different from the counter initial value. Before starting (when the timer is waiting for the trigger), the configuration must be:

- In upcounting: CNT < CCRx ≤ ARR (in particular, 0 < CCRx)
- In downcounting: CNT > CCRx

Figure 538. Example of one pulse mode.



In the following example, the user wants to generate a positive pulse on tim_oc1 with a length of t_{PULSE} and after a delay of t_{DELAY} as soon as a positive edge is detected on the tim_ti2 input pin.

Use tim_ti2fp2 as trigger 1:

- Map tim_ti2fp2 to tim_ti2 by writing CC2S = 01 in the TIMx_CCMR1 register.
- tim_ti2fp2 must detect a rising edge, write CC2P = 0 and CC2NP = 0 in the TIMx_CCER register.
- Configure tim_ti2fp2 as trigger for the slave mode controller (tim_trgi) by writing TS = 00110 in the TIMx_SMCR register.
- tim_ti2fp2 is used to start the counter by writing SMS to 110 in the TIMx_SMCR register (trigger mode).

The OPM waveform is defined by writing the compare registers (taking into account the clock frequency and the counter prescaler).

- The t_{DELAY} is defined by the value written in the TIMx_CCR1 register.
- The t_{PULSE} is defined by the difference between the autoreload value and the compare value (TIMx_ARR - TIMx_CCR1).
- Suppose the user wants to build a waveform with a transition from 0 to 1 when a compare match occurs and a transition from 1 to 0 when the counter reaches the auto-reload value. This is achieved by enabling PWM mode 2 (OC1M = 111 in TIMx_CCMR1). Optionally the preload registers can be enabled by writing OC1PE = 1 in the TIMx_CCMR1 register and ARPE in the TIMx_CR1 register. In this case one has to write the compare value in the TIMx_CCR1 register, the autoreload value in the TIMx_ARR register, generate an update by setting the UG bit and wait for external trigger event on tim_ti2. CC1P is written to 0 in this example.

In this example, the DIR and CMS bits in the TIMx_CR1 register must be low.

Since only one pulse (Single mode) is needed, a 1 must be written in the OPM bit in the TIMx_CR1 register to stop the counter at the next update event (when the counter rolls over

from the autoreload value back to 0). When OPM bit in the TIMx_CR1 register is set to 0, so the Repetitive mode is selected.

Particular case: tim_ocx fast enable:

In One-pulse mode, the edge detection on tim_tix input set the CEN bit which enables the counter. Then the comparison between the counter and the compare value makes the output toggle. But several clock cycles are needed for these operations and it limits the minimum delay t_{DELAY} min that can be achieved.

To output a waveform with the minimum delay, the OCxFE bit can be set in the TIMx_CCMRx register. Then tim_ocxref (and tim_ocx) are forced in response to the stimulus, without taking in account the comparison. Its new level is the same as if a compare match had occurred. OCxFE acts only if the channel is configured in PWM1 or PWM2 mode.

49.3.23 Retriggerable One-pulse mode

This mode allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length, but with the following differences with nonretriggerable one-pulse mode described in *Section 49.3.22*:

- The pulse starts as soon as the trigger occurs (no programmable delay).
- The pulse is extended if a new trigger occurs before the previous one is completed.

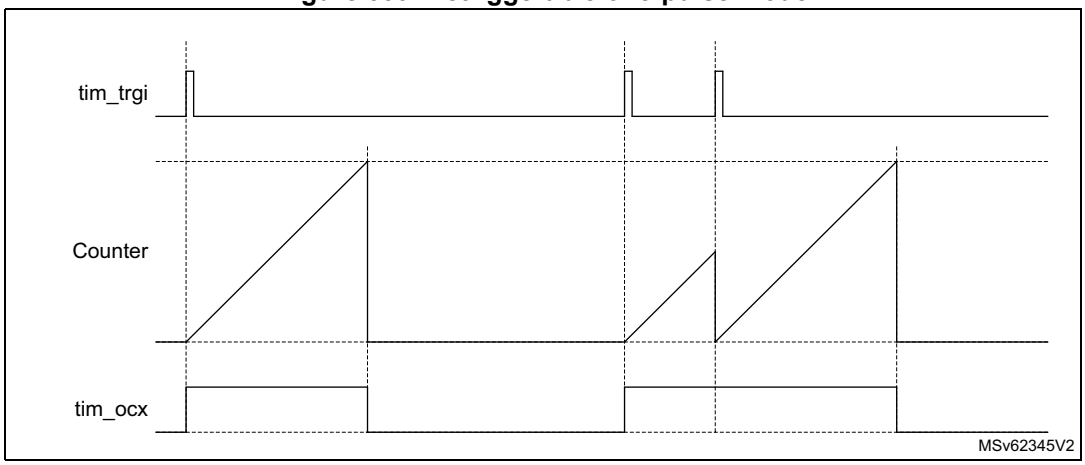
The timer must be in Slave mode, with the bits SMS[3:0] = 1000 (Combined Reset + trigger mode) in the TIMx_SMCR register, and the OCxM[3:0] bits set to 1000 or 1001 for retriggerable OPM mode 1 or 2.

If the timer is configured in Up-counting mode, the corresponding CCRx must be set to 0 (the ARR register sets the pulse length). If the timer is configured in Down-counting mode, CCRx must be above or equal to ARR.

Note: The OCxM[3:0] and SMS[3:0] bitfields are split into two parts for compatibility reasons, the most significant bit are not contiguous with the three least significant ones.

This mode must not be used with center-aligned PWM modes. It is mandatory to have CMS[1:0] = 00 in TIMx_CR1.

Figure 539. Retriggerable one-pulse mode



49.3.24 Pulse on compare mode

A pulse can be generated upon compare match event. A signal with a programmable pulsewidth generated when the counter value equals a given compare value, for debugging or synchronization purposes.

This mode is available for any slave mode selection, including encoder modes, in edge and center aligned counting modes. It is solely available for channel 3 and channel 4. The pulse generator is unique and is shared by the two channels, as shown on *Figure 540*.

Figure 540. Pulse generator circuitry

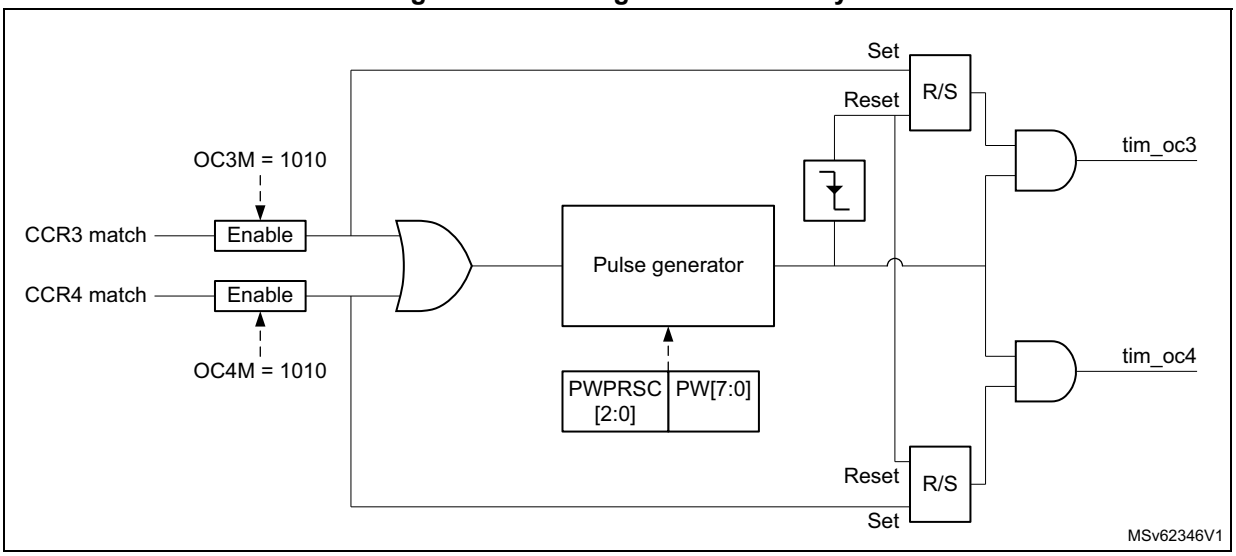
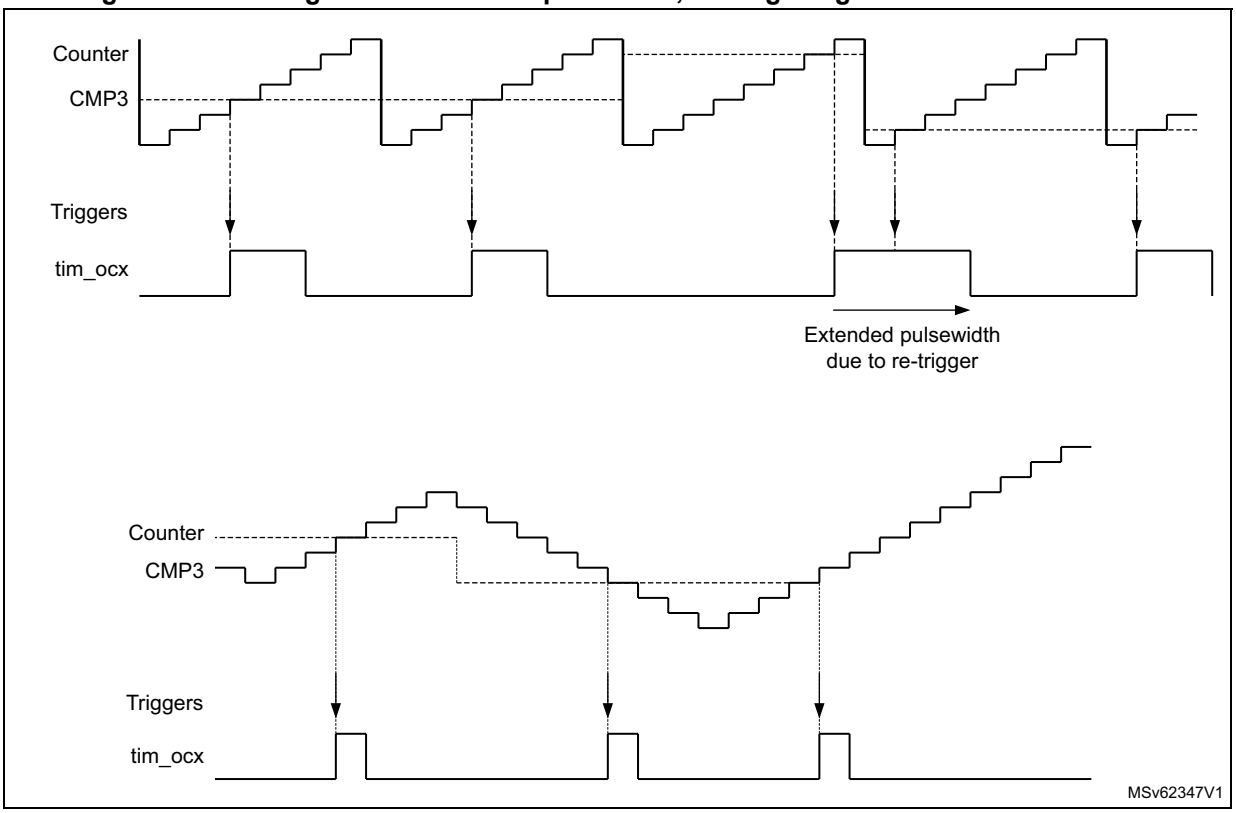


Figure 541 shows how the pulse is generated for edge-aligned and encoder operating modes.

Figure 541. Pulse generation on compare event, for edge-aligned and encoder modes



This output compare mode is selected using the OC3M[3:0] and OC4M[3:0] bitfields in TIMx_CCMR2 register.

The pulsewidth is programmed using the PW[7:0] bitfield in the register, using a specific clock prescaled according to PWPRSC[2:0] bits, as follows:

t_{PW} = PW[7:0] x t_{PWG}

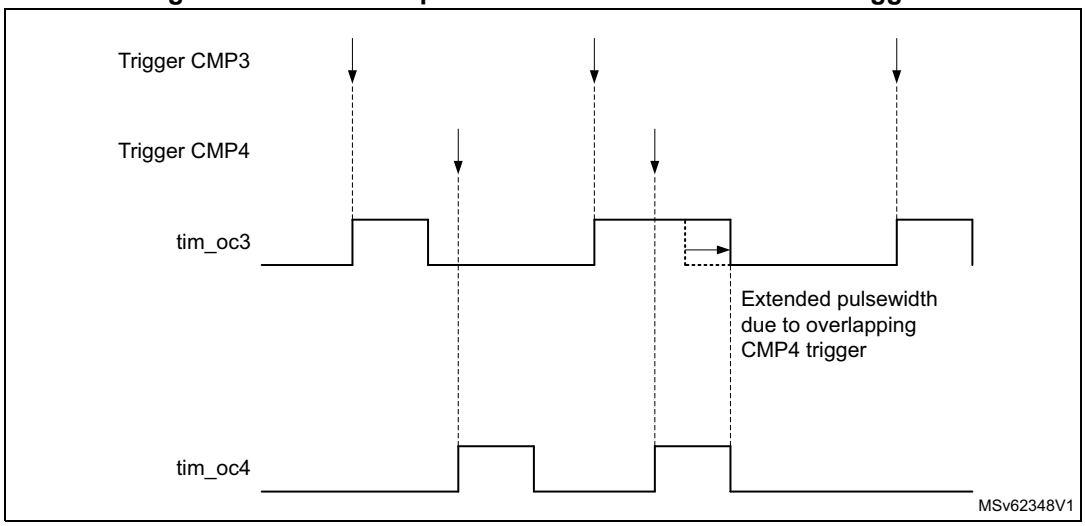
where $t_{PWG} = (2^{(PWPRSC[2:0])}) \times t_{tim_ker_ck}$

gives the resolution and maximum values depending on the prescaler value.

The pulse is retriggerable: a new trigger while the pulse is ongoing, causes the pulse to be extended.

Note: If the two channels are enabled simultaneously, the pulses are issued independently as long as the trigger on one channel is not overlapping the pulse generated on the concurrent output. On the opposite, if the two triggers are overlapping, the pulse width related to the first arriving trigger is extended (because of the retrigger), while the pulse width of the last arriving trigger is correct (as shown on Figure 542).

Figure 542. Extended pulsewidth in case of concurrent triggers



49.3.25 Encoder interface mode

Quadrature encoder

To select Encoder Interface mode write SMS = 0001 in the TIMx_SMCR register if the counter is counting on tim_ti1 edges only, SMS = 0010 if it is counting on tim_ti2 edges only and SMS = 0011 if it is counting on both tim_ti1 and tim_ti2 edges.

Select the tim_ti1 and tim_ti2 polarity by programming the CC1P and CC2P bits in the TIMx_CCER register. When needed, the input filter can be programmed as well. CC1NP and CC2NP must be kept low.

The two inputs tim_ti1 and tim_ti2 are used to interface to an quadrature encoder. Refer to *Table 525*. The counter is clocked by each valid transition on tim_ti1fp1 or tim_ti2fp2 (tim_ti1 and tim_ti2 after input filter and polarity selection, tim_ti1fp1 = tim_ti1 if not filtered and not inverted, tim_ti2fp2 = tim_ti2 if not filtered and not inverted) assuming that it is enabled (CEN bit in TIMx_CR1 register written to 1). The sequence of transitions of the two inputs is evaluated and generates count pulses as well as the direction signal. Depending on the sequence the counter counts up or down, the DIR bit in the TIMx_CR1 register is modified by hardware accordingly. The DIR bit is calculated at each transition on any input (tim_ti1 or tim_ti2), whatever the counter is counting on tim_ti1 only, tim_ti2 only or both tim_ti1 and tim_ti2.

Encoder interface mode acts simply as an external clock with direction selection. This means that the counter just counts continuously between 0 and the autoreload value in the TIMx_ARR register (0 to ARR or ARR down to 0 depending on the direction). So the TIMx_ARR must be configured before starting. In the same way, the capture, compare, prescaler, repetition counter, trigger output features continue to work as normal. Encoder mode and External clock mode 2 are not compatible and must not be selected together.

In this mode, the counter is modified automatically following the speed and the direction of the quadrature encoder and its content, therefore, always represents the encoder's position. The count direction correspond to the rotation direction of the connected sensor. The table summarizes the possible combinations, assuming tim_ti1 and tim_ti2 do not switch at the same time.

Table 525. Counting direction versus encoder signals (CC1P = CC2P = 0)

Active edge	SMS[3:0]	Level on opposite signal (tim_ti1fp1 for tim_ti2, tim_ti2fp2 for tim_ti1)	tim_ti1fp1 signal		tim_ti2fp2 signal	
			Rising	Falling	Rising	Falling
Counting on tim_ti1 only x1 mode	1110	High	Down	Up	No count	No count
		Low	No count	No count	No count	No count
Counting on tim_ti2 only x1 mode	1111	High	No count	No count	Up	Down
		Low	No count	No count	No count	No count
Counting on tim_ti1 only x2 mode	0001	High	Down	Up	No count	No count
		Low	Up	Down	No count	No count
Counting on tim_ti2 only x2 mode	0010	High	No count	No count	Up	Down
		Low	No count	No count	Down	Up
Counting on tim_ti1 and tim_ti2 x4 mode	0011	High	Down	Up	Up	Down
		Low	Up	Down	Down	Up

A quadrature encoder can be connected directly to the MCU without external interface logic. However, comparators are normally be used to convert the encoder's differential outputs to digital signals. This greatly increases noise immunity. The third encoder output which indicate the mechanical zero position, may be connected to the external trigger input and trigger a counter reset.

Figure 543 gives an example of counter operation, showing count signal generation and direction control. It also shows how input jitter is compensated where both edges are selected. This might occur if the sensor is positioned near to one of the switching points. For this example the configuration is the following:

- CC1S = 01 (TIMx_CCMR1 register, tim_ti1fp1 mapped on tim_ti1).
- CC2S = 01 (TIMx_CCMR1 register, tim_ti2fp2 mapped on tim_ti2).
- CC1P = 0 and CC1NP = 0 (TIMx_CCER register, tim_ti1fp1 noninverted, tim_ti1fp1 = tim_ti1).
- CC2P = 0 and CC2NP = 0 (TIMx_CCER register, tim_ti1fp2 noninverted, tim_ti1fp2= tim_ti2).
- SMS = 0011 (TIMx_SMCR register, both inputs are active on both rising and falling edges).
- CEN = 1 (TIMx_CR1 register, Counter enabled).

Figure 543. Example of counter operation in encoder interface mode.

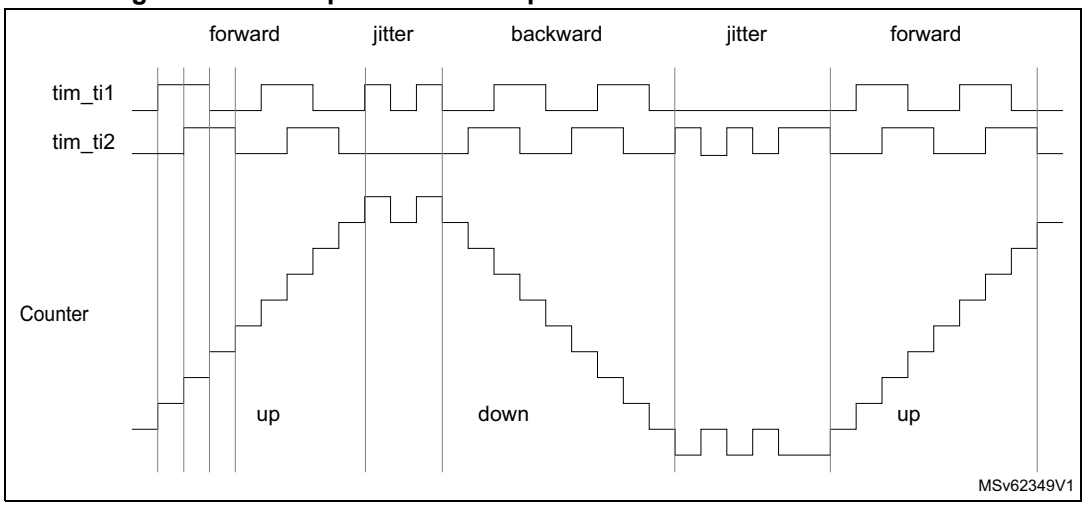


Figure 544 gives an example of counter behavior when tim_ti1fp1 polarity is inverted (same configuration as above except CC1P = 1).

Figure 544. Example of encoder interface mode with tim_ti1fp1 polarity inverted.

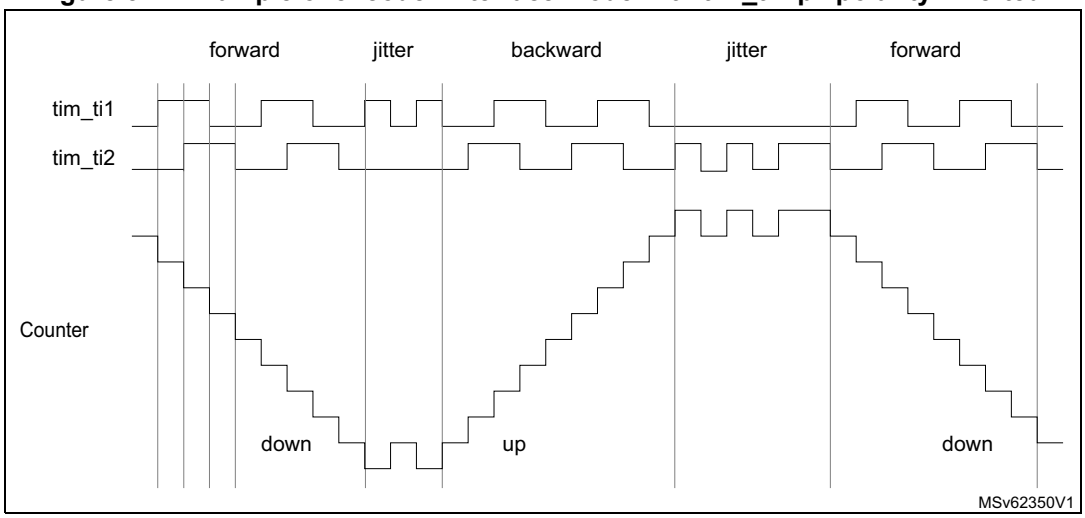
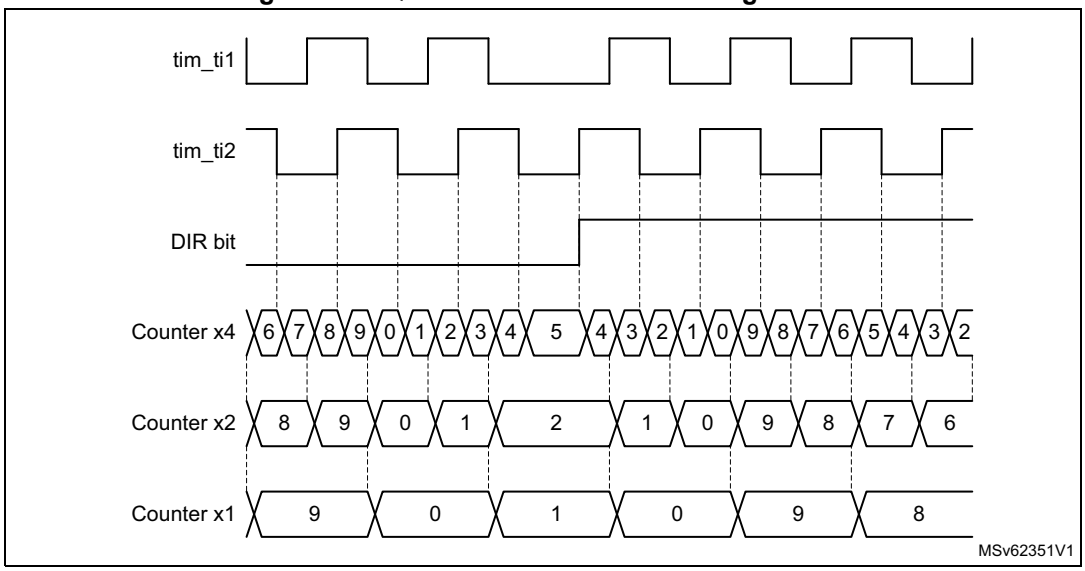


Figure 545 shows the timer counter value during a speed reversal, for various counting modes.

Figure 545. Quadrature encoder counting modes



The timer, when configured in Encoder Interface mode provides information on the sensor's current position. Dynamic information can be obtained (speed, acceleration, deceleration) by measuring the period between two encoder events using a second timer configured in capture mode. The output of the encoder which indicates the mechanical zero can be used for this purpose. Depending on the time between two events, the counter can also be read at regular times. This can be done by latching the counter value into a third input capture register if available (then the capture signal must be periodic and can be generated by another timer). When available, it is also possible to read its value through a DMA request.

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the update interrupt flag (UIF) into the timer counter register's bit 31 (TIMxCNT[31]). This allows both the counter value and a potential roll-over condition signaled by the UIFCPY flag to be read in an atomic way. It eases the calculation of angular speed by avoiding race conditions caused, for instance, by a processing shared between a background task (counter reading) and an interrupt (update interrupt).

There is no latency between the UIF and UIFCPY flag assertions.

In 32-bit timer implementations, when the IUFREMAP bit is set, bit 31 of the counter is overwritten by the UIFCPY flag upon read access (the counter's most significant bit is only accessible in write mode).

Clock plus direction encoder mode

In addition to the quadrature encoder mode, the timer offers support for other types of encoders.

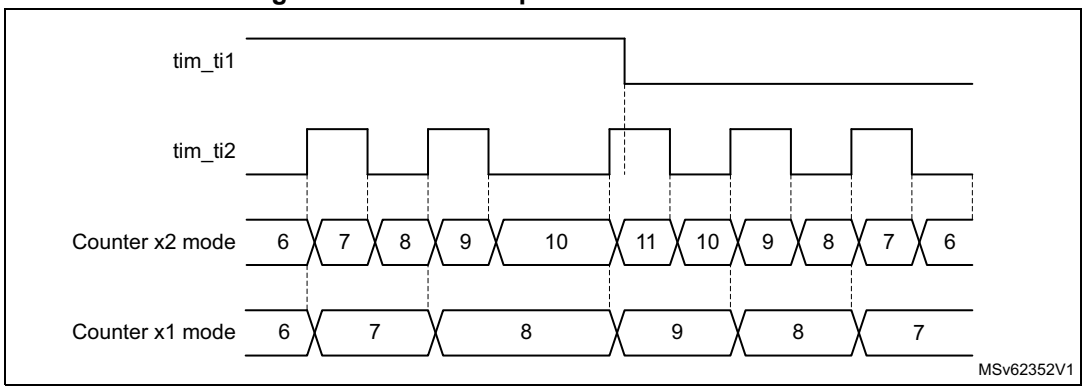
In the clock plus direction mode shown on *Figure 546*, the clock is provided on a single line, on tim_ti2, while the direction is forced using the tim_ti1 input.

This mode is enabled with the SMS[3:0] bitfield in the TIMx_SMCR register, as following:

- 1010: x2 mode, the counter is updated on both rising and falling edges of the clock
- 1011: x1 mode, the counter is updated on a single clock edge, as per CC2P bit value: CC2P = 0 corresponds to rising edge sensitivity and CC2P = 1 corresponds to falling edge sensitivity

The polarity of the direction signal on tim_ti1 is set with the CC1P bit: 0 corresponds to positive polarity (up-counting when tim_ti1 is high and down-counting when tim_ti1 is low) and CC1P = 1 corresponds to negative polarity (up-counting when tim_ti1 is low).

Figure 546. Direction plus clock encoder mode



Directional clock encoder mode

In the directional clock mode on *Figure 547*, the clocks are provided on two lines, with a single one at once, depending on the direction, so as to have one up-counting clock line and one down-counting clock line.

This mode is enabled with the SMS[3:0] bitfield in the TIMx_SMCR register, as following:

- 1100: x2 mode, the counter is updated on both rising and falling edges of any of the two clock line. The CC1P and CC2P bits are coding for the clock idle state. CCxP = 0 corresponds to high-level idle state (refer to *Figure 547*) and CCxP = 1 corresponds to low-level idle state (refer to *Figure 548*).
- 1101: x1 mode, the counter is updated on a single clock edge, as per CC1P and CC2P bit value. CCxP = 0 corresponds to falling edge sensitivity and high-level idle state (refer to *Figure 547*), CCxP = 1 corresponds to rising edge sensitivity and low-level idle state (refer to *Figure 548*).

Figure 547. Directional clock encoder mode (CC1P = CC2P = 0)

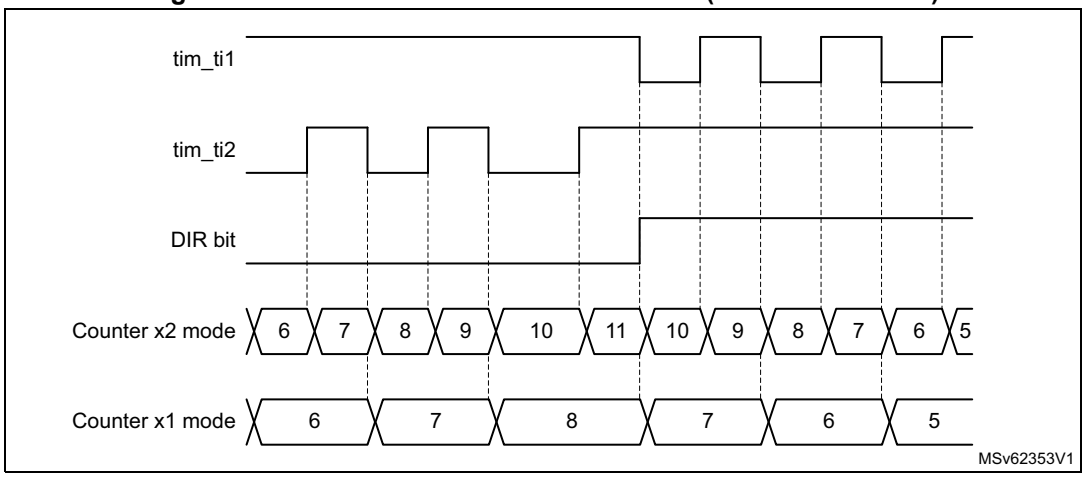


Figure 548. Directional clock encoder mode (CC1P = CC2P = 1)

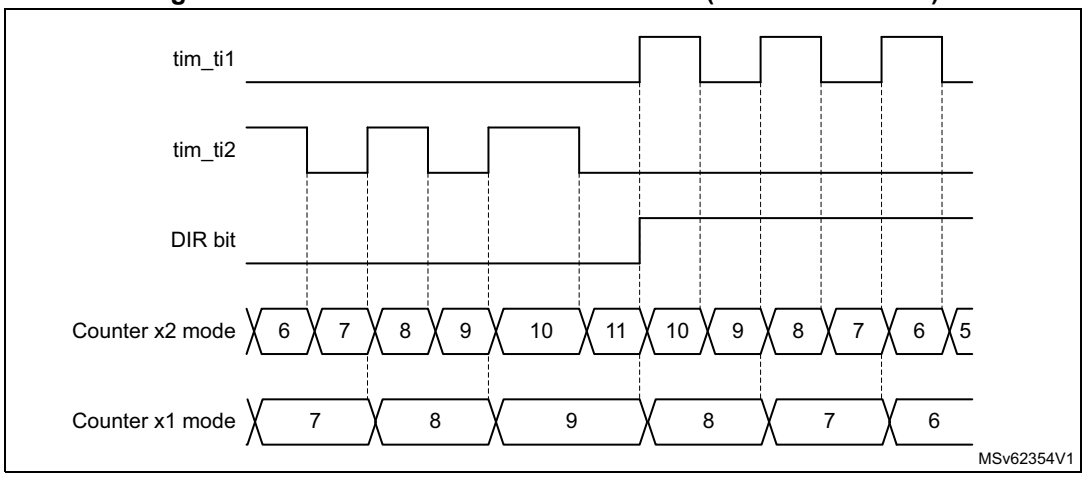


Table 526 here-below details how the directional clock mode operates, for any input transition.

Table 526. Counting direction versus encoder signals and polarity settings

Directional clock mode	SMS[3:0]	Level on opposite signal (tim_ti1fp1 for tim_ti2, tim_ti2fp2 for tim_ti1)	tim_ti1fp1 signal		tim_ti2fp2 signal	
			Rising	Falling	Rising	Falling
x2 mode CCxP = 0	1100	High	Down	Down	Up	Up
		Low	No count	No count	No count	No count
x2 mode CCxP = 1	1100	High	No count	No count	No count	No count
		Low	Down	Down	Up	Up
x1 mode CCxP = 0	1101	High	No count	Down	No count	Up
		Low	No count	No count	No count	No count
x1 mode CCxP = 1	1101	High	No count	No count	No count	No count
		Low	Down	No count	Up	No count

Index input

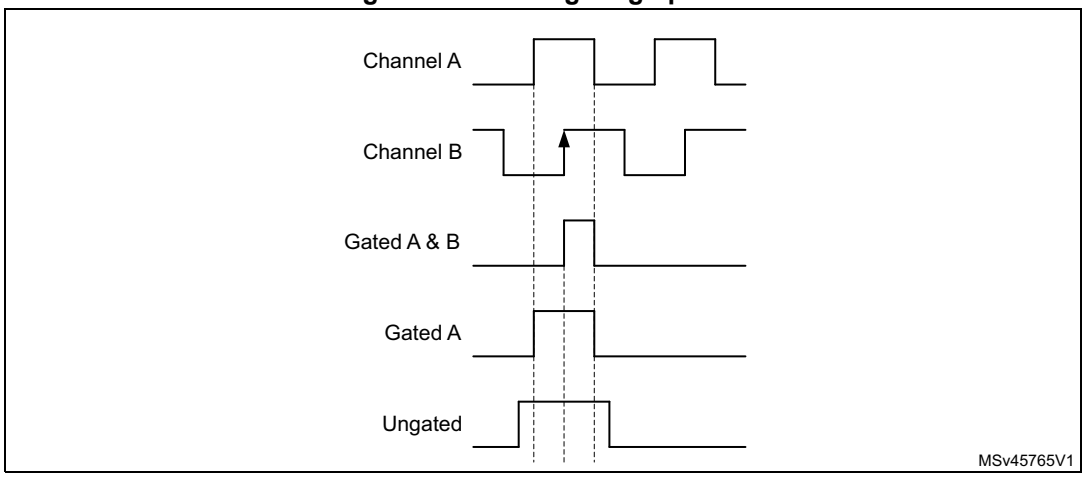
The counter can be reset by an index signal coming from the encoder, indicating an absolute reference position. The index signal must be connected to the tim_etr_in input. It can be filtered using the digital input filter.

The index functionality is enabled with the IE bit in the TIMX_ECR register. The IE bit must be set only in encoder mode, when the SMS[3:0] bitfield has the following values: 0001, 0010, 011, 1010, 1011, 1100, 1101, 1110, 1111.

Available encoders are proposed with several options for index pulse conditioning, as per *Figure 549*:

- gated with A and B: the pulsewidth is 1/4 of one channel period, aligned with both A and B edges
- gated with A (or gated with B): the pulsewidth is 1/2 of one channel period, aligned with the two edges on channel A (resp. channel B)
- ungated: the pulsewidth is up to one channel period, without any alignment to the edges

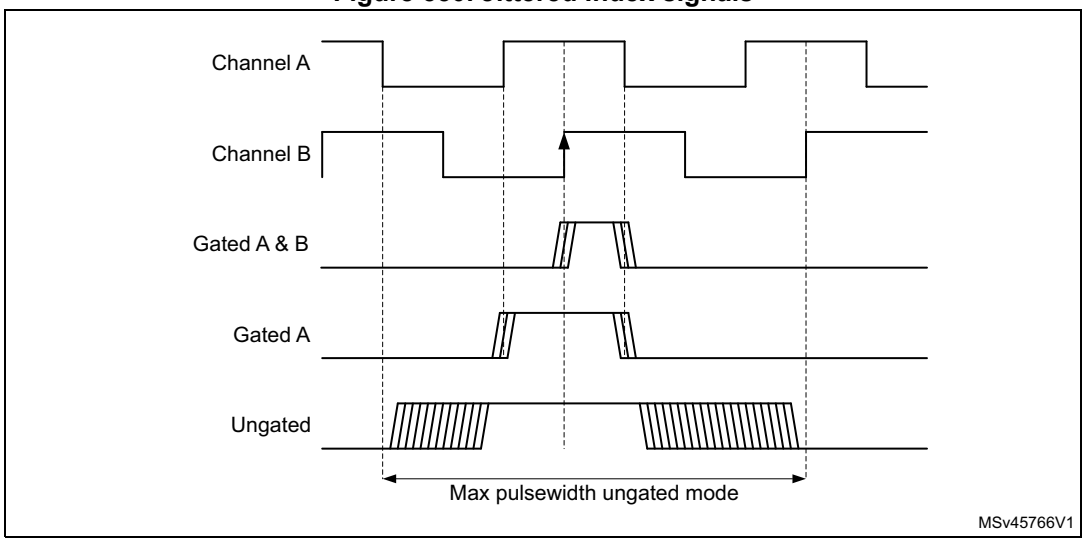
Figure 549. Index gating options



The circuitry tolerates jitter on index signal, whatever the gating mode, as show on *Figure 550*.

In ungated mode, the signal must be strictly below two encoder periods. If the pulsewidth is greater or equal to two encoder period, the counter is reset multiple times.

Figure 550. Jittered Index signals



The timer supports the three gating options identically, without any specific programming needed. It is only necessary to define on which encoder state (for example channel A and

channel B state combination) the index must be synchronized, using the IPOS[1:0] bitfield in the TIMx_ECR register.

The index detection event acts differently depending on counting direction to ensure symmetrical operation during speed reversal:

- The counter is reset during up-counting (DIR bit = 0).
- The counter is set to TIMx_ARR when down counting.

This allows the index to be generated on the very same mechanical angular position whatever the counting direction. *Figure 551* shows at which position is the index generated, for a simplistic example (an encoder providing four edges par mechanical rotation).

Figure 551. Index generation for IPOS[1:0] = 11

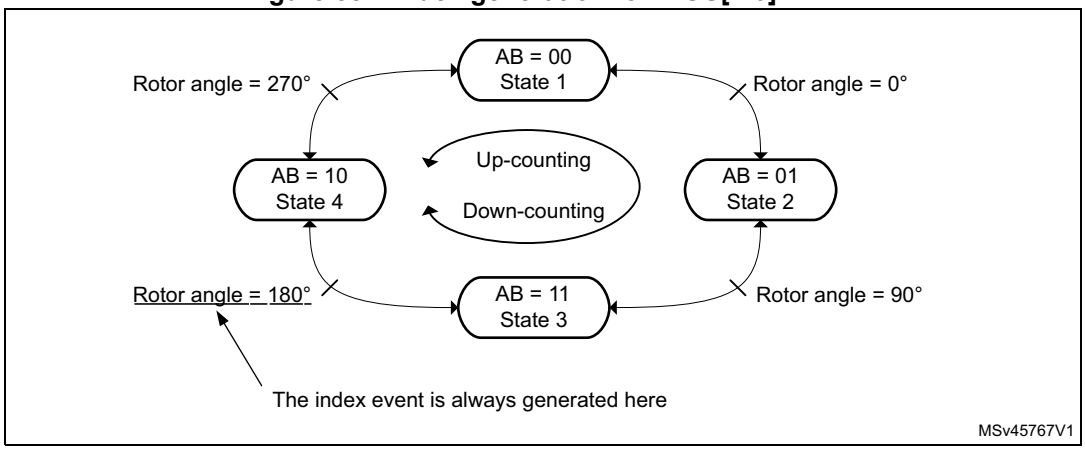


Figure 552 presents waveforms and corresponding values for IPOS[1:0] = 11. It shows that the instant at which the counter value is forced is automatically adjusted depending on the counting direction:

- Counter set to 0 when encoder state is 11 (ChA = 1, ChB = 1), when up-counting (DIR bit = 0).
- Counter set to TIMx_ARR when exiting the 11 state, when down-counting (DIR bit = 1).

An interrupt can be issued upon index detection event.

The arrows are indicating on which transition is the index event interrupt generated.

Figure 552. Counter reading with index gated on channel A (IPOS[1:0] = 11)

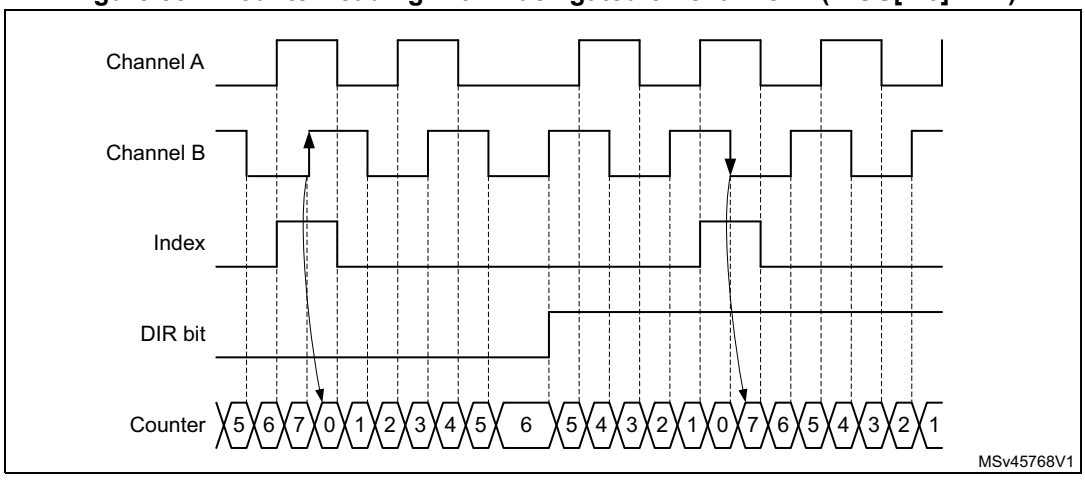


Figure 553. presents waveforms and corresponding values for the ungated mode. The arrows are indicating on which transition is the index event generated.

Figure 553. Counter reading with index ungated (IPOS[1:0] = 00)

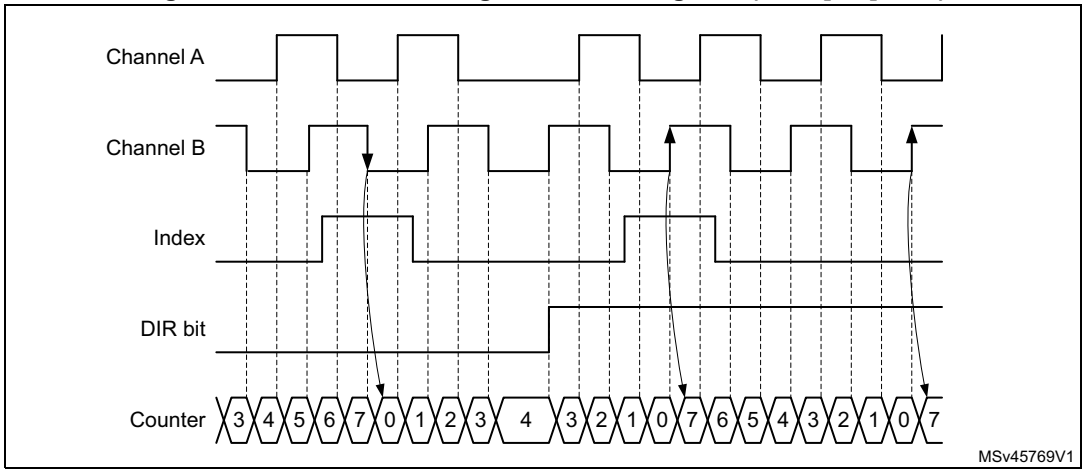


Figure 554. shows how the 'gated on A & B' mode is handled, for various pulse alignment scenario. The arrows are indicating on which transition is the index event generated.

Figure 554. Counter reading with index gated on channel A and B

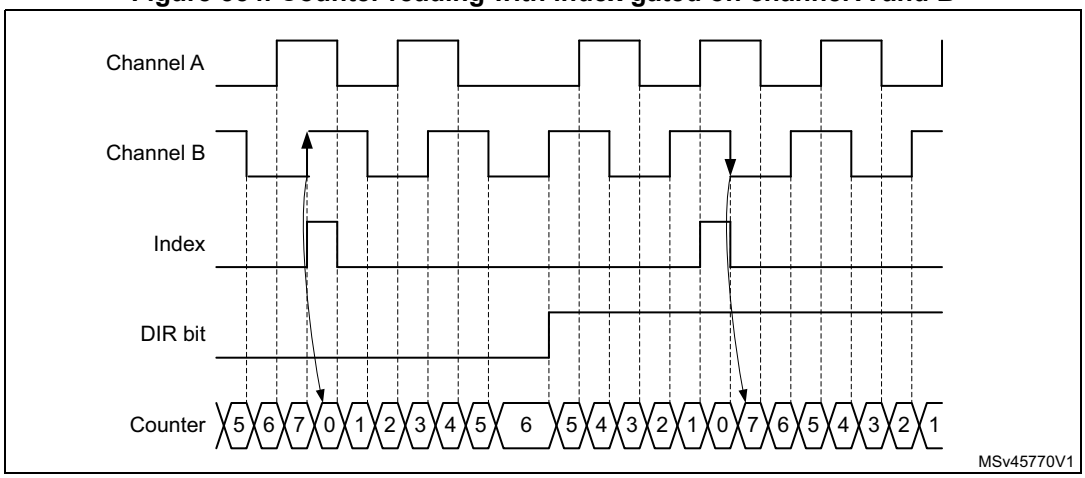


Figure 555 and *Figure 556* detail the case where the subsequent index pulse may be narrower than one quarter of the encoder clock period.

Figure 555. Encoder mode behavior in case of narrow index pulse (IPOS[1:0] = 11)

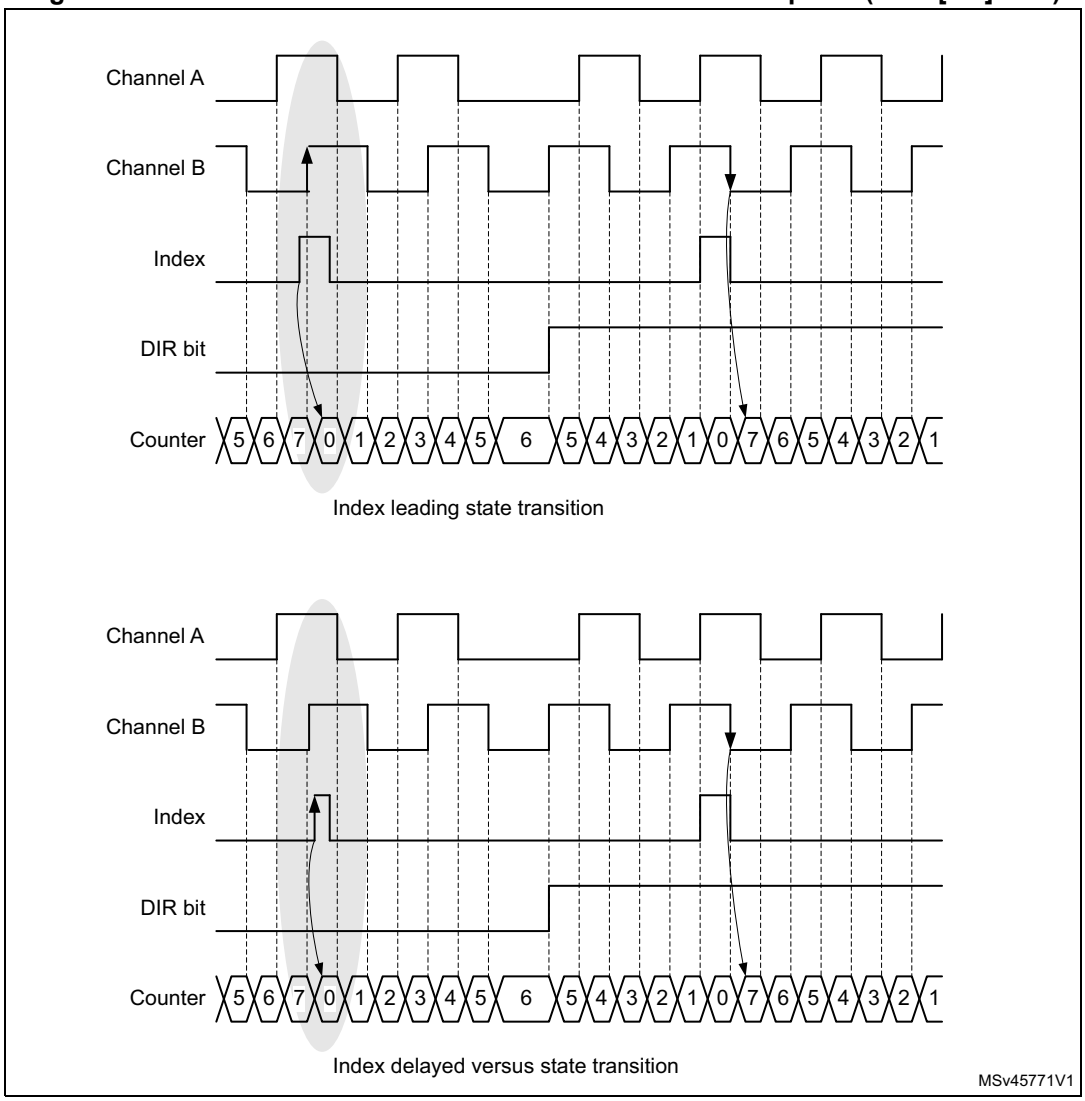


Figure 556. Counter reset Narrow index pulse (closer view, ARR = 0x07)

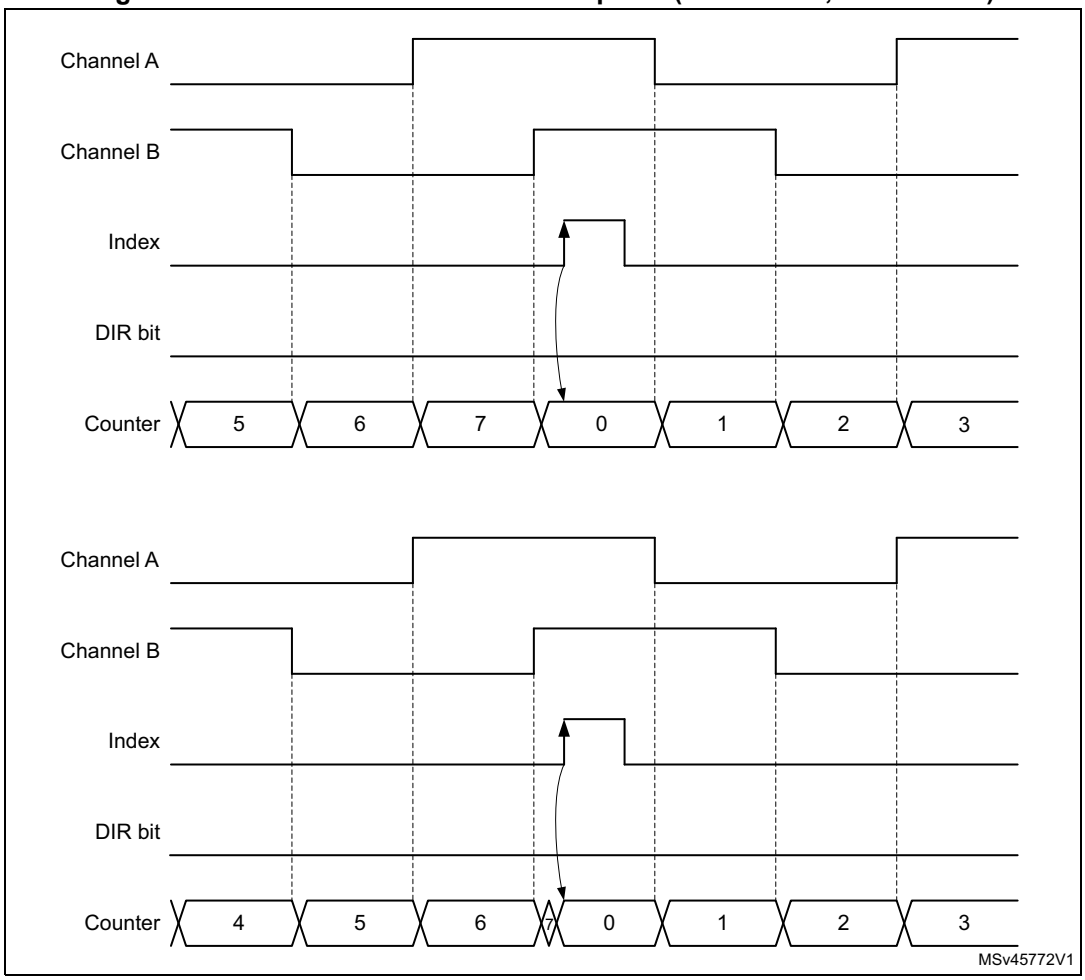
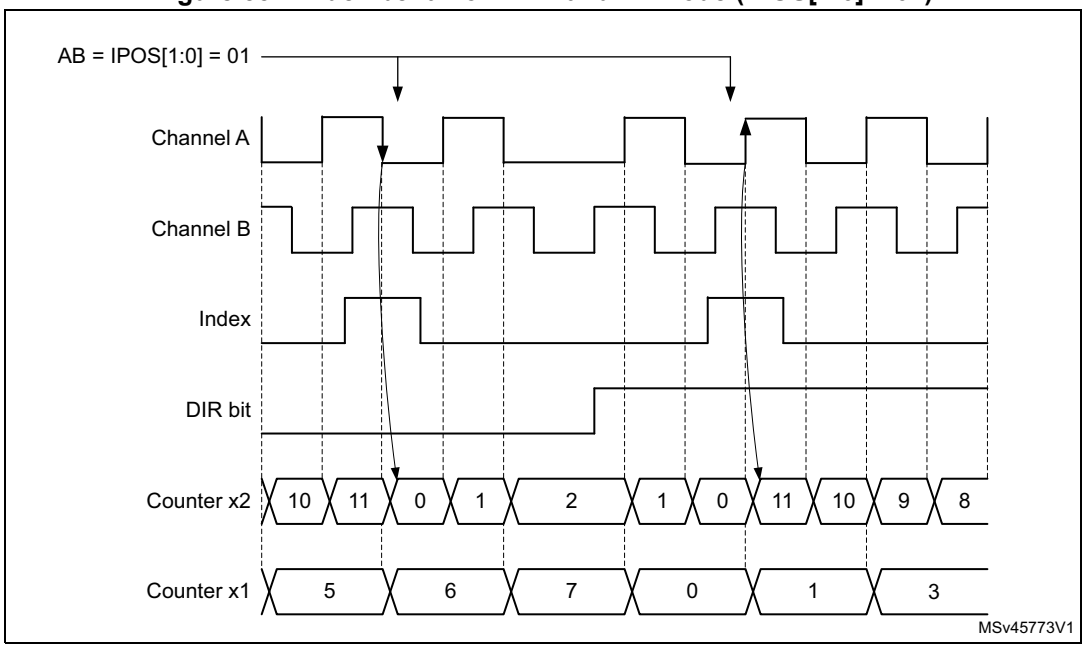


Figure 557 shows how the index is managed in x1 and x2 modes.

Figure 557. Index behavior in x1 and x2 mode (IPOS[1:0] = 01)

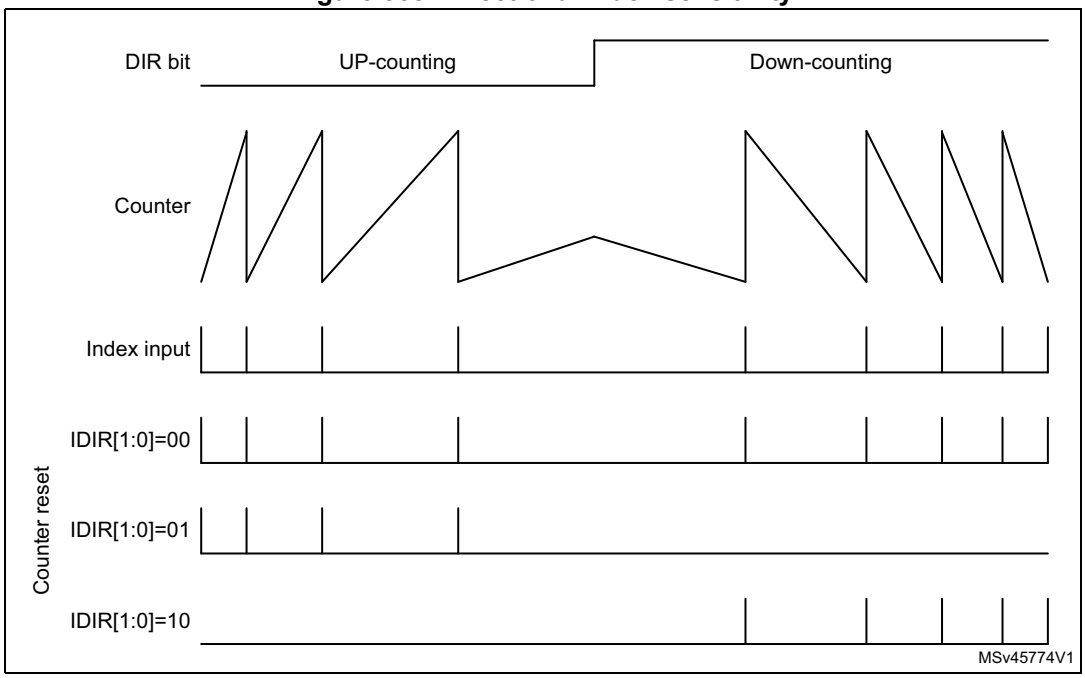


Directional index sensitivity

The IDIR[1:0] bitfield in the TIMx_ECR register allows the index to be active only in a selected counting direction.

Figure 558 shows the relationship between index and counter reset events, depending on IDIR[1:0] value.

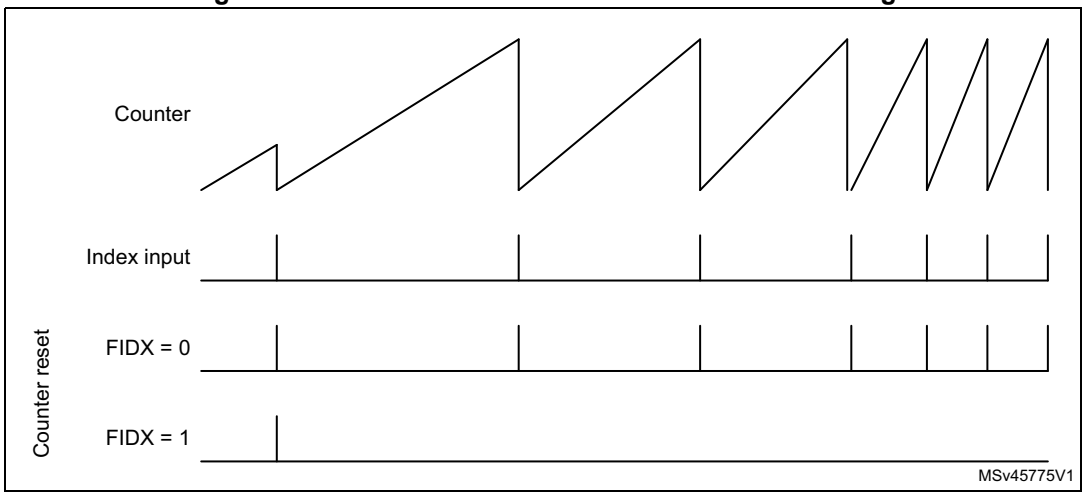
Figure 558. Directional index sensitivity



Special first index event management

The FIDX bit in the TIMx_ECR register allows the index to be taken only once, as shown on *Figure 559*. Once the first index has arrived, any subsequent index is ignored. If needed, the circuitry can be rearmed by writing the FIDX bit to 0 and setting it again to 1.

Figure 559. Counter reset as function of FIDX bit setting



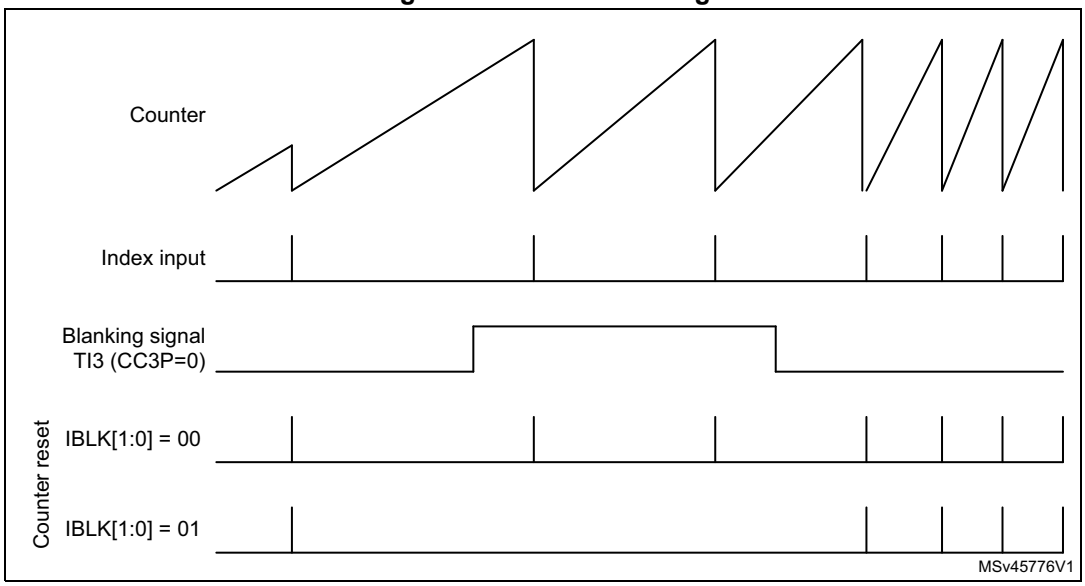
Index blanking

The index event can be blanked using the tim_ti3 or tim_ti4 inputs. During the blanking window, the index events are no longer resetting the counter, as shown on the *Figure 560* below.

This mode is enabled using the IBLK[1:0] bitfield in the TIMx_ECR register, as following:

- IBLK[1:0] = 00: Index signal always active
- IBLK[1:0] = 01: Index signal blanking on tim_ti3 input
- IBLK[1:0] = 10: Index signal blanking on tim_ti4 input

Figure 560. Index blanking



Index management in nonquadrature mode

Figure 561 and *Figure 562* detail how the index is managed in directional clock mode and clock plus direction mode, when the SMS[3:0] bitfield is equal to 1010, 1011, 1100, 1101.

For both of these modes, the index sensitivity is set with the IPOS[0] bit as following:

- IPOS[0] = 0: Index is detected on clock low level
- IPOS[0] = 1: Index is detected on clock high level

The IPOS[1] bit is not-significant.

Figure 561. Index behavior in clock + direction mode, IPOS[0] = 1

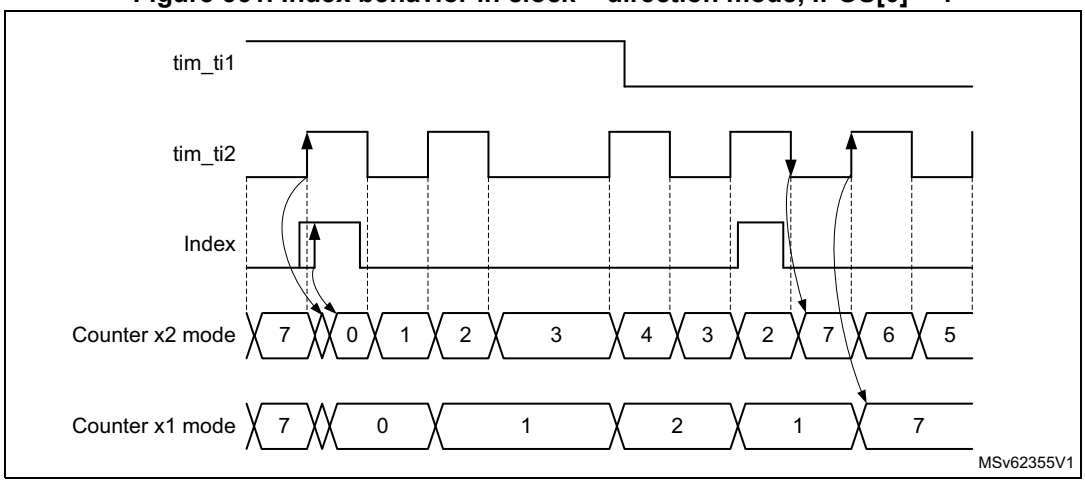
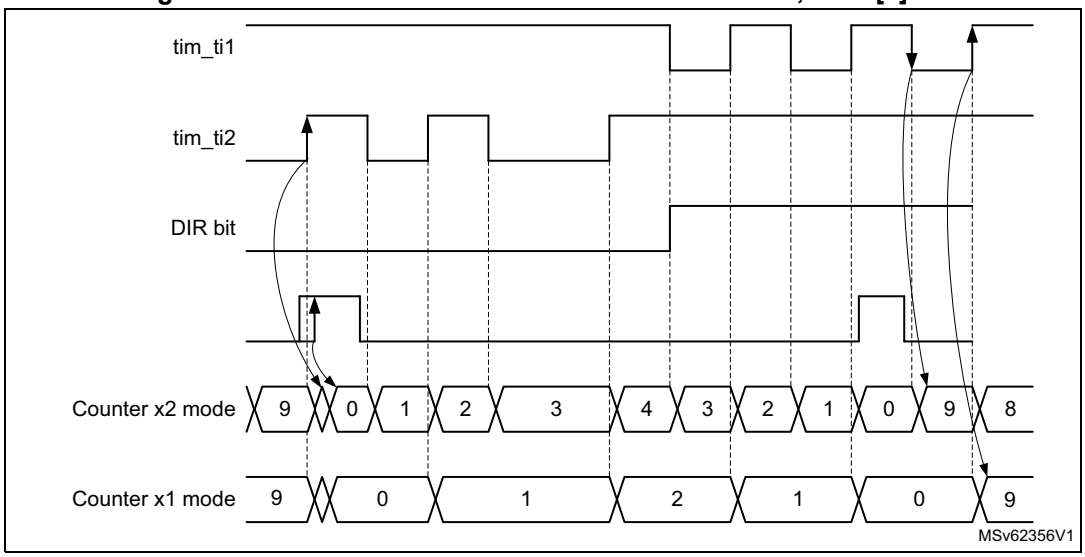


Figure 562. Index behavior in directional clock mode, IPOS[0] = 1

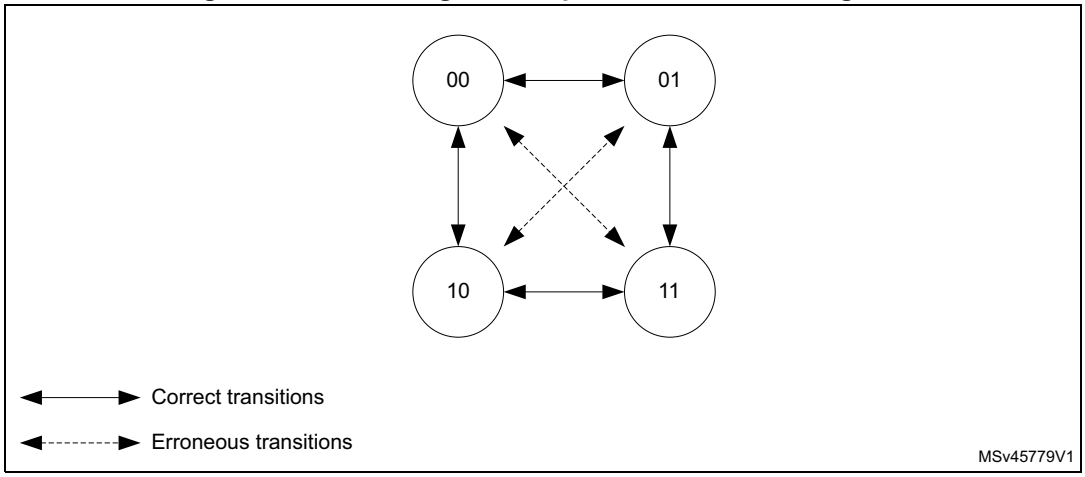


Encoder error management

For encoder configurations where two quadrature signals are available, it is possible to detect transition errors. The reading on the two inputs corresponds to a 2-bit gray code which can be represented as a state diagram, on *Figure 563.*. A single bit is expected to change at once. An erroneous transition sets the TERRF interrupt flag in the TIMx_SR

status register. A transition error interrupt is generated if the TERRIE bit is set in the TIMx_DIER register.

Figure 563. State diagram for quadrature encoded signals



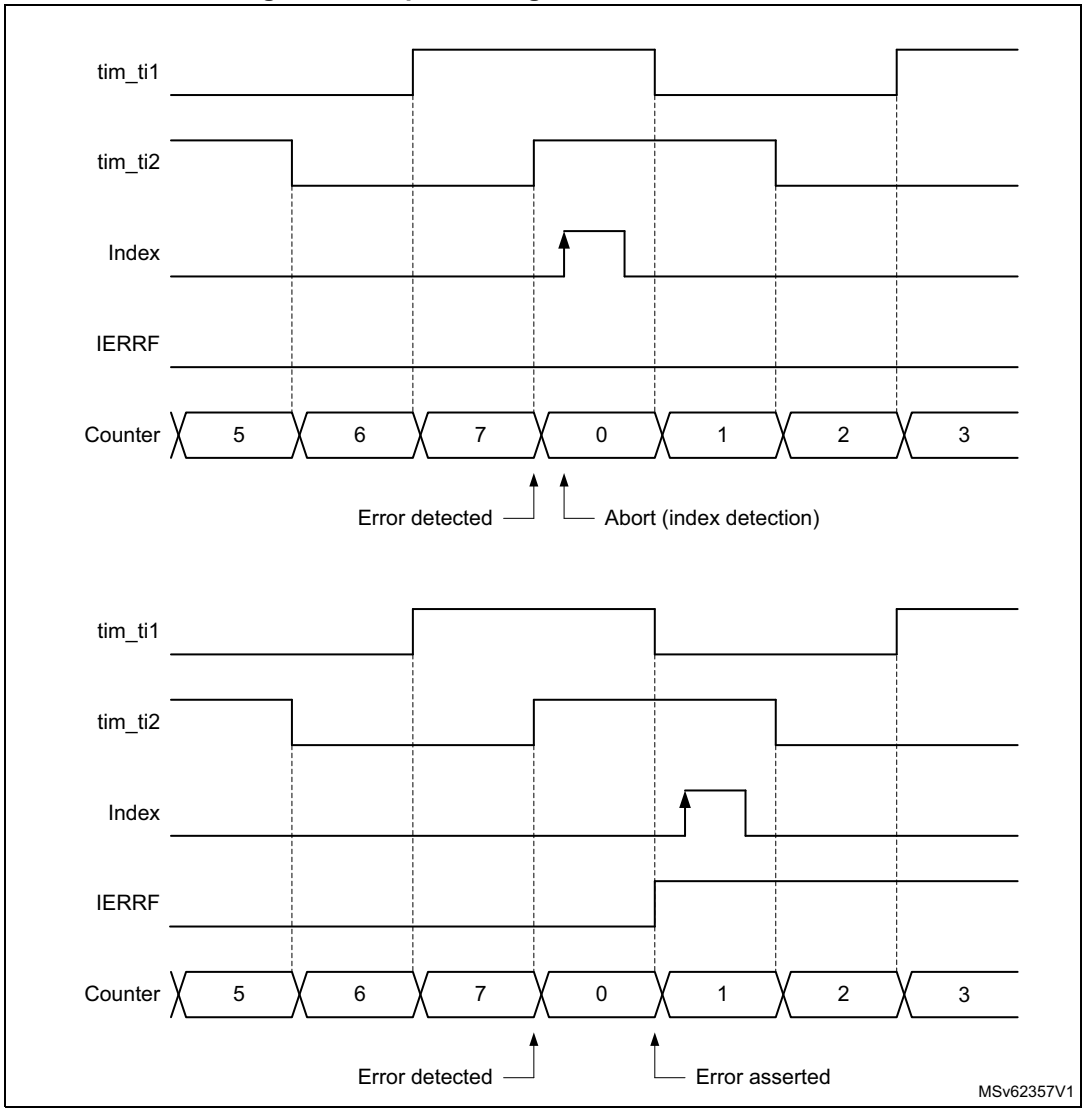
For encoder having an index signal, it is possible to detect abnormal operation resulting in an excess of pulses per revolution. An encoder with N pulses per revolution provides 4xN counts per revolution. The index signal resets the counter every 4xN clock periods.

If the counter value is incremented from TIMx_ARR to 0 or decremented from 0 to TIMxARR value without any index event, this is reported as an index position error.

The overflow threshold is programmed using the TIMx_ARR register. A 1000 lines encoder results in a counter value being between 0 and 3999 (in 4x reading mode). The overflow detection threshold must be programmed by setting TIMx_ARR = 3999 + 1 = 4000.

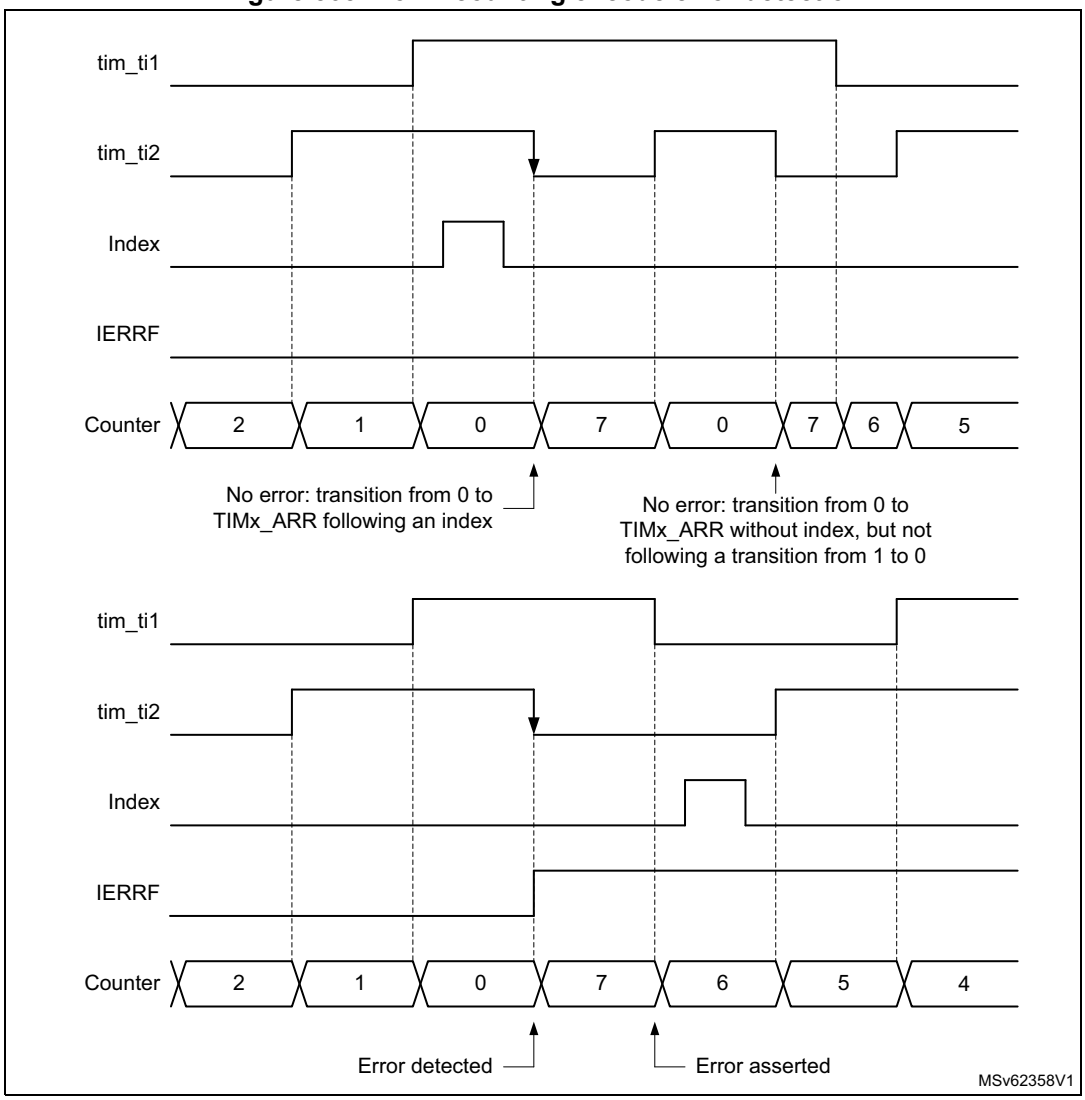
The error assertion is delayed to the transition 0 to 1 when in up-counting. This is cope with narrow index pulses in gated A and B mode, as shown on *Figure 564*.

Figure 564. Up-counting encoder error detection



In down-counting mode, the detection is conditioned by a preliminary transition from 1 to 0. This is to cope with narrow index pulses in gated A and B mode, as shown on *Figure 565*, to avoid any false error detection in case the encoder dithers between TIMx_ARR and 0 immediately after the index detection.

Figure 565. Down-counting encode error detection



An index error sets the IERRF interrupt flag in the TIMx_SR status register. An index error interrupt is generated if the IERRIE bit is set in the TIMx_DIER register.

Functional encoder interrupts

The following interrupts are also available in encoder mode

- Direction change: any change of the counting direction in encoder mode causes the DIR bit in the TIMx_CR1 register to toggle. The direction change sets the DIRF interrupt flag in the TIMx_SR status register. A direction change interrupt is generated if the DIRIE bit is set in the TIMx_DIER register.
- Index event: the index event sets the IDXF interrupt flag in the TIMx_SR status register. An index interrupt is generated if the IDXIE bit is set in the TIMx_DIER register.

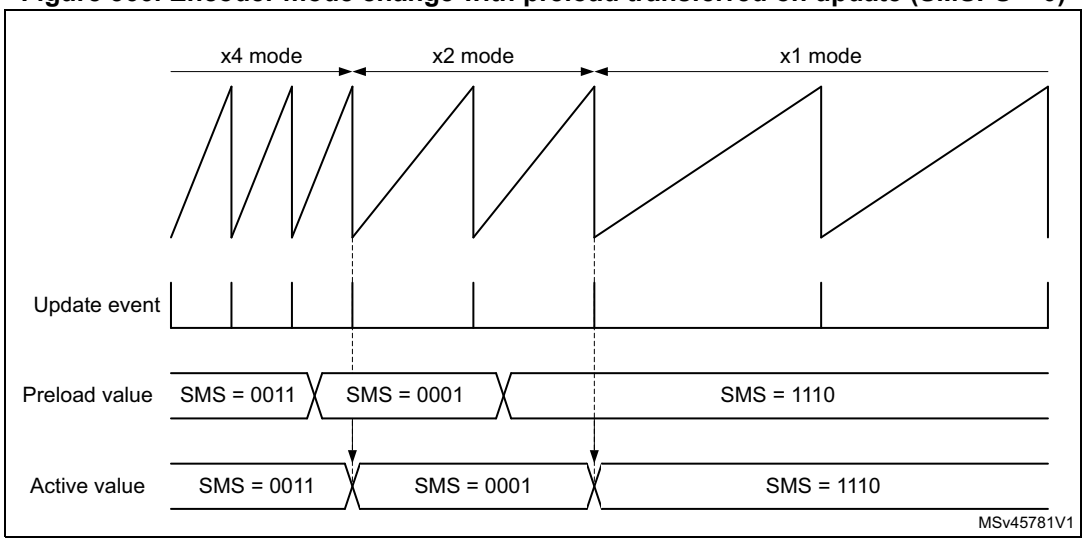
Slave mode selection preload for run-time encoder mode update

It may be necessary to switch from one encoder mode to another during run-time. This is typically done at high-speed to decrease the update interrupt rate, by switching from x4 to x2 to x1 mode, as shown on *Figure 566*.

For this purpose, the SMS[3:0] bit can be preloaded. This is enabled by setting the SMSPE enable bit in the TIMx_SMCR register. The trigger for the transfer from SMS[3:0] preload to active value can be selected with the SMSPS bit in the TIMx_SMCR register.

- SMSPS = 0: the transfer is triggered by the update event (UEV) occurring when the counter overflows when upcounting, and underflows when downcounting.
- SMSPS = 1: the transfer is triggered by the index event.

Figure 566. Encoder mode change with preload transferred on update (SMSPS = 0)



Encoder clock output

The encoder mode operating principle is not perfectly suited for high-resolution velocity measurements, at low speed, as it requires a relatively long integration time to have a sufficient number of clock edges and a precise measurement.

At low speed, a better solution is to do an edge-to-edge clock period measurement. This can be achieved using a slave timer. The timer can output the encoder clock information on the tim_trgo output. The slave timer can then perform a period measurement and provide velocity information for each and every encoder clock edge.

This mode is enabled by setting the MMS[3:0] bitfield to 1000, in the TIMx_CR2 register.It is valid for the following SMS[3:0] values: 0001, 0010, 0011, 1010, 1011, 1100, 1101, 1110, 1111. Any other SMS[3:0] code is not allowed and may lead to unexpected behavior.

49.3.26 Direction bit output

Its is possible to output a direction signal out of the timer, on the tim_oc3n and tim_oc4 output signals (copy of the DIR bit in the TIMx_CR1 register). This is achieved by setting the OC3M[3:0] or the OC4M[3:0] bitfield to 1011 in the TIMx_CCMR2 register.

This feature can be used for monitoring the counting direction (or rotation direction) in encoder mode, or to have a signal indicating the up/down phases in center-aligned PWM mode.

49.3.27 UIF bit remapping

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the update interrupt flag UIF into the timer counter register's bit 31 (TIMxCNT[31]). This allows both the counter value and a potential roll-over condition signaled by the UIFCPY flag to be read in an atomic way. In particular cases, it can ease the calculations by avoiding race conditions, caused for instance by a processing shared between a background task (counter reading) and an interrupt (update interrupt).

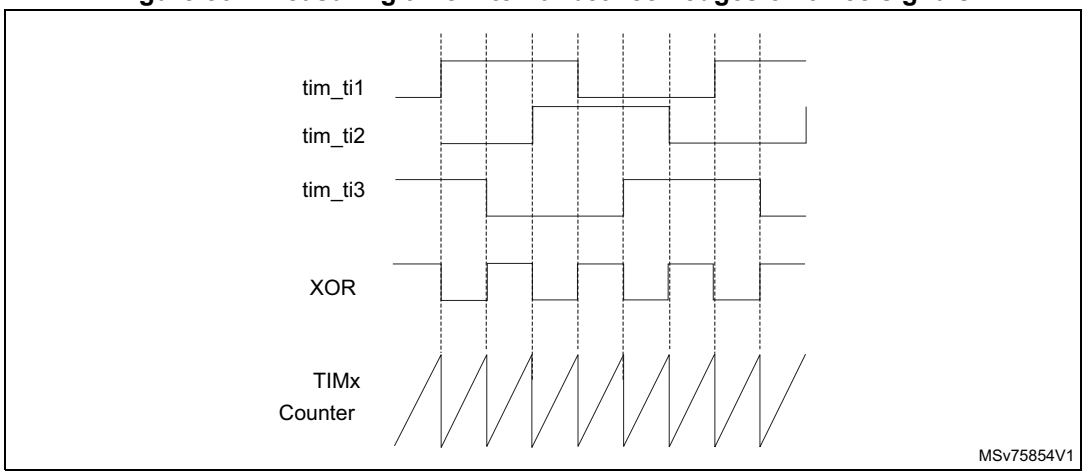
There is no latency between the UIF and UIFCPY flags assertion.

49.3.28 Timer input XOR function

The TI1S bit in the TIMx_CR2 register, allows the input filter of channel 1 to be connected to the output of an XOR gate, combining the three input pins tim_ti1, tim_ti2 and tim_ti3.

The XOR output can be used with all the timer input functions such as trigger or input capture. It is convenient to measure the interval between edges on two input signals, as per *Figure 567*.

Figure 567. Measuring time interval between edges on three signals



49.3.29 Interfacing with Hall sensors

This is done using the advanced-control timers to generate PWM signals to drive the motor and another timer TIMx referred to as "interfacing timer" in *Figure 568*. The "interfacing timer" captures the three timer input pins (tim_ti1, tim_ti2 and tim_ti3) connected through a XOR to the tim_ti1 input channel (selected by setting the TI1S bit in the TIMx_CR2 register).

The slave mode controller is configured in reset mode; the slave input is tim_ti1f_ed. Thus, each time one of the three inputs toggles, the counter restarts counting from 0. This creates a time base triggered by any change on the Hall inputs.

On the "interfacing timer", capture/compare channel 1 is configured in capture mode, capture signal is tim_trc (See *Figure 510*). The captured value, which corresponds to the time elapsed between two changes on the inputs, gives information about motor speed.

The “interfacing timer” can be used in output mode to generate a pulse which changes the configuration of the channels of the advanced-control timer (by triggering a COM event). The advanced-control timer is used to generate PWM signals to drive the motor. To do this, the interfacing timer channel must be programmed so that a positive pulse is generated after a programmed delay (in output compare or PWM mode). This pulse is sent to the advanced-control timer through the tim_trgo output.

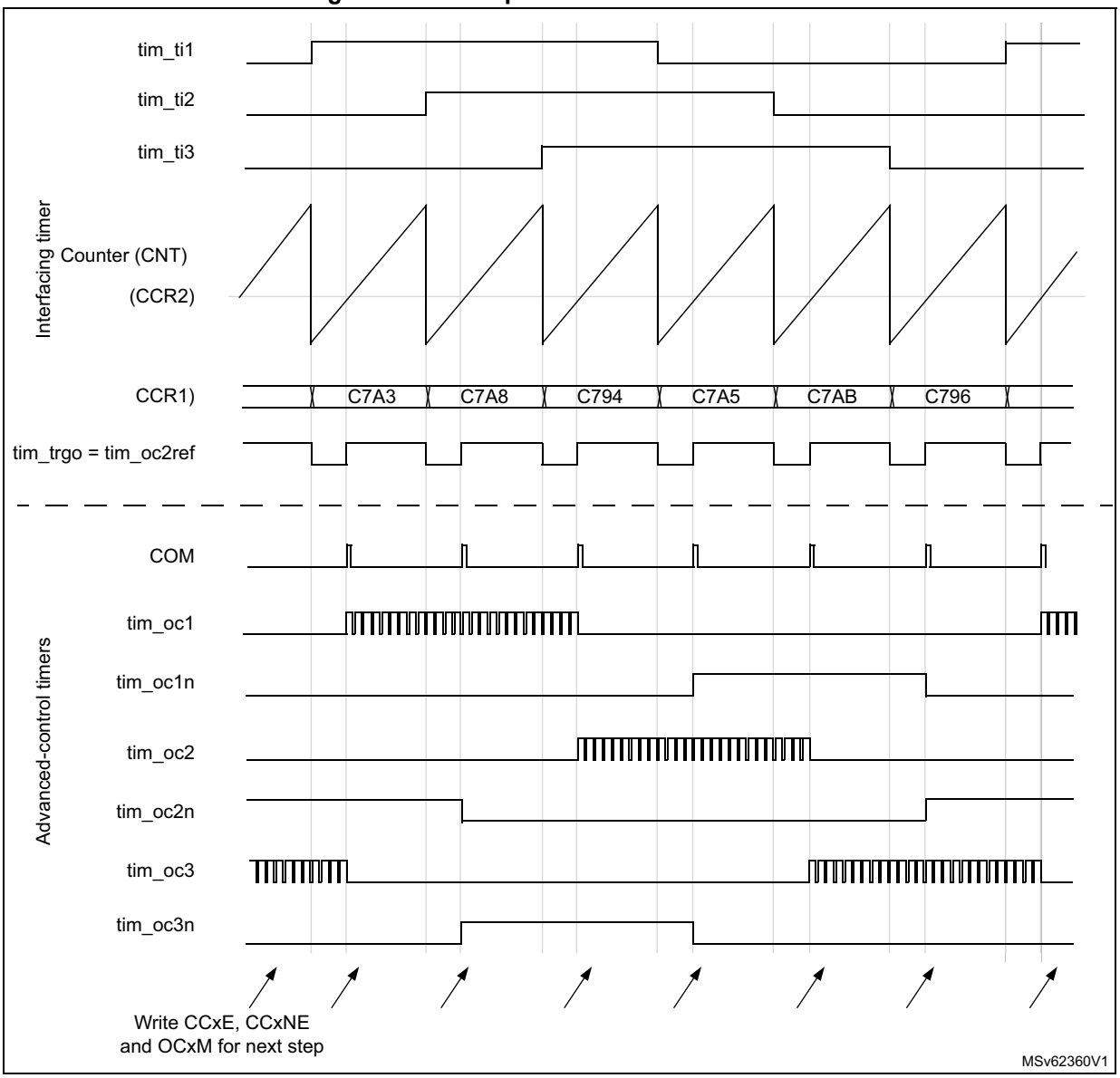
In this example the user wants to change the PWM configuration of the advanced-control timer after a programmed delay each time a change occurs on the Hall inputs connected to one of the TIMx timers.

- Configure three timer inputs ORed to the tim_ti1 input channel by writing the TI1S bit in the TIMx_CR2 register to 1.
- Program the time base: write the TIMx_ARR to the max value (the counter must be cleared by the tim_ti1 change. Set the prescaler to get a maximum counter period longer than the time between two changes on the sensors.
- Program the channel 1 in capture mode (tim_trc selected): write the CC1S bits in the TIMx_CCMR1 register to 01. The digital filter can also be programmed if needed.
- Program the channel 2 in PWM 2 mode with the desired delay: write the OC2M bits to 111 and the CC2S bits to 00 in the TIMx_CCMR1 register.
- Select tim_oc2ref as trigger output on tim_trgo: write the MMS bits in the TIMx_CR2 register to 101.

In the advanced-control timer, the right tim_itrx input must be selected as trigger input, the timer is programmed to generate PWM signals, the capture/compare control signals are preloaded (CCPC = 1 in the TIMx_CR2 register) and the COM event is controlled by the trigger input (CCUS = 1 in the TIMx_CR2 register). The PWM control bits (CCxE, OCxM) are written after a COM event for the next step (this can be done in an interrupt subroutine generated by the rising edge of tim_oc2ref).

Figure 568 describes this example.

Figure 568. Example of Hall sensor interface



49.3.30 Timer synchronization

The TIMx timers are linked together internally for timer synchronization or chaining. Refer to *Section 50.4.23: Timer synchronization* for details. They can be synchronized in several modes: Reset mode, Gated mode, Trigger mode, Reset + trigger, and gated + reset modes.

Slave mode: Reset mode

The counter and its prescaler can be reinitialized in response to an event on a trigger input. Moreover, if the URS bit from the TIMx_CR1 register is low, an update event UEV is generated. Then all the preloaded registers (TIMx_ARR, TIMx_CCRx) are updated.

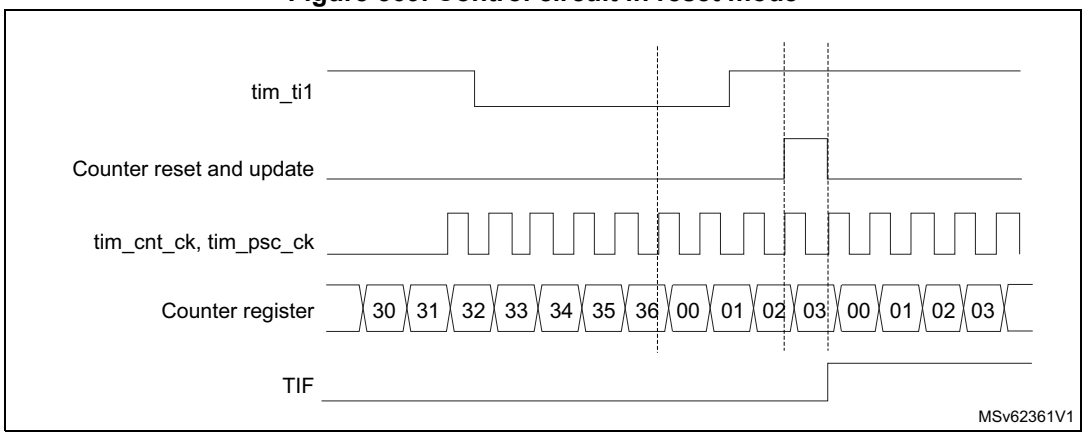
In the following example, the upcounter is cleared in response to a rising edge on tim_ti1 input:

- Configure the channel 1 to detect rising edges on tim_ti1. Configure the input filter duration (in this example, we do not need any filter, so we keep IC1F = 0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S = 01 in the TIMx_CCMR1 register. Write CC1P = 0 and CC1NP = 0 in TIMx_CCER register to validate the polarity (and detect rising edges only).
- Configure the timer in reset mode by writing SMS = 100 in TIMx_SMCR register. Select tim_ti1 as the input source by writing TS = 00101 in TIMx_SMCR register.
- Start the counter by writing CEN = 1 in the TIMx_CR1 register.

The counter starts counting on the internal clock, then behaves normally until tim_ti1 rising edge. When tim_ti1 rises, the counter is cleared and restarts from 0. In the meantime, the trigger flag is set (TIF bit in the TIMx_SR register) and an interrupt request, or a DMA request can be sent if enabled (depending on the TIE and TDE bits in TIMx_DIER register).

The following figure shows this behavior when the autoreload register TIMx_ARR = 0x36. The delay between the rising edge on tim_ti1 and the actual reset of the counter is due to the resynchronization circuit on tim_ti1 input.

Figure 569. Control circuit in reset mode



Slave mode: Gated mode

The counter can be enabled depending on the level of a selected input.

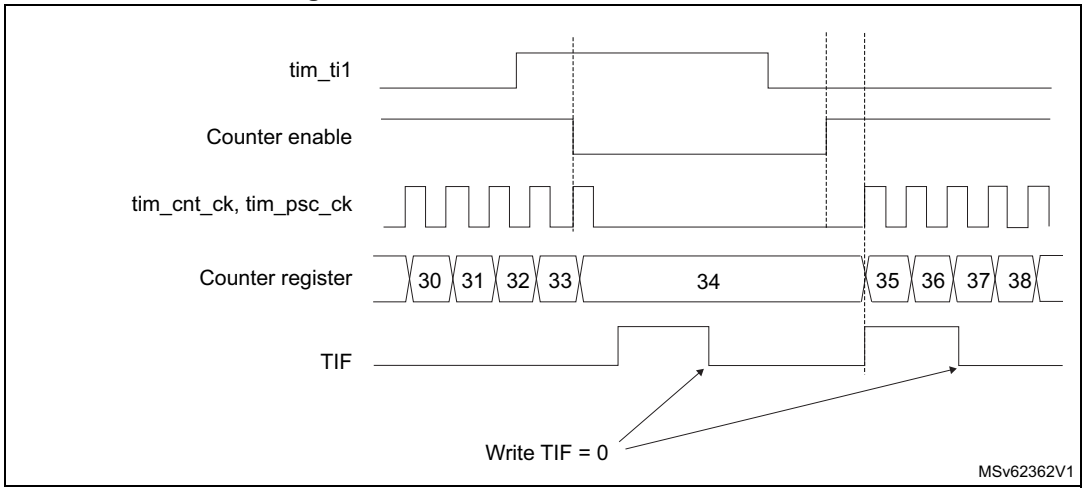
In the following example, the upcounter counts only when tim_ti1 input is low:

- Configure the channel 1 to detect low levels on tim_ti1. Configure the input filter duration (in this example, we do not need any filter, so we keep IC1F = 0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S = 01 in TIMx_CCMR1 register. Write CC1P = 1 and CC1NP = 0 in TIMx_CCER register to validate the polarity (and detect low level only).
- Configure the timer in gated mode by writing SMS = 101 in TIMx_SMCR register. Select tim_ti1 as the input source by writing TS = 00101 in TIMx_SMCR register.
- Enable the counter by writing CEN = 1 in the TIMx_CR1 register (in gated mode, the counter does not start if CEN = 0, whatever is the trigger input level).

The counter starts counting on the internal clock as long as tim_ti1 is low and stops as soon as tim_ti1 becomes high. The TIF flag in the TIMx_SR register is set both when the counter starts or stops.

The delay between the rising edge on tim_ti1 and the actual stop of the counter is due to the resynchronization circuit on tim_ti1 input.

Figure 570. Control circuit in Gated mode



Slave mode: Trigger mode

The counter can start in response to an event on a selected input.

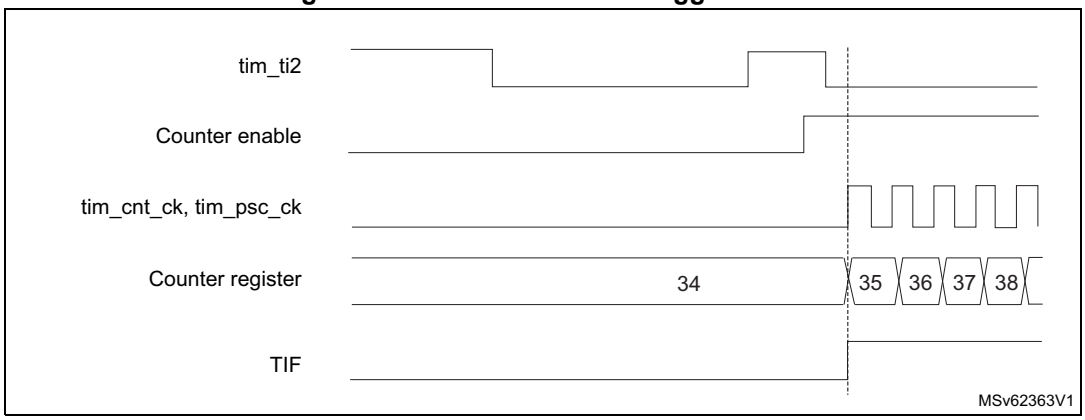
In the following example, the upcounter starts in response to a rising edge on tim_ti2 input:

- Configure the channel 2 to detect rising edges on tim_ti2. Configure the input filter duration (in this example, we do not need any filter, so we keep IC2F = 0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC2S bits are configured to select the input capture source only, CC2S = 01 in TIMx_CCMR1 register. Write CC2P = 1 and CC2NP = 0 in TIMx_CCER register to validate the polarity (and detect low level only).
- Configure the timer in trigger mode by writing SMS = 110 in TIMx_SMCR register. Select tim_ti2 as the input source by writing TS = 00110 in TIMx_SMCR register.

When a rising edge occurs on tim_ti2, the counter starts counting on the internal clock and the TIF flag is set.

The delay between the rising edge on tim_ti2 and the actual start of the counter is due to the resynchronization circuit on tim_ti2 input.

Figure 571. Control circuit in trigger mode



Slave mode: Combined reset + trigger mode

In this case, a rising edge of the selected trigger input (tim_trgi) reinitializes the counter, generates an update of the registers, and starts the counter.

This mode is used for One-pulse mode.

Slave mode: Combined gated + reset mode

The counter clock is enabled when the trigger input (tim_trgi) is high. The counter stops and is reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

This mode is used to detect out-of-range PWM signal (duty cycle exceeding a maximum expected value).

Slave mode: external clock mode 2 + trigger mode

The external clock mode 2 can be used in addition to another slave mode (except external clock mode 1 and encoder mode). In this case, the tim_etr_in signal is used as external clock input, and another input can be selected as trigger input (in reset mode, gated mode or trigger mode). It is recommended not to select tim_etr_in as tim_trgi through the TS bits of TIMx_SMCR register.

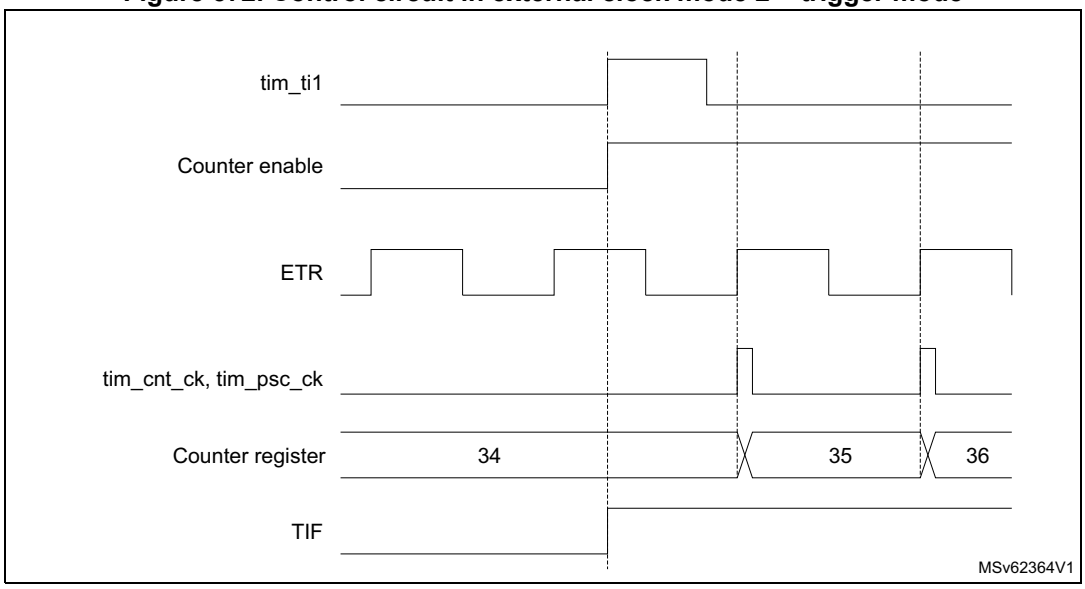
In the following example, the upcounter is incremented at each rising edge of the tim_etr_in signal as soon as a rising edge of tim_ti1 occurs:

1. Configure the external trigger input circuit by programming the TIMx_SMCR register as follows:
   - ETF = 0000: no filter
   - ETPS = 00: prescaler disabled
   - ETP = 0: detection of rising edges on tim_etr_in and ECE = 1 to enable the external clock mode 2.
2. Configure the channel 1 as follows, to detect rising edges on TI:
   - IC1F = 0000: no filter.
   - The capture prescaler is not used for triggering and does not need to be configured.
   - CC1S = 01in TIMx_CCMR1 register to select only the input capture source
   - CC1P = 0 and CC1NP = 0 in TIMx_CCER register to validate the polarity (and detect rising edge only).
3. Configure the timer in trigger mode by writing SMS = 110 in TIMx_SMCR register. Select tim_ti1 as the input source by writing TS = 00101 in TIMx_SMCR register.

A rising edge on tim_ti1 enables the counter and sets the TIF flag. The counter then counts on tim_etr_in rising edges.

The delay between the rising edge of the tim_etr_in signal and the actual reset of the counter is due to the resynchronization circuit on tim_etrp input.

Figure 572. Control circuit in external clock mode 2 + trigger mode



Note: The clock of the slave peripherals (such as timer, ADC) receiving the tim_trgo or the tim_trgo2 signals must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

49.3.31 ADC triggers

The timer can generate an ADC triggering event with various internal signals, such as reset, enable or compare events. It is also possible to generate a pulse issued by internal edge detectors, such as:

- Rising and falling edges of OC4ref
- Rising edge on OC5ref or falling edge on OC6ref

The triggers are issued on the tim_trgo2 internal line which is redirected to the ADC. There is a total of 16 possible events, which can be selected using the MMS2[3:0] bits in the TIMx_CR2 register.

An example of an application for 3-phase motor drives is given in *Figure 525*.

Note: The clock of the slave peripherals (timer, ADC, ...) receiving the tim_trgo or the tim_trgo2 signals must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

The clock of the ADC must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the timer.

49.3.32 DMA burst mode

The TIMx timers have the capability to generate multiple DMA requests upon a single event. The main purpose is to be able to reprogram part of the timer multiple times without software overhead, but it can also be used to read several registers in a row, at regular intervals.

The DMA controller destination is unique and must point to the virtual register TIMx_DMAR. On a given timer event, the timer launches a sequence of DMA requests (burst). Each write into the TIMx_DMAR register is actually redirected to one of the timer registers.

The DBL[4:0] bits in the TIMx_DCR register set the DMA burst length. The timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address), i.e. the number of transfers (either in half-words or in bytes).

The DBA[4:0] bits in the TIMx_DCR register define the DMA base address for DMA transfers (when read/write access are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register:

Example:

00000: TIMx_CR1

00001: TIMx_CR2

00010: TIMx_SMCR

The DBSS[3:0] bits in the TIMx_DCR register defines the interrupt source that triggers the DMA burst transfers (see *Section 49.6.29: TIMx DMA control register (TIMx_DCR)(x = 1, 8)* for details).

As an example, the timer DMA burst feature is used to update the contents of the CCRx registers (x = 2, 3, 4) upon an update event, with the DMA transferring half words into the CCRx registers.

This is done in the following steps:

1. Configure the corresponding DMA channel as follows:
   – DMA channel peripheral address is the DMAR register address.
   – DMA channel memory address is the address of the buffer in the RAM containing the data to be transferred by DMA into CCRx registers.
   – Number of data to transfer = 3 (see note below).
   – Circular mode disabled.
2. Configure the DCR register by configuring the DBA and DBL bitfields as follows: DBL = 3 transfers, DBA = 0xE and DBSS = 1.
3. Enable the TIMx update DMA request (set the UDE bit in the DIER register).
4. Enable TIMx.
5. Enable the DMA channel.

This example is for the case where every CCRx register to be updated once. If every CCRx register is to be updated twice for example, the number of data to transfer must be 6. Let's take the example of a buffer in the RAM containing data1, data2, data3, data4, data5, and data6. The data is transferred to the CCRx registers as follows: on the first update DMA request, data1 is transferred to CCR2, data2 is transferred to CCR3, data3 is transferred to CCR4 and on the second update DMA request, data4 is transferred to CCR2, data5 is transferred to CCR3, and data6 is transferred to CCR4.

Note: A null value can be written to the reserved registers.

49.3.33 TIM1/TIM8 DMA requests

The TIM1/TIM8 can generate a DMA request, as shown in the table below.

Table 527. DMA request

DMA request signal	DMA request	Enable control bit
tim_upd_dma	Update	UDE
tim_cc1_dma	Capture/compare 1	CC1DE
tim_cc2_dma	Capture/compare 2	CC2DE
tim_cc3_dma	Capture/compare 3	CC3DE
tim_cc4_dma	Capture/compare 4	CC4DE
tim_com_dma	Commutation (COM)	COMDE
tim_trgi_dma	Trigger	TDE

49.3.34 Debug mode

When the microcontroller enters debug mode (Cortex®-M33 core halted), the TIMx counter can either continue to work normally or stop, depending on DBG_TIMx_STOP configuration bit in DBG module.

The behavior in debug mode can be programmed with a dedicated configuration bit per timer in the Debug support (DBG) module.

For safety purposes, when the counter is stopped, the outputs are disabled (as if the MOE bit was reset). The outputs can either be forced to an inactive state (OSSI bit = 1), or have their control taken over by the GPIO controller (OSSI bit = 0), typically to force a Hi-Z.

For more details, refer to section Debug support (DBG).

49.4 TIM1/TIM8 low-power modes

Table 528. Effect of low-power modes on TIM1/TIM8

Mode	Description
Sleep	No effect, peripheral is active. The interrupts can cause the device to exit from Sleep mode.
Stop	The timer operation is stopped and the register content is kept. No interrupt can be generated.
Standby	The timer is powered-down and must be reinitialized after exiting the Standby mode.

49.5 TIM1/TIM8 interrupts

The TIM1/TIM8 can generate multiple interrupts, as shown in *Table 529*.

Table 529. Interrupt requests

Interrupt acronym		Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop and Standby mode
TIM_UPD		Update	UIF	UIE	write 0 in UIF	Yes	No
TIM_CC		Capture/compare 1	CC1IF	CC1IE	write 0 in CC1IF	Yes	No
		Capture/compare 2	CC2IF	CC2IE	write 0 in CC2IF	Yes	No
		Capture/compare 3	CC3IF	CC3IE	write 0 in CC3IF	Yes	No
		Capture/compare 4	CC4IF	CC4IE	write 0 in CC4IF	Yes	No
TIM_TRGI_COM_DIR_IDX	TIM_COM	Commutation (COM)	COMIF	COMIE	write 0 in COMIF	Yes	No
	TIM_TRGI	Trigger	TIF	TIE	write 0 in TIF	Yes	No
	TIM_IDX	Index	IDXF	IDXIE	write 0 in IDXF	Yes	No
	TIM_DIR	Direction	DIRF	DIRIE	write 0 in DIRF	Yes	No
TIM_BRK_TERR_IERR	TIM_BRK	Break	BIF	BIE	write 0 in BIF	Yes	No
		Break2	B2IF		write 0 in B2IF	Yes	No
		System Break	SBIF		write 0 in SBIF	Yes	No
	TIM_IERR	Index Error	IERRF	IERRIE	write 0 in IERRF	Yes	No
	TIM_TERR	Transition Error	TERRF	TERRIE	write 0 in TERRF	Yes	No

49.6 TIM1/TIM8 registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by half-words (16-bit) or words (32-bit).

49.6.1 TIMx control register 1 (TIMx_CR1)(x = 1, 8)

Address offset: 0x000

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DITHEN	UIFREMAP	Res.	CKD[1:0]		ARPE	CMS[1:0]		DIR	OPM	URS	UDIS	CEN
			rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **DITHEN**: Dithering enable

0: Dithering disabled
1: Dithering enabled

Note: The DITHEN bit can only be modified when CEN bit is reset.

Bit 11 **UIFREMAP**: UIF status bit remapping

0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bit 10 Reserved, must be kept at reset value.

Bits 9:8 **CKD[1:0]**: Clock division

This bitfield indicates the division ratio between the timer clock (tim_ker_ck) frequency and the dead-time and sampling clock (t_{DTS})used by the dead-time generators and the digital filters (tim_etr_in, tim_tix),

00: $t_{DTS} = t_{tim_ker_ck}$
01: $t_{DTS} = 2*t_{tim_ker_ck}$
10: $t_{DTS} = 4*t_{tim_ker_ck}$
11: Reserved, do not program this value

Bit 7 **ARPE**: Autoreload preload enable

0: TIMx_ARR register is not buffered
1: TIMx_ARR register is buffered

Bits 6:5 **CMS[1:0]**: Center-aligned mode selection

00: Edge-aligned mode. The counter counts up or down depending on the direction bit (DIR).
01: Center-aligned mode 1. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS = 00 in TIMx_CCMRx register) are set only when the counter is counting down.
10: Center-aligned mode 2. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS = 00 in TIMx_CCMRx register) are set only when the counter is counting up.
11: Center-aligned mode 3. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS = 00 in TIMx_CCMRx register) are set both when the counter is counting up or down.

Note: It is not allowed to switch from edge-aligned mode to center-aligned mode as long as the counter is enabled (CEN = 1)

Bit 4 **DIR**: Direction
0: Counter used as upcounter
1: Counter used as downcounter
Note: This bit is read only when the timer is configured in Center-aligned mode or Encoder mode.

Bit 3 **OPM**: One-pulse mode
0: Counter is not stopped at update event
1: Counter stops counting at the next update event (clearing the bit CEN)

Bit 2 **URS**: Update request source
This bit is set and cleared by software to select the UEV event sources.
0: Any of the following events generate an update interrupt or DMA request if enabled. These events can be:
– Counter overflow/underflow
– Setting the UG bit
– Update generation through the slave mode controller
1: Only counter overflow/underflow generates an update interrupt or DMA request if enabled.

Bit 1 **UDIS**: Update disable
This bit is set and cleared by software to enable/disable UEV event generation.
0: UEV enabled. The Update (UEV) event is generated by one of the following events:
– Counter overflow/underflow
– Setting the UG bit
– Update generation through the slave mode controller
Buffered registers are then loaded with their preload values.
1: UEV disabled. The Update event is not generated, shadow registers keep their value (ARR, PSC, CCRx). However the counter and the prescaler are reinitialized if the UG bit is set or if a hardware reset is received from the slave mode controller.

Bit 0 **CEN**: Counter enable
0: Counter disabled
1: Counter enabled
Note: External clock, gated mode and encoder mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

49.6.2 TIMx control register 2 (TIMx_CR2)(x = 1, 8)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	MMS[3]	Res.	MMS2[3:0]				Res.	OIS6	Res.	OIS5
						rw		rw	rw	rw	rw		rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OIS4N	OIS4	OIS3N	OIS3	OIS2N	OIS2	OIS1N	OIS1	TI1S	MMS[2:0]			CCDS	CCUS	Res.	CCPC
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 24 Reserved, must be kept at reset value.

Bits 23:20 **MMS2[3:0]**: Master mode selection 2

These bits allow the information to be sent to ADC for synchronization (tim_trgo2) to be selected. The combination is as follows:

0000: **Reset** - the UG bit from the TIMx_EGR register is used as trigger output (tim_trgo2). If the reset is generated by the trigger input (slave mode controller configured in reset mode), the signal on tim_trgo2 is delayed compared to the actual reset.

0001: **Enable** - the Counter Enable signal CNT_EN is used as trigger output (tim_trgo2). It is useful to start several timers at the same time or to control a window in which a slave timer is enabled. The Counter Enable signal is generated by a logic AND between the CEN control bit and the trigger input when configured in Gated mode. When the Counter Enable signal is controlled by the trigger input, there is a delay on tim_trgo2, except if the Master/Slave mode is selected (see the MSM bit description in TIMx_SMCR register).

0010: **Update** - the update event is selected as trigger output (tim_trgo2). For instance, a master timer can then be used as a prescaler for a slave timer.

0011: **Compare pulse** - the trigger output sends a positive pulse when the CC1IF flag is to be set (even if it was already high), as soon as a capture or compare match occurs (tim_trgo2).

0100: **Compare** - tim_oc1refc signal is used as trigger output (tim_trgo2)

0101: **Compare** - tim_oc2refc signal is used as trigger output (tim_trgo2)

0110: **Compare** - tim_oc3refc signal is used as trigger output (tim_trgo2)

0111: **Compare** - tim_oc4refc signal is used as trigger output (tim_trgo2)

1000: **Compare** - tim_oc5refc signal is used as trigger output (tim_trgo2)

1001: **Compare** - tim_oc6refc signal is used as trigger output (tim_trgo2)

1010: **Compare Pulse** - tim_oc4refc rising or falling edges generate pulses on tim_trgo2

1011: **Compare pulse** - tim_oc6refc rising or falling edges generate pulses on tim_trgo2

1100: **Compare pulse** - tim_oc4refc or tim_oc6refc rising edges generate pulses on tim_trgo2

1101: **Compare pulse** - tim_oc4refc rising or tim_oc6refc falling edges generate pulses on tim_trgo2

1110: **Compare pulse** - tim_oc5refc or tim_oc6refc rising edges generate pulses on tim_trgo2

1111: **Compare pulse** - tim_oc5refc rising or tim_oc6refc falling edges generate pulses on tim_trgo2

Note: The clock of the slave timer or ADC must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the master timer.

Bit 19 Reserved, must be kept at reset value.

Bit 18 **OIS6**: Output idle state 6 (tim_oc6 output)
Refer to OIS1 bit

Bit 17 Reserved, must be kept at reset value.

Bit 16 **OIS5**: Output idle state 5 (tim_oc5 output)
Refer to OIS1 bit

Bit 15 **OIS4N**: Output idle state 4 (tim_oc4n output)
Refer to OIS1N bit

Bit 14 **OIS4**: Output idle state 4 (tim_oc4 output)
Refer to OIS1 bit

Bit 13 **OIS3N**: Output idle state 3 (tim_oc3n output)
Refer to OIS1N bit

Bit 12 **OIS3**: Output idle state 3 (tim_oc3n output)
Refer to OIS1 bit

Bit 11 **OIS2N**: Output idle state 2 (tim_oc2n output)
Refer to OIS1N bit

Bit 10 **OIS2**: Output idle state 2 (tim_oc2 output)
Refer to OIS1 bit

Bit 9 **OIS1N**: Output idle state 1 (tim_oc1n output)
0: tim_oc1n = 0 after a dead-time when MOE = 0
1: tim_oc1n = 1 after a dead-time when MOE = 0
Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **OIS1**: Output idle state 1 (tim_oc1 output)
0: tim_oc1 = 0 (after a dead-time) when MOE = 0
1: tim_oc1 = 1 (after a dead-time) when MOE = 0
Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 7 **TI1S**: tim_ti1 selection
0: The tim_ti1_in[15:0] multiplexer output is connected to tim_ti1 input
1: tim_ti1_in[15:0], tim_ti2_in[15:0] and tim_ti3_in[15:0] multiplexers outputs are XORed and connected to the tim_ti1 input

Bits 25, 6:4 **MMS[3:0]**: Master mode selection

These bits select the information to be sent in master mode to slave timers for synchronization (tim_trgo). The combination is as follows:

0000: **Reset** - the UG bit from the TIMx_EGR register is used as trigger output (tim_trgo). If the reset is generated by the trigger input (slave mode controller configured in reset mode) then the signal on tim_trgo is delayed compared to the actual reset.

0001: **Enable** - the Counter Enable signal CNT_EN is used as trigger output (tim_trgo). It is useful to start several timers at the same time or to control a window in which a slave timer is enable. The Counter Enable signal is generated by a logic AND between CEN control bit and the trigger input when configured in gated mode. When the Counter Enable signal is controlled by the trigger input, there is a delay on tim_trgo, except if the master/slave mode is selected (see the MSM bit description in TIMx_SMCR register).

0010: **Update** - The update event is selected as trigger output (tim_trgo). For instance a master timer can then be used as a prescaler for a slave timer.

0011: **Compare Pulse** - The trigger output send a positive pulse when the CC1IF flag is to be set (even if it was already high), as soon as a capture or a compare match occurred. (tim_trgo).

0100: **Compare** - tim_oc1refc signal is used as trigger output (tim_trgo)

0101: **Compare** - tim_oc2refc signal is used as trigger output (tim_trgo)

0110: **Compare** - tim_oc3refc signal is used as trigger output (tim_trgo)

0111: **Compare** - tim_oc4refc signal is used as trigger output (tim_trgo)

1000: **Encoder Clock output** - The encoder clock signal is used as trigger output (tim_trgo). This code is valid for the following SMS[3:0] values: 0001, 0010, 0011, 1010, 1011, 1100, 1101, 1110, 1111. Any other SMS[3:0] code is not allowed and may lead to unexpected behavior.

Other codes reserved

Note: The clock of the slave timer or ADC must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the master timer.

Bit 3 **CCDS**: Capture/compare DMA selection

0: CCx DMA request sent when CCx event occurs

1: CCx DMA requests sent when update event occurs

Bit 2 **CCUS**: Capture/compare control update selection

0: When capture/compare control bits are preloaded (CCPC = 1), they are updated by setting the COMG bit only

1: When capture/compare control bits are preloaded (CCPC = 1), they are updated by setting the COMG bit or when an rising edge occurs on tim_trgi

Note: This bit acts only on channels that have a complementary output.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **CCPC**: Capture/compare preloaded control

0: CCxE, CCxNE and OCxM bits are not preloaded

1: CCxE, CCxNE and OCxM bits are preloaded, after having been written, they are updated only when a commutation event (COM) occurs (COMG bit set or rising edge detected on tim_trgi, depending on the CCUS bit).

Note: This bit acts only on channels that have a complementary output.

49.6.3 TIMx slave mode control register (TIMx_SMCR)(x = 1, 8)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	SMSPS	SMSPE	Res.	Res.	TS[4:3]		Res.	Res.	Res.	SMS[3]
						rw	rw			rw	rw				rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETP	ECE	ETPS[1:0]		ETF[3:0]				MSM	TS[2:0]			OCCS	SMS[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **SMSPS**: SMS preload source

This bit selects whether the events that triggers the SMS[3:0] bitfield transfer from preload to active

0: The transfer is triggered by the Timer's Update event

1: The transfer is triggered by the Index event

Bit 24 **SMSPE**: SMS preload enable

This bit selects whether the SMS[3:0] bitfield is preloaded

0: SMS[3:0] bitfield is not preloaded

1: SMS[3:0] preload is enabled

Bits 23:22 Reserved, must be kept at reset value.

Bits 21:20 **TS[4:3]**: Trigger selection - bit 4:3

Refer to TS[2:0] description - bits 6:4

Bits 19:17 Reserved, must be kept at reset value.

Bit 15 **ETP**: External trigger polarity

This bit selects whether tim_etr_in or tim_$\overline{\text{etr_in}}$ is used for trigger operations

0: tim_etr_in is non-inverted, active at high level or rising edge.

1: tim_etr_in is inverted, active at low level or falling edge.

Bit 14 **ECE**: External clock enable

This bit enables External clock mode 2.

0: External clock mode 2 disabled

1: External clock mode 2 enabled. The counter is clocked by any active edge on the tim_etrf signal.

Note: Setting the ECE bit has the same effect as selecting external clock mode 1 with tim_trgi connected to tim_etrf (SMS = 111 and TS = 00111).

It is possible to simultaneously use external clock mode 2 with the following slave modes: reset mode, gated mode and trigger mode. Nevertheless, tim_trgi must not be connected to tim_etrf in this case (TS bits must not be 00111).

If external clock mode 1 and external clock mode 2 are enabled at the same time, the external clock input is tim_etrf.

Bits 13:12 **ETPS[1:0]**: External trigger prescaler

External trigger signal tim_etrp frequency must be at most 1/4 of TIMxCLK frequency. A prescaler can be enabled to reduce tim_etrp frequency. It is useful when inputting fast external clocks on tim_etr_in.

00: Prescaler OFF
01: tim_etr_in frequency divided by 2
10: tim_etr_in frequency divided by 4
11: tim_etr_in frequency divided by 8

Bits 11:8 **ETF[3:0]**: External trigger filter

This bitfield then defines the frequency used to sample tim_etrp signal and the length of the digital filter applied to tim_etrp. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}
0001: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 2
0010: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 4
0011: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 8
0100: $f_{SAMPLING} = f_{DTS}/2$, N = 6
0101: $f_{SAMPLING} = f_{DTS}/2$, N = 8
0110: $f_{SAMPLING} = f_{DTS}/4$, N = 6
0111: $f_{SAMPLING} = f_{DTS}/4$, N = 8
1000: $f_{SAMPLING} = f_{DTS}/8$, N = 6
1001: $f_{SAMPLING} = f_{DTS}/8$, N = 8
1010: $f_{SAMPLING} = f_{DTS}/16$, N = 5
1011: $f_{SAMPLING} = f_{DTS}/16$, N = 6
1100: $f_{SAMPLING} = f_{DTS}/16$, N = 8
1101: $f_{SAMPLING} = f_{DTS}/32$, N = 5
1110: $f_{SAMPLING} = f_{DTS}/32$, N = 6
1111: $f_{SAMPLING} = f_{DTS}/32$, N = 8

Bit 7 **MSM:** Master/slave mode

0: No action
1: The effect of an event on the trigger input (tim_trgi) is delayed to allow a perfect synchronization between the current timer and its slaves (through tim_trgo). It is useful if we want to synchronize several timers on a single external event.

Bits 6:4 **TS[2:0]:** Trigger selection

This bitfield is combined with TS[4:3] bits.

This bitfield selects the trigger input to be used to synchronize the counter.

00000: Internal Trigger 0 (tim_itr0)
00001: Internal Trigger 1 (tim_itr1)
00010: Internal Trigger 2 (tim_itr2)
00011: Internal Trigger 3 (tim_itr3)
00100: tim_ti1 Edge Detector (tim_ti1f_ed)
00101: Filtered Timer Input 1 (tim_ti1fp1)
00110: Filtered Timer Input 2 (tim_ti2fp2)
00111: External Trigger input (tim_etrf)
01000: Internal Trigger 4 (tim_itr4)
01001: Internal Trigger 5 (tim_itr5)
01010: Internal Trigger 6 (tim_itr6)
01011: Internal Trigger 7 (tim_itr7)
01100: Internal Trigger 8 (tim_itr8)
01101: Internal Trigger 9 (tim_itr9)
01110: Internal Trigger 10 (tim_itr10)
01111: Internal trigger 11 (tim_itr11)
10000: Internal trigger 12 (tim_itr12)
10001: Internal trigger 13 (tim_itr13)
10010: Internal trigger 14 (tim_itr14)
10011: Internal trigger 15 (tim_itr15)
Others: Reserved

See *Table 515: Internal trigger connection* for more details on tim_itrx meaning for each Timer.

Note: These bits must be changed only when they are not used (for example when SMS = 000) to avoid wrong edge detections at the transition.

Bit 3 **OCCS:** OCREF clear selection

This bit is used to select the OCREF clear source.

0: tim_ocref_clr_int is connected to the tim_ocref_clr input
1: tim_ocref_clr_int is connected to tim_etrf

Bits 16, 2:0 **SMS[3:0]:** Slave mode selection

When external signals are selected the active edge of the trigger signal (tim_trgi) is linked to the polarity selected on the external input (refer to ETP bit in TIMx_SMCR for tim_etr_in and CCxP/CCxNP bits in TIMx_CCER register for tim_ti1fp1 and tim_ti2fp2).

0000: Slave mode disabled - if CEN = 1 then the prescaler is clocked directly by the internal clock.

0001: Quadrature encoder mode 1, x2 mode- Counter counts up/down on tim_ti1fp1 edge depending on tim_ti2fp2 level.

0010: Quadrature encoder mode 2, x2 mode - Counter counts up/down on tim_ti2fp2 edge depending on tim_ti1fp1 level.

0011: Quadrature encoder mode 3, x4 mode - Counter counts up/down on both tim_ti1fp1 and tim_ti2fp2 edges depending on the level of the other input.

0100: Reset mode - Rising edge of the selected trigger input (tim_trgi) reinitializes the counter and generates an update of the registers.

0101: Gated mode - The counter clock is enabled when the trigger input (tim_trgi) is high. The counter stops (but is not reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

0110: Trigger mode - The counter starts at a rising edge of the trigger tim_trgi (but it is not reset). Only the start of the counter is controlled.

0111: External Clock mode 1 - Rising edges of the selected trigger (tim_trgi) clock the counter.

1000: Combined reset + trigger mode - Rising edge of the selected trigger input (tim_trgi) reinitializes the counter, generates an update of the registers and starts the counter.

1001: Combined gated + reset mode - The counter clock is enabled when the trigger input (tim_trgi) is high. The counter stops and is reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

1010: Encoder mode: Clock plus direction, x2 mode.

1011: Encoder mode: Clock plus direction, x1 mode, tim_ti2fp2 edge sensitivity is set by CC2P

1100: Encoder mode: Directional Clock, x2 mode.

1101: Encoder mode: Directional Clock, x1 mode, tim_ti1fp1 and tim_ti2fp2 edge sensitivity is set by CC1P and CC2P.

1110: Quadrature encoder mode: x1 mode, counting on tim_ti1fp1 edges only, edge sensitivity is set by CC1P.

1111: Quadrature encoder mode: x1 mode, counting on tim_ti2fp2 edges only, edge sensitivity is set by CC2P.

Note: The gated mode must not be used if tim_ti1f_ed is selected as the trigger input (TS = 00100). Indeed, tim_ti1f_ed outputs 1 pulse for each transition on TI1F, whereas the gated mode checks the level of the trigger signal.

Note: The clock of the slave peripherals (timer, ADC, ...) receiving the tim_trgo or the tim_trgo2 signals must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

49.6.4 TIMx DMA/interrupt enable register (TIMx_DIER)(x = 1, 8)

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TERRIE	IERRIE	DIRIE	IDXIE	Res.	Res.	Res.	Res.
								rw	rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TDE	COMDE	CC4DE	CC3DE	CC2DE	CC1DE	UDE	BIE	TIE	COMIE	CC4IE	CC3IE	CC2IE	CC1IE	UIE
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **TERRIE**: Transition error interrupt enable
0: Transition error interrupt disabled
1: Transition error interrupt enabled

Bit 22 **IERRIE**: Index error interrupt enable
0: Index error interrupt disabled
1: Index error interrupt enabled

Bit 21 **DIRIE**: Direction change interrupt enable
0: Direction Change interrupt disabled
1: Direction Change interrupt enabled

Bit 20 **IDXIE**: Index interrupt enable
0: Index interrupt disabled
1: Index Change interrupt enabled

Bits 19:15 Reserved, must be kept at reset value.

Bit 14 **TDE**: Trigger DMA request enable
0: Trigger DMA request disabled
1: Trigger DMA request enabled

Bit 13 **COMDE**: COM DMA request enable
0: COM DMA request disabled
1: COM DMA request enabled

Bit 12 **CC4DE**: Capture/compare 4 DMA request enable
0: CC4 DMA request disabled
1: CC4 DMA request enabled

Bit 11 **CC3DE**: Capture/compare 3 DMA request enable
0: CC3 DMA request disabled
1: CC3 DMA request enabled

Bit 10 **CC2DE**: Capture/compare 2 DMA request enable
0: CC2 DMA request disabled
1: CC2 DMA request enabled

Bit 9 **CC1DE**: Capture/compare 1 DMA request enable
0: CC1 DMA request disabled
1: CC1 DMA request enabled

Bit 8 **UDE**: Update DMA request enable
0: Update DMA request disabled
1: Update DMA request enabled

Bit 7 **BIE**: Break interrupt enable
0: Break interrupt disabled
1: Break interrupt enabled

Bit 6 **TIE**: Trigger interrupt enable
0: Trigger interrupt disabled
1: Trigger interrupt enabled

Bit 5 **COMIE**: COM interrupt enable
0: COM interrupt disabled
1: COM interrupt enabled

Bit 4 **CC4IE**: Capture/compare 4 interrupt enable
0: CC4 interrupt disabled
1: CC4 interrupt enabled

Bit 3 **CC3IE**: Capture/compare 3 interrupt enable
0: CC3 interrupt disabled
1: CC3 interrupt enabled

Bit 2 **CC2IE**: Capture/compare 2 interrupt enable
0: CC2 interrupt disabled
1: CC2 interrupt enabled

Bit 1 **CC1IE**: Capture/compare 1 interrupt enable
0: CC1 interrupt disabled
1: CC1 interrupt enabled

Bit 0 **UIE**: Update interrupt enable
0: Update interrupt disabled
1: Update interrupt enabled

49.6.5 TIMx status register (TIMx_SR)(x = 1, 8)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TERRF	IERRF	DIRF	IDXF	Res.	Res.	CC6IF	CC5IF
								rc_w0	rc_w0	rc_w0	rc_w0			rc_w0	rc_w0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	SBIF	CC4OF	CC3OF	CC2OF	CC1OF	B2IF	BIF	TIF	COMIF	CC4IF	CC3IF	CC2IF	CC1IF	UIF
		rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **TERRF**: Transition error interrupt flag
This flag is set by hardware when a transition error is detected in encoder mode. It is cleared by software by writing it to 0.
0: No encoder transition error has been detected.
1: An encoder transition error has been detected

Bit 22 **IERRF**: Index error interrupt flag
This flag is set by hardware when an index error is detected. It is cleared by software by writing it to 0.
0: No index error has been detected.
1: An index error has been detected

Bit 21 **DIRF**: Direction change interrupt flag
This flag is set by hardware when the direction changes in encoder mode (DIR bit value in TIMx_CR is changing). It is cleared by software by writing it to 0.
0: No direction change
1: Direction change

Bit 20 **IDXF**: Index interrupt flag
This flag is set by hardware when an index event is detected. It is cleared by software by writing it to 0.
0: No index event occurred.
1: An index event has occurred

Bits 19:18 Reserved, must be kept at reset value.

Bit 17 **CC6IF**: Compare 6 interrupt flag
Refer to CC1IF description
Note: Channel 6 can only be configured as output.

Bit 16 **CC5IF**: Compare 5 interrupt flag
Refer to CC1IF description
Note: Channel 5 can only be configured as output.

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **SBIF**: System break interrupt flag
This flag is set by hardware as soon as the system break input goes active. It can be cleared by software if the system break input is not active.
This flag must be reset to re-start PWM operation.
0: No break event occurred.
1: An active level has been detected on the system break input. An interrupt is generated if BIE = 1 in the TIMx_DIER register.

Bit 12 **CC4OF**: Capture/compare 4 overcapture flag
Refer to CC1OF description

Bit 11 **CC3OF**: Capture/compare 3 overcapture flag
Refer to CC1OF description

Bit 10 **CC2OF**: Capture/compare 2 overcapture flag
Refer to CC1OF description

Bit 9 **CC1OF**: Capture/compare 1 overcapture flag

This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to 0.

0: No overcapture has been detected.

1: The counter value has been captured in TIMx_CCR1 register while CC1IF flag was already set

Bit 8 **B2IF**: Break 2 interrupt flag

This flag is set by hardware as soon as the break 2 input goes active. It can be cleared by software if the break 2 input is not active.

0: No break event occurred.

1: An active level has been detected on the break 2 input. An interrupt is generated if BIE = 1 in the TIMx_DIER register.

Bit 7 **BIF**: Break interrupt flag

This flag is set by hardware as soon as the break input goes active. It can be cleared by software if the break input is not active.

0: No break event occurred.

1: An active level has been detected on the break input. An interrupt is generated if BIE = 1 in the TIMx_DIER register.

Bit 6 **TIF**: Trigger interrupt flag

This flag is set by hardware on the TRG trigger event (active edge detected on tim_trgi input when the slave mode controller is enabled in all modes but gated mode. It is set when the counter starts or stops when gated mode is selected. It is cleared by software.

0: No trigger event occurred.

1: Trigger interrupt pending.

Bit 5 **COMIF**: COM interrupt flag

This flag is set by hardware on COM event (when capture/compare Control bits - CCxE, CCxNE, OCxM - have been updated). It is cleared by software.

0: No COM event occurred.

1: COM interrupt pending.

Bit 4 **CC4IF**: Capture/compare 4 interrupt flag

Refer to CC1IF description

Bit 3 **CC3IF**: Capture/compare 3 interrupt flag

Refer to CC1IF description

Bit 2 **CC2IF**: Capture/compare 2 interrupt flag
Refer to CC1IF description

Bit 1 **CC1IF**: Capture/compare 1 interrupt flag
This flag is set by hardware. It is cleared by software (input capture or output compare mode) or by reading the TIMx_CCR1 register (input capture mode only).
0: No compare match / No input capture occurred
1: A compare match or an input capture occurred
If channel CC1 is configured as output: this flag is set when the content of the counter TIMx_CNT matches the content of the TIMx_CCR1 register. When the content of TIMx_CCR1 is greater than the content of TIMx_ARR, the CC1IF bit goes high on the counter overflow (in up-counting and up/down-counting modes) or underflow (in downcounting mode). There are 3 possible options for flag setting in center-aligned mode, refer to the CMS bits in the TIMx_CR1 register for the full description.
If channel CC1 is configured as input: this bit is set when counter value has been captured in TIMx_CCR1 register (an edge has been detected on IC1, as per the edge sensitivity defined with the CC1P and CC1NP bits setting, in TIMx_CCER).

Bit 0 **UIF**: Update interrupt flag
This bit is set by hardware on an update event. It is cleared by software.
0: No update occurred.
1: Update interrupt pending. This bit is set by hardware when the registers are updated:
–At overflow or underflow regarding the repetition counter value (update if repetition counter = 0) and if the UDIS = 0 in the TIMx_CR1 register.
–When CNT is reinitialized by software using the UG bit in TIMx_EGR register, if URS = 0 and UDIS = 0 in the TIMx_CR1 register.
–When CNT is reinitialized by a trigger event (refer to *Section 49.6.3: TIMx slave mode control register (TIMx_SMCR)(x = 1, 8)*), if URS = 0 and UDIS = 0 in the TIMx_CR1 register.

49.6.6 TIMx event generation register (TIMx_EGR)(x = 1, 8)

Address offset: 0x014

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	B2G	BG	TG	COMG	CC4G	CC3G	CC2G	CC1G	UG
							w	w	w	w	w	w	w	w	w

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **B2G**: Break 2 generation
This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action
1: A break 2 event is generated. MOE bit is cleared and B2IF flag is set. Related interrupt can occur if enabled.

Bit 7 **BG**: Break generation
This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action
1: A break event is generated. MOE bit is cleared and BIF flag is set. Related interrupt or DMA transfer can occur if enabled.

Bit 6 **TG**: Trigger generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: The TIF flag is set in TIMx_SR register. Related interrupt or DMA transfer can occur if enabled.

Bit 5 **COMG**: Capture/compare control update generation

This bit can be set by software, it is automatically cleared by hardware

0: No action

1: CCxE, CCxNE and OCxM bits update (providing CCPC bit is set)

Note: This bit acts only on channels having a complementary output.

Bit 4 **CC4G**: Capture/compare 4 generation

Refer to CC1G description

Bit 3 **CC3G**: Capture/compare 3 generation

Refer to CC1G description

Bit 2 **CC2G**: Capture/compare 2 generation

Refer to CC1G description

Bit 1 **CC1G**: Capture/compare 1 generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: A capture/compare event is generated on channel 1:

If channel CC1 is configured as output:

CC1IF flag is set, Corresponding interrupt or DMA request is sent if enabled.

If channel CC1 is configured as input:

The current value of the counter is captured in TIMx_CCR1 register. The CC1IF flag is set, the corresponding interrupt or DMA request is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation

This bit can be set by software, it is automatically cleared by hardware.

0: No action

1: Reinitialize the counter and generates an update of the registers. Note that the prescaler counter is cleared too (anyway the prescaler ratio is not affected). The counter is cleared if the center-aligned mode is selected or if DIR = 0 (upcounting), else it takes the autoreload value (TIMx_ARR) if DIR = 1 (downcounting).

49.6.7 TIMx capture/compare mode register 1 (TIMx_CCMR1) (x = 1, 8)

Address offset: 0x018

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (for example channel 1 in input capture mode and channel 2 in output compare mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IC2F[3:0]				IC2PSC[1:0]		CC2S[1:0]		IC1F[3:0]				IC1PSC[1:0]		CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Input capture mode:

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **IC2F[3:0]**: Input capture 2 filter

Bits 11:10 **IC2PSC[1:0]**: Input capture 2 prescaler

Bits 9:8 **CC2S[1:0]**: Capture/compare 2 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC2 channel is configured as output

01: CC2 channel is configured as input, tim_ic2 is mapped on tim_ti2

10: CC2 channel is configured as input, tim_ic2 is mapped on tim_ti1

11: CC2 channel is configured as input, tim_ic2 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx_CCER).

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bitfield defines the frequency used to sample tim_ti1 input and the length of the digital filter applied to tim_ti1. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}

0001: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 2

0010: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 4

0011: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 8

0100: $f_{SAMPLING} = f_{DTS}/2$, N = 6

0101: $f_{SAMPLING} = f_{DTS}/2$, N = 8

0110: $f_{SAMPLING} = f_{DTS}/4$, N = 6

0111: $f_{SAMPLING} = f_{DTS}/4$, N = 8

1000: $f_{SAMPLING} = f_{DTS}/8$, N = 6

1001: $f_{SAMPLING} = f_{DTS}/8$, N = 8

1010: $f_{SAMPLING} = f_{DTS}/16$, N = 5

1011: $f_{SAMPLING} = f_{DTS}/16$, N = 6

1100: $f_{SAMPLING} = f_{DTS}/16$, N = 8

1101: $f_{SAMPLING} = f_{DTS}/32$, N = 5

1110: $f_{SAMPLING} = f_{DTS}/32$, N = 6

1111: $f_{SAMPLING} = f_{DTS}/32$, N = 8

Bits 3:2 **IC1PSC[1:0]**: Input capture 1 prescaler

This bitfield defines the ratio of the prescaler acting on CC1 input (tim_ic1). The prescaler is reset as soon as CC1E = 0 (TIMx_CCER register).

00: no prescaler, capture is done each time an edge is detected on the capture input

01: capture is done once every 2 events

10: capture is done once every 4 events

11: capture is done once every 8 events

Bits 1:0 **CC1S[1:0]**: Capture/compare 1 Selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output

01: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti1

10: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti2

11: CC1 channel is configured as input, tim_ic1 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

49.6.8 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 1, 8)

Address offset: 0x018

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (for example channel 1 in input capture mode and channel 2 in output compare mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]
							rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC2 CE	OC2M[2:0]			OC2 PE	OC2 FE	CC2S[1:0]		OC1 CE	OC1M[2:0]			OC1 PE	OC1 FE	CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Output compare mode:

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 **OC2CE:** Output compare 2 clear enable

Bits 24, 14:12 **OC2M[3:0]**: Output compare 2 mode

Bit 11 **OC2PE**: Output compare 2 preload enable

Bit 10 **OC2FE**: Output compare 2 fast enable

Bits 9:8 **CC2S[1:0]**: Capture/compare 2 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC2 channel is configured as output

01: CC2 channel is configured as input, tim_ic2 is mapped on tim_ti2

10: CC2 channel is configured as input, tim_ic2 is mapped on tim_ti1

11: CC2 channel is configured as input, tim_ic2 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through the TS bit (TIMx_SMCR register)

Note: CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx_CCER).

Bit 7 **OC1CE:** Output compare 1 clear enable

0: tim_oc1ref is not affected by the tim_ocref_clr_int signal

1: tim_oc1ref is cleared as soon as a High level is detected on tim_ocref_clr_int signal (tim_ocref_clr input or tim_etrf input)

Bits 16, 6:4 **OC1M[3:0]**: Output compare 1 mode

These bits define the behavior of the output reference signal tim_oc1ref from which tim_oc1 and tim_oc1n are derived. tim_oc1ref is active high whereas tim_oc1 and tim_oc1n active level depends on CC1P and CC1NP bits.

0000: Frozen - The comparison between the output compare register TIMx_CCR1 and the counter TIMx_CNT has no effect on the outputs.This mode can be used when the timer serves as a software timebase. When the frozen mode is enabled during timer operation, the ouput keeps the state (active or inactive) it had before entering the frozen state.

0001: Set channel 1 to active level on match. tim_oc1ref signal is forced high when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0010: Set channel 1 to inactive level on match. tim_oc1ref signal is forced low when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0011: Toggle - tim_oc1ref toggles when TIMx_CNT = TIMx_CCR1.

0100: Force inactive level - tim_oc1ref is forced low.

0101: Force active level - tim_oc1ref is forced high.

0110: PWM mode 1 - In upcounting, channel 1 is active as long as TIMx_CNT<TIMx_CCR1 else inactive. In downcounting, channel 1 is inactive (tim_oc1ref = 0) as long as TIMx_CNT>TIMx_CCR1 else active (tim_oc1ref = 1).

0111: PWM mode 2 - In upcounting, channel 1 is inactive as long as TIMx_CNT<TIMx_CCR1 else active. In downcounting, channel 1 is active as long as TIMx_CNT>TIMx_CCR1 else inactive.

1000: Retrigerrable OPM mode 1 - In up-counting mode, the channel is active until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update. In down-counting mode, the channel is inactive until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes inactive again at the next update.

1001: Retrigerrable OPM mode 2 - In up-counting mode, the channel is inactive until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 2 and the channels becomes inactive again at the next update. In down-counting mode, the channel is active until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update.

1010: Reserved,

1011: Reserved,

1100: Combined PWM mode 1 - tim_oc1ref has the same behavior as in PWM mode 1. tim_oc1refc is the logical OR between tim_oc1ref and tim_oc2ref.

1101: Combined PWM mode 2 - tim_oc1ref has the same behavior as in PWM mode 2. tim_oc1refc is the logical AND between tim_oc1ref and tim_oc2ref.

1110: Asymmetric PWM mode 1 - tim_oc1ref has the same behavior as in PWM mode 1. tim_oc1refc outputs tim_oc1ref when the counter is counting up, tim_oc2ref when it is counting down.

1111: Asymmetric PWM mode 2 - tim_oc1ref has the same behavior as in PWM mode 2. tim_oc1refc outputs tim_oc1ref when the counter is counting up, tim_oc2ref when it is counting down.

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S = 00 (the channel is configured in output).

Note: In PWM mode, the OCREF level changes when the result of the comparison changes, when the output compare mode switches from “frozen” mode to “PWM” mode and when the output compare mode switches from “force active/inactive” mode to “PWM” mode.

Note: On channels having a complementary output, this bitfield is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the OC1M active bits take the new value from the preloaded bits only when a COM event is generated.

Bit 3 **OC1PE**: Output compare 1 preload enable

0: Preload register on TIMx_CCR1 disabled. TIMx_CCR1 can be written at anytime, the new value is taken in account immediately.

1: Preload register on TIMx_CCR1 enabled. Read/Write operations access the preload register. TIMx_CCR1 preload value is loaded in the active register at each update event.

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S = 00 (the channel is configured in output).

Bit 2 **OC1FE**: Output compare 1 fast enable

This bit decreases the latency between a trigger event and a transition on the timer output. It must be used in one-pulse mode (OPM bit set in TIMx_CR1 register), to have the output pulse starting as soon as possible after the starting trigger.

0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.

1: An active edge on the trigger input acts like a compare match on CC1 output. Then, OC is set to the compare level independently from the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OCFE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S[1:0]**: Capture/compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output

01: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti1

10: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti2

11: CC1 channel is configured as input, tim_ic1 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

49.6.9 TIMx capture/compare mode register 2 (TIMx_CCMR2) (x = 1, 8)

Address offset: 0x01C

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (for example channel 3 in input capture mode and channel 4 in output compare mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IC4F[3:0]				IC4PSC[1:0]		CC4S[1:0]		IC3F[3:0]				IC3PSC[1:0]		CC3S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Input capture mode

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **IC4F[3:0]**: Input capture 4 filter

Bits 11:10 **IC4PSC[1:0]**: Input capture 4 prescaler

Bits 9:8 **CC4S[1:0]**: Capture/compare 4 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC4 channel is configured as output
01: CC4 channel is configured as input, tim_ic4 is mapped on tim_ti4
10: CC4 channel is configured as input, tim_ic4 is mapped on tim_ti3
11: CC4 channel is configured as input, tim_ic4 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC4S bits are writable only when the channel is OFF (CC4E = 0 in TIMx_CCER).

Bits 7:4 **IC3F[3:0]**: Input capture 3 filter

Bits 3:2 **IC3PSC[1:0]**: Input capture 3 prescaler

Bits 1:0 **CC3S[1:0]**: Capture/compare 3 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC3 channel is configured as output
01: CC3 channel is configured as input, tim_ic3 is mapped on tim_ti3
10: CC3 channel is configured as input, tim_ic3 is mapped on tim_ti4
11: CC3 channel is configured as input, tim_ic3 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC3S bits are writable only when the channel is OFF (CC3E = 0 in TIMx_CCER).

49.6.10 TIMx capture/compare mode register 2 [alternate] (TIMx_CCMR2)(x = 1, 8)

Address offset: 0x01C

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (for example channel 3 in input capture mode and channel 4 in output compare mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC4M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC3M[3]
							rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC4 CE	OC4M[2:0]			OC4 PE	OC4 FE	CC4S[1:0]		OC3 CE	OC3M[2:0]			OC3 PE	OC3 FE	CC3S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Output compare mode

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 **OC4CE**: Output compare 4 clear enable

Bits 24, 14:12 **OC4M[3:0]**: Output compare 4 mode
Refer to OC3M[3:0] bit description

Bit 11 **OC4PE**: Output compare 4 preload enable

Bit 10 **OC4FE**: Output compare 4 fast enable

Bits 9:8 **CC4S[1:0]**: Capture/compare 4 selection
This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC4 channel is configured as output
01: CC4 channel is configured as input, tim_ic4 is mapped on tim_ti4
10: CC4 channel is configured as input, tim_ic4 is mapped on tim_ti3
11: CC4 channel is configured as input, tim_ic4 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)
Note: CC4S bits are writable only when the channel is OFF (CC4E = 0 in TIMx_CCER).

Bit 7 **OC3CE:** Output compare 3 clear enable

Bits 16, 6:4 **OC3M[3:0]**: Output compare 3 mode

These bits define the behavior of the output reference signal tim_oc3ref from which tim_oc3 and tim_oc3n are derived. tim_oc3ref is active high whereas tim_oc3 and tim_oc3n active level depends on CC3P and CC3NP bits.

0000: Frozen - The comparison between the output compare register TIMx_CCR3 and the counter TIMx_CNT has no effect on the outputs.(this mode is used to generate a timing base).

0001: Set channel 3 to active level on match. tim_oc3ref signal is forced high when the counter TIMx_CNT matches the capture/compare register 3 (TIMx_CCR3).

0010: Set channel 3 to inactive level on match. tim_oc3ref signal is forced low when the counter TIMx_CNT matches the capture/compare register 3 (TIMx_CCR3).

0011: Toggle - tim_oc3ref toggles when TIMx_CNT = TIMx_CCR3.

0100: Force inactive level - tim_oc3ref is forced low.

0101: Force active level - tim_oc3ref is forced high.

0110: PWM mode 1 - In upcounting, channel 3 is active as long as TIMx_CNT<TIMx_CCR3 else inactive. In downcounting, channel 3 is inactive (tim_oc3ref = 0) as long as TIMx_CNT>TIMx_CCR3 else active (tim_oc3ref = 1).

0111: PWM mode 2 - In upcounting, channel 3 is inactive as long as TIMx_CNT<TIMx_CCR3 else active. In downcounting, channel 3 is active as long as TIMx_CNT>TIMx_CCR3 else inactive.

1000: Retrigerrable OPM mode 1 - In up-counting mode, the channel is active until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update. In down-counting mode, the channel is inactive until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes inactive again at the next update.

1001: Retrigerrable OPM mode 2 - In up-counting mode, the channel is inactive until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 2 and the channels becomes inactive again at the next update. In down-counting mode, the channel is active until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update.

1010: Pulse on compare: a pulse is generated on tim_oc3ref upon CCR3 match event, as per PWPRSC[2:0] and PW[7:0] bitfields programming in TIMxECR.

1011: Direction output. The tim_oc3ref signal is overridden by a copy of the DIR bit.

1100: Combined PWM mode 1 - tim_oc3ref has the same behavior as in PWM mode 1. tim_oc3refc is the logical OR between tim_oc3ref and tim_oc4ref.

1101: Combined PWM mode 2 - tim_oc3ref has the same behavior as in PWM mode 2. tim_oc3refc is the logical AND between tim_oc3ref and tim_oc4ref.

1110: Asymmetric PWM mode 1 - tim_oc3ref has the same behavior as in PWM mode 1. tim_oc3refc outputs tim_oc3ref when the counter is counting up, tim_oc4ref when it is counting down.

1111: Asymmetric PWM mode 2 - tim_oc3ref has the same behavior as in PWM mode 2. tim_oc3refc outputs tim_oc3ref when the counter is counting up, tim_oc4ref when it is counting down.

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S = 00 (the channel is configured in output).

Note: In PWM mode, the OCREF level changes only when the result of the comparison changes or when the output compare mode switches from “frozen” mode to “PWM” mode.

On channels having a complementary output, this bitfield is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the OC3M active bits take the new value from the preloaded bits only when a COM event is generated.

Bit 3 **OC3PE**: Output compare 3 preload enable

Bit 2 **OC3FE**: Output compare 3 fast enable

Bits 1:0 **CC3S[1:0]**: Capture/compare 3 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC3 channel is configured as output

01: CC3 channel is configured as input, tim_ic3 is mapped on tim_ti3

10: CC3 channel is configured as input, tim_ic3 is mapped on tim_ti4

11: CC3 channel is configured as input, tim_ic3 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC3S bits are writable only when the channel is OFF (CC3E = 0 in TIMx_CCER).

49.6.11 TIMx capture/compare enable register (TIMx_CCER)(x = 1, 8)

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC6P	CC6E	Res.	Res.	CC5P	CC5E
										rw	rw			rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CC4NP	CC4NE	CC4P	CC4E	CC3NP	CC3NE	CC3P	CC3E	CC2NP	CC2NE	CC2P	CC2E	CC1NP	CC1NE	CC1P	CC1E
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **CC6P**: Capture/compare 6 output polarity
Refer to CC1P description

Bit 20 **CC6E**: Capture/compare 6 output enable
Refer to CC1E description

Bits 19:18 Reserved, must be kept at reset value.

Bit 17 **CC5P**: Capture/compare 5 output polarity
Refer to CC1P description

Bit 16 **CC5E**: Capture/compare 5 output enable
Refer to CC1E description

Bit 15 **CC4NP**: Capture/compare 4 complementary output polarity
Refer to CC1NP description

Bit 14 **CC4NE**: Capture/compare 4 complementary output enable
Refer to CC1NE description

Bit 13 **CC4P**: Capture/compare 4 output polarity
Refer to CC1P description

Bit 12 **CC4E**: Capture/compare 4 output enable
Refer to CC1E description

Bit 11 **CC3NP**: Capture/compare 3 complementary output polarity
Refer to CC1NP description

Bit 10 **CC3NE**: Capture/compare 3 complementary output enable
Refer to CC1NE description

Bit 9 **CC3P**: Capture/compare 3 output polarity
Refer to CC1P description

Bit 8 **CC3E**: Capture/compare 3 output enable
Refer to CC1E description

Bit 7 **CC2NP**: Capture/compare 2 complementary output polarity
Refer to CC1NP description

Bit 6 **CC2NE**: Capture/compare 2 complementary output enable
Refer to CC1NE description

Bit 5 **CC2P**: Capture/compare 2 output polarity
Refer to CC1P description

Bit 4 **CC2E**: Capture/compare 2 output enable
Refer to CC1E description

Bit 3 **CC1NP**: Capture/compare 1 complementary output polarity
CC1 channel configured as output:
0: tim_oc1n active high.
1: tim_oc1n active low.
CC1 channel configured as input:
This bit is used in conjunction with CC1P to define the polarity of tim_ti1fp1 and tim_ti2fp1. Refer to CC1P description.

Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S = 00 (channel configured as output).

Note: On channels having a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1NP active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Bit 2 **CC1NE**: Capture/compare 1 complementary output enable
0: Off - tim_oc1n is not active. tim_oc1n level is then function of MOE, OSSI, OSSR, OIS1, OIS1N and CC1E bits.
1: On - tim_oc1n signal is output on the corresponding output pin depending on MOE, OSSI, OSSR, OIS1, OIS1N and CC1E bits.

Note: On channels having a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1NE active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Bit 1 **CC1P**: Capture/compare 1 output polarity

0: OC1 active high (output mode) / Edge sensitivity selection (input mode, see below)

1: OC1 active low (output mode) / Edge sensitivity selection (input mode, see below)

When CC1 channel is configured as input, both CC1NP/CC1P bits select the active polarity of TI1FP1 and TI2FP1 for trigger or capture operations.

CC1NP = 0, CC1P = 0:non-inverted/rising edge. The circuit is sensitive to TIxFP1 rising edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode or encoder mode).

CC1NP = 0, CC1P = 1:inverted/falling edge. The circuit is sensitive to TIxFP1 falling edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is inverted (trigger operation in gated mode or encoder mode).

CC1NP = 1, CC1P = 1: non-inverted/both edges/ The circuit is sensitive to both TIxFP1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), TIxFP1is not inverted (trigger operation in gated mode). This configuration must not be used in encoder mode.

CC1NP = 1, CC1P = 0:the configuration is reserved, it must not be used.

Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

Note: On channels having a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1P active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Bit 0 **CC1E**: Capture/compare 1 output enable

0: Capture mode disabled / OC1 is not active (see below)

1: Capture mode enabled / OC1 signal is output on the corresponding output pin

When CC1 channel is configured as output, the OC1 level depends on MOE, OSSI, OSSR, OIS1, OIS1N and CC1NE bits, regardless of the CC1E bits state. Refer to *Table 530* for details.

Note: On channels having a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1E active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Table 530. Output control bits for complementary tim_ocx and tim_ocxn channels with break feature

Control bits					Output states[1]	
MOE bit	OSSI bit	OSSR bit	CCxE bit	CCxNE bit	tim_ocx output state	tim_ocxn output state
1	X	X	0	0	Output disabled (not driven by the timer: Hi-Z) tim_ocx = 0, tim_ocxn = 0	
		0	0	1	Output disabled (not driven by the timer: Hi-Z) tim_ocx = 0	tim_ocxref + Polarity tim_ocxn = tim_ocxref xor CCxNP
		0	1	0	tim_ocxref + Polarity tim_ocx = tim_ocxref xor CCxP	Output Disabled (not driven by the timer: Hi-Z) tim_ocxn = 0
		X	1	1	OCREF + Polarity + dead-time	Complementary to OCREF (not OCREF) + Polarity + dead-time
		1	0	1	Off-State (output enabled with inactive state) tim_ocx = CCxP	tim_ocxref + Polarity tim_ocxn = tim_ocxref x or CCxNP
		1	1	0	tim_ocxref + Polarity tim_ocx = tim_ocxref xor CCxP	Off-State (output enabled with inactive state) tim_ocxn = CCxNP
0	0	X	X	X	Output disabled (not driven by the timer: Hi-Z).	
	1		0	0		
			0	1	Off-State (output enabled with inactive state) Asynchronously: tim_ocx = CCxP, tim_ocxn = CCxNP (if tim_brk or tim_brk2 is triggered). Then (this is valid only if tim_brk is triggered), if the clock is present: tim_ocx = OISx and tim_ocxn = OISxN after a dead-time, assuming that OISx and OISxN do not correspond to OCX and tim_ocxn both in active state (may cause a short circuit when driving switches in half-bridge configuration). *Note: tim_brk2 can only be used if OSSI = OSSR = 1.*	
			1	0		
			1	1		

1. When both outputs of a channel are not used (control taken over by GPIO), the OISx, OISxN, CCxP and CCxNP bits must be kept cleared.

Note: The state of the external I/O pins connected to the complementary tim_ocx and tim_ocxn channels depends on the tim_ocx and tim_ocxn channel state and the GPIO registers.

49.6.12 TIMx counter (TIMx_CNT)(x = 1, 8)

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF copy

This bit is a read-only copy of the UIF bit of the TIMx_ISR register. If the UIFREMAP bit in the TIMxCR1 is reset, bit 31 is reserved and read at 0.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value

Non-dithering mode (DITHEN = 0)

The register holds the counter value.

Dithering mode (DITHEN = 1)

The register only holds the non-dithered part in CNT[15:0]. The fractional part is not available.

49.6.13 TIMx prescaler (TIMx_PSC)(x = 1, 8)

Address offset: 0x028

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency ($f_{tim_cnt_ck}$) is equal to $f_{tim_psc_ck}$ / (PSC[15:0] + 1).
PSC contains the value to be loaded in the active prescaler register at each update event (including when the counter is cleared through UG bit of TIMx_EGR register or through trigger controller when configured in “reset mode”).

49.6.14 TIMx autoreload register (TIMx_ARR)(x = 1, 8)

Address offset: 0x02C

Reset value: 0x0000 FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **ARR[19:0]**: Autoreload value

ARR is the value to be loaded in the actual autoreload register.

Refer to the *Section 49.3.3: Time-base unit* for more details about ARR update and behavior.

The counter is blocked while the autoreload value is null.

Non-dithering mode (DITHEN = 0)

The register holds the autoreload value.

Dithering mode (DITHEN = 1)

The register holds the integer part in ARR[19:4]. The ARR[3:0] bitfield contains the dithered part.

49.6.15 TIMx repetition counter register (TIMx_RCR)(x = 1, 8)

Address offset: 0x030

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **REP[15:0]**: Repetition counter reload value

This bitfield defines the update rate of the compare registers (i.e. periodic transfers from preload to active registers) when preload registers are enable. It also defines the update interrupt generation rate, if this interrupt is enable.

When the repetition down-counter reaches zero, an update event is generated and it restarts counting from REP value. As the repetition counter is reloaded with REP value only at the repetition update event UEV, any write to the TIMx_RCR register is not taken in account until the next repetition update event.

It means in PWM mode (REP+1) corresponds to:

– the number of PWM periods in edge-aligned mode

– the number of half PWM period in center-aligned mode.

49.6.16 TIMx capture/compare register 1 (TIMx_CCR1)(x = 1, 8)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[19:16]			
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR1[19:0]**: Capture/compare 1 value

If channel CC1 is configured as output: CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc1 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value in CCR1[15:0]. The CCR1[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR1[19:4]. The CCR1[3:0] bitfield contains the dithered part.

If channel CC1 is configured as input: CR1 is the counter value transferred by the last input capture 1 event (tim_ic1). The TIMx_CCR1 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The register holds the capture value in CCR1[15:0]. The CCR1[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR1[19:4]. The CCR1[3:0] bits are reset.

49.6.17 TIMx capture/compare register 2 (TIMx_CCR2)(x = 1, 8)

Address offset: 0x038

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR2[19:16]			
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR2[19:0]**: Capture/compare 2 value

If channel CC2 is configured as output: CCR2 is the value to be loaded in the actual capture/compare 2 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC2PE). Else the preload value is copied in the active capture/compare 2 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc2 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value in CCR2[15:0]. The CCR2[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR2[19:4]. The CCR2[3:0] bitfield contains the dithered part.

If channel CC2 is configured as input: CCR2 is the counter value transferred by the last input capture 2 event (tim_ic2). The TIMx_CCR2 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The register holds the capture value in CCR2[15:0]. The CCR2[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR2[19:4]. The CCR2[3:0] bits are reset.

49.6.18 TIMx capture/compare register 3 (TIMx_CCR3)(x = 1, 8)

Address offset: 0x03C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR3[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR3[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR3[19:0]**: Capture/compare value

If channel CC3 is configured as output: CCR3 is the value to be loaded in the actual capture/compare 3 register (preload value).
It is loaded permanently if the preload feature is not selected in the TIMx_CCMR2 register (bit OC3PE). Else the preload value is copied in the active capture/compare 3 register when an update event occurs.
The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc3 output.
Non-dithering mode (DITHEN = 0)
The register holds the compare value in CCR3[15:0]. The CCR3[19:16] bits are reset.
Dithering mode (DITHEN = 1)
The register holds the integer part in CCR3[19:4]. The CCR3[3:0] bitfield contains the dithered part.
If channel CC3 is configured as input: CCR3 is the counter value transferred by the last input capture 3 event (tim_ic3). The TIMx_CCR3 register is read-only and cannot be programmed.
Non-dithering mode (DITHEN = 0)
The register holds the capture value in CCR3[15:0]. The CCR3[19:16] bits are reset.
Dithering mode (DITHEN = 1)
The register holds the capture in CCR3[19:4]. The CCR3[3:0] bits are reset.

49.6.19 TIMx capture/compare register 4 (TIMx_CCR4)(x = 1, 8)

Address offset: 0x040

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR4[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR4[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR4[19:0]**: Capture/compare value

If channel CC4 is configured as output: CCR4 is the value to be loaded in the actual capture/compare 4 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR2 register (bit OC4PE). Else the preload value is copied in the active capture/compare 4 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signalled on tim_oc4 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value in CCR4[15:0]. The CCR4[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR4[19:4]. The CCR4[3:0] bitfield contains the dithered part.

If channel CC4 is configured as input: CCR4 is the counter value transferred by the last input capture 4 event (tim_ic4). The TIMx_CCR4 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The register holds the capture value in CCR4[15:0]. The CCR4[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR4[19:4]. The CCR4[3:0] bits are reset.

49.6.20 TIMx break and dead-time register (TIMx_BDTR)(x = 1, 8)

Address offset: 0x044

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	BK2BID	BKBID	BK2 DSRM	BK DSRM	BK2P	BK2E	BK2F[3:0]				BKF[3:0]			
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK[1:0]		DTG[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Note: As the bits BKBID/BK2BID/BK2P, BK2E, BK2F[3:0], BKF[3:0], AOE, BKP, BKE, OSSI, OSSR, and DTG[7:0] can be write-locked depending on the LOCK configuration, it can be necessary to configure all of them during the first write access to the TIMx_BDTR register.

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **BK2BID**: Break2 bidirectional

Refer to BKBID description

Bit 28 **BKBID**: Break bidirectional

0: Break input tim_brk in input mode

1: Break input tim_brk in bidirectional mode

In the bidirectional mode (BKBID bit set to 1), the break input is configured both in input mode and in open drain output mode. Any active break event asserts a low logic level on the Break input to indicate an internal break event to external devices.

Note: This bit cannot be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 27 **BK2DSRM**: Break2 disarm

Refer to BKDSRM description

Bit 26 **BKDSRM**: Break disarm

0: Break input tim_brk is armed

1: Break input tim_brk is disarmed

This bit is cleared by hardware when no break source is active.

The BKDSRM bit must be set by software to release the bidirectional output control (open-drain output in Hi-Z state) and then be polled it until it is reset by hardware, indicating that the fault condition has disappeared.

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 25 **BK2P**: Break 2 polarity

0: Break input tim_brk2 is active low

1: Break input tim_brk2 is active high

Note: This bit cannot be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 24 **BK2E**: Break 2 enable

This bit enables the complete break 2 protection, see *Figure 530: Break and Break2 circuitry overview*).

0: Break2 function disabled

1: Break2 function enabled

Note: The BRKIN2 must only be used with OSSR = OSSI = 1.

Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bits 23:20 **BK2F[3:0]**: Break 2 filter

This bitfield defines the frequency used to sample tim_brk2 input and the length of the digital filter applied to tim_brk2. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, tim_brk2 acts asynchronously
0001: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 2
0010: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 4
0011: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 8
0100: $f_{SAMPLING} = f_{DTS}/2$, N = 6
0101: $f_{SAMPLING} = f_{DTS}/2$, N = 8
0110: $f_{SAMPLING} = f_{DTS}/4$, N = 6
0111: $f_{SAMPLING} = f_{DTS}/4$, N = 8
1000: $f_{SAMPLING} = f_{DTS}/8$, N = 6
1001: $f_{SAMPLING} = f_{DTS}/8$, N = 8
1010: $f_{SAMPLING} = f_{DTS}/16$, N = 5
1011: $f_{SAMPLING} = f_{DTS}/16$, N = 6
1100: $f_{SAMPLING} = f_{DTS}/16$, N = 8
1101: $f_{SAMPLING} = f_{DTS}/32$, N = 5
1110: $f_{SAMPLING} = f_{DTS}/32$, N = 6
1111: $f_{SAMPLING} = f_{DTS}/32$, N = 8

Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 19:16 **BKF[3:0]**: Break filter

This bitfield defines the frequency used to sample tim_brk input and the length of the digital filter applied to tim_brk. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, tim_brk acts asynchronously
0001: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 2
0010: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 4
0011: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 8
0100: $f_{SAMPLING} = f_{DTS}/2$, N = 6
0101: $f_{SAMPLING} = f_{DTS}/2$, N = 8
0110: $f_{SAMPLING} = f_{DTS}/4$, N = 6
0111: $f_{SAMPLING} = f_{DTS}/4$, N = 8
1000: $f_{SAMPLING} = f_{DTS}/8$, N = 6
1001: $f_{SAMPLING} = f_{DTS}/8$, N = 8
1010: $f_{SAMPLING} = f_{DTS}/16$, N = 5
1011: $f_{SAMPLING} = f_{DTS}/16$, N = 6
1100: $f_{SAMPLING} = f_{DTS}/16$, N = 8
1101: $f_{SAMPLING} = f_{DTS}/32$, N = 5
1110: $f_{SAMPLING} = f_{DTS}/32$, N = 6
1111: $f_{SAMPLING} = f_{DTS}/32$, N = 8

Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 15 **MOE**: Main output enable

This bit is cleared asynchronously by hardware as soon as one of the break inputs is active (tim_brk or tim_brk2). It is set by software or automatically depending on the AOE bit. It is acting only on the channels which are configured in output.

0: In response to a break 2 event. OC and OCN outputs are disabled
In response to a break event or if MOE is written to 0: OC and OCN outputs are disabled or forced to idle state depending on the OSSI bit.

1: OC and OCN outputs are enabled if their respective enable bits are set (CCxE, CCxNE in TIMx_CCER register).
See OC/OCN enable description for more details (*Section 49.6.11: TIMx capture/compare enable register (TIMx_CCER)(x = 1, 8)*).

Bit 14 **AOE**: Automatic output enable

0: MOE can be set only by software

1: MOE can be set by software or automatically at the next update event (if none of the break inputs tim_brk and tim_brk2 is active)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 13 **BKP**: Break polarity

0: Break input tim_brk is active low

1: Break input tim_brk is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 12 **BKE**: Break enable

This bit enables the complete break protection (including all sources connected to tim_sys_brk and BKIN sources, as per *Figure 530: Break and Break2 circuitry overview*).

0: Break function disabled

1: Break function enabled

Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 11 **OSSR**: Off-state selection for Run mode

This bit is used when MOE = 1 on channels having a complementary output which are configured as outputs. OSSR is not implemented if no complementary output is implemented in the timer.

See OC/OCN enable description for more details (*Section 49.6.11: TIMx capture/compare enable register (TIMx_CCER)(x = 1, 8)*).

0: When inactive, OC/OCN outputs are disabled (the timer releases the output control which is taken over by the GPIO logic, which forces a Hi-Z state).

1: When inactive, OC/OCN outputs are enabled with their inactive level as soon as CCxE = 1 or CCxNE = 1 (the output is still controlled by the timer).

Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **OSSI**: Off-state selection for idle mode

This bit is used when MOE = 0 due to a break event or by a software write, on channels configured as outputs.
See OC/OCN enable description for more details (*Section 49.6.11: TIMx capture/compare enable register (TIMx_CCER)(x = 1, 8)*).

0: When inactive, OC/OCN outputs are disabled (the timer releases the output control which is taken over by the GPIO logic and which imposes a Hi-Z state).

1: When inactive, OC/OCN outputs are first forced with their inactive level then forced to their idle level after the deadtime. The timer maintains its control over the output.

Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 9:8 **LOCK[1:0]**: Lock configuration

These bits offer a write protection against software errors.

00: LOCK OFF - No bit is write protected.

01: LOCK Level 1 = DTG bits in TIMx_BDTR register, OISx and OISxN bits in TIMx_CR2 register and BKBID/BK2BID/BKE/BKP/AOE bits in TIMx_BDTR register can no longer be written.

10: LOCK Level 2 = LOCK Level 1 + CC Polarity bits (CCxP/CCxNP bits in TIMx_CCER register, as long as the related channel is configured in output through the CCxS bits) as well as OSSR and OSSI bits can no longer be written.

11: LOCK Level 3 = LOCK Level 2 + CC Control bits (OCxM and OCxPE bits in TIMx_CCMRx registers, as long as the related channel is configured in output through the CCxS bits) can no longer be written.

Note: The LOCK bits can be written only once after the reset. Once the TIMx_BDTR register has been written, their content is frozen until the next reset.

Bits 7:0 **DTG[7:0]**: Dead-time generator setup

This bitfield defines the duration of the dead-time inserted between the complementary outputs. DT correspond to this duration.
DTG[7:5] = 0xx => DT = DTG[7:0]x t_{dtg} with $t_{dtg} = t_{DTS}$.
DTG[7:5] = 10x => DT = (64+DTG[5:0])xt_{dtg} with $T_{dtg} = 2xt_{DTS}$.
DTG[7:5] = 110 => DT = (32+DTG[4:0])xt_{dtg} with $T_{dtg} = 8xt_{DTS}$.
DTG[7:5] = 111 => DT = (32+DTG[4:0])xt_{dtg} with $T_{dtg} = 16xt_{DTS}$.
Example if T_{DTS} = 125 ns (8 MHz), dead-time possible values are:
0 to 15875 ns by 125 ns steps,
16 µs to 31750 ns by 250 ns steps,
32 µs to 63 µs by 1 µs steps,
64 µs to 126 µs by 2 µs steps

Note: This bitfield can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

49.6.21 TIMx capture/compare register 5 (TIMx_CCR5)(x = 1, 8)

Address offset: 0x048

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GC5C3	GC5C2	GC5C1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR5[19:16]			
rw	rw	rw										rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR5[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **GC5C3**: Group channel 5 and channel 3
Distortion on channel 3 output:
0: No effect of tim_oc5ref on tim_oc3refc
1: tim_oc3refc is the logical AND of tim_oc3ref and tim_oc5ref
This bit can either have immediate effect or be preloaded and taken into account after an update event (if preload feature is selected in TIMxCCMR2).
Note: it is also possible to apply this distortion on combined PWM signals.

Bit 30 **GC5C2**: Group channel 5 and channel 2
Distortion on channel 2 output:
0: No effect of tim_oc5ref on tim_oc2refc
1: tim_oc2refc is the logical AND of tim_oc2ref and tim_oc5ref
This bit can either have immediate effect or be preloaded and taken into account after an update event (if preload feature is selected in TIMxCCMR1).
Note: it is also possible to apply this distortion on combined PWM signals.

Bit 29 **GC5C1**: Group channel 5 and channel 1
Distortion on channel 1 output:
0: No effect of oc5ref on oc1refc
1: oc1refc is the logical AND of oc1ref and oc5ref
This bit can either have immediate effect or be preloaded and taken into account after an update event (if preload feature is selected in TIMxCCMR1).
Note: it is also possible to apply this distortion on combined PWM signals.

Bits 28:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR5[19:0]**: Capture/compare 5 value
CCR5 is the value to be loaded in the actual capture/compare 5 register (preload value).
It is loaded permanently if the preload feature is not selected in the TIMx_CCMR3 register (bit OC5PE). Else the preload value is copied in the active capture/compare 5 register when an update event occurs.
The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc5 output.
Non-dithering mode (DITHEN = 0)
The register holds the compare value in CCR5[15:0]. The CCR5[19:16] bits are reset.
Dithering mode (DITHEN = 1)
The register holds the integer part in CCR5[19:4]. The CCR5[3:0] bitfield contains the dithered part.

49.6.22 TIMx capture/compare register 6 (TIMx_CCR6)(x = 1, 8)

Address offset: 0x04C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR6[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR6[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR6[19:0]**: Capture/compare 6 value

CCR6 is the value to be loaded in the actual capture/compare 6 register (preload value).
It is loaded permanently if the preload feature is not selected in the TIMx_CCMR3 register (bit OC6PE). Else the preload value is copied in the active capture/compare 6 register when an update event occurs.
The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc6 output.
Non-dithering mode (DITHEN = 0)
The register holds the compare value in CCR6[15:0]. The CCR6[19:16] bits are reset.
Dithering mode (DITHEN = 1)
The register holds the integer part in CCR6[19:4]. The CCR6[3:0] bitfield contains the dithered part.

49.6.23 TIMx capture/compare mode register 3 (TIMx_CCMR3) (x = 1, 8)

Address offset: 0x050

Reset value: 0x0000 0000

Refer to the above CCMR1 register description. Channels 5 and 6 can only be configured in output.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC6M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC5M[3]
							rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC6 CE	OC6M[2:0]			OC6 PE	OC6FE	Res.	Res.	OC5 CE	OC5M[2:0]			OC5PE	OC5FE	Res.	Res.
rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw		

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 **OC6CE**: Output compare 6 clear enable

Bits 24, 14:12 **OC6M[3:0]**: Output compare 6 mode

Bit 11 **OC6PE**: Output compare 6 preload enable

Bit 10 **OC6FE**: Output compare 6 fast enable

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 **OC5CE:** Output compare 5 clear enable

Bits 16, 6:4 **OC5M[3:0]**: Output compare 5 mode

Bit 3 **OC5PE**: Output compare 5 preload enable

Bit 2 **OC5FE**: Output compare 5 fast enable

Bits 1:0 Reserved, must be kept at reset value.

49.6.24 TIMx timer deadtime register 2 (TIMx_DTR2)(x = 1, 8)

Address offset: 0x054

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTPE	DTAE
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTGF[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **DTPE**: Deadtime preload enable

0: Deadtime value is not preloaded

1: Deadtime value preload is enabled

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 16 **DTAE**: Deadtime asymmetric enable

0: Deadtime on rising and falling edges are identical, and defined with DTG[7:0] register

1: Deadtime on rising edge is defined with DTG[7:0] register and deadtime on falling edge is defined with DTGF[7:0] bits.

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **DTGF[7:0]**: Dead-time falling edge generator setup

This bitfield defines the duration of the dead-time inserted between the complementary outputs, on the falling edge.

DTGF[7:5] = 0xx => DTF = DTGF[7:0]x t_{dtg} with $t_{dtg} = t_{DTS}$.

DTGF[7:5] = 10x => DTF = (64+DTGF[5:0])xt_{dtg} with $T_{dtg} = 2xt_{DTS}$.

DTGF[7:5] = 110 => DTF = (32+DTGF[4:0])xt_{dtg} with $T_{dtg} = 8xt_{DTS}$.

DTGF[7:5] = 111 => DTF = (32+DTGF[4:0])xt_{dtg} with $T_{dtg} = 16xt_{DTS}$.

Example if T_{DTS} = 125 ns (8 MHz), dead-time possible values are:

0 to 15875 ns by 125 ns steps,

16 µs to 31750 ns by 250 ns steps,

32 µs to 63 µs by 1 µs steps,

64 µs to 126 µs by 2 µs steps

Note: This bitfield can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

49.6.25 TIMx timer encoder control register (TIMx_ECR)(x = 1, 8)

Address offset: 0x058

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	PWPRSC[2:0]			PW[7:0]							
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IPOS[1:0]		FIDX	IBLK[1:0]		IDIR[1:0]		IE
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bits 26:24 **PWPRSC[2:0]**: Pulse width prescaler

This bitfield sets the clock prescaler for the pulse generator, as following:

$t_{PWG} = (2^{(PWPRSC[2:0])}) \times t_{tim_ker_ck}$

Bits 23:16 **PW[7:0]**: Pulse width

This bitfield defines the pulse duration, as following:

$t_{PW} = PW[7:0] \times t_{PWG}$

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:6 **IPOS[1:0]**: Index positioning

In quadrature encoder mode (SMS[3:0] = 0001, 0010, 0011, 1110, 1111), this bit indicates in which AB input configuration the Index event resets the counter.

00: Index resets the counter when AB = 00
01: Index resets the counter when AB = 01
10: Index resets the counter when AB = 10
11: Index resets the counter when AB = 11

In directional clock mode or clock plus direction mode (SMS[3:0] = 1010, 1011, 1100, 1101), these bits indicates on which level the Index event resets the counter. In bidirectional clock mode, this applies for both clock inputs.

x0: Index resets the counter when clock is 0
x1: Index resets the counter when clock is 1

Note: IPOS[1] bit is not significant

Bit 5 **FIDX**: First index

This bit indicates if the first index only is taken into account

0: Index is always active
1: the first Index only resets the counter

Bits 4:3 **IBLK[1:0]**: Index blanking
This bit indicates if the Index event is conditioned by the tim_ti3 or tim_ti4 input
00: Index always active
01: Index disabled when tim_ti3 input is active, as per CC3P bitfield
10: Index disabled when tim_ti4 input is active, as per CC4P bitfield
11: Reserved

Bits 2:1 **IDIR[1:0]**: Index direction
This bit indicates in which direction the Index event resets the counter.
00: Index resets the counter whatever the direction
01: Index resets the counter when up-counting only
10: Index resets the counter when down-counting only
11: Reserved

Bit 0 **IE**: Index enable
This bit indicates if the Index event resets the counter.
0: Index disabled
1: Index enabled

49.6.26 TIMx timer input selection register (TIMx_TISEL)(x = 1, 8)

Address offset: 0x05C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **TI4SEL[3:0]**: Selects tim_ti4[15:0] input
0000: tim_ti4_in0: TIMx_CH4
0001: tim_ti4_in1
...
1111: tim_ti4_in15
Refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals* for interconnects list.

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **TI3SEL[3:0]**: Selects tim_ti3[15:0] input
0000: tim_ti3_in0: TIMx_CH2
0001: tim_ti3_in1
...
1111: tim_ti3_in15
Refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals* for interconnects list.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: Selects tim_ti2[15:0] input
0000: tim_ti2_in0: TIMx_CH2
0001: tim_ti2_in1
...
1111: tim_ti2_in15
Refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals* for interconnects list.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: Selects tim_ti1[15:0] input
0000: tim_ti1_in0: TIMx_CH1
0001: tim_ti1_in1
...
1111: tim_ti1_in15
Refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals* for interconnects list.

49.6.27 TIMx alternate function option register 1 (TIMx_AF1)(x = 1, 8)

Address offset: 0x060

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL[3:2]	
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETRSEL[1:0]		BK CMP4P	BK CMP3P	BK CMP2P	BK CMP1P	BKINP	BK CMP8E	BK CMP7E	BK CMP6E	BK CMP5E	BK CMP4E	BK CMP3E	BK CMP2E	BK CMP1E	BKINE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:14 **ETRSEL[3:0]**: etr_in source selection
These bits select the etr_in input source.
0000: tim_etr0: TIMx_ETR input
0001: tim_etr1
...
1111: tim_etr15
Refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals* for product specific implementation.

Note: These bits can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 13 **BKCMP4P**: tim_brk_cmp4 input polarity
This bit selects the tim_brk_cmp4 input sensitivity. It must be programmed together with the BKP polarity bit.
0: tim_brk_cmp4 input polarity is not inverted (active low if BKP = 0, active high if BKP = 1)
1: tim_brk_cmp4 input polarity is inverted (active high if BKP = 0, active low if BKP = 1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 12 **BKCMP3P**: tim_brk_cmp3 input polarity

This bit selects the tim_brk_cmp3 input sensitivity. It must be programmed together with the BKP polarity bit.

0: tim_brk_cmp3 input polarity is not inverted (active low if BKP = 0, active high if BKP = 1)

1: tim_brk_cmp3 input polarity is inverted (active high if BKP = 0, active low if BKP = 1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 11 **BKCMP2P**: tim_brk_cmp2 input polarity

This bit selects the tim_brk_cmp2 input sensitivity. It must be programmed together with the BKP polarity bit.

0: tim_brk_cmp2 input polarity is not inverted (active low if BKP = 0, active high if BKP = 1)

1: tim_brk_cmp2 input polarity is inverted (active high if BKP = 0, active low if BKP = 1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **BKCMP1P**: tim_brk_cmp1 input polarity

This bit selects the tim_brk_cmp1 input sensitivity. It must be programmed together with the BKP polarity bit.

0: tim_brk_cmp1 input polarity is not inverted (active low if BKP = 0, active high if BKP = 1)

1: tim_brk_cmp1 input polarity is inverted (active high if BKP = 0, active low if BKP = 1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 9 **BKINP**: TIMx_BKIN input polarity

This bit selects the TIMx_BKIN alternate function input sensitivity. It must be programmed together with the BKP polarity bit.

0: TIMx_BKIN input polarity is not inverted (active low if BKP = 0, active high if BKP = 1)

1: TIMx_BKIN input polarity is inverted (active high if BKP = 0, active low if BKP = 1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **BKCMP8E**: tim_brk_cmp8 enable

This bit enables the tim_brk_cmp8 for the timer's tim_brk input. tim_brk_cmp8 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp8 input disabled

1: tim_brk_cmp8 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 7 **BKCMP7E**: tim_brk_cmp7 enable

This bit enables the tim_brk_cmp7 for the timer's tim_brk input. tim_brk_cmp7 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp7 input disabled

1: tim_brk_cmp7 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 6 **BKCMP6E**: tim_brk_cmp6 enable

This bit enables the tim_brk_cmp6 for the timer's tim_brk input. tim_brk_cmp6 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp6 input disabled

1: tim_brk_cmp6 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 5 **BKCMP5E**: tim_brk_cmp5 enable

This bit enables the tim_brk_cmp5 for the timer's tim_brk input. tim_brk_cmp5 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp5 input disabled

1: tim_brk_cmp5 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 4 **BKCMP4E**: tim_brk_cmp4 enable

This bit enables the tim_brk_cmp4 for the timer's tim_brk input. tim_brk_cmp4 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp4 input disabled

1: tim_brk_cmp4 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 3 **BKCMP3E**: tim_brk_cmp3 enable

This bit enables the tim_brk_cmp3 for the timer's tim_brk input. tim_brk_cmp3 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp3 input disabled

1: tim_brk_cmp3 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 2 **BKCMP2E**: tim_brk_cmp2 enable

This bit enables the tim_brk_cmp2 for the timer's tim_brk input. tim_brk_cmp2 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp2 input disabled

1: tim_brk_cmp2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 1 **BKCMP1E**: tim_brk_cmp1 enable

This bit enables the tim_brk_cmp1 for the timer's tim_brk input. tim_brk_cmp1 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp1 input disabled

1: tim_brk_cmp1 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 0 **BKINE**: TIMx_BKIN input enable

This bit enables the TIMx_BKIN alternate function input for the timer's tim_brk input. TIMx_BKIN input is 'ORed' with the other tim_brk sources.

0: TIMx_BKIN input disabled

1: TIMx_BKIN input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Refer to Section 49.3.2: TIM1/TIM8 pins and internal signals for product specific implementation.

49.6.28 TIMx alternate function register 2 (TIMx_AF2)(x = 1, 8)

Address offset: 0x064

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCRSEL[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	BK2CMP4P	BK2CMP3P	BK2CMP2P	BK2CMP1P	BK2INP	BK2CMP8E	BK2CMP7E	BK2CMP6E	BK2CMP5E	BK2CMP4E	BK2CMP3E	BK2CMP2E	BK2CMP1E	BK2INE
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **OCRSEL[2:0]**: ocref_clr source selection

These bits select the ocref_clr input source.

000: tim_ocref_clr0

001: tim_ocref_clr1

...

111: tim_ocref_clr7

Refer to *Section 49.3.2: TIM1/TIM8 pins and internal signals* for product specific information.

Note: These bits can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **BK2CMP4P**: tim_brk2_cmp4 input polarity

This bit selects the tim_brk2_cmp4 input sensitivity. It must be programmed together with the BK2P polarity bit.

0: tim_brk2_cmp4 input polarity is not inverted (active low if BK2P = 0, active high if BK2P = 1)

1: tim_brk2_cmp4 input polarity is inverted (active high if BK2P = 0, active low if BK2P = 1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 12 **BK2CMP3P**: tim_brk2_cmp3 input polarity

This bit selects the tim_brk2_cmp3 input sensitivity. It must be programmed together with the BK2P polarity bit.

0: tim_brk2_cmp3 input polarity is not inverted (active low if BK2P = 0, active high if BK2P = 1)

1: tim_brk2_cmp3 input polarity is inverted (active high if BK2P = 0, active low if BK2P = 1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 11 **BK2CMP2P**: tim_brk2_cmp2 input polarity

This bit selects the tim_brk2_cmp2 input sensitivity. It must be programmed together with the BK2P polarity bit.

0: tim_brk2_cmp2 input polarity is not inverted (active low if BK2P = 0, active high if BK2P = 1)

1: tim_brk2_cmp2 input polarity is inverted (active high if BK2P = 0, active low if BK2P = 1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **BK2CMP1P**: tim_brk2_cmp1 input polarity

This bit selects the tim_brk2_cmp1 input sensitivity. It must be programmed together with the BK2P polarity bit.

0: tim_brk2_cmp1 input polarity is not inverted (active low if BK2P = 0, active high if BK2P = 1)

1: tim_brk2_cmp1 input polarity is inverted (active high if BK2P = 0, active low if BK2P = 1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 9 **BK2INP**: TIMx_BKIN2 input polarity

This bit selects the TIMx_BKIN2 alternate function input sensitivity. It must be programmed together with the BK2P polarity bit.

0: TIMx_BKIN2 input polarity is not inverted (active low if BK2P = 0, active high if BK2P = 1)

1: TIMx_BKIN2 input polarity is inverted (active high if BK2P = 0, active low if BK2P = 1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **BK2CMP8E**: tim_brk2_cmp8 enable

This bit enables the tim_brk2_cmp8 for the timer's tim_brk2 input. tim_brk2_cmp8 output is 'ORed' with the other tim_brk2 sources.

0: tim_brk2_cmp8 input disabled

1: tim_brk2_cmp8 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 7 **BK2CMP7E**: tim_brk2_cmp7 enable

This bit enables the tim_brk2_cmp7 for the timer's tim_brk2 input. tim_brk2_cmp7 output is 'ORed' with the other tim_brk2 sources.

0: tim_brk2_cmp7 input disabled

1: tim_brk2_cmp7 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 6 **BK2CMP6E**: tim_brk2_cmp6 enable

This bit enables the tim_brk2_cmp6 for the timer's tim_brk2 input. tim_brk2_cmp6 output is 'ORed' with the other tim_brk2 sources.

0: tim_brk2_cmp6 input disabled

1: tim_brk2_cmp6 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 5 **BK2CMP5E**: tim_brk2_cmp5 enable

This bit enables the tim_brk2_cmp5 for the timer's tim_brk2 input. tim_brk2_cmp5 output is 'ORed' with the other tim_brk2 sources.

0: tim_brk2_cmp5 input disabled

1: tim_brk2_cmp5 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 4 **BK2CMP4E**: tim_brk2_cmp4 enable

This bit enables the tim_brk2_cmp4 for the timer's tim_brk2 input. tim_brk2_cmp4 output is 'ORed' with the other tim_brk2 sources.

0: tim_brk2_cmp4 input disabled

1: tim_brk2_cmp4 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 3 **BK2CMP3E**: tim_brk2_cmp3 enable

This bit enables the tim_brk2_cmp3 for the timer's tim_brk2 input. tim_brk2_cmp3 output is 'ORed' with the other tim_brk2 sources.

0: tim_brk2_cmp3 input disabled

1: tim_brk2_cmp3 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 2 **BK2CMP2E**: tim_brk2_cmp2 enable

This bit enables the tim_brk2_cmp2 for the timer's tim_brk2 input. tim_brk2_cmp2 output is 'ORed' with the other tim_brk2 sources.

0: tim_brk2_cmp2 input disabled

1: tim_brk2_cmp2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 1 **BK2CMP1E**: tim_brk2_cmp1 enable

This bit enables the tim_brk2_cmp1 for the timer's tim_brk2 input. tim_brk2_cmp1 output is 'ORed' with the other tim_brk2 sources.

0: tim_brk2_cmp1 input disabled

1: tim_brk2_cmp1 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 0 **BK2INE**: TIMx_BKIN2 input enable

This bit enables the TIMx_BKIN2 alternate function input for the timer's tim_brk2 input. TIMx_BKIN2 input is 'ORed' with the other tim_brk2 sources.

0: TIMx_BKIN2 input disabled

1: TIMx_BKIN2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Refer to Section 49.3.2: TIM1/TIM8 pins and internal signals for product specific implementation.

49.6.29 TIMx DMA control register (TIMx_DCR)(x = 1, 8)

Address offset: 0x3DC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBSS[3:0]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:16 **DBSS[3:0]**: DMA burst source selection

This bitfield defines the interrupt source that triggers the DMA burst transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address).

0000: Reserved
0001: Update
0010: CC1
0011: CC2
0100: CC3
0101: CC4
0110: COM
0111: Trigger
Others: reserved

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **DBL[4:0]**: DMA burst length

This 5-bit vector defines the length of DMA transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address), i.e. the number of transfers. Transfers can be in half-words or in bytes (see example below).

00000: 1 transfer
00001: 2 transfers
00010: 3 transfers
...
11010: 26 transfers

Example: Let us consider the following transfer: DBL = 7 bytes & DBA = TIM2_CR1.

–If DBL = 7 bytes and DBA = TIM2_CR1 represents the address of the byte to be transferred, the address of the transfer is given by the following equation:

(TIMx_CR1 address) + DBA + (DMA index), where DMA index = DBL

In this example, 7 bytes are added to (TIMx_CR1 address) + DBA, which gives us the address from/to which the data are copied. In this case, the transfer is done to 7 registers starting from the following address: (TIMx_CR1 address) + DBA

According to the configuration of the DMA Data Size, several cases may occur:

–If the DMA Data Size is configured in half-words, 16-bit data are transferred to each of the 7 registers.

–If the DMA Data Size is configured in bytes, the data are also transferred to 7 registers: the first register contains the first MSB byte, the second register, the first LSB byte and so on. So with the transfer Timer, one also has to specify the size of data transferred by DMA.

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **DBA[4:0]**: DMA base address

This 5-bits vector defines the base-address for DMA transfers (when read/write access are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register.

Example:

00000: TIMx_CR1
00001: TIMx_CR2
00010: TIMx_SMCR
...

49.6.30 TIMx DMA address for full transfer (TIMx_DMAR)(x = 1, 8)

Address offset: 0x3E0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMAB[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAB[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DMAB[31:0]**: DMA register for burst accesses

A read or write operation to the DMAR register accesses the register located at the address (TIMx_CR1 address) + (DBA + DMA index) x 4

where TIMx_CR1 address is the address of the control register 1, DBA is the DMA base address configured in TIMx_DCR register, DMA index is automatically controlled by the DMA transfer, and ranges from 0 to DBL (DBL configured in TIMx_DCR).

49.6.31 TIMx register map

TIMx registers are mapped as 16-bit addressable registers as described in the table below:

Table 531. TIMx register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	TIMx_CR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DITHEN	UIFREMA	Res.	CKD [1:0]		ARPE	CMS [1:0]		DIR	OPM	URS	UDIS	CEN
	Reset value																				0	0		0	0	0	0	0	0	0	0	0	0
0x004	TIMx_CR2	Res.	Res.	Res.	Res.	Res.	Res.	MMS[3]	Res.	MMS2[3:0]				Res.	OIS6	Res.	OIS5	OIS4N	OIS4	OIS3N	OIS3	OIS2N	OIS2	OIS1N	OIS1	TI1S	MMS [2:0]			CCDS	CCUS	Res.	CCPC
	Reset value							0		0	0	0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
0x008	**TIMx_SMCR**	Res.	Res.	Res.	Res.	Res.	Res.	SMSPS	SMSPE	Res.	Res.	TS [4:3]		Res.	Res.	Res.	SMS[3]	ETP	ECE	ETP S [1:0]		ETF[3:0]				MSM	TS[2:0]			OCCS	SMS[2:0]		
	Reset value							0	0			0	0				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C	TIMx_DIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TERRIE	IERRIE	DIRIE	IDXIE	Res.	Res.	Res.	Res.	Res.	TDE	COMDE	CC4DE	CC3DE	CC2DE	CC1DE	UDE	BIE	TIE	COMIE	CC4IE	CC3IE	CC2IE	CC1IE	UIE
	Reset value									0	0	0	0						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x010	TIMx_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TERRF	IERRF	DIRF	IDXF	Res.	Res.	CC6IF	CC5IF	Res.	Res.	SBIF	CC4OF	CC3OF	CC2OF	CC1OF	B2IF	BIF	TIF	COMIF	CC4IF	CC3IF	CC2IF	CC1IF	UIF
	Reset value									0	0	0	0			0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	TIMx_EGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	B2G	BG	TG	COMG	CC4G	CC3G	CC2G	CC1G	UG
	Reset value																								0	0	0	0	0	0	0	0	0

Table 531. TIMx register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x018	TIMx_CCMR1 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC2F[3:0]				IC2 PSC [1:0]		CC2 S [1:0]		IC1F[3:0]				IC1 PSC [1:0]		CC1 S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TIMx_CCMR1 Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]	OC2CE	OC2M [2:0]			OC2PE	OC2FE	CC2 S [1:0]		OC1CE	OC1M [2:0]			OC1PE	OC1FE	CC1 S [1:0]	
	Reset value								0								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x01C	TIMx_CCMR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC4M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC3M[3]	OC4CE	OC4M [2:0]			OC4PE	OC4FE	CC4 S [1:0]		OC3CE	OC3M [2:0]			OC3PE	OC3FE	CC3 S [1:0]	
	Reset value								0								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TIMx_CCMR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC4F[3:0]				IC4 PSC [1:0]		CC4 S [1:0]		IC3F[3:0]				IC3 PSC [1:0]		CC3 S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	TIMx_CCER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC6P	CC6E	Res.	Res.	CC5P	CC5E	CC4NP	CC4NE	CC4P	CC4E	CC3NP	CC3NE	CC3P	CC3E	CC2NP	CC2NE	CC2P	CC2E	CC1NP	CC1NE	CC1P	CC1E
	Reset value											0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	TIMx_CNT	UIFCPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x028	TIMx_PSC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x02C	TIMx_ARR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:0]																			
	Reset value													0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x030	TIMx_RCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x034	TIMx_CCR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x038	TIMx_CCR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR2[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x03C	TIMx_CCR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR3[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x040	TIMx_CCR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR4[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x044	TIMx_BDTR	Res.	Res.	BK2BID	BKBID	BK2DSRM	BKDSRM	BK2P	BK2E	BK2F[3:0]				BKF[3:0]				MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK [1:0]		DT[7:0]							
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 531. TIMx register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x048	TIMx_CCR5	GC5C3	GC5C2	GC5C1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR5[19:0]																			
	Reset value	0	0	0										0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04C	TIMx_CCR6	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR6[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x050	TIMx_CCMR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC6M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC5M[3]	OC6CE	OC6M [2:0]			OC6PE	OC6FE	Res.	Res.	OC5CE	OC5M [2:0]			OC5PE	OC5FE	Res.	Res.
	Reset value								0								0	0	0	0	0	0	0			0	0	0	0	0	0		
0x054	TIMx_DTR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTPE	DTAE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTGF[7:0]							
	Reset value															0	0									0	0	0	0	0	0	0	0
0x058	TIMx_ECR	Res.	Res.	Res.	Res.	Res.	PWPRSC[2:0]			PW[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IPOS [1:0]		FIDX	IBLK [1:0]		IDIR [1:0]		IE
	Reset value						0	0	0	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0
0x05C	TIMx_TISEL	Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]				Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value					0	0	0	0					0	0	0	0					0	0	0	0					0	0	0	0
0x060	TIMx_AF1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res ETRSEL [3:0]				BKCMP4P	BKCMP3P	BKCMP2P	BKCMP1P	BKINP	BKCMP8E	BKCMP7E	BKCMP6E	BKCMP5E	BKCMP4E	BKCMP3E	BKCMP2E	BKCMP1E	BKINE
	Reset value															0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x064	TIMx_AF2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCRSEL [2:0]			Res.	Res.	BK2CMP4P	BK2CMP3P	BK2CMP2P	BK2CMP1P	BK2INP	BK2CMP8E	BK2CMP7E	BK2CMP6E	BK2CMP5E	BK2CMP4E	BK2CMP3E	BK2CMP2E	BK2CMP1E	BK2INE
	Reset value														0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x068.. 0x3D8	Reserved	Res.																															
0x3DC	TIMx_DCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBSS[3:0]				Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
	Reset value													0	0	0	0				0	0	0	0	0				0	0	0	0	0
0x3E0	TIMx_DMAR	DMAB[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

50 General-purpose timers (TIM2/TIM3/TIM4/TIM5)

50.1 TIM2/TIM3/TIM4/TIM5 introduction

The general-purpose timers consist of a 16-bit or 32-bit autoreload counter driven by a programmable prescaler.

They can be used for a variety of purposes, including measuring the pulse lengths of input signals (*input capture*) or generating output waveforms (*output compare and PWM*).

Pulse lengths and waveform periods can be modulated from a few microseconds to several milliseconds using the timer prescaler and the RCC clock controller prescalers.

The timers are completely independent, and do not share any resources. They can be synchronized together as described in *Section 50.4.23: Timer synchronization*.

50.2 TIM2/TIM3/TIM4/TIM5 main features

General-purpose TIMx timer features include:

- 16-bit or 32-bit up, down, up/down autoreload counter.
- 16-bit programmable prescaler used to divide (also “on the fly”) the counter clock frequency by any factor between 1 and 65535.
- Up to four independent channels for:
  - Input capture.
  - Output compare.
  - PWM generation (edge- and center-aligned modes).
  - One-pulse mode output.
- Synchronization circuit to control the timer with external signals and to interconnect several timers.
- Interrupt/DMA generation on the following events:
  - Update: counter overflow/underflow, counter initialization (by software or internal/external trigger).
  - Trigger event (counter start, stop, initialization, or count by internal/external trigger).
  - Input capture.
  - Output compare.
- Supports incremental (quadrature) encoder and hall-sensor circuitry for positioning purposes.
- Trigger input for external clock or cycle-by-cycle current management.

50.3 TIM2/TIM3/TIM4/TIM5 implementation

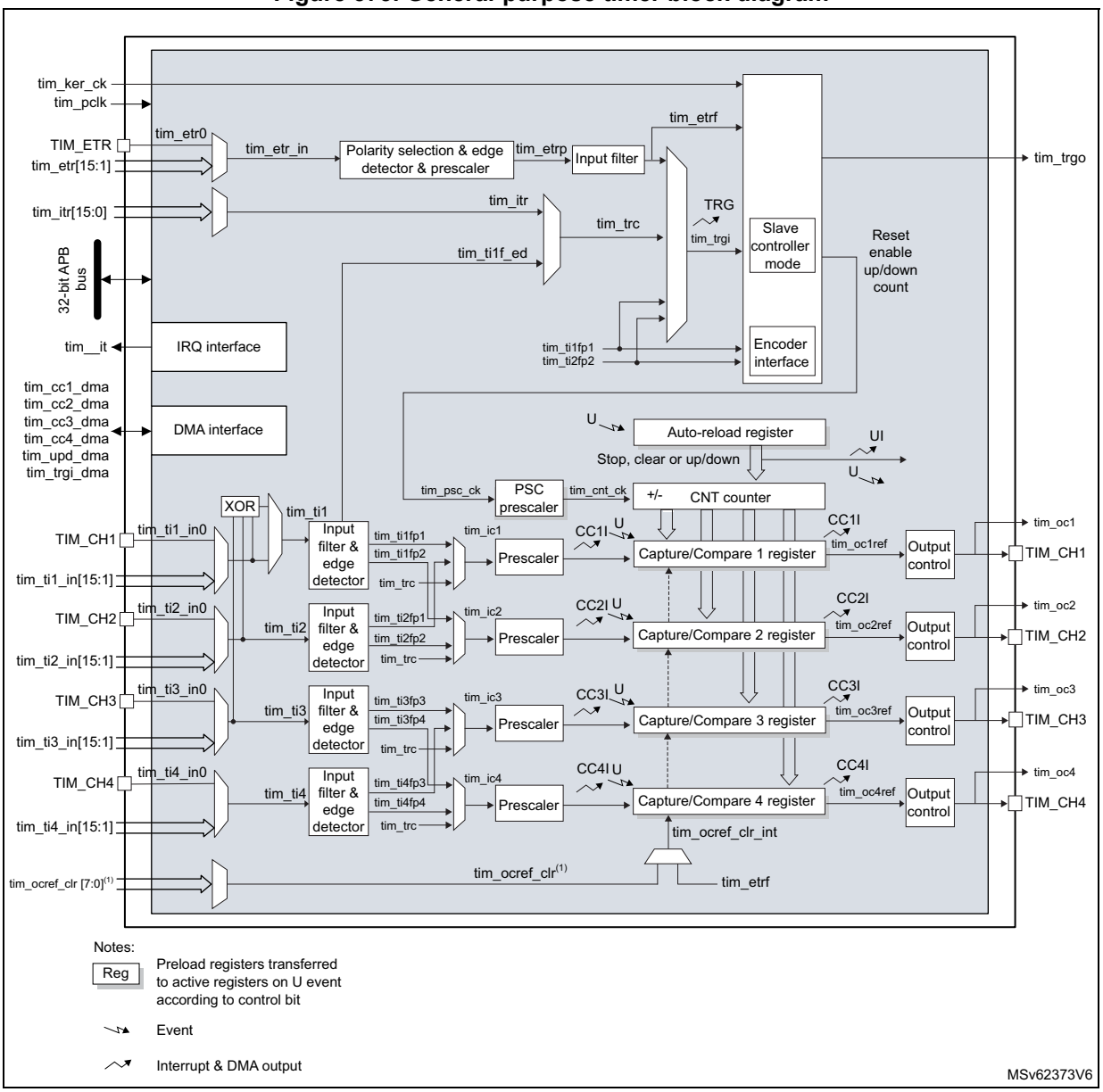
Table 532. STM32H5E4/5F4 and STM32H5E5/5F5 general purpose timers

Timer instance	TIM2	TIM3	TIM4	TIM5
Resolution	32-bit	16-bit	16-bit	32-bit
OCREF clear selection Sources	Yes tim_etrf tim_ocref_clr	Yes tim_etrf tim_ocref_clr	Yes tim_etrf tim_ocref_clr	Yes tim_etrf tim_ocref_clr

50.4 TIM2/TIM3/TIM4/TIM5 functional description

50.4.1 Block diagram

Figure 573. General-purpose timer block diagram



1. This feature is not available on all timers, refer to *Section 50.3: TIM2/TIM3/TIM4/TIM5 implementation*.

50.4.2 TIM2/TIM3/TIM4/TIM5 pins and internal signals

Table 533 and *Table 534* in this section summarize the TIM inputs and outputs.

Table 533. TIM input/output pins

Pin name	Signal type	Description
TIM_CH1 TIM_CH2 TIM_CH3 TIM_CH4	Input/Output	Timer multi-purpose channels. Each channel be used for capture, compare, or PWM. TIM_CH1 and TIM_CH2 can also be used as external clock (below 1/4 of the tim_ker_ck clock) , external trigger and quadrature encoder inputs. TIM_CH1, TIM_CH2 and TIM_CH3 can be used to interface with digital hall effect sensors.
TIM_ETR	Input	External trigger input. This input can be used as external trigger or as external clock source. This input can receive a clock with a frequency higher than the tim_ker_ck if the tim_etr_in prescaler is used.

Table 534. TIM internal input/output signals

Internal signal name	Signal type	Description
tim_ti1_in[15:0] tim_ti2_in[15:0] tim_ti3_in[15:0] tim_ti4_in[15:0]	Input	Internal timer inputs bus. The tim_ti1_in[15:0] and tim_ti2_in[15:0] inputs can be used for capture or as external clock (below 1/4 of the tim_ker_ck clock) and for quadrature encoder signals.
tim_etr[15:0]	Input	External trigger internal input bus. These inputs can be used as trigger, external clock or for hardware cycle-by-cycle pulse width control. These inputs can receive clock with a frequency higher than the tim_ker_ck if the tim_etr_in prescaler is used.
tim_itr[15:0]	Input	Internal trigger input bus. These inputs can be used for the slave mode controller or as a input clock (below 1/4 of the tim_ker_ck clock).
tim_trgo	Output	Internal trigger output. This trigger can trigger other on-chip peripherals.
tim_ocref_clr[7:0]	Input	Timer tim_ocref_clr input bus. These inputs can be used to clear the tim_ocxref signals, typically for hardware cycle-by-cycle pulse width control.
tim_pclk	Input	Timer APB clock.
tim_ker_ck	Input	Timer kernel clock

Table 534. TIM internal input/output signals (continued)

Internal signal name	Signal type	Description
tim_it	Output	Global Timer interrupt, gathering capture/compare, update and break trigger requests.
tim_cc1_dma tim_cc2_dma tim_cc3_dma tim_cc4_dma	Output	Timer capture/compare [4:1] dma requests.
tim_upd_dma	Output	Timer update dma request.
tim_trgi_dma	Output	Timer trigger dma request.

Table 535, *Table 536*, *Table 537* and *Table 538* are listing the sources connected to the tim_ti[4:1] input multiplexers.

Table 535. Interconnect to the tim_ti1 input multiplexer

tim_ti1 inputs	Sources			
	TIM2	TIM3	TIM4	TIM5
tim_ti1_in0	TIM2_CH1	TIM3_CH1	TIM4_CH1	TIM5_CH1
tim_ti1_in1	eth_ptp_pps_o	eth_ptp_pps_o	Reserved	Reserved
tim_ti1_in2	comp1_out	comp1_out	comp1_out	comp1_out
tim_ti1_in3	comp2_out	comp2_out	comp2_out	comp2_out
tim_ti1_in4	play1_out3	play1_out3	Reserved	Reserved
tim_ti1_in[15:5]	Reserved			

Table 536. Interconnect to the tim_ti2 input multiplexer

tim_ti2 inputs	Sources			
	TIM2	TIM3	TIM4	TIM5
tim_ti2_in0	TIM2_CH2	TIM3_CH2	TIM4_CH2	TIM5_CH2
tim_ti2_in1	comp1_out	comp1_out	Reserved	Reserved
tim_ti2_in2	comp2_out	comp2_out	Reserved	Reserved
tim_ti2_in3	play1_out4	play1_out4	Reserved	Reserved
tim_ti2_in[15:3]	Reserved			

Table 537. Interconnect to the tim_ti3 input multiplexer

tim_ti3 inputs	Sources			
	TIM2	TIM3	TIM4	TIM5
tim_ti3_in0	TIM2_CH3	TIM3_CH3	TIM4_CH3	TIM5_CH3
tim_ti3_in[15:1]	Reserved			

Table 538. Interconnect to the tim_ti4 input multiplexer

tim_ti4 inputs	Sources			
	TIM2	TIM3	TIM4	TIM5
tim_ti4_in0	TIM2_CH4	TIM3_CH4	TIM4_CH4	TIM5_CH4
tim_ti4_in[15:1]	Reserved			

Table 539 lists the internal sources connected to the tim_etr input multiplexer.

Table 539. TIMx internal trigger connection

TIMx	TIM2	TIM3	TIM4	TIM5
tim_itr0	tim1_trgo	tim1_trgo	tim1_trgo	tim1_trgo
tim_itr1	Reserved	tim2_trgo	tim2_trgo	tim2_trgo
tim_itr2	tim3_trgo	Reserved	tim3_trgo	tim3_trgo
tim_itr3	tim4_trgo	tim4_trgo	Reserved	tim4_trgo
tim_itr4	tim5_trgo	tim5_trgo	tim5_trgo	Reserved
tim_itr5	tim8_trgo	tim8_trgo	tim8_trgo	tim8_trgo
tim_itr6	tim12_trgo	tim12_trgo	tim12_trgo	tim12_trgo
tim_itr7	tim13_oc1	tim13_oc1	tim13_oc1	tim13_oc1
tim_itr8	tim14_oc1	tim14_oc1	tim14_oc1	tim14_oc1
tim_itr9	tim15_trgo	tim15_trgo	tim15_trgo	tim15_trgo
tim_itr10	tim16_oc1	tim16_oc1	tim16_oc1	tim16_oc1
tim_itr11	tim17_oc1	tim17_oc1	tim17_oc1	tim17_oc1
tim_itr12	Reserved			
tim_itr[15:13]	Reserved			

Table 540 lists the internal sources connected to the tim_etr input multiplexer.

Table 540. Interconnect to the tim_etr input multiplexer

Timer external trigger input signal	Timer external trigger signals assignment			
	TIM2	TIM3	TIM4	TIM5
tim_etr0	TIM2_ETR	TIM3_ETR	TIM4_ETR	TIM5_ETR
tim_etr1	comp1_out	comp1_out	comp1_out	sai2_fs_a
tim_etr2	comp2_out	comp2_out	comp2_out	sai2_fs_b
tim_etr3	RCC_LSE	adc2_awd1_out	Reserved	Reserved
tim_etr4	sai1_fs_a	adc2_awd2_out		
tim_etr5	sai1_fs_b	adc2_awd3_out		
tim_etr6	Reserved	Reserved		comp1_out
tim_etr7				comp2_out
tim_etr8		TIM2_ETR	TIM2_ETR	TIM2_ETR
tim_etr9	TIM3_ETR	Reserved	TIM3_ETR	TIM3_ETR
tim_etr10	TIM4_ETR	TIM4_ETR	Reserved	TIM4_ETR
tim_etr11	TIM5_ETR	TIM5_ETR	TIM5_ETR	Reserved
tim_etr12	otg_hs_sof	Reserved	Reserved	otg_hs_sof
tim_etr13	otg_fs_sof			otg_fs_sof
tim_etr14	eth_ptp_pps_o	eth_ptp_pps_o		Reserved
tim_etr15	play1_out0	play1_out0		

Table 541. Interconnect to the tim_ocref_clr input multiplexer

Timer OCREF clear signal	Timer OCREF clear signal assignment	
	TIM2	TIM3
tim_ocref_clr0	COMP1_OUT	COMP1_OUT
im_ocref_clr1	COMP2_OUT	COMP2_OUT
tim_ocref_clr[7:2]	Reserved	Reserved

50.4.3 Time-base unit

The main block of the programmable timer is a 16-bit/32-bit counter with its related autoreload register. The counter can count up, down or both up and down. The counter clock can be divided by a prescaler.

The counter, the autoreload register and the prescaler register can be written or read by software. This is true even when the counter is running.

The time-base unit includes:

- Counter register (TIMx_CNT)
- Prescaler register (TIMx_PSC)
- Autoreload register (TIMx_ARR).

The autoreload register is preloaded. Writing to or reading from the autoreload register accesses the preload register. The content of the preload register is transferred into the shadow register permanently or at each update event (UEV), depending on the autoreload preload enable bit (ARPE) in TIMx_CR1 register. The update event is sent when the counter reaches the overflow (or underflow when down-counting) and if the UDIS bit equals 0 in the TIMx_CR1 register. It can also be generated by software. The generation of the update event is described in detail for each configuration.

The counter is clocked by the prescaler output tim_cnt_ck, which is enabled only when the counter enable bit (CEN) in TIMx_CR1 register is set (refer also to the slave mode controller description to get more details on counter enabling).

Note that the actual counter enable signal CNT_EN is set one clock cycle after CEN.

Prescaler description

The prescaler can divide the counter clock frequency by any factor between 1 and 65536. It is based on a 16-bit counter controlled through a 16-bit/32-bit register (in the TIMx_PSC register). It can be changed on the fly as this control register is buffered. The new prescaler ratio is taken into account at the next update event.

Figure 574 and *Figure 575* give some examples of the counter behavior when the prescaler ratio is changed on the fly:

Figure 574. Counter timing diagram with prescaler division change from 1 to 2

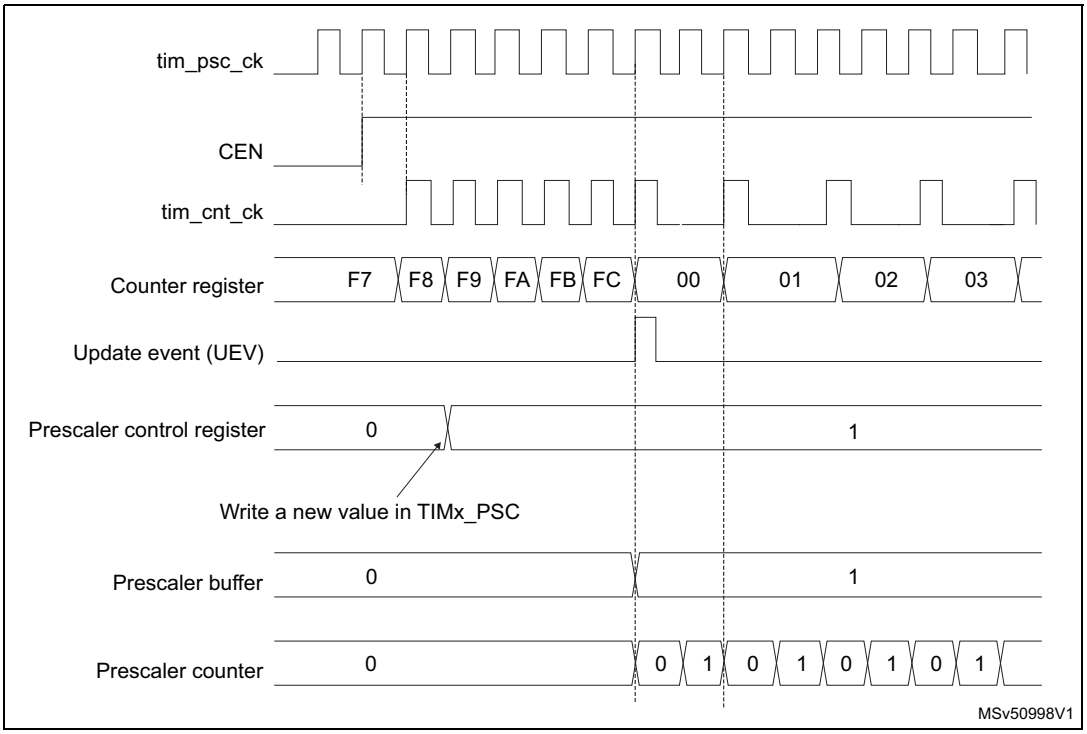
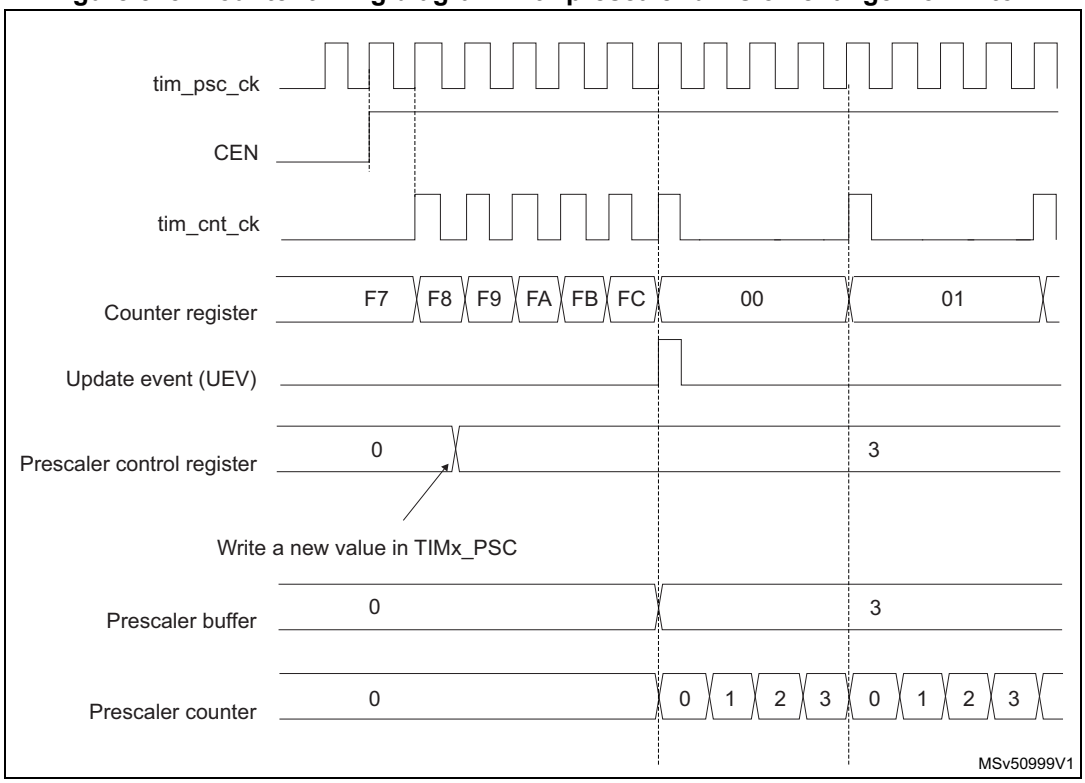


Figure 575. Counter timing diagram with prescaler division change from 1 to 4



50.4.4 Counter modes

Up-counting mode

In up-counting mode, the counter counts from 0 to the autoreload value (content of the TIMx_ARR register), then restarts from 0 and generates a counter overflow event.

An update event can be generated at each counter overflow or by setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller).

The UEV event can be disabled by software by setting the UDIS bit in TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter restarts from 0, as well as the counter of the prescaler (but the prescale rate does not change). In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).
- The autoreload shadow register is updated with the preload value (TIMx_ARR).

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR = 0x36.

Figure 576. Counter timing diagram, internal clock divided by 1

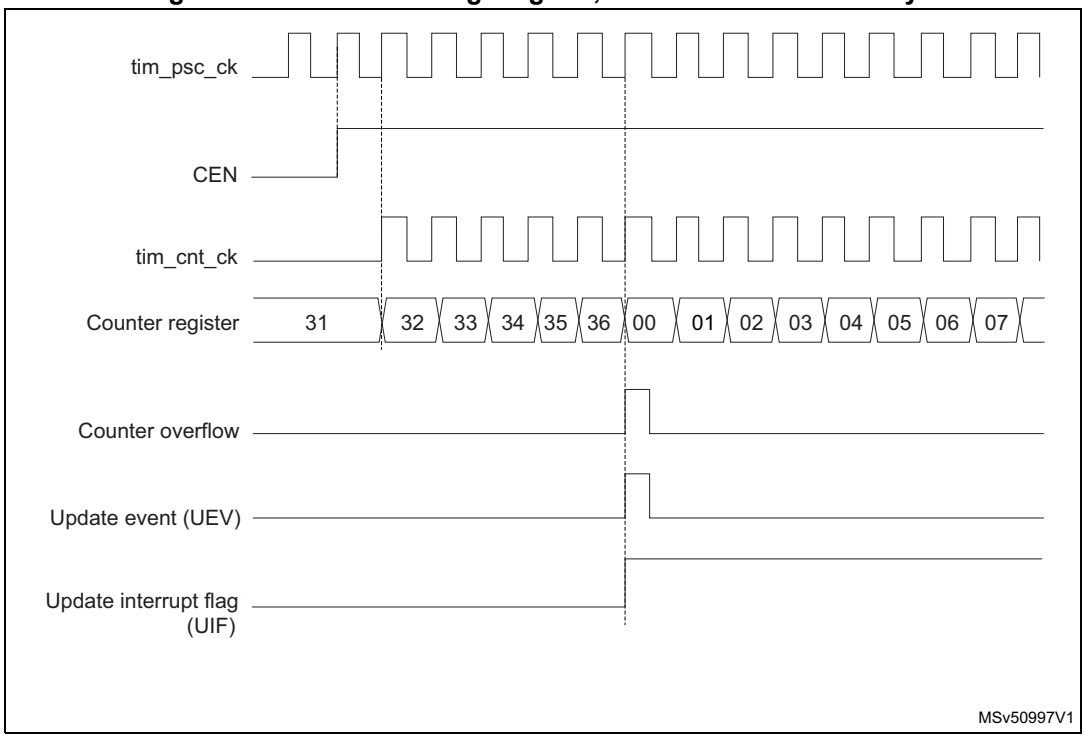


Figure 577. Counter timing diagram, internal clock divided by 2

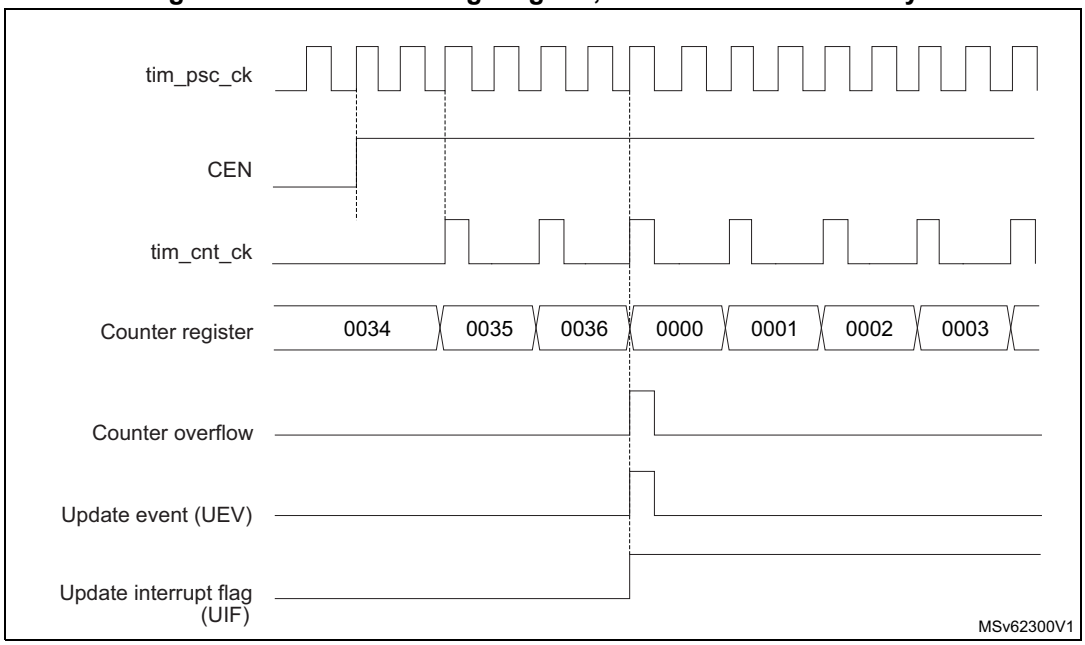


Figure 578. Counter timing diagram, internal clock divided by 4

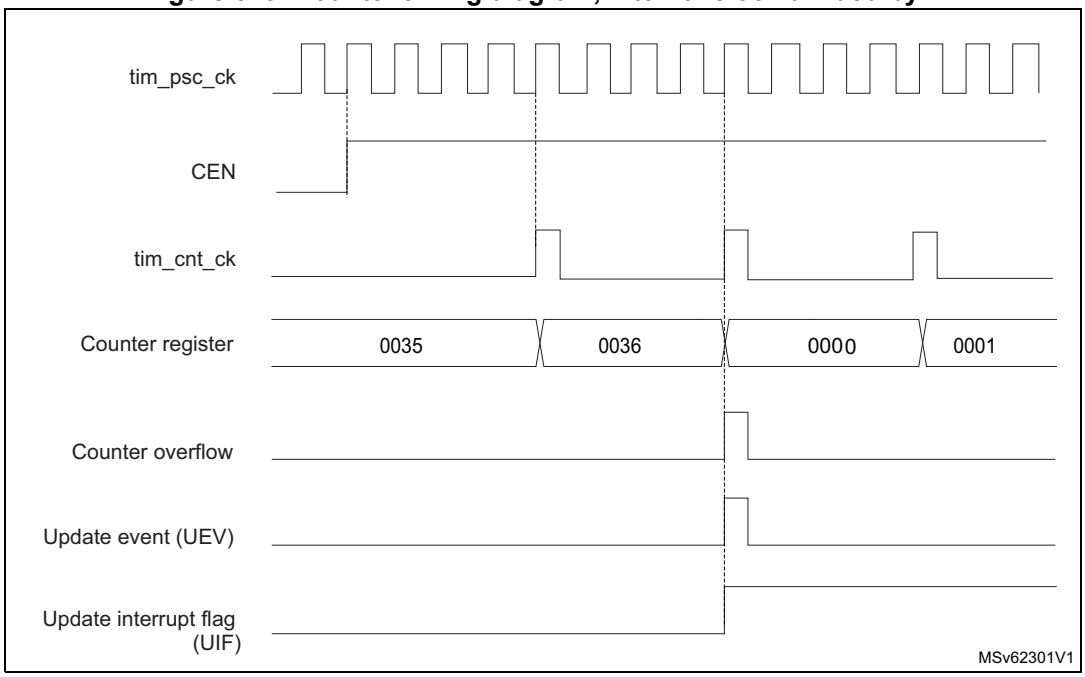


Figure 579. Counter timing diagram, internal clock divided by N

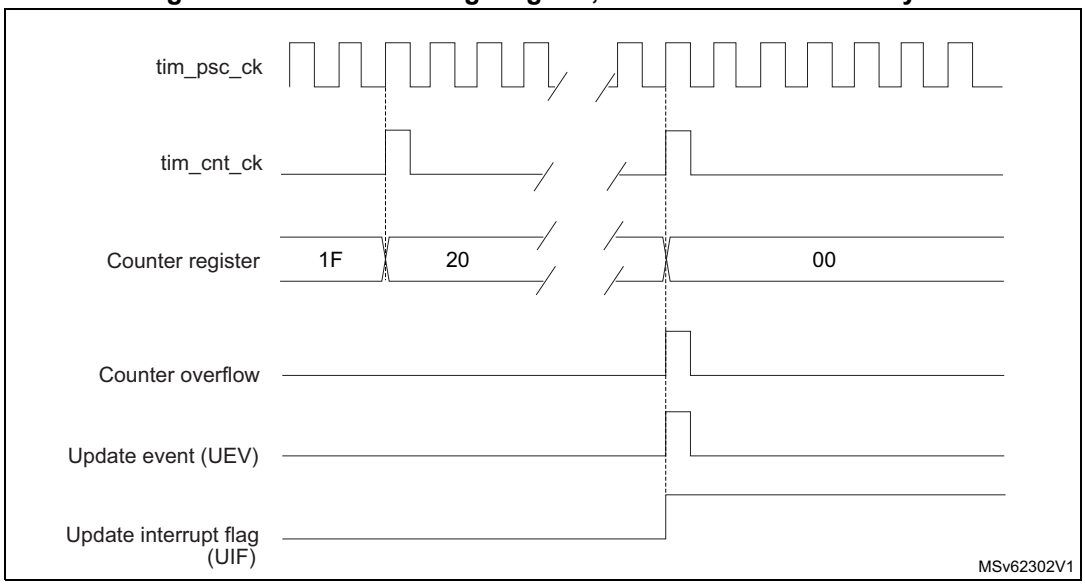


Figure 580. Counter timing diagram, Update event when ARPE = 0 (TIMx_ARR not preloaded)

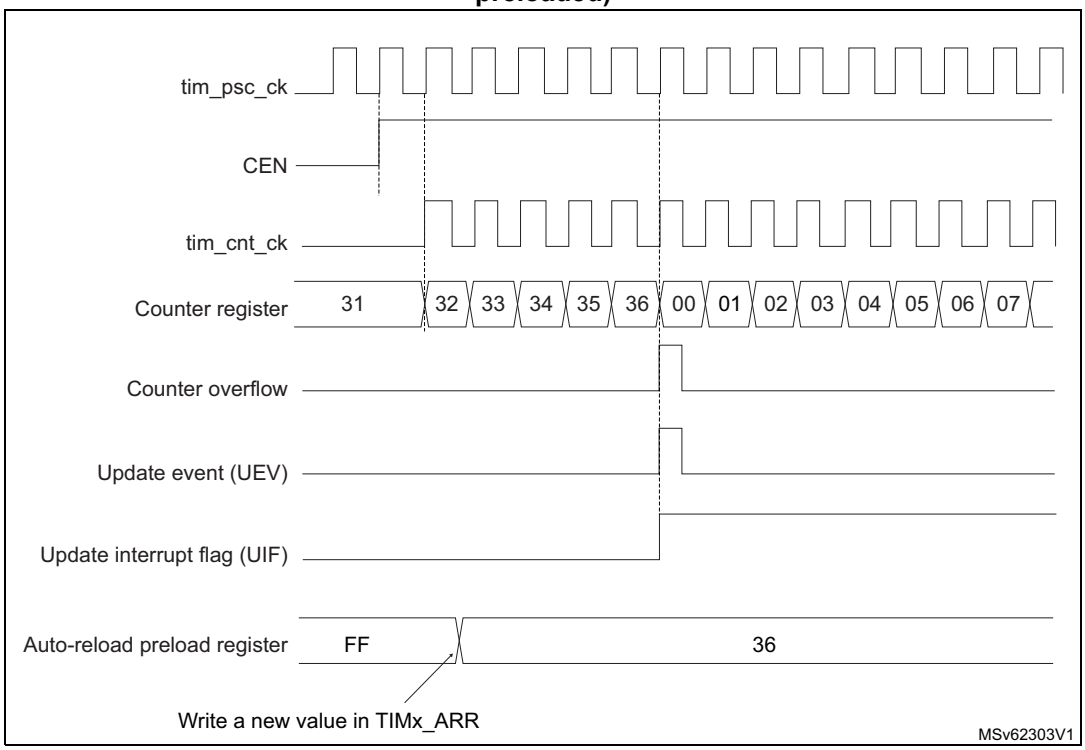
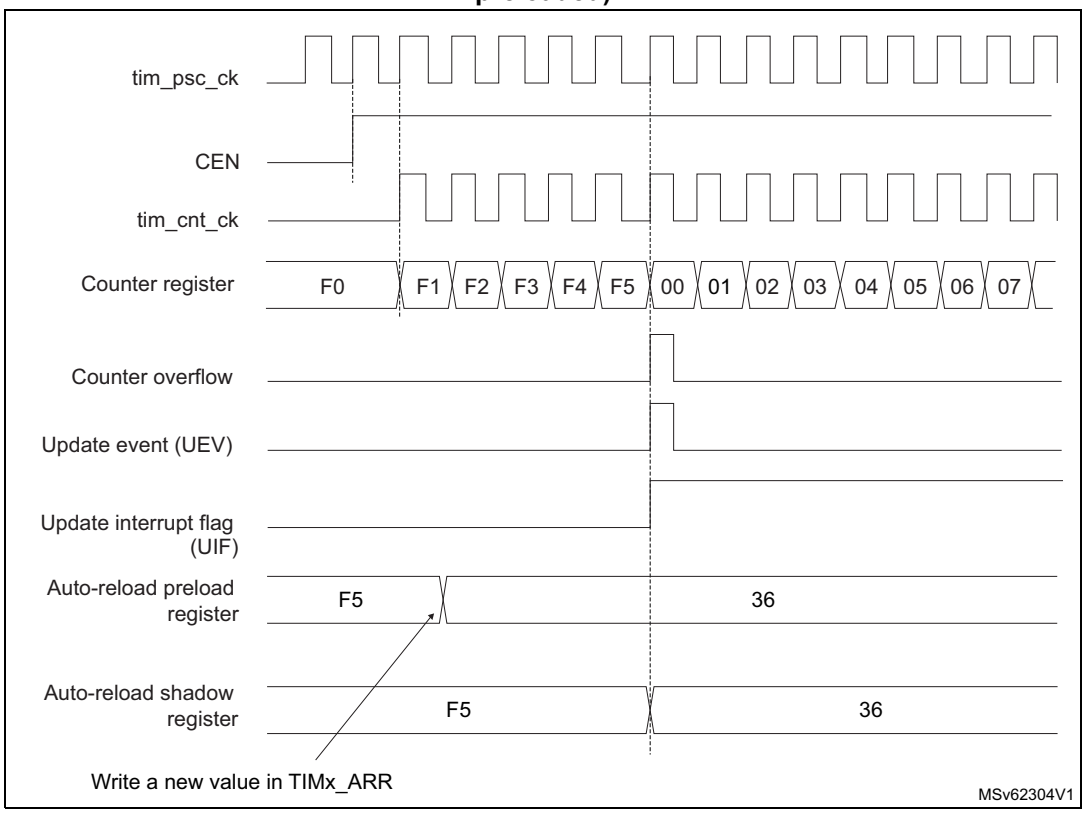


Figure 581. Counter timing diagram, Update event when ARPE = 1 (TIMx_ARR preloaded)



Down-counting mode

In down-counting mode, the counter counts from the autoreload value (content of the TIMx_ARR register) down to 0, then restarts from the autoreload value and generates a counter underflow event.

An update event can be generated at each counter underflow or by setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller)

The UEV update event can be disabled by software by setting the UDIS bit in TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until UDIS bit has been written to 0. However, the counter restarts from the current autoreload value, whereas the counter of the prescaler restarts from 0 (but the prescale rate does not change).

In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).
- The autoreload active register is updated with the preload value (content of the TIMx_ARR register). Note that the autoreload is updated before the counter is reloaded, so that the next period is the expected one.

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR = 0x36.

Figure 582. Counter timing diagram, internal clock divided by 1

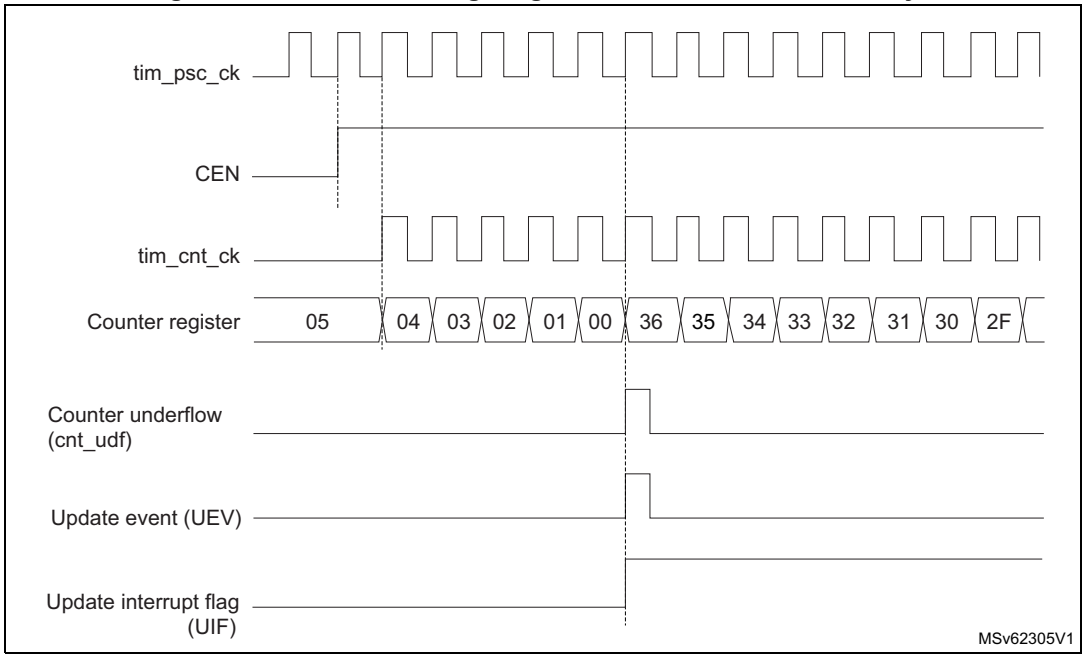


Figure 583. Counter timing diagram, internal clock divided by 2

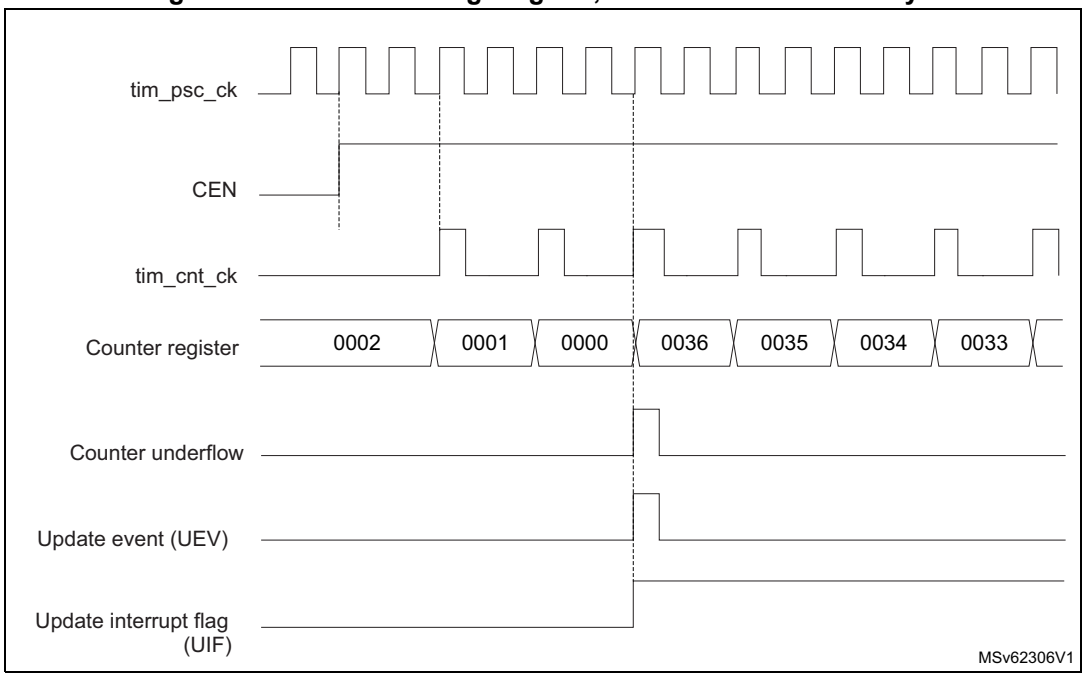


Figure 584. Counter timing diagram, internal clock divided by 4

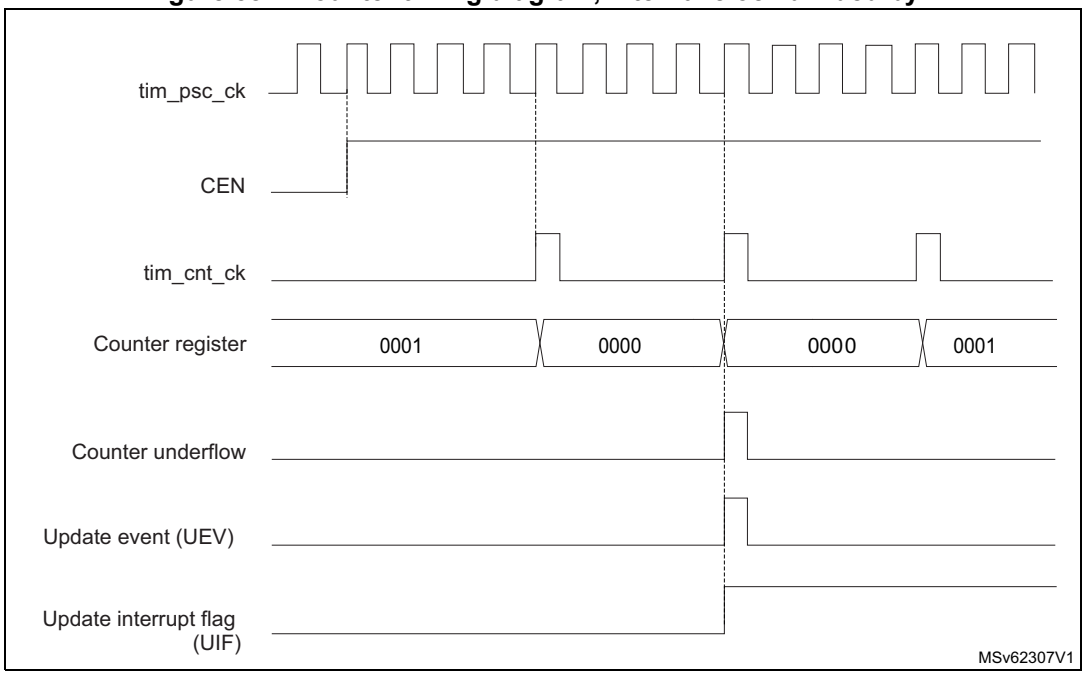


Figure 585. Counter timing diagram, internal clock divided by N

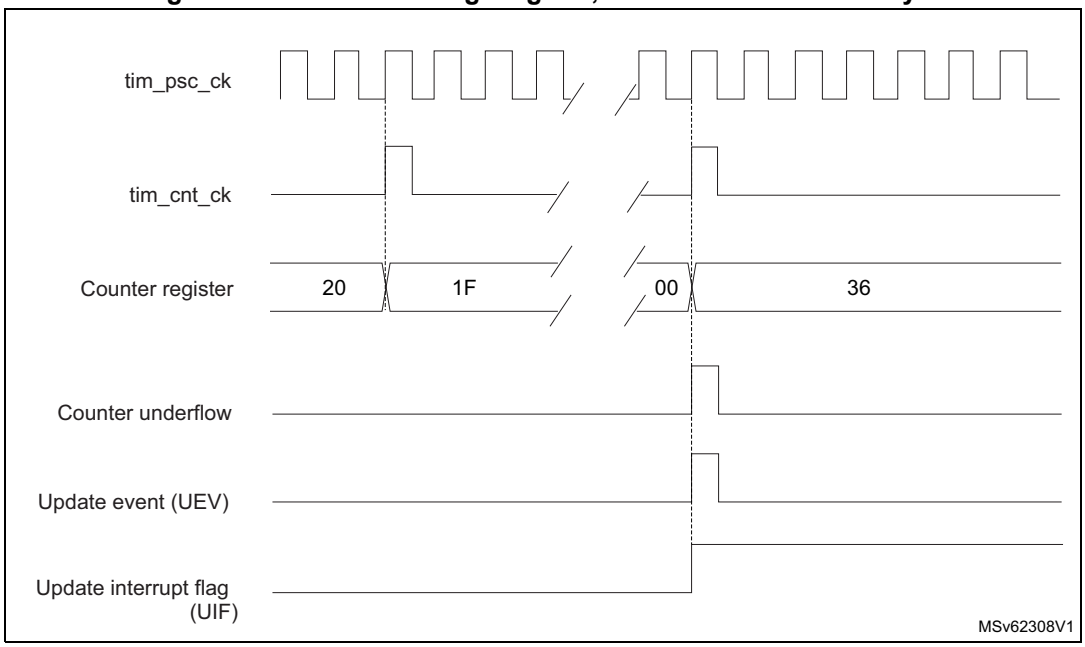
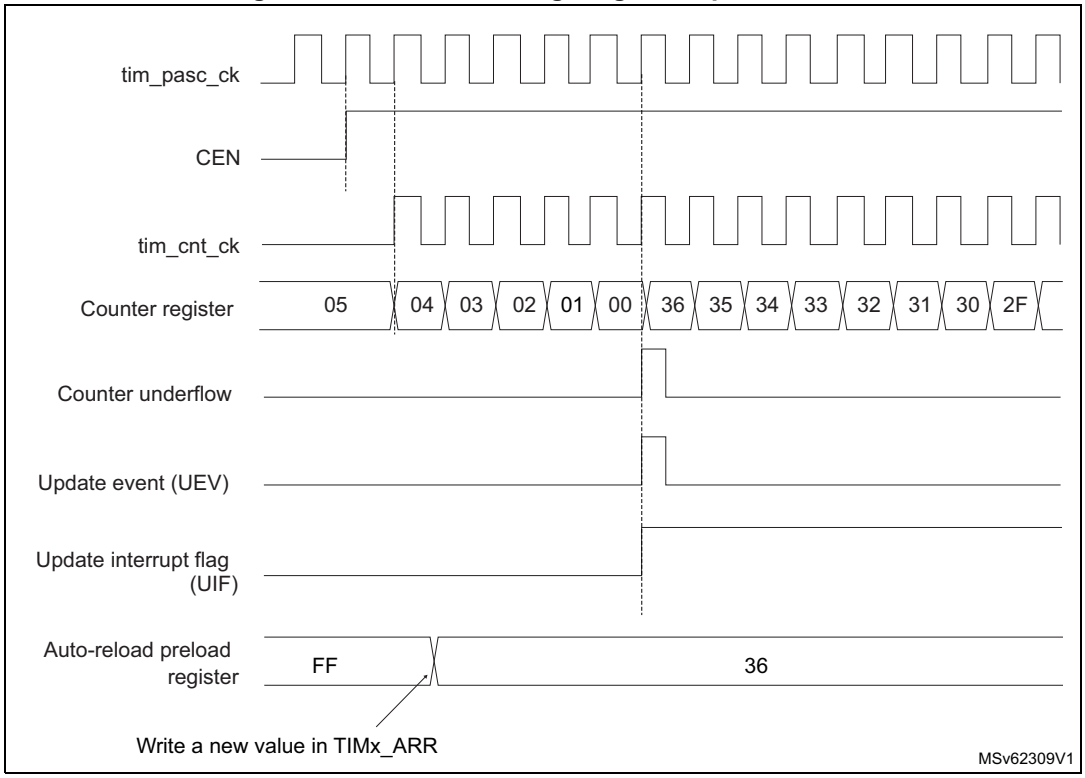


Figure 586. Counter timing diagram, Update event



Center-aligned mode (up/down-counting)

In center-aligned mode, the counter counts from 0 to the autoreload value (content of the TIMx_ARR register) – 1, generates a counter overflow event, then counts from the

autoreload value down to 1 and generates a counter underflow event. Then it restarts counting from 0.

Center-aligned mode is active when the CMS bits in TIMx_CR1 register are not equal to 00. The output compare interrupt flag of channels configured in output is set when: the counter counts down (Center aligned mode 1, CMS = 01), the counter counts up (Center aligned mode 2, CMS = 10) the counter counts up and down (Center aligned mode 3, CMS = 11).

In this mode, the direction bit (DIR from TIMx_CR1 register) cannot be written. It is updated by hardware and gives the current direction of the counter.

The update event can be generated at each counter overflow and at each counter underflow or by setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller) also generates an update event. In this case, the counter restarts counting from 0, as well as the counter of the prescaler.

The UEV update event can be disabled by software by setting the UDIS bit in TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter continues counting up and down, based on the current autoreload value.

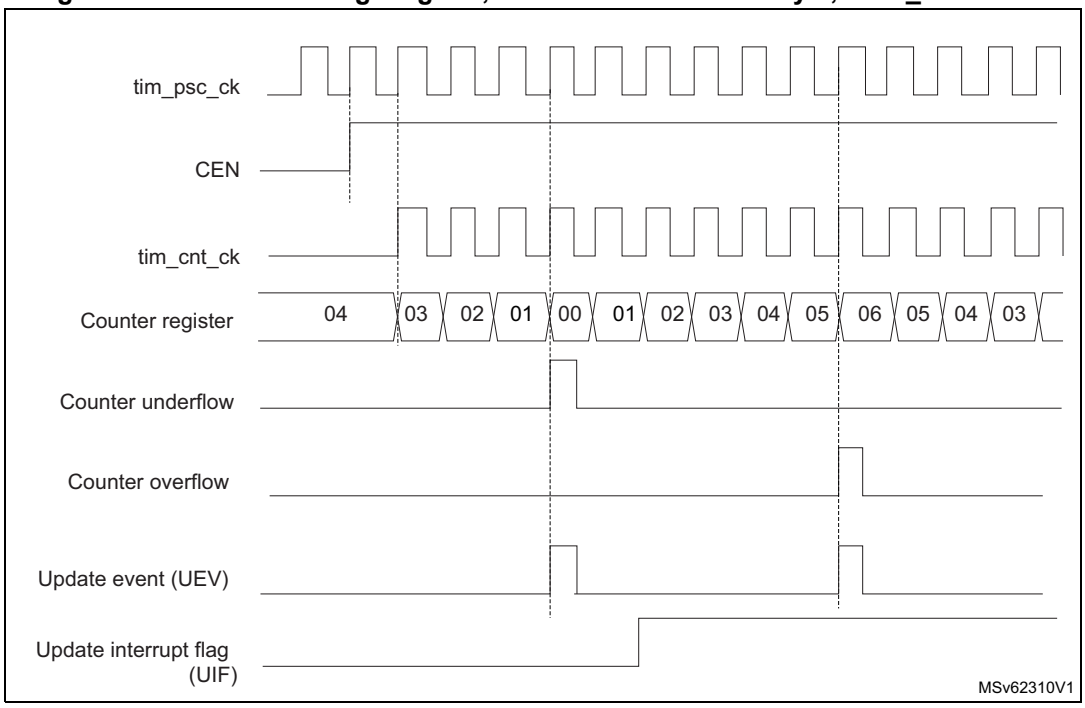
In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).
- The autoreload active register is updated with the preload value (content of the TIMx_ARR register). Note that if the update source is a counter overflow, the autoreload is updated before the counter is reloaded, so that the next period is the expected one (the counter is loaded with the new value).

The following figures show some examples of the counter behavior for different clock frequencies.

Figure 587. Counter timing diagram, internal clock divided by 1, TIMx_ARR = 0x6



1. Here, center-aligned mode 1 is used (for more details refer to *Section 50.5.1: TIMx control register 1 (TIMx_CR1)(x = 2 to 5)*).

Figure 588. Counter timing diagram, internal clock divided by 2

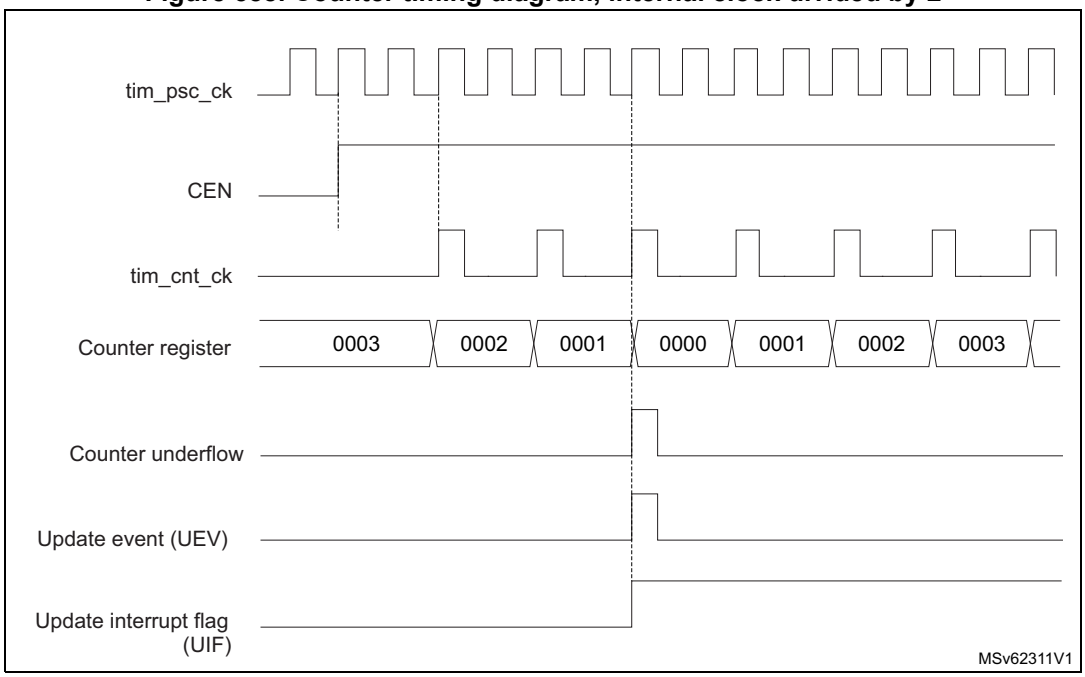
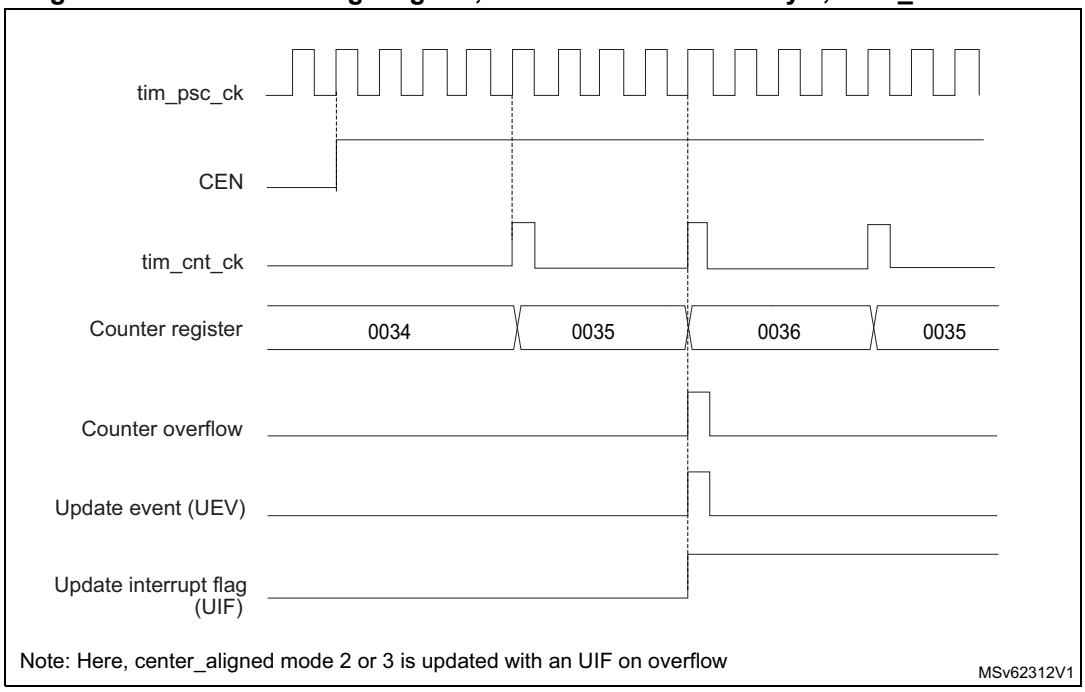


Figure 589. Counter timing diagram, internal clock divided by 4, TIMx_ARR = 0x36



1. Center-aligned mode 2 or 3 is used with a UIF on overflow.

Figure 590. Counter timing diagram, internal clock divided by N

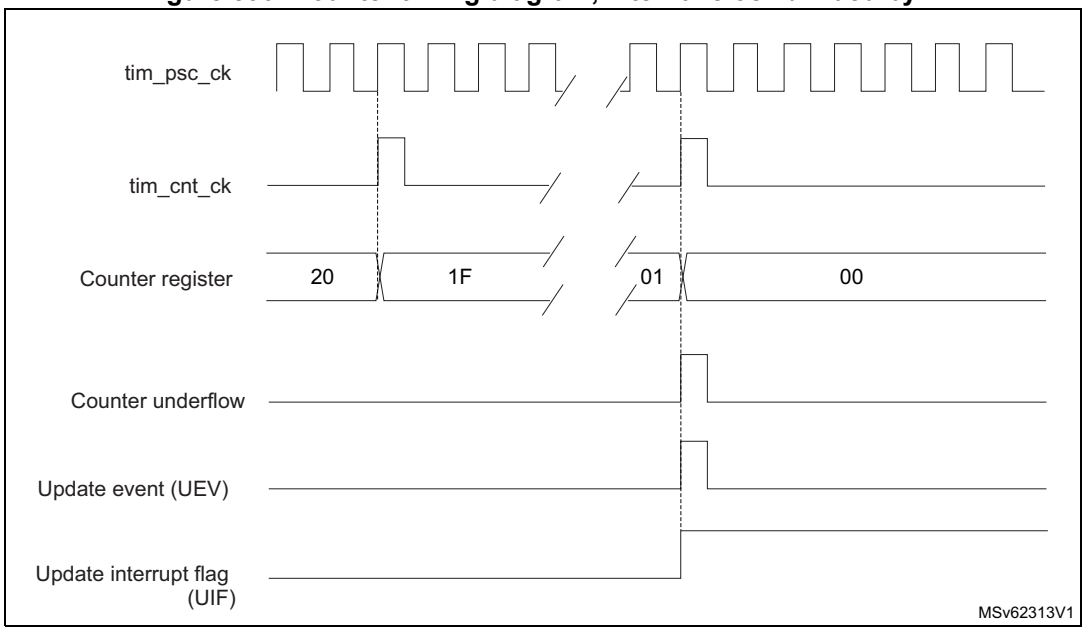


Figure 591. Counter timing diagram, Update event with ARPE = 1 (counter underflow)

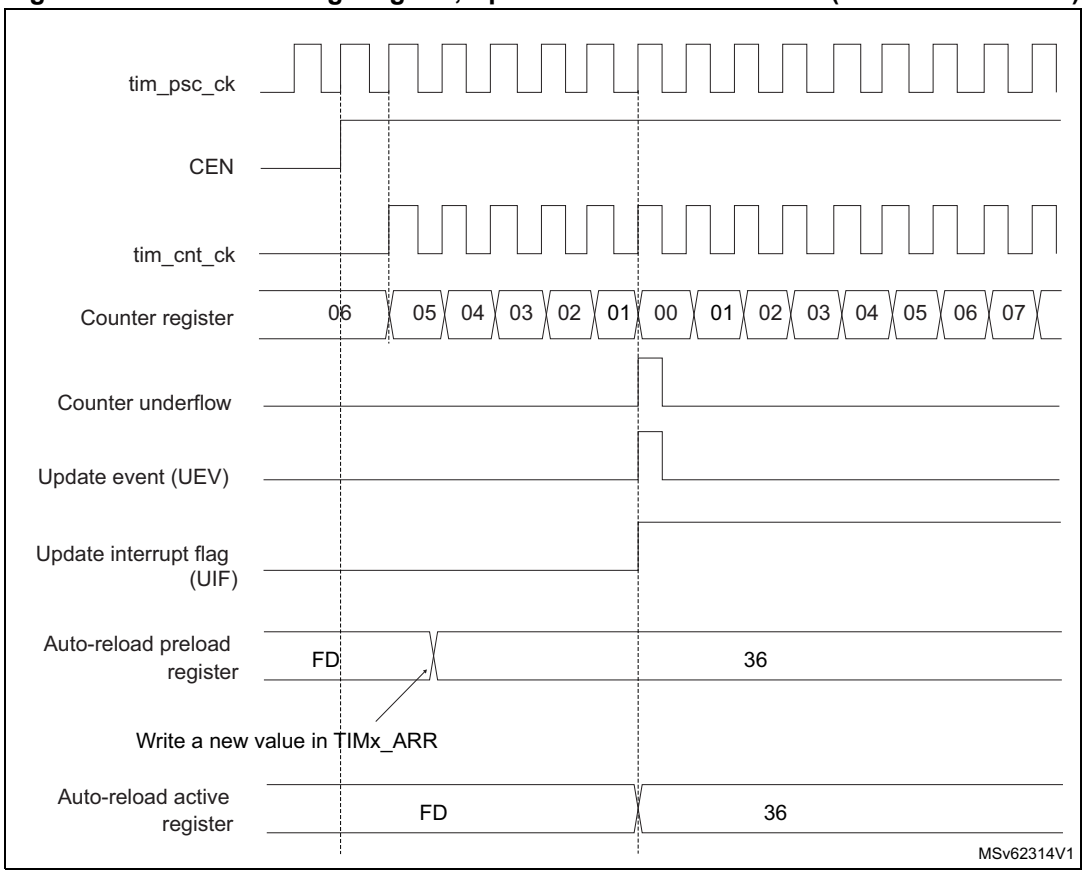
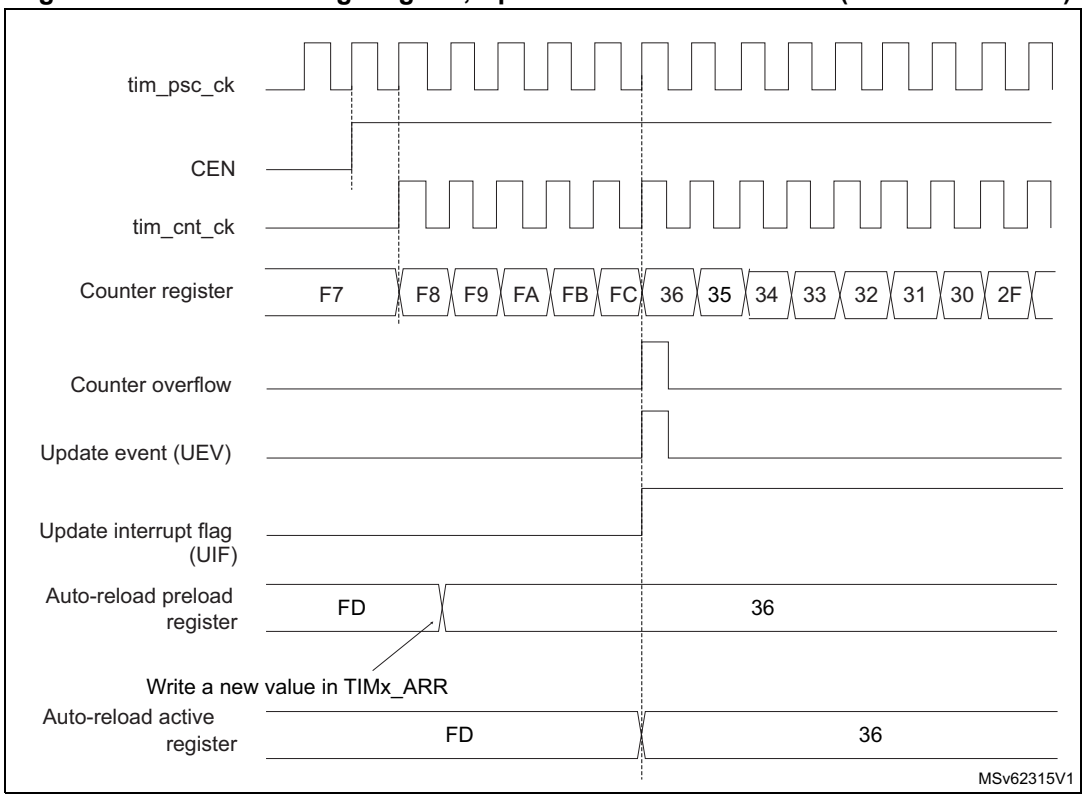


Figure 592. Counter timing diagram, Update event with ARPE = 1 (counter overflow)



50.4.5 Clock selection

The counter clock can be provided by the following clock sources:

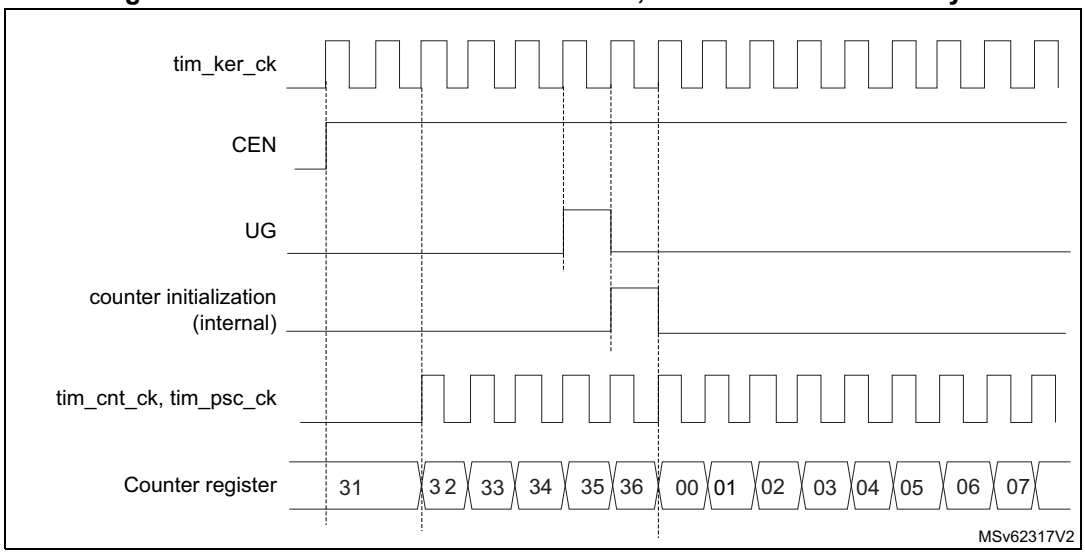
- Internal clock (tim_ker_ck).
- External clock mode1: external input pin (tim_ti1 or tim_ti2).
- External clock mode2: external trigger input (tim_etr_in).
- Internal trigger inputs (tim_itr): using one timer as prescaler for another timer, for example, timer 1 can be configured to act as a prescaler for timer 2. Refer to *Using one timer as prescaler for another timer* for more details.

Internal clock source (tim_ker_ck)

If the slave mode controller is disabled (SMS = 000 in the TIMx_SMCR register), then the CEN, DIR (in the TIMx_CR1 register), and UG bits (in the TIMx_EGR register) are actual control bits and can be changed only by software (except UG which remains cleared automatically). As soon as the CEN bit is written to 1, the prescaler is clocked by the internal clock tim_ker_ck.

Figure 593 shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

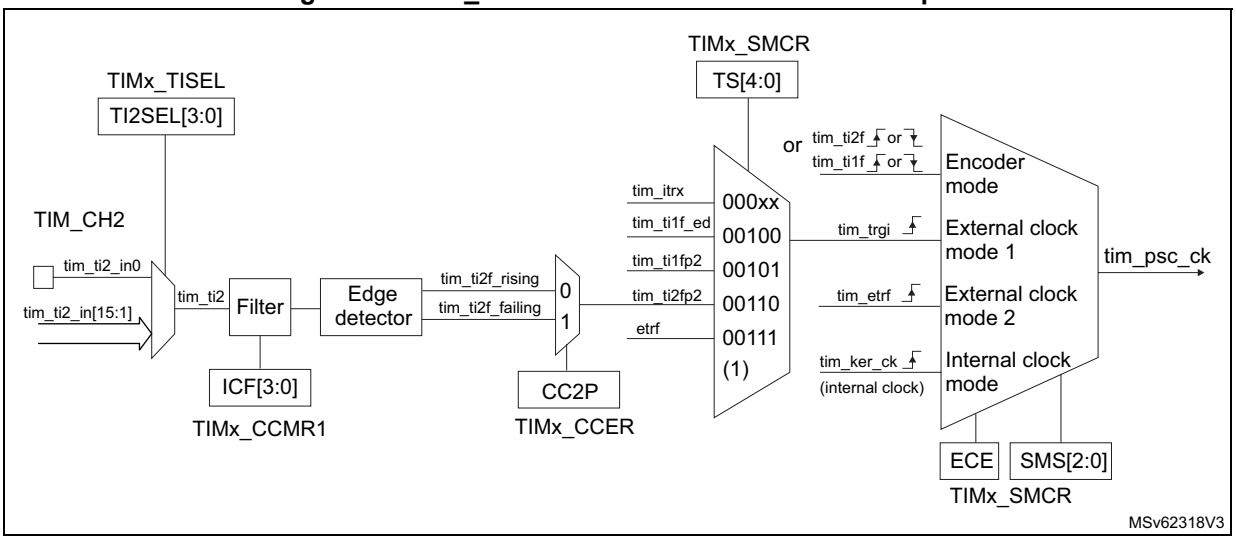
Figure 593. Control circuit in normal mode, internal clock divided by 1



External clock source mode 1

This mode is selected when SMS = 111 in the TIMx_SMCR register. The counter can count at each rising or falling edge on a selected input.

Figure 594. tim_ti2 external clock connection example



1. Codes ranging from 01000 to 11111: tim_itr[15:0].

For example, to configure the upcounter to count in response to a rising edge on the tim_ti2 input, use the following procedure:

1. Select the proper tim_ti2_in[15:0] source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Configure channel 2 to detect rising edges on the tim_ti2 input by writing CC2S= 01 in the TIMx_CCMR1 register.
3. Configure the input filter duration by writing the IC2F[3:0] bits in the TIMx_CCMR1 register (if no filter is needed, keep IC2F = 0000).

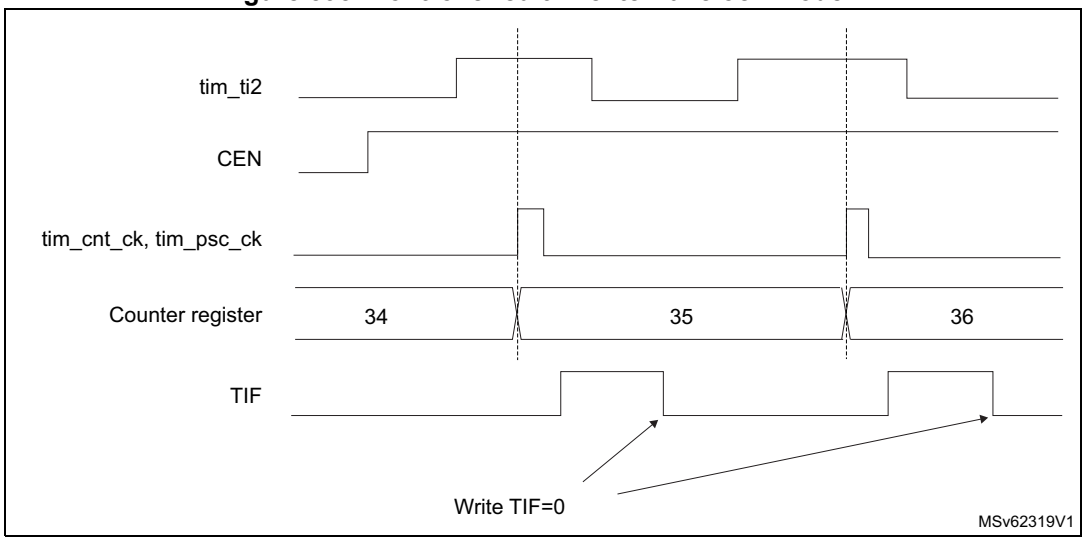
Note: The capture prescaler is not used for triggering, so it does not need to be configured.

4. Select rising edge polarity by writing CC2P = 0 and CC2NP = 0 in the TIMx_CCER register.
5. Configure the timer in external clock mode 1 by writing SMS = 111 in the TIMx_SMCR register.
6. Select tim_ti2 as the input source by writing TS = 00110 in the TIMx_SMCR register.
7. Enable the counter by writing CEN = 1 in the TIMx_CR1 register.

When a rising edge occurs on tim_ti2, the counter counts once and the TIF flag is set.

The delay between the rising edge on tim_ti2 and the actual clock of the counter is due to the resynchronization circuit on tim_ti2 input.

Figure 595. Control circuit in external clock mode 1



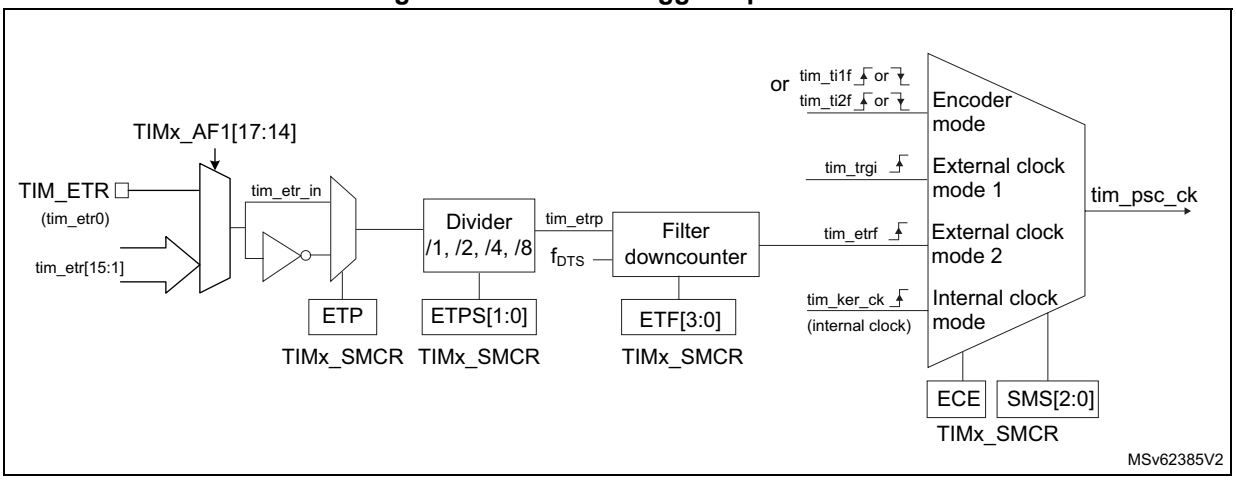
External clock source mode 2

This mode is selected by writing ECE = 1 in the TIMx_SMCR register.

The counter can count at each rising or falling edge on the external trigger input tim_etr_in.

Figure 596 gives an overview of the external trigger input block.

Figure 596. External trigger input block



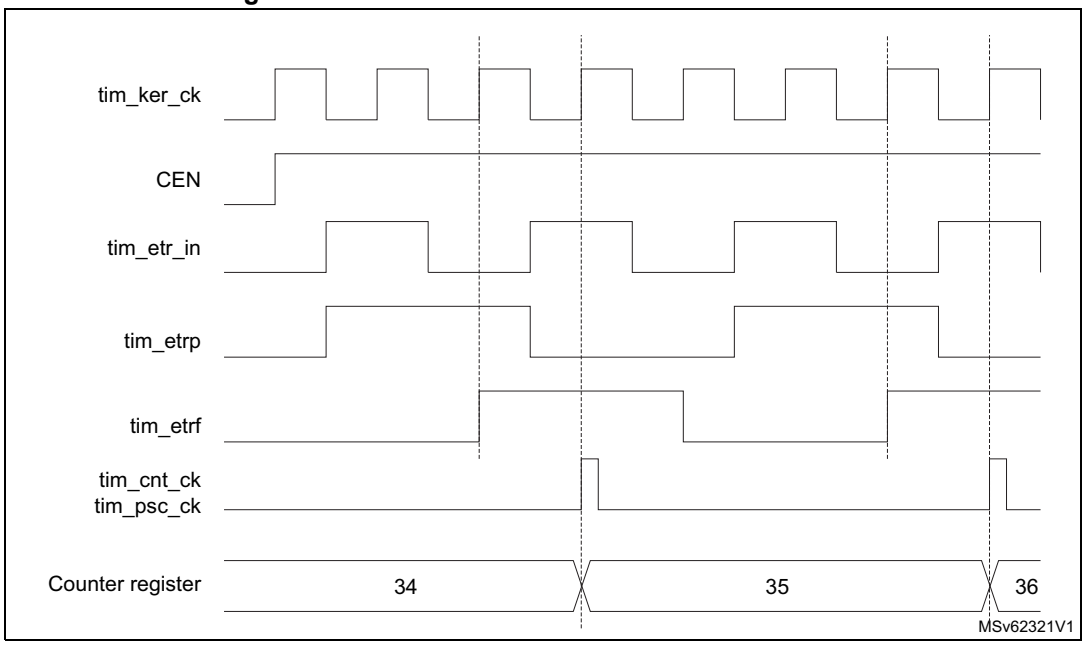
For example, to configure the upcounter to count each two rising edges on tim_etr_in, use the following procedure:

1. Select the proper tim_etr_in source (internal or external) with the ETRSEL[3:0] bits in the TIMx_AF1 register.
2. As no filter is needed in this example, write ETF[3:0] = 0000 in the TIMx_SMCR register.
3. Set the prescaler by writing ETPS[1:0] = 01 in the TIMx_SMCR register.
4. Select rising edge detection on the tim_etr_in by writing ETP = 0 in the TIMx_SMCR register.
5. Enable external clock mode 2 by writing ECE = 1 in the TIMx_SMCR register.
6. Enable the counter by writing CEN = 1 in the TIMx_CR1 register.

The counter counts once each two tim_etr_in rising edges.

The delay between the rising edge on tim_etr_in and the actual clock of the counter is due to the resynchronization circuit on the tim_etrp signal. As a consequence, the maximum frequency that can be correctly captured by the counter is at most ¼ of tim_ker_ck frequency. When the ETRP signal is faster, the user must apply a division of the external signal by a proper ETPS prescaler setting.

Figure 597. Control circuit in external clock mode 2



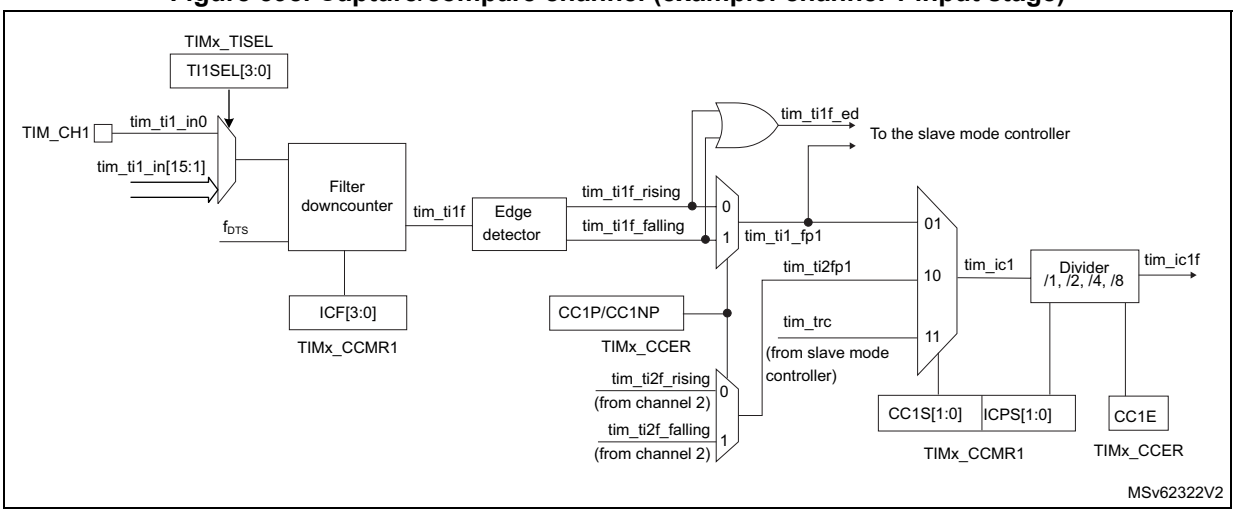
50.4.6 Capture/compare channels

Each Capture/Compare channel is built around a capture/compare register (including a shadow register), an input stage for capture (with digital filter, multiplexing and prescaler) and an output stage (with comparator and output control).

The following figure gives an overview of one Capture/Compare channel.

The input stage samples the corresponding tim_tix input to generate a filtered signal tim_tixf. Then, an edge detector with polarity selection generates a signal (tim_tixfpy) which can be used as trigger input by the slave mode controller or as the capture command. It is prescaled before the capture register (ICxPS).

Figure 598. Capture/compare channel (example: channel 1 input stage)



The output stage generates an intermediate waveform which is then used for reference: tim_ocxref (active high). The polarity acts at the end of the chain.

Figure 599. Capture/compare channel 1 main circuit

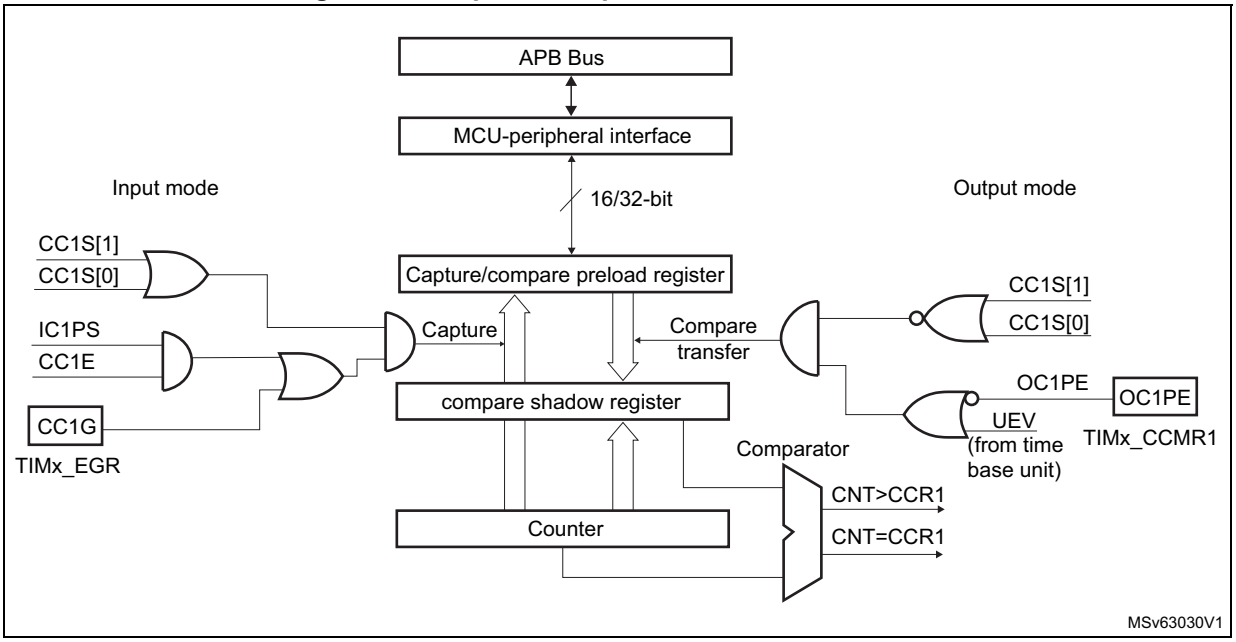
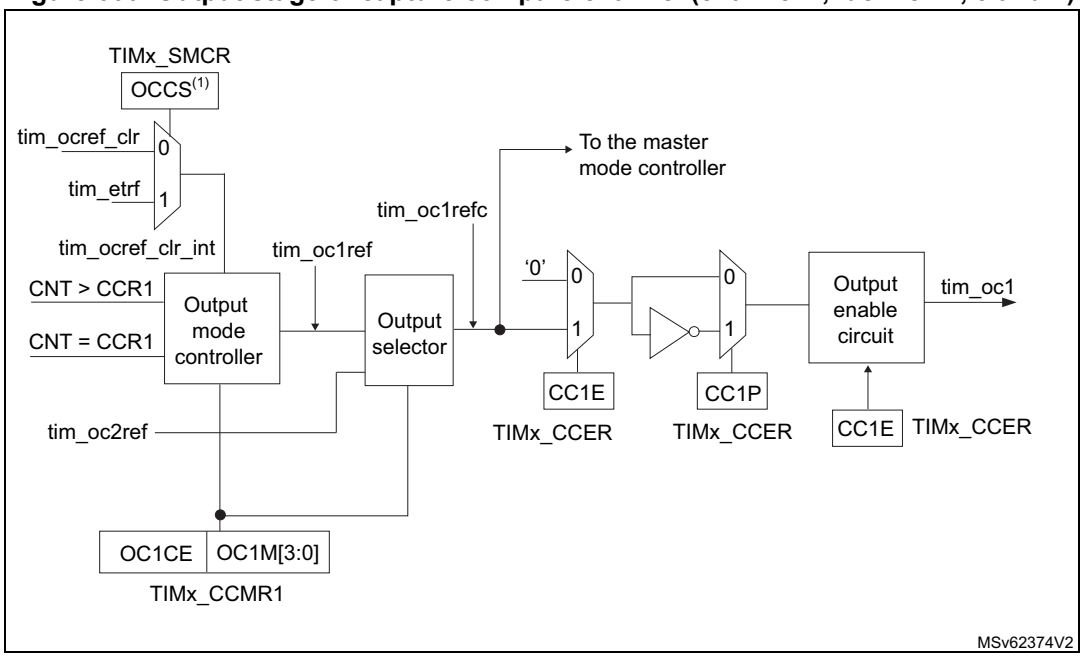


Figure 600. Output stage of capture/compare channel (channel 1, idem ch.2, 3 and 4)



1. Available on some instances only. If not available, tim_etrf is directly connected to tim_ocref_clr_int.

The capture/compare block is made of one preload register and one shadow register. Write and read always access the preload register.

In capture mode, captures are actually done in the shadow register, which is copied into the preload register.

In compare mode, the content of the preload register is copied into the shadow register which is compared to the counter.

50.4.7 Input capture mode

In input capture mode, the capture/compare registers (TIMx_CCRx) are used to latch the value of the counter after a transition detected by the corresponding ICx signal. When a capture occurs, the corresponding CCXIF flag (TIMx_SR register) is set and an interrupt or a DMA request can be sent if they are enabled. If a capture occurs while the CCxIF flag was already high, then the overcapture flag CCxOF (TIMx_SR register) is set. CCxIF can be cleared by software by writing it to 0 or by reading the captured data stored in the TIMx_CCRx register. CCxOF is cleared when it is written with 0.

The following example shows how to capture the counter value in TIMx_CCR1 when tim_ti1 input rises. To do this, use the following procedure:

1. Select the proper tim_tix_in[15:0] source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input: TIMx_CCR1 must be linked to the tim_ti1 input, so write the CC1S bits to 01 in the TIMx_CCMR1 register. As soon as CC1S becomes different from 00, the channel is configured in input and the TIMx_CCR1 register becomes read-only.
3. Program the needed input filter duration in relation with the signal connected to the timer (when the input is one of the tim_tix (ICxF bits in the TIMx_CCMRx register). Let's imagine that, when toggling, the input signal is not stable during at most five internal clock cycles. We must program a filter duration longer than these five clock cycles. We can validate a transition on tim_ti1 when eight consecutive samples with the new level have been detected (sampled at f_{DTS} frequency). Then write IC1F bits to 0011 in the TIMx_CCMR1 register.
4. Select the edge of the active transition on the tim_ti1 channel by writing the CC1P and CC1NP bits to 000 in the TIMx_CCER register (rising edge in this case).
5. Program the input prescaler. In this example, the capture is to be performed at each valid transition, so the prescaler is disabled (write IC1PS bits to 00 in the TIMx_CCMR1 register).
6. Enable capture from the counter into the capture register by setting the CC1E bit in the TIMx_CCER register.
7. If needed, enable the related interrupt request by setting the CC1IE bit in the TIMx_DIER register, and/or the DMA request by setting the CC1DE bit in the TIMx_DIER register.

When an input capture occurs:

- The TIMx_CCR1 register gets the value of the counter on the active transition.
- CC1IF flag is set (interrupt flag). CC1OF is also set if at least two consecutive captures occurred whereas the flag was not cleared.
- An interrupt is generated depending on the CC1IE bit.
- A DMA request is generated depending on the CC1DE bit.

In order to handle the overcapture, it is recommended to read the data before the overcapture flag. This is to avoid missing an overcapture which may happen after reading the flag and before reading the data.

Note: IC interrupt and/or DMA requests can be generated by software by setting the corresponding CCxG bit in the TIMx_EGR register.

50.4.8 PWM input mode

This mode is used to measure both the period and the duty cycle of a PWM signal connected to single tim_tix input:

- The TIMx_CCR1 register holds the period value (interval between two consecutive rising edges).
- The TIMx_CCR2 register holds the pulse width (interval between two consecutive rising and falling edges).

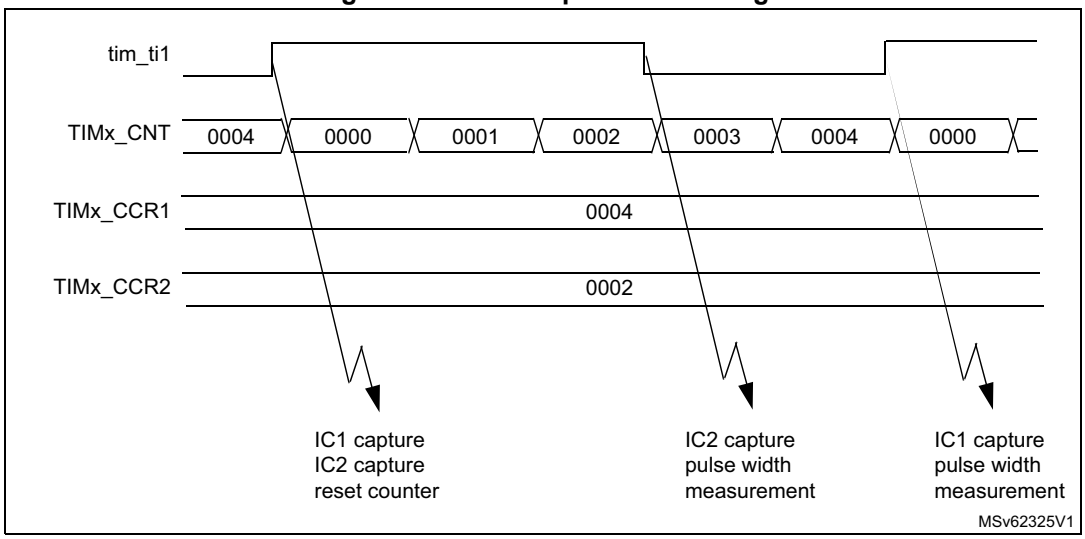
This mode is a particular case of input capture mode. The set-up procedure is similar with the following differences:

- Two ICx signals are mapped on the same tim_tix input.
- These two ICx signals are active on edges with opposite polarity.
- One of the two TIxFP signals is selected as trigger input and the slave mode controller is configured in reset mode.

The period and the pulse width of a PWM signal applied on tim_ti1 can be measured using the following procedure:

1. Select the proper tim_tix_in[15:0] source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input for TIMx_CCR1: write the CC1S bits to 01 in the TIMx_CCMR1 register (tim_ti1 selected).
3. Select the active polarity for tim_ti1fp1 (used both for capture in TIMx_CCR1 and counter clear): write the CC1P to 0 and the CC1NP bit to 0 (active on rising edge).
4. Select the active input for TIMx_CCR2: write the CC2S bits to 10 in the TIMx_CCMR1 register (tim_ti1 selected).
5. Select the active polarity for tim_ti1fp2 (used for capture in TIMx_CCR2): write the CC2P bit to 1 and the CC2NP bit to 0 (active on falling edge).
6. Select the valid trigger input: write the TS bits to 00101 in the TIMx_SMCR register (tim_ti1fp1 selected).
7. Configure the slave mode controller in reset mode: write the SMS bits to 100 in the TIMx_SMCR register.
8. Enable the captures: write the CC1E and CC2E bits to 1 in the TIMx_CCER register.

Figure 601. PWM input mode timing



1. The PWM input mode can be used only with the TIMx_CH1/TIMx_CH2 signals due to the fact that only tim_ti1fp1 and tim_ti2fp2 are connected to the slave mode controller.

50.4.9 Forced output mode

In output mode (CCxS bits = 00 in the TIMx_CCMRx register), each output compare signal (tim_ocxref and then tim_ocx) can be forced to active or inactive level directly by software, independently of any comparison between the output compare register and the counter.

To force an output compare signal (tim_ocxref/tim_ocx) to its active level, the user just needs to write 101 in the OCxM bits in the corresponding TIMx_CCMRx register. Thus tim_ocxref is forced high (tim_ocxref is always active high) and tim_ocx get opposite value to CCxP polarity bit.

For example: CCxP = 0 (tim_ocx active high) => tim_ocx is forced to high level.

tim_ocxref signal can be forced low by writing the OCxM bits to 100 in the TIMx_CCMRx register.

Anyway, the comparison between the TIMx_CCRx shadow register and the counter is still performed and allows the flag to be set. Interrupt and DMA requests can be sent accordingly. This is described in the Output Compare mode section.

50.4.10 Output compare mode

This function is used to control an output waveform or indicating when a period of time has elapsed.

When a match is found between the capture/compare register and the counter, the output compare function:

- Assigns the corresponding output pin to a programmable value defined by the output compare mode (OCxM bits in the TIMx_CCMRx register) and the output polarity (CCxP bit in the TIMx_CCER register). The output pin can keep its level (OCXM = 000), be set

active (OCxM = 001), be set inactive (OCxM = 010) or can toggle (OCxM = 011) on match.

- Sets a flag in the interrupt status register (CCxIF bit in the TIMx_SR register).
- Generates an interrupt if the corresponding interrupt mask is set (CCXIE bit in the TIMx_DIER register).
- Sends a DMA request if the corresponding enable bit is set (CCxDE bit in the TIMx_DIER register, CCDS bit in the TIMx_CR2 register for the DMA request selection).

The TIMx_CCRx registers can be programmed with or without preload registers using the OCxPE bit in the TIMx_CCMRx register.

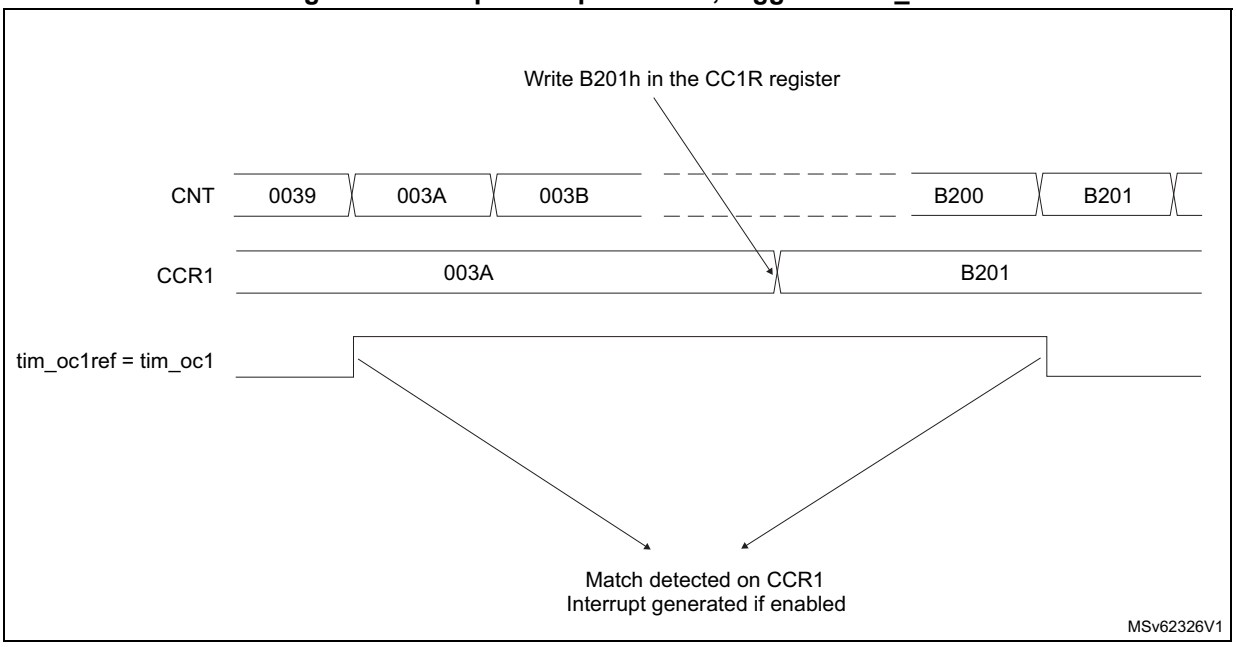
In output compare mode, the update event UEV has no effect on tim_ocxref and tim_ocx output. The timing resolution is one count of the counter. Output compare mode can also be used to output a single pulse (in One-pulse mode).

Procedure

1. Select the counter clock (internal, external, prescaler).
2. Write the desired data in the TIMx_ARR and TIMx_CCRx registers.
3. Set the CCxIE and/or CCxDE bits if an interrupt and/or a DMA request is to be generated.
4. Select the output mode. For example:
   a) Write OCxM = 0011 to toggle tim_ocx output pin when CNT matches CCRx.
   b) Write OCxPE = 0 to disable preload register.
   c) Write CCxP = 0 to select active high polarity.
   d) Write CCxE = 1 to enable the output.
5. Enable the counter by setting the CEN bit in the TIMx_CR1 register.

The TIMx_CCRx register can be updated at any time by software to control the output waveform, provided that the preload register is not enabled (OCxPE = 0, else TIMx_CCRx shadow register is updated only at the next update event UEV). An example is given in *Figure 602*.

Figure 602. Output compare mode, toggle on tim_oc1



50.4.11 PWM mode

Pulse width modulation mode is used to generate a signal with a frequency determined by the value of the TIMx_ARR register and a duty cycle determined by the value of the TIMx_CCRx register.

The PWM mode can be selected independently on each channel (one PWM per tim_ocx output) by writing 110 (PWM mode 1) or 111 (PWM mode 2) in the OCxM bits in the TIMx_CCMRx register. The corresponding preload register must be enabled by setting the OCxPE bit in the TIMx_CCMRx register, and eventually the autoreload preload register (in up-counting or center-aligned modes) by setting the ARPE bit in the TIMx_CR1 register.

As the preload registers are transferred to the shadow registers only when an update event occurs, before starting the counter, all registers must be initialized by setting the UG bit in the TIMx_EGR register.

tim_ocx polarity is software programmable using the CCxP bit in the TIMx_CCER register. It can be programmed as active high or active low. tim_ocx output is enabled by the CCxE bit in the TIMx_CCER register. Refer to the TIMx_CCERx register description for more details.

In PWM mode (1 or 2), TIMx_CNT and TIMx_CCRx are always compared to determine whether TIMx_CCRx ≤ TIMx_CNT or TIMx_CNT ≤ TIMx_CCRx (depending on the direction of the counter). The tim_ocref_clr can be cleared by an external event through the tim_etr_in or the tim_oceref_clr signals. In this case the tim_ocref_clr signal is asserted only:

- After a compare match event.
- When the output compare mode (OCxM bits in TIMx_CCMRx register) switches from the “frozen” configuration (no comparison, OCxM = 000) to one of the PWM modes (OCxM = 110 or 111). This forces the PWM by software while the timer is running.

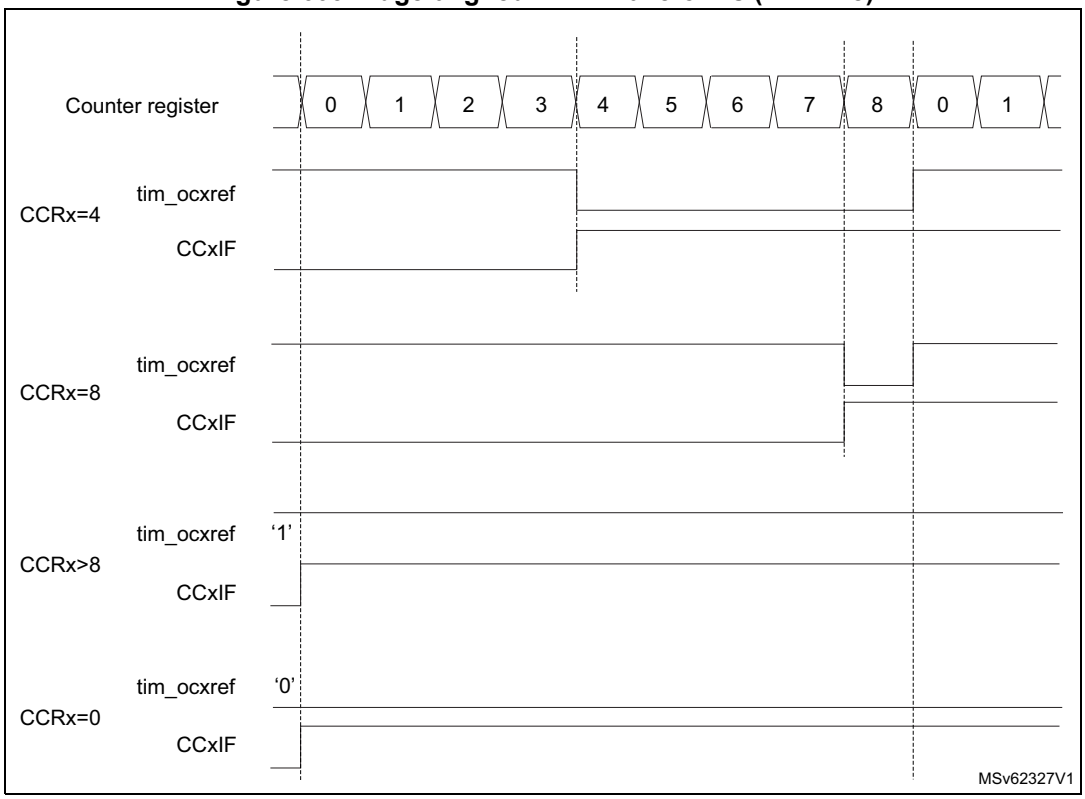
The timer is able to generate PWM in edge-aligned mode or center-aligned mode depending on the CMS bits in the TIMx_CR1 register.

PWM edge-aligned mode

- Up-counting configuration
- Up-counting is active when the DIR bit in the TIMx_CR1 register is low. Refer to *Up-counting mode*.

  In the following example, we consider PWM mode 1. The reference PWM signal tim_ocxref is high as long as TIMx_CNT <TIMx_CCRx else it becomes low. If the compare value in TIMx_CCRx is greater than the autoreload value (in TIMx_ARR) then tim_ocxref is held at 1. If the compare value is 0 then tim_ocxref is held at 0. *Figure 603* shows some edge-aligned PWM waveforms in an example where TIMx_ARR = 8.

Figure 603. Edge-aligned PWM waveforms (ARR = 8)



Down-counting configuration

- Down-counting is active when DIR bit in TIMx_CR1 register is high. Refer to *Down-counting mode*.

  In PWM mode 1, the reference signal tim_ocxref is low as long as TIMx_CNT>TIMx_CCRx else it becomes high. If the compare value in TIMx_CCRx is greater than the autoreload value in TIMx_ARR, then tim_ocxref is held at 100%. PWM is not possible in this mode.

PWM center-aligned mode

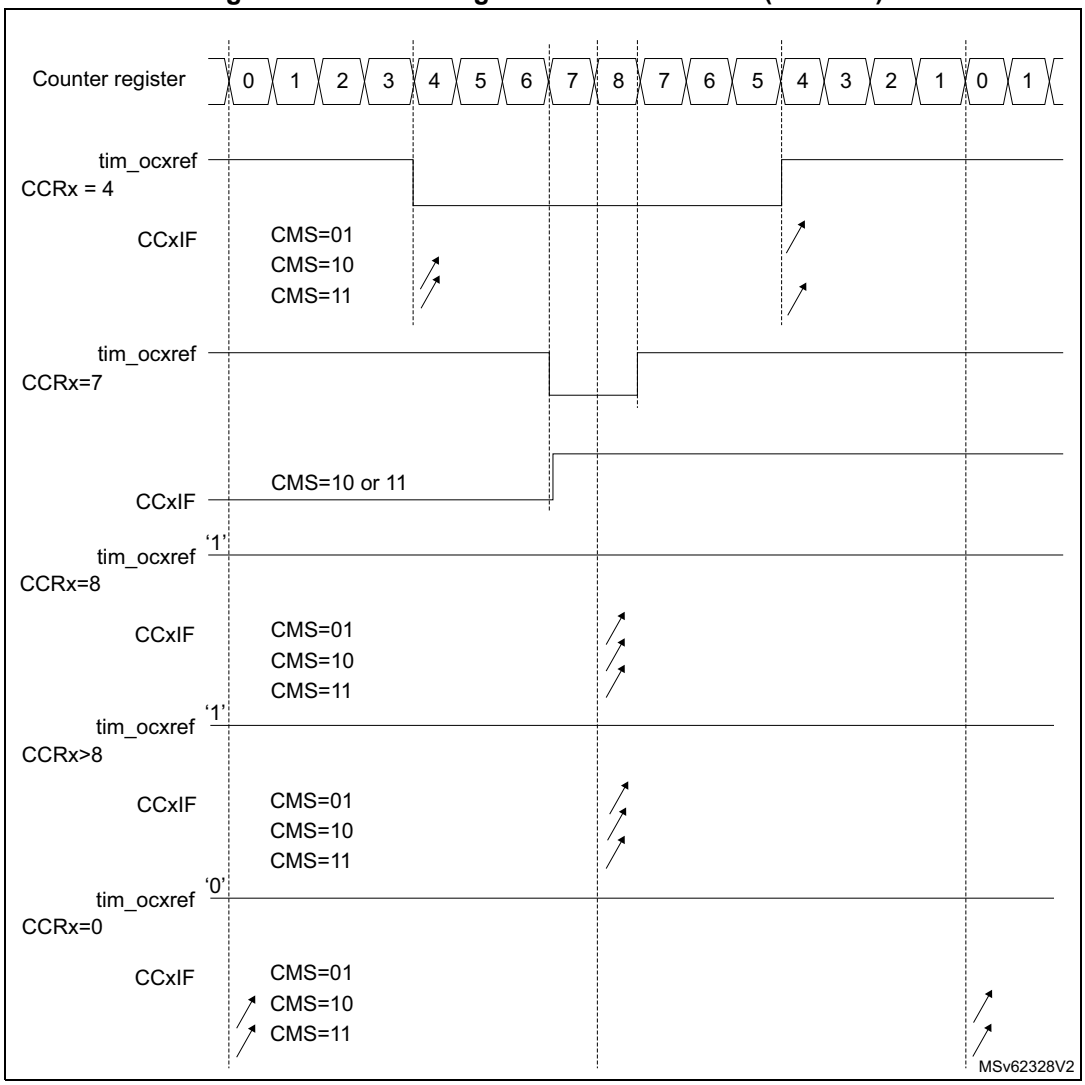
Center-aligned mode is active when the CMS bits in TIMx_CR1 register are different from 00 (all the remaining configurations having the same effect on the tim_ocxref/tim_ocx signals). The compare flag is set when the counter counts up, when it counts down or both when it counts up and down depending on the CMS bits configuration. The direction bit

(DIR) in the TIMx_CR1 register is updated by hardware and must not be changed by software. Refer to *Center-aligned mode (up/down-counting)*.

Figure 604 shows some center-aligned PWM waveforms in an example where:

- TIMx_ARR = 8.
- PWM mode is the PWM mode 1.
- The flag is set when the counter counts down corresponding to the center-aligned mode 1 selected for CMS = 01 in TIMx_CR1 register.

Figure 604. Center-aligned PWM waveforms (ARR = 8)



Hints on using center-aligned mode:

- When starting in center-aligned mode, the current up-down configuration is used. It means that the counter counts up or down depending on the value written in the DIR bit

in the TIMx_CR1 register. Moreover, the DIR and CMS bits must not be changed at the same time by the software.

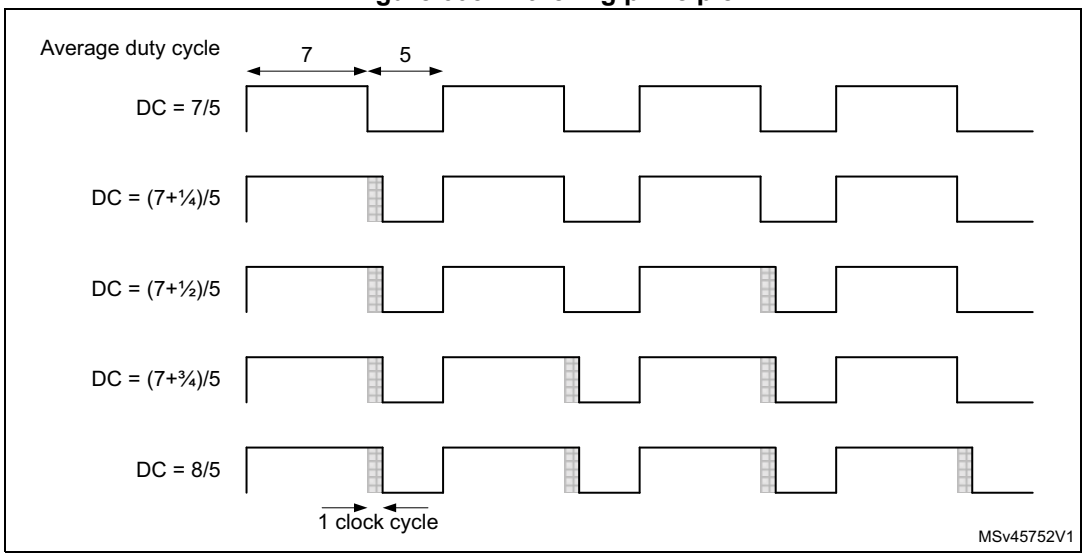
- Writing to the counter while running in center-aligned mode is not recommended as it can lead to unexpected results. In particular:
  - The direction is not updated if a value greater than the autoreload value is written in the counter (TIMx_CNT>TIMx_ARR). For example, if the counter was counting up, it continues to count up.
  - The direction is updated if 0 or the TIMx_ARR value is written in the counter but no update event UEV is generated.
- The safest way to use center-aligned mode is to generate an update by software (setting the UG bit in the TIMx_EGR register) just before starting the counter and not to write the counter while it is running.

Dithering mode

The PWM mode effective resolution can be increased by enabling the dithering mode, using the DITHEN bit in the TIMx_CR1 register. This applies to both the CCR (for duty cycle resolution increase) and ARR (for PWM frequency resolution increase).

The operating principle is to have the actual CCR (or ARR) value slightly changed (adding or not one timer clock period) over 16 consecutive PWM periods, with predefined patterns. This allows a 16-fold resolution increase, considering the average duty cycle or PWM period. *Figure 605* presents the dithering principle applied to four consecutive PWM cycles.

Figure 605. Dithering principle



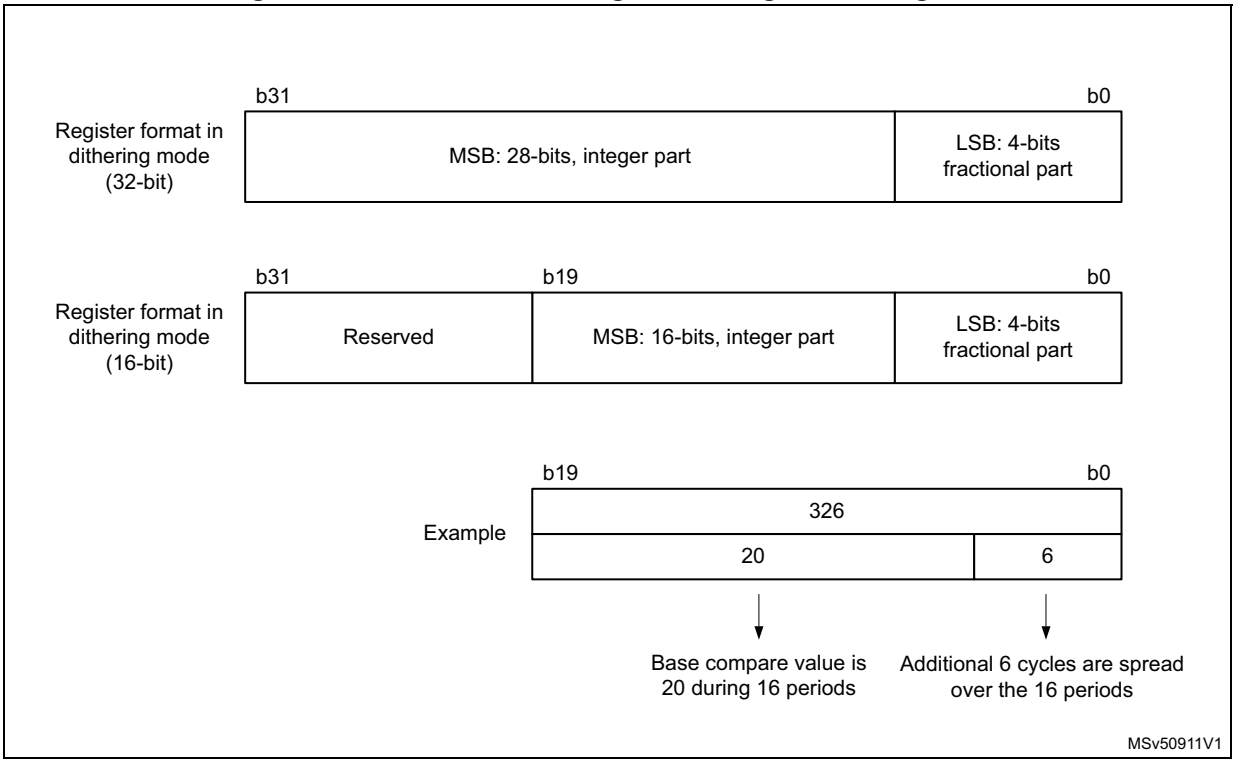
When the dithering mode is enabled, the register coding is changed as following (see *Figure 606* for example):

- The four LSBs are coding for the enhanced resolution part (fractional part).
- The MSBs are left-shifted by four places and are coding for the base value. In 16-bit mode, the 16-bit format is maintained.

Note: The following sequence must be followed when resetting the DITHEN bit:

1. *CEN and ARPE bits must be reset.*
2. *The DITHEN bit must be reset.*
3. *The CCIF flags must be cleared.*
4. *The CEN bit can be set (eventually with ARPE = 1).*

Figure 606. Data format and register coding in dithering mode



The minimum frequency is given by the following formula:

$$\text{Resolution} = \frac{F_{Tim}}{F_{pwm}} \Rightarrow F_{pwmMin} = \frac{F_{Tim}}{Max_{Resolution}}$$

$$\text{Dithering mode disabled: } F_{pwmMin} = \frac{F_{Tim}}{65536}$$

$$\text{Dithering mode (16-bit timer): } F_{pwmMin} = \frac{F_{Tim}}{65535 + \frac{15}{16}}$$

$$\text{Dithering mode (32-bit timer): } F_{pwmMin} = \frac{F_{Tim}}{268435454 + \frac{15}{16}}$$

Note: For 16-bit timers, the maximum TIMx_ARR and TIMx_CCRy values are limited to 0xFFFEF in dithering mode (corresponds to 65534 for the integer part and 15 for the dithered part). For 32-bit timers, the maximum TIMx_ARR and TIMx_CCRy values are limited to

0xFFFFFFEF in dithering mode (corresponds to 264435454 for the integer part and 15 for the dithered part).

As shown on *Figure 607* and *Figure 608*, the dithering mode is used to increase the PWM resolution.

Figure 607. PWM resolution vs frequency (16-bit mode)

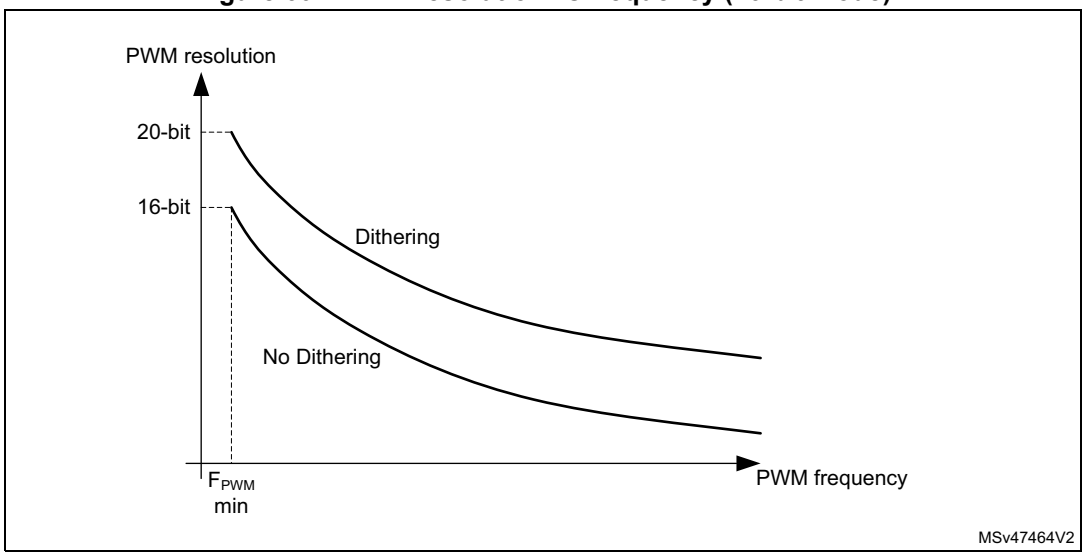
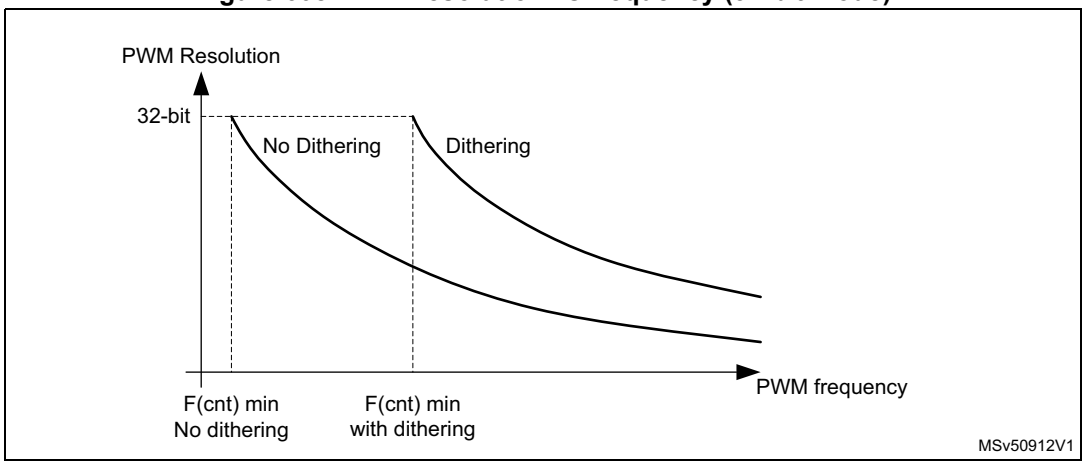
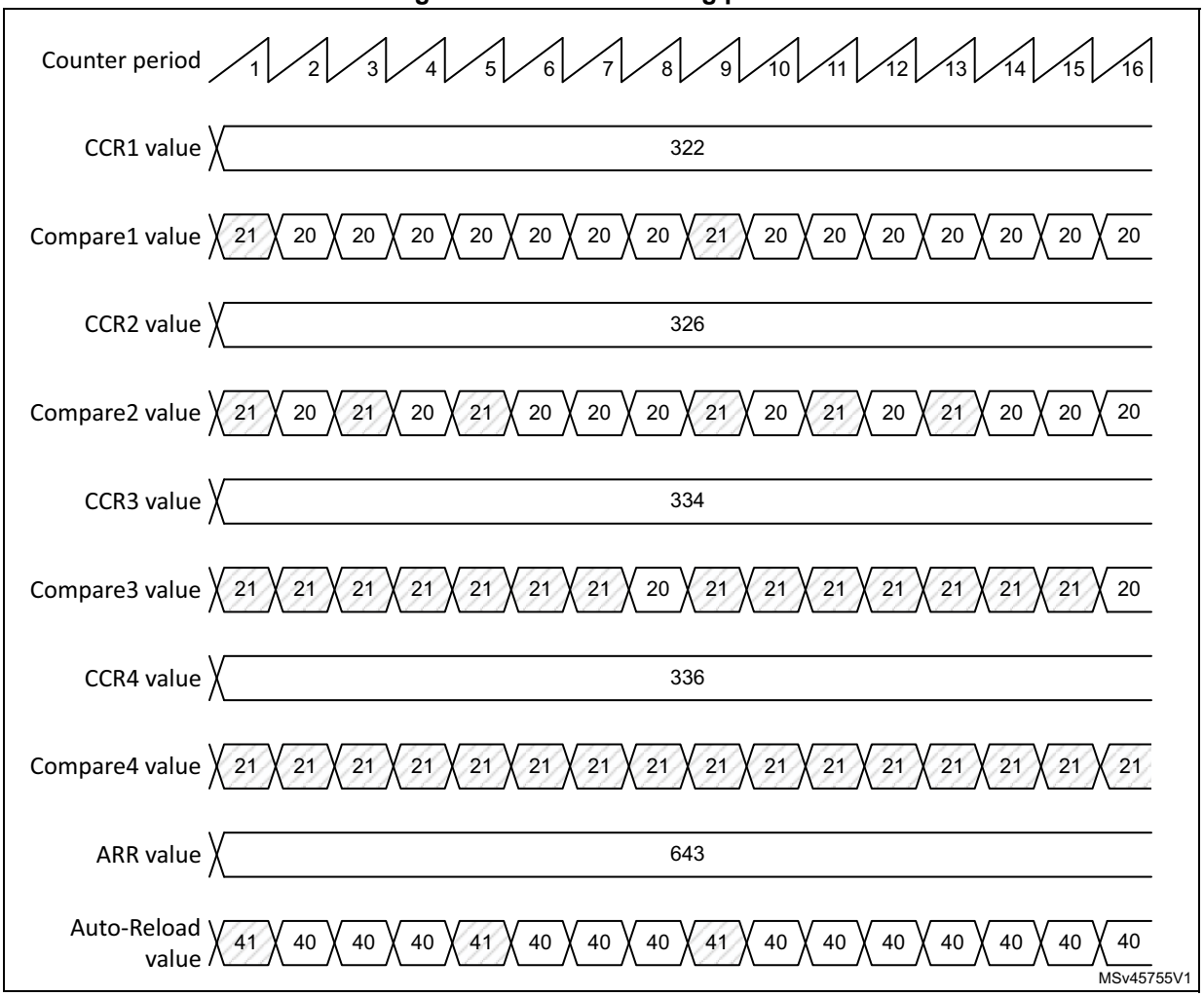


Figure 608. PWM resolution vs frequency (32-bit mode)



The duty cycle and/or period changes are spread over 16 consecutive periods, as described in *Figure 609*.

Figure 609. PWM dithering pattern



The autoreload and compare values increments are spread following specific patterns described in *Table 542*. The dithering sequence is done to have increments distributed as evenly as possible and minimize the overall ripple.

Table 542. CCR and ARR register change dithering pattern

LSB value	PWM period															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0001	+1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0010	+1	-	-	-	-	-	-	-	+1	-	-	-	-	-	-	-
0011	+1	-	-	-	+1	-	-	-	+1	-	-	-	-	-	-	-
0100	+1	-	-	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0101	+1	-	+1	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0110	+1	-	+1	-	+1	-	-	-	+1	-	+1	-	+1	-	-	-
0111	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	-	-
1000	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1001	+1	+1	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1010	+1	+1	+1	-	+1	-	+1	-	+1	+1	+1	-	+1	-	+1	-
1011	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	-	+1	-
1100	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-
1101	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-
1110	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	+1	+1	+1	+1	-
1111	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	-

The dithering mode is also available in center-aligned PWM mode (CMS bits in TIMx_CR1 register are not equal to 00). In this case, the dithering pattern is applied over eight consecutive PWM periods, considering the up and down-counting phases as shown in *Figure 610*.

Figure 610. Dithering effect on duty cycle in center-aligned PWM mode

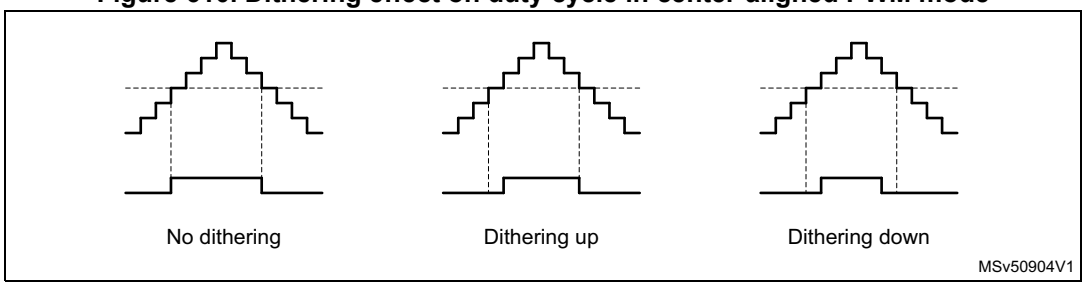


Table 543 shows how the dithering pattern is added in center-aligned PWM mode.

Table 543. CCR register change dithering pattern in center-aligned PWM mode

LSB value	PWM period															
	1		2		3		4		5		6		7		8	
	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn
0000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0001	+1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0010	+1	-	-	-	-	-	-	-	+1	-	-	-	-	-	-	-
0011	+1	-	-	-	+1	-	-	-	+1	-	-	-	-	-	-	-
0100	+1	-	-	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0101	+1	-	+1	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0110	+1	-	+1	-	+1	-	-	-	+1	-	+1	-	+1	-	-	-
0111	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	-	-
1000	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1001	+1	+1	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1010	+1	+1	+1	-	+1	-	+1	-	+1	+1	+1	-	+1	-	+1	-
1011	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	-	+1	-
1100	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-
1101	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-
1110	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	+1	+1	+1	+1	-
1111	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	-

50.4.12 Asymmetric PWM mode

Asymmetric mode allows two center-aligned PWM signals to be generated with a programmable phase shift. While the frequency is determined by the value of the TIMx_ARR register, the duty cycle and the phase-shift are determined by a pair of TIMx_CCRx registers. One register controls the PWM during up-counting, the second during down-counting, so that PWM is adjusted every half PWM cycle:

- tim_oc1refc (or tim_oc2refc) is controlled by TIMx_CCR1 and TIMx_CCR2.
- tim_oc3refc (or tim_oc4refc) is controlled by TIMx_CCR3 and TIMx_CCR4.

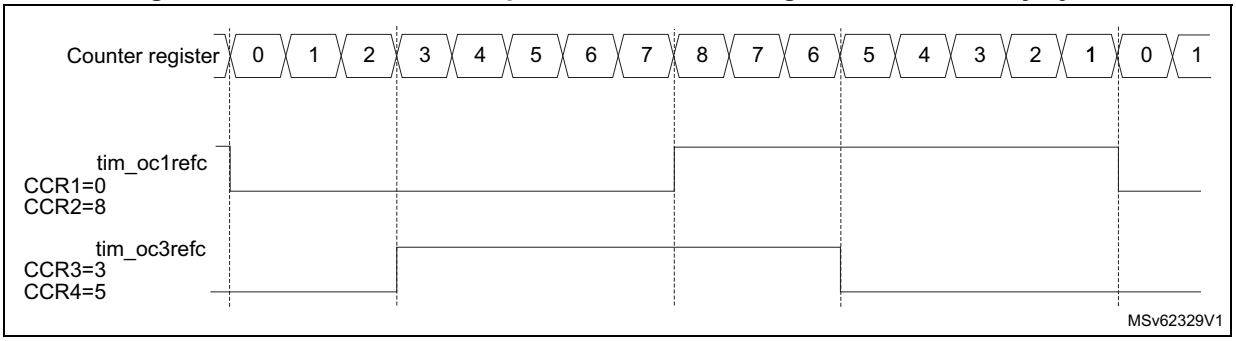
Asymmetric PWM mode can be selected independently on two channels (one tim_ocx output per pair of CCR registers) by writing 1110 (Asymmetric PWM mode 1) or 1111 (Asymmetric PWM mode 2) in the OCxM bits in the TIMx_CCMRx register.

Note: The OCxM[3:0] bitfield is split into two parts for compatibility reasons, the most significant bit is not contiguous with the three least significant ones.

When a given channel is used as asymmetric PWM channel, its secondary channel can also be used. For instance, if an tim_oc1refc signal is generated on channel 1 (Asymmetric PWM mode 1), it is possible to output either the tim_oc2ref signal on channel 2, or an tim_oc2refc signal resulting from asymmetric PWM mode 2.

Figure 611 shows an example of signals that can be generated using asymmetric PWM mode (channels 1 to 4 are configured in asymmetric PWM mode 2).

Figure 611. Generation of two phase-shifted PWM signals with 50% duty cycle



50.4.13 Combined PWM mode

Combined PWM mode allows two edge or center-aligned PWM signals to be generated with programmable delay and phase shift between respective pulses. While the frequency is determined by the value of the TIMx_ARR register, the duty cycle and delay are determined by the two TIMx_CCRx registers. The resulting signals, tim_ocxrefc, are made of an OR or AND logical combination of two reference PWMs:

- tim_oc1refc (or tim_oc2refc) is controlled by TIMx_CCR1 and TIMx_CCR2
- tim_oc3refc (or tim_oc4refc) is controlled by TIMx_CCR3 and TIMx_CCR4

Combined PWM mode can be selected independently on two channels (one tim_ocx output per pair of CCR registers) by writing 1100 (Combined PWM mode 1) or 1101 (Combined PWM mode 2) in the OCxM bits in the TIMx_CCMRx register.

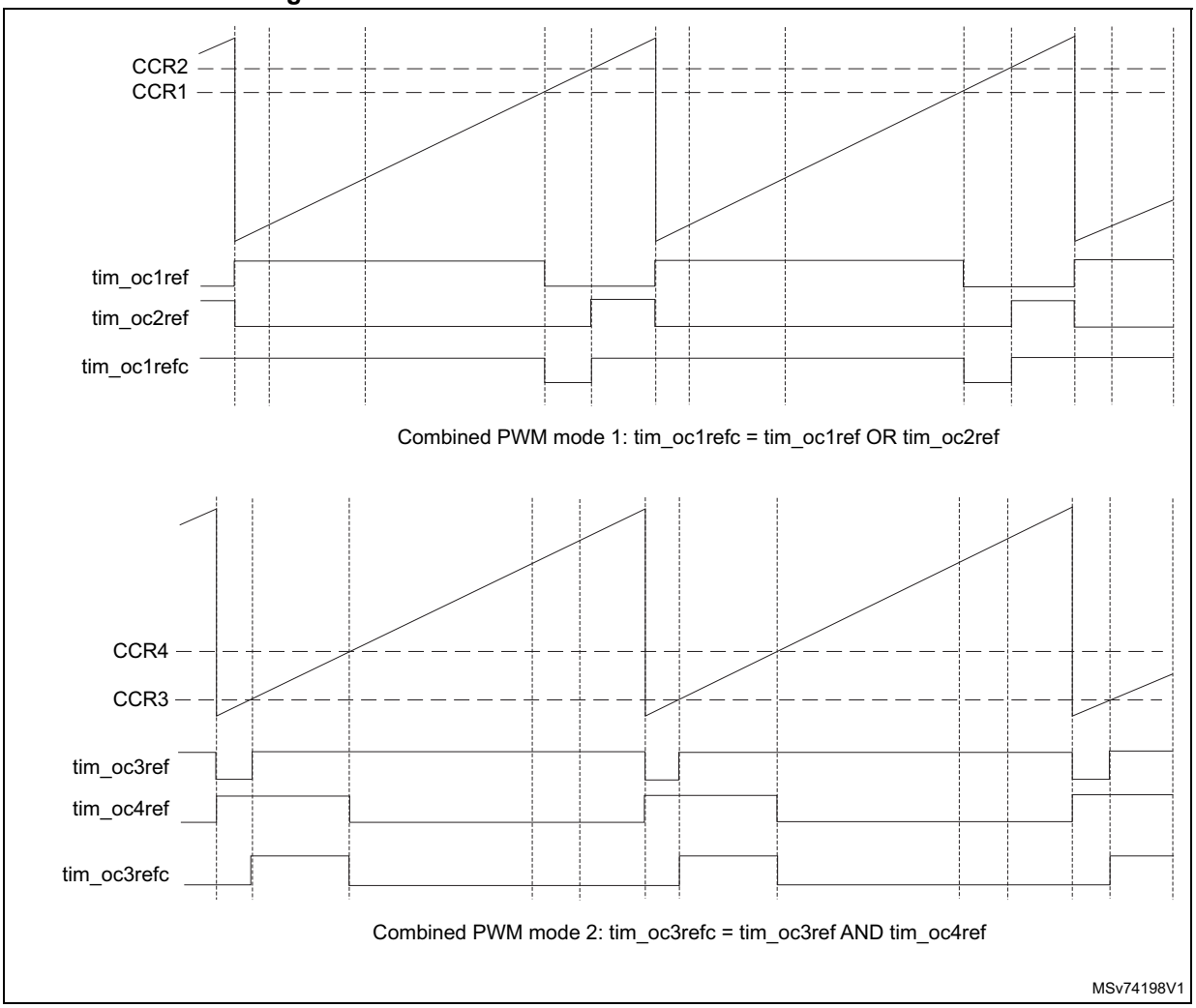
When a given channel is used as combined PWM channel, its secondary channel must be configured in the opposite PWM mode (for instance, one in Combined PWM mode 1 and the other in Combined PWM mode 2).

Note: The OCxM[3:0] bitfield is split into two parts for compatibility reasons, the most significant bit is not contiguous with the three least significant ones.

Figure 612 shows an example of signals that can be generated using combined PWM mode, obtained with the following configuration:

- Channel 1 is configured in Combined PWM mode 1.
- Channel 2 is configured in PWM mode 2.
- Channel 3 is configured in Combined PWM mode 2.
- Channel 4 is configured in PWM mode 1.

Figure 612. Combined PWM mode on channels 1 and 3



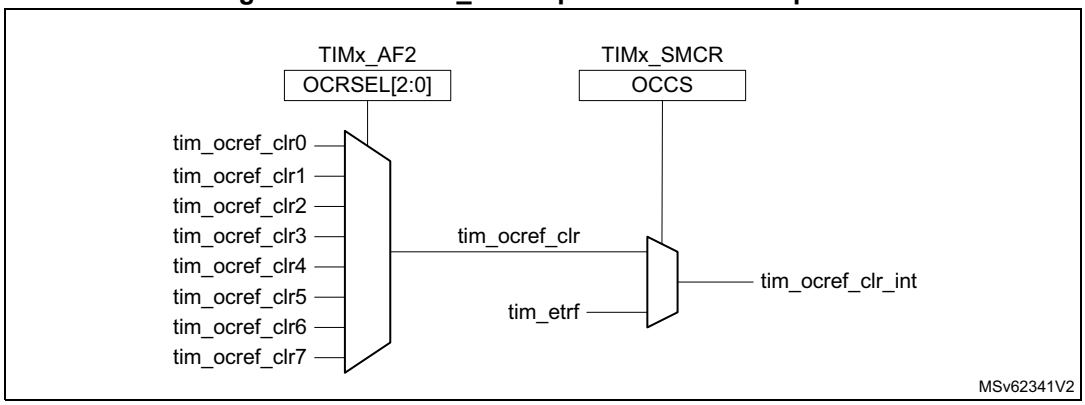
50.4.14 Clearing the tim_ocxref signal on an external event

The tim_ocxref signal of a given channel can be cleared when a high level is applied on the tim_ocref_clr_int input (OCxCE enable bit in the corresponding TIMx_CCMRx register set to 1). tim_ocxref remains low until the next transition to the active state, on the following PWM cycle. This function can only be used in Output compare and PWM modes. It does not work in Forced mode.

The tim_ocref_clr_int source depends on the OCREF clear selection feature implementation, refer to *Section 50.3: TIM2/TIM3/TIM4/TIM5 implementation*.

If the OCREF clear selection feature is implemented, the tim_ocref_clr_int can be selected between the tim_ocref_clr input and the tim_etrf input (tim_etr_in after the filter) by configuring the OCCS bit in the TIMx_SMCR register. The tim_ocref_clr input can be selected among several tim_ocref_clr[7:0] inputs, using the OCRSEL[2:0] bitfield in the TIMx_AF2 register, as shown in *Figure 613*.

Figure 613. OCREF_CLR input selection multiplexer



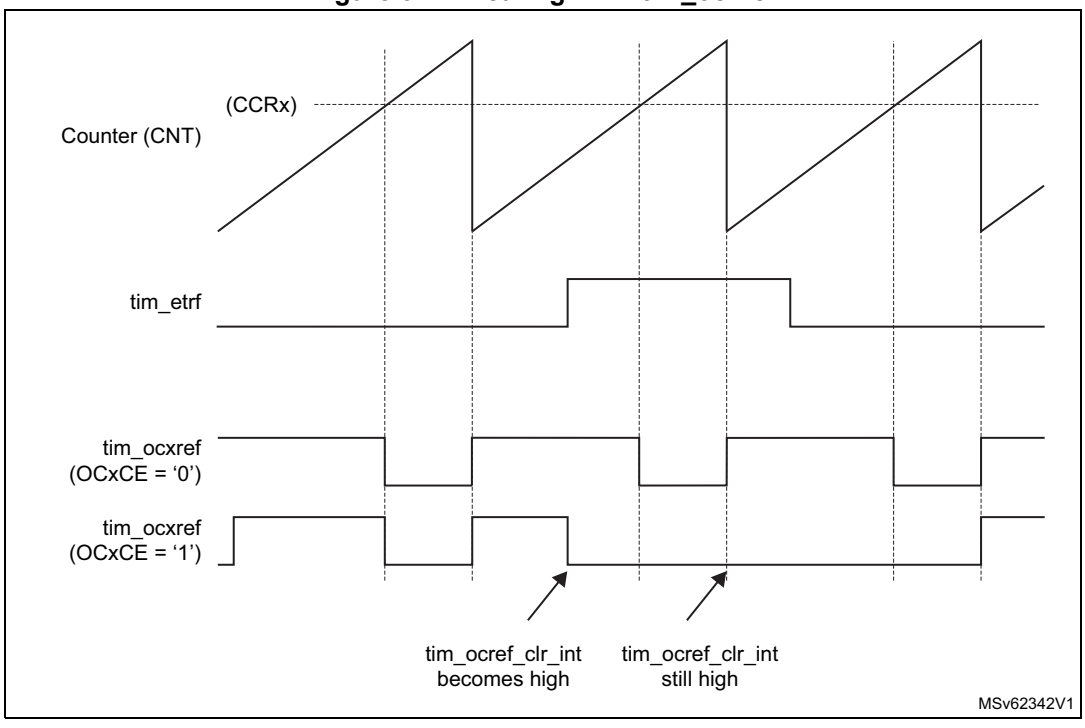
If the OCREF clear selection feature is not implemented, the tim_ocref_clr_int input is directly connected to the tim_etrf input.

For example, the tim_ocref_clr_int signal can be connected to the output of a comparator to be used for current handling. In this case, tim_etr_in must be configured as follows:

1. The external trigger prescaler must be kept off: bits ETPS[1:0] in the TIMx_SMCR register are cleared to 00.
2. The external clock mode 2 must be disabled: bit ECE in the TIMx_SMCR register is cleared to 0.
3. The external trigger polarity (ETP) and the external trigger filter (ETF) can be configured according to the application's needs.

Figure 614 shows the behavior of the tim_ocxref signal when the tim_etrf input becomes high, for both values of the OCxCE enable bit. In this example, the timer TIMx is programmed in PWM mode.

Figure 614. Clearing TIMx tim_ocxref



Note: In case of a PWM with a 100% duty cycle (if CCRx>ARR), tim_ocxref is enabled again at the next counter overflow.

50.4.15 One-pulse mode

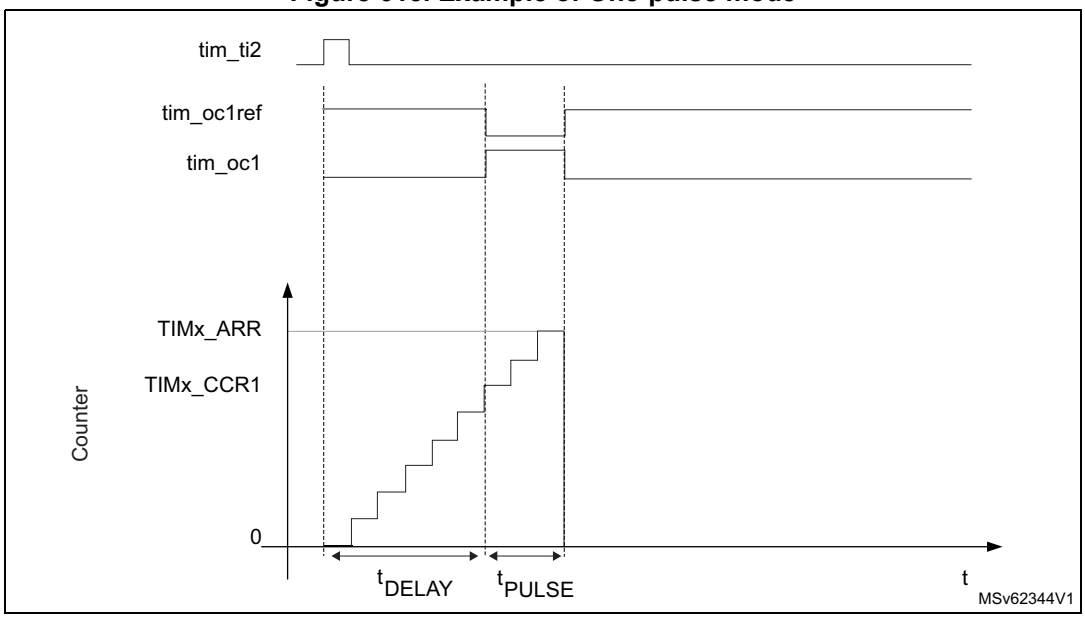
One-pulse mode (OPM) is a particular case of the previous modes. It allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length after a programmable delay.

Starting the counter can be controlled through the slave mode controller. Generating the waveform can be done in output compare mode or PWM mode. One-pulse mode is selected by setting the OPM bit in the TIMx_CR1 register. This makes the counter stop automatically at the next update event UEV.

A pulse can be correctly generated only if the compare value is different from the counter initial value. Before starting (when the timer is waiting for the trigger), the configuration must be:

CNT<CCRx ≤ ARR (in particular, 0<CCRx).

Figure 615. Example of One-pulse mode



For example if the user wants to generate a positive pulse on tim_oc1 with a length of t_{PULSE} and after a delay of t_{DELAY} as soon as a positive edge is detected on the tim_ti2 input pin.

Use tim_ti2fp2 as trigger 1:

1. Select the proper tim_ti2_in[15:0] source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Map tim_ti2fp2 on tim_ti2 by writing CC2S = 01 in the TIMx_CCMR1 register.
3. tim_ti2fp2 must detect a rising edge, write CC2P = 0 and CC2NP = 0 in the TIMx_CCER register.
4. Configure tim_ti2fp2 as trigger for the slave mode controller (tim_trgi) by writing TS = 00110 in the TIMx_SMCR register.
5. tim_ti2fp2 is used to start the counter by writing SMS to 110 in the TIMx_SMCR register (trigger mode).

The OPM waveform is defined by writing the compare registers (taking into account the clock frequency and the counter prescaler).

- The t_{DELAY} is defined by the value written in the TIMx_CCR1 register.
- The t_{PULSE} is defined by the difference between the autoreload value and the compare value (TIMx_ARR - TIMx_CCR1).
- Suppose the user wants to build a waveform with a transition from 0 to 1 when a compare match occurs and a transition from 1 to 0 when the counter reaches the autoreload value. To do this PWM mode 2 must be enabled by writing OC1M = 111 in the TIMx_CCMR1 register. Optionally the preload registers can be enabled by writing OC1PE = 1 in the TIMx_CCMR1 register and ARPE in the TIMx_CR1 register. In this case one has to write the compare value in the TIMx_CCR1 register, the autoreload value in the TIMx_ARR register, generate an update by setting the UG bit and wait for external trigger event on tim_ti2. CC1P is written to 0 in this example.

In this example, the DIR and CMS bits in the TIMx_CR1 register must be low.

Since only one pulse (Single mode) is needed, a one must be written in the OPM bit in the TIMx_CR1 register to stop the counter at the next update event (when the counter rolls over from the autoreload value back to 0). When OPM bit in the TIMx_CR1 register is set to 0, so the Repetitive mode is selected.

Particular case: tim_ocx fast enable:

In One-pulse mode, the edge detection on tim_tix input set the CEN bit which enables the counter. Then the comparison between the counter and the compare value makes the output toggle. But several clock cycles are needed for these operations and it limits the minimum delay t_{DELAY} min we can get.

If one wants to output a waveform with the minimum delay, the OCxFE bit can be set in the TIMx_CCMRx register. Then tim_ocxref (and tim_ocx) is forced in response to the stimulus, without taking in account the comparison. Its new level is the same as if a compare match had occurred. OCxFE acts only if the channel is configured in PWM1 or PWM2 mode.

50.4.16 Retriggerable one-pulse mode

This mode allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length, but with the following differences with non-retriggerable one-pulse mode described in *Section 50.4.15*:

- The pulse starts as soon as the trigger occurs (no programmable delay).
- The pulse is extended if a new trigger occurs before the previous one is completed.

The timer must be in Slave mode, with the bits SMS[3:0] = 1000 (Combined Reset + trigger mode) in the TIMx_SMCR register, and the OCxM[3:0] bits set to 1000 or 1001 for Retriggerable OPM mode 1 or 2.

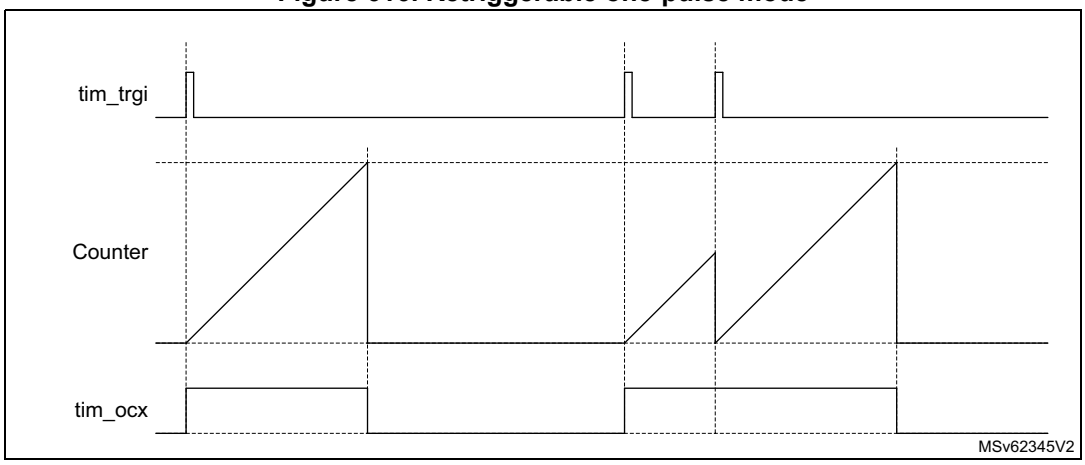
If the timer is configured in Up-counting mode, the corresponding CCRx must be set to 0 (the ARR register sets the pulse length). If the timer is configured in down-counting mode CCRx must be above or equal to ARR.

Note: In Retriggerable one-pulse mode, the CCxIF flag is not significant.

The OCxM[3:0] and SMS[3:0] bitfields are split into two parts for compatibility reasons, the most significant bit is not contiguous with the three least significant ones.

This mode must not be used with center-aligned PWM modes. It is mandatory to have CMS[1:0] = 00 in TIMx_CR1.

Figure 616. Retriggerable one-pulse mode



50.4.17 Pulse on compare mode

A pulse can be generated upon compare match event. A signal with a programmable pulse width generated when the counter value equals a given compare value, for debugging or synchronization purposes.

This mode is available for any slave mode selection, including encoder modes, in edge and center aligned counting modes. It is solely available for channel 3 and channel 4. The pulse generator is unique and is shared by the two channels, as shown on *Figure 617*.

Figure 617. Pulse generator circuitry

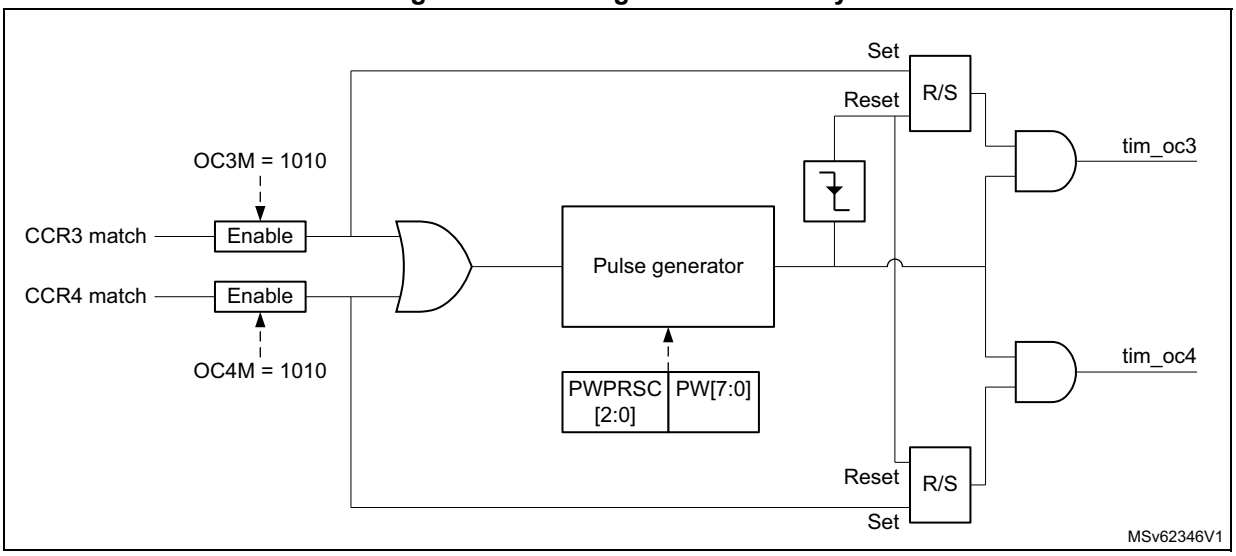
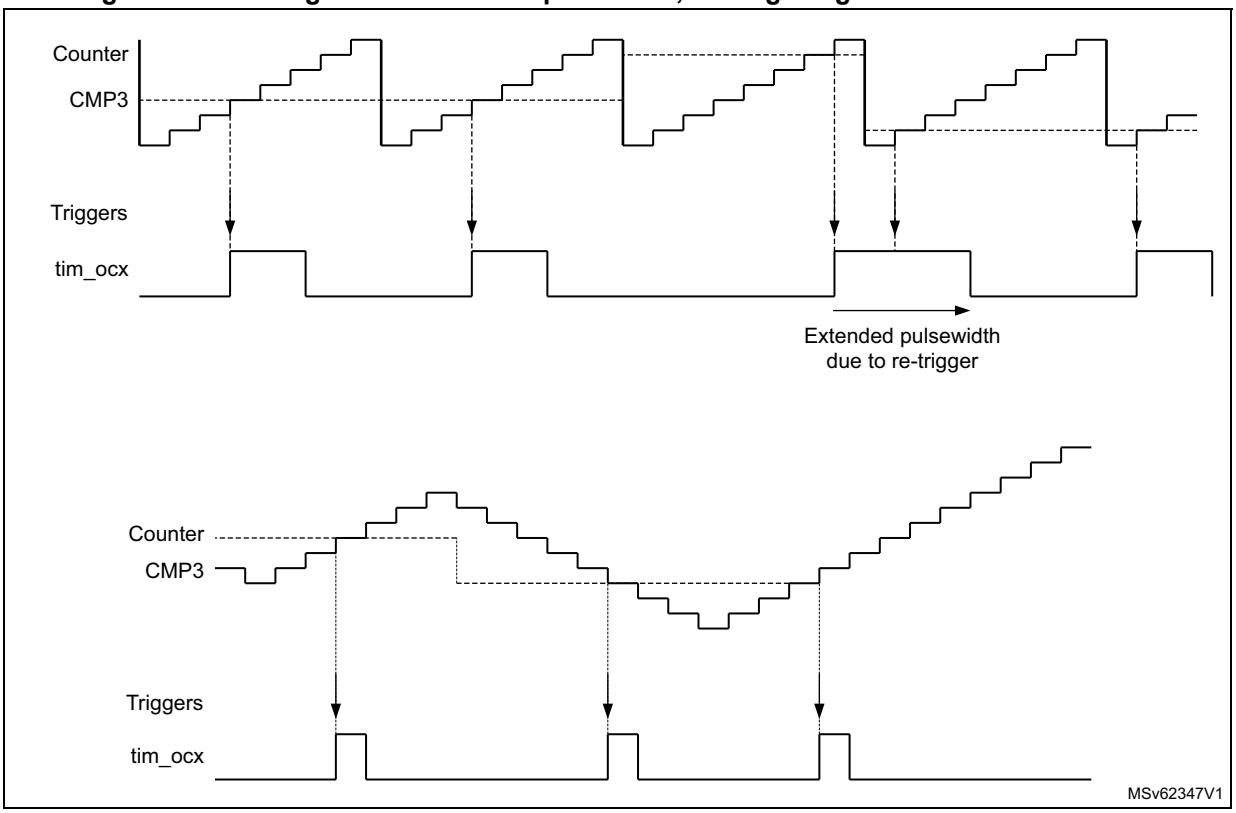


Figure 618 shows how the pulse is generated for edge-aligned and encoder operating modes.

Figure 618. Pulse generation on compare event, for edge-aligned and encoder modes



This output compare mode is selected using the OC3M[3:0] and OC4M[3:0] bitfields in TIMx_CCMR2 register.

The pulse width is programmed using the PW[7:0] bitfield in the register, using a specific clock prescaled according to PWPRSC[2:0] bits, as follows:

$t_{PW} = PW[7:0] \times t_{PWG}$

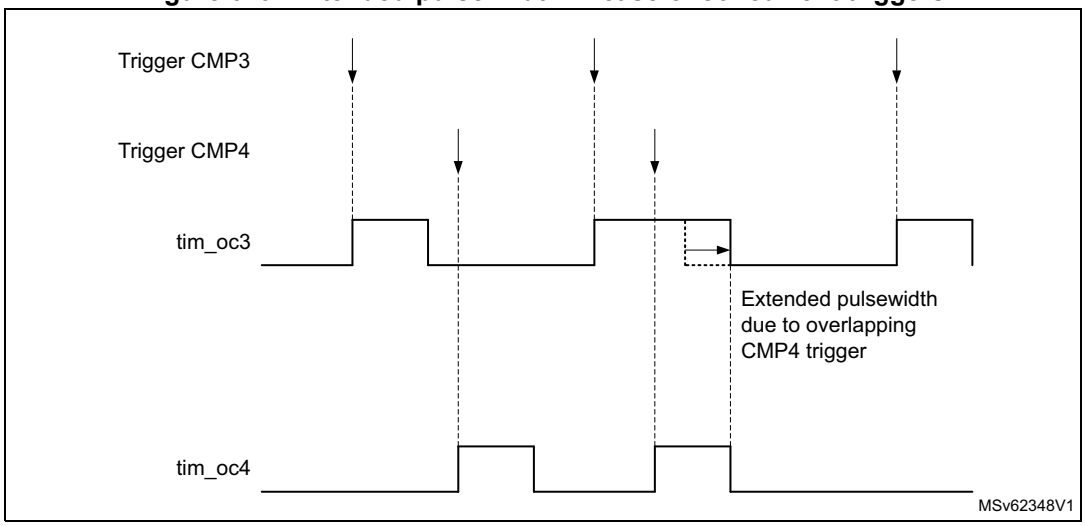
where $t_{PWG} = (2^{(PWPRSC[2:0])}) \times t_{tim_ker_ck}$.

gives the resolution and maximum values depending on the prescaler value.

The pulse is retriggerable: a new trigger while the pulse is ongoing, causes the pulse to be extended.

Note: If the two channels are enabled simultaneously, the pulses are issued independently as long as the trigger on one channel is not overlapping the pulse generated on the concurrent output. On the opposite, if the two triggers are overlapping, the pulse width related to the first arriving trigger is extended (because of the retrigger), while the pulse width of the last arriving trigger is correct (as shown on Figure 619).

Figure 619. Extended pulse width in case of concurrent triggers



50.4.18 Encoder interface mode

Quadrature encoder

To select Encoder interface mode write SMS = 0001 in the TIMx_SMCR register if the counter is counting on tim_ti1 edges only, SMS = 0010 if it is counting on tim_ti2 edges only and SMS = 0011 if it is counting on both tim_ti1 and tim_ti2 edges.

Select the tim_ti1 and tim_ti2 polarity by programming the CC1P and CC2P bits in the TIMx_CCER register. CC1NP and CC2NP must be kept cleared. When needed, the input filter can be programmed as well.

The two inputs tim_ti1 and tim_ti2 are used to interface to an incremental encoder. Refer to *Table 544*. The counter is clocked by each valid transition on tim_ti1fp1 or tim_ti2fp2 (tim_ti1 and tim_ti2 after input filter and polarity selection, tim_ti1fp1 = tim_ti1 if not filtered and not inverted, tim_ti2fp2 = tim_ti2 if not filtered and not inverted) assuming that it is enabled (CEN bit in TIMx_CR1 register written to 1). The sequence of transitions of the two inputs is evaluated and generates count pulses as well as the direction signal. Depending on the sequence the counter counts up or down, the DIR bit in the TIMx_CR1 register is modified by hardware accordingly. The DIR bit is calculated at each transition on any input (tim_ti1 or

tim_ti2), whatever the counter is counting on tim_ti1 only, tim_ti2 only or both tim_ti1 and tim_ti2.

Encoder interface mode acts simply as an external clock with direction selection. This means that the counter just counts continuously between 0 and the autoreload value in the TIMx_ARR register (0 to ARR or ARR down to 0 depending on the direction). So the TIMx_ARR must be configured before starting. In the same way, the capture, compare, prescaler, trigger output features continue to work as normal. Encoder mode and External clock mode 2 are not compatible and must not be selected together.

In this mode, the counter is modified automatically following the speed and the direction of the quadrature encoder and its content, therefore, always represents the encoder's position. The count direction corresponds to the rotation direction of the connected sensor. The table summarizes the possible combinations, assuming tim_ti1 and tim_ti2 do not switch at the same time.

Table 544. Counting direction versus encoder signals(CC1P = CC2P = 0)

Active edge	SMS[3:0]	Level on opposite signal (tim_ti1fp1 for tim_ti2, tim_ti2fp2 for tim_ti1)	tim_ti1fp1 signal		tim_ti2fp2 signal	
			Rising	Falling	Rising	Falling
Counting on tim_ti1 only x1 mode	1110	High	Down	Up	No count	No count
		Low	No count	No count	No count	No count
Counting on tim_ti2 only x1 mode	1111	High	No count	No count	Up	Down
		Low	No count	No count	No count	No count
Counting on tim_ti1 only x2 mode	0001	High	Down	Up	No count	No count
		Low	Up	Down	No count	Down
Counting on tim_ti2 only x2 mode	0010	High	No count	No count	Up	Down
		Low	No count	No count	Down	Up
Counting on tim_ti1 and tim_ti2 x4 mode	0011	High	Down	Up	Up	Down
		Low	Up	Down	Down	Up

A quadrature encoder can be connected directly to the MCU without external interface logic. However, comparators are normally be used to convert the encoder's differential outputs to digital signals. This greatly increases noise immunity. The third encoder output which indicates the mechanical zero position, can be connected to the external trigger input and trigger a counter reset.

Figure 620 gives an example of counter operation, showing count signal generation and direction control. It also shows how input jitter is compensated where both edges are

selected. This might occur if the sensor is positioned near to one of the switching points. For this example we assume that the configuration is the following:

- CC1S = 01 (TIMx_CCMR1 register, tim_ti1fp1 mapped on tim_ti1).
- CC2S = 01 (TIMx_CCMR1 register, tim_ti2fp2 mapped on tim_ti2).
- CC1P and CC1NP = 0 (TIMx_CCER register, tim_ti1fp1 noninverted, tim_ti1fp1 = tim_ti1).
- CC2P and CC2NP = 0 (TIMx_CCER register, tim_ti2fp2 noninverted, tim_ti2fp2 = tim_ti2).
- SMS = 0011 (TIMx_SMCR register, both inputs are active on both rising and falling edges).
- CEN = 1 (TIMx_CR1 register, counter is enabled).

Figure 620. Example of counter operation in encoder interface mode

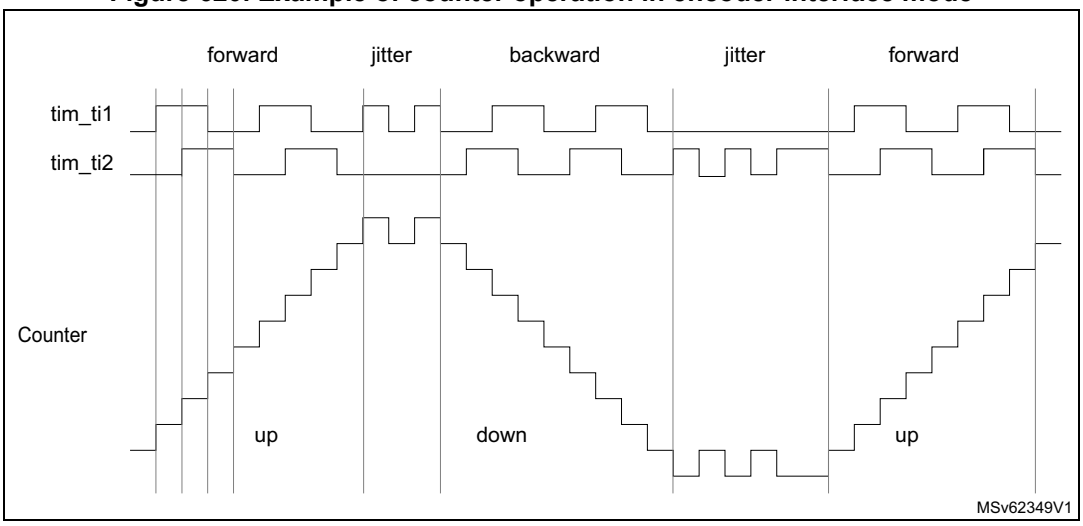


Figure 621 gives an example of counter behavior when tim_ti1fp1 polarity is inverted (same configuration as above except CC1P = 1).

Figure 621. Example of encoder interface mode with tim_ti1fp1 polarity inverted

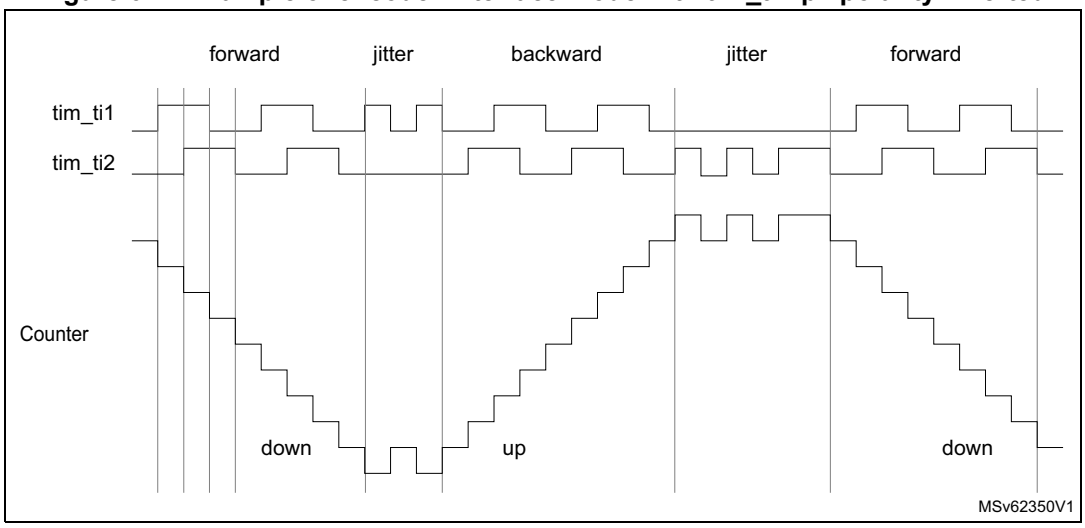
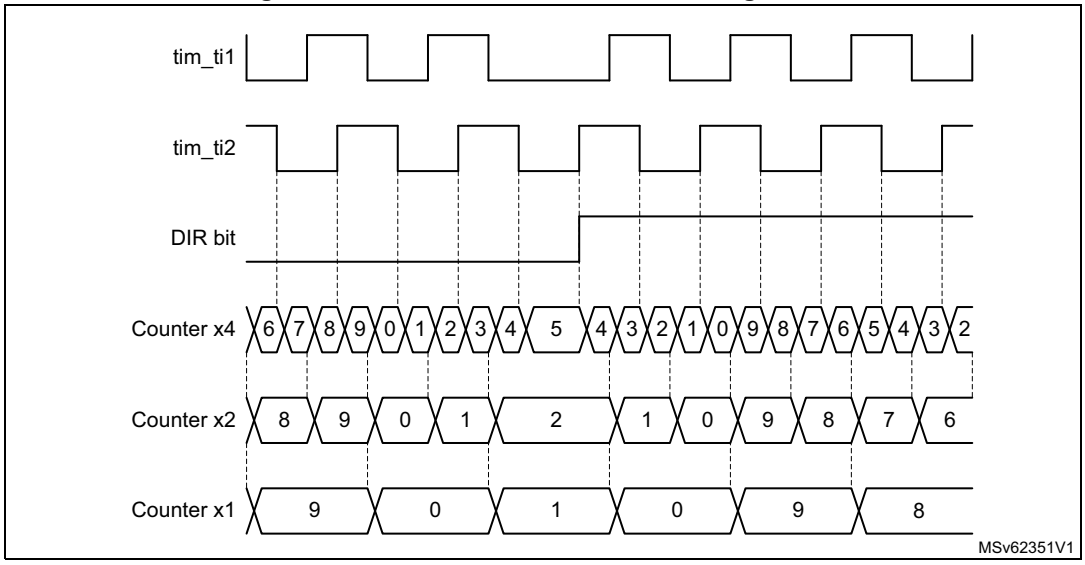


Figure 622 shows the timer counter value during a speed reversal, for various counting modes.

Figure 622. Quadrature encoder counting modes



The timer, when configured in Encoder Interface mode provides information on the sensor's current position. Dynamic information can be obtained (speed, acceleration, deceleration) by measuring the period between two encoder events using a second timer configured in capture mode. The output of the encoder which indicates the mechanical zero can be used for this purpose. Depending on the time between two events, the counter can also be read at regular times. This can be done by latching the counter value into a third input capture register if available (then the capture signal must be periodic and can be generated by another timer). When available, it is also possible to read its value through a DMA request.

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the update interrupt flag (UIF) into the timer counter register's bit 31 (TIMx_CNT[31]). This allows both the counter value and a potential roll-over condition signaled by the UIFCPY flag to be read in an atomic way. It eases the calculation of angular speed by avoiding race conditions caused, for instance, by a processing shared between a background task (counter reading) and an interrupt (update interrupt).

There is no latency between the UIF and UIFCPY flag assertions.

In 32-bit timer implementations, when the IUFREMAP bit is set, bit 31 of the counter is overwritten by the UIFCPY flag upon read access (the counter's most significant bit is only accessible in write mode).

Clock plus direction encoder mode

In addition to the quadrature encoder mode, the timer offers support for other types of encoders.

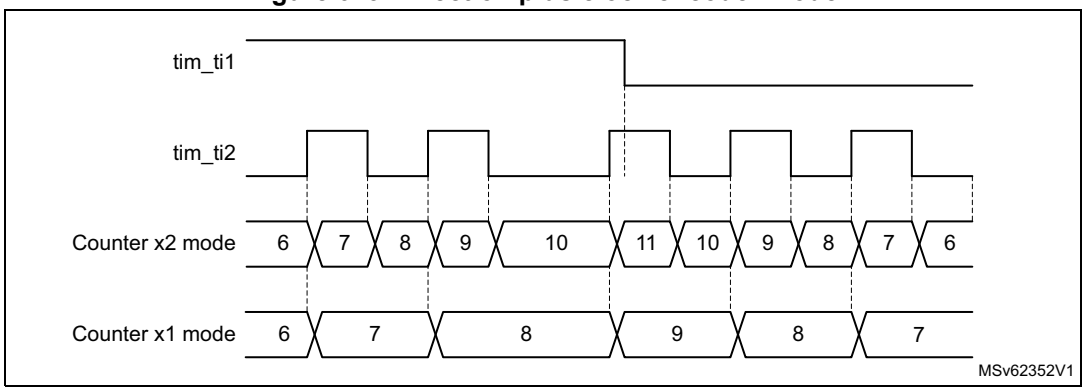
In the "clock plus direction" mode shown on *Figure 623*, the clock is provided on a single line, on tim_ti2, while the direction is forced using the tim_ti1 input.

This mode is enabled with the SMS[3:0] bitfield in the TIMx_SMCR register, as following:

- 1010: x2 mode, the counter is updated on both rising and falling edges of the clock.
- 1011: x1 mode, the counter is updated on a single clock edge, as per CC2P bit value: CC2P = 0 corresponds to rising edge sensitivity and CC2P = 1 corresponds to falling edge sensitivity.

The polarity of the direction signal on tim_ti1 is set with the CC1P bit: 0 corresponds to positive polarity (up-counting when tim_ti1 is high and down-counting when tim_ti1 is low) and CC1P = 1 corresponds to negative polarity (up-counting when tim_ti1 is low).

Figure 623. Direction plus clock encoder mode



Directional clock encoder mode

In the “directional clock” mode on *Figure 624*, the clocks are provided on two lines, with a single one at once, depending on the direction, so as to have one up-counting clock line and one down-counting clock line.

This mode is enabled with the SMS[3:0] bitfield in the TIMx_SMCR register, as following:

- 1100: x2 mode, the counter is updated on both rising and falling edges of any of the two clock lines. The CC1P and CC2P bits are coding for the clock idle state. CCxP = 0 corresponds to high-level idle state (refer to *Figure 624*) and CCxP = 1 corresponds to low-level idle state (refer to *Figure 625*).
- 1101: x1 mode, the counter is updated on a single clock edge, as per CC1P and CC2P bit value. CCxP = 0 corresponds to falling edge sensitivity and high-level idle state (refer to *Figure 624*), CCxP = 1 corresponds to rising edge sensitivity and low-level idle state (refer to *Figure 625*).

Figure 624. Directional clock encoder mode (CC1P = CC2P = 0)

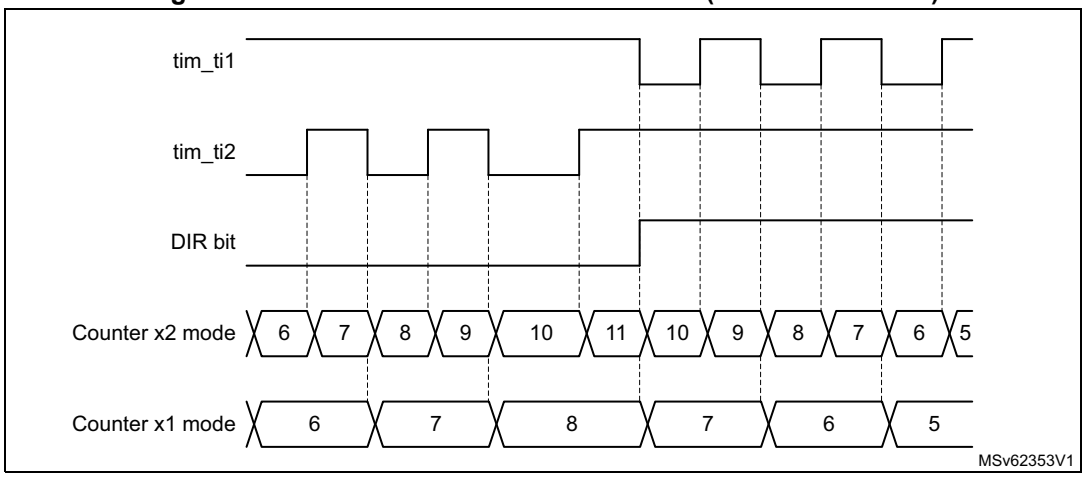


Figure 625. Directional clock encoder mode (CC1P = CC2P = 1)

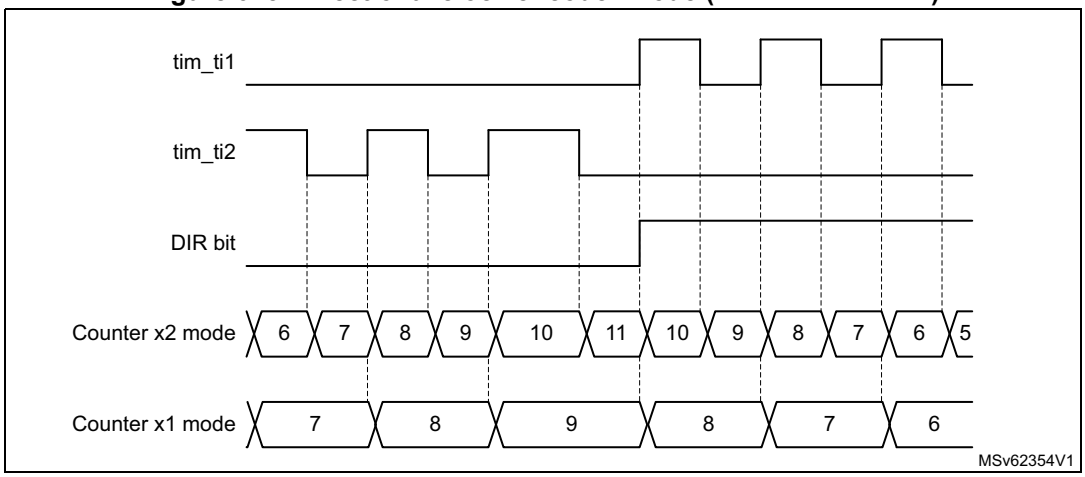


Table 545 details how the directional clock mode operates, for any input transition.

Table 545. Counting direction versus encoder signals and polarity settings

Directional clock mode	SMS[3:0]	Level on opposite signal (tim_ti1fp1 for tim_ti2, tim_ti2fp2 for tim_ti1)	tim_ti1fp1 signal		tim_ti2fp2 signal	
			Rising	Falling	Rising	Falling
x2 mode CCxP = 0	1100	High	Down	Down	Up	Up
		Low	No count	No count	No count	No count
x2 mode CCxP = 1	1100	High	No count	No count	No count	No count
		Low	Down	Down	Up	Up
x1 mode CCxP = 0	1101	High	No count	Down	No count	Up
		Low	No count	No count	No count	No count
x1 mode CCxP = 1	1101	High	No count	No count	No count	No count
		Low	Down	No count	Up	No count

Index input

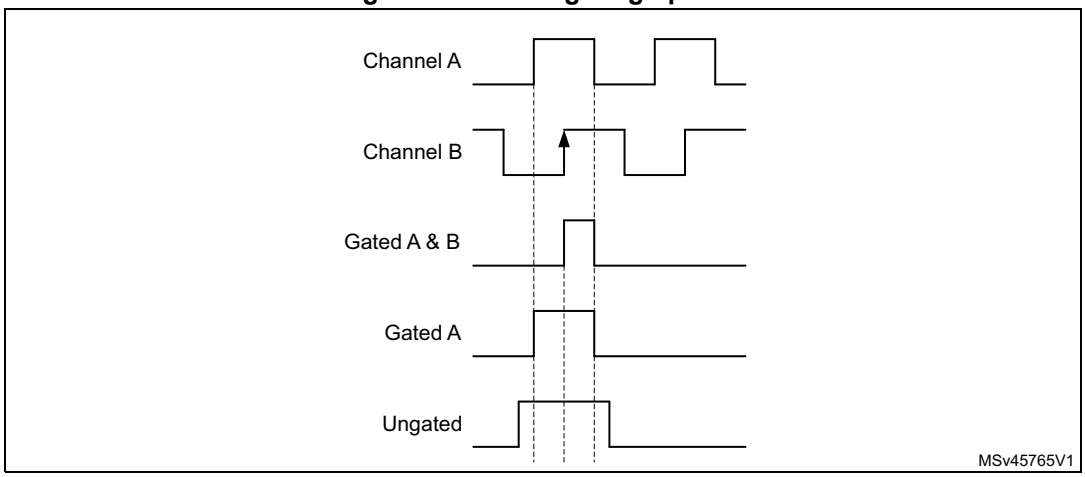
The counter can be reset by an index signal coming from the encoder, indicating an absolute reference position. The index signal must be connected to the tim_etr_in input. It can be filtered using the digital input filter.

The index functionality is enabled with the IE bit in the TIMx_ECR register. The IE bit must be set only in encoder mode, when the SMS[3:0] bitfield has the following values: 0001, 0010, 011, 1010, 1011, 1100, 1101, 1110, 1111.

Available encoders are proposed with several options for index pulse conditioning, as per *Figure 626*:

- Gated with A and B: the pulse width is 1/4 of one channel period, aligned with both A and B edges.
- Gated with A (or gated with B): the pulse width is 1/2 of one channel period, aligned with the two edges on channel A (resp. channel B).
- Ungated: the pulse width is up to one channel period, without any alignment to the edges.

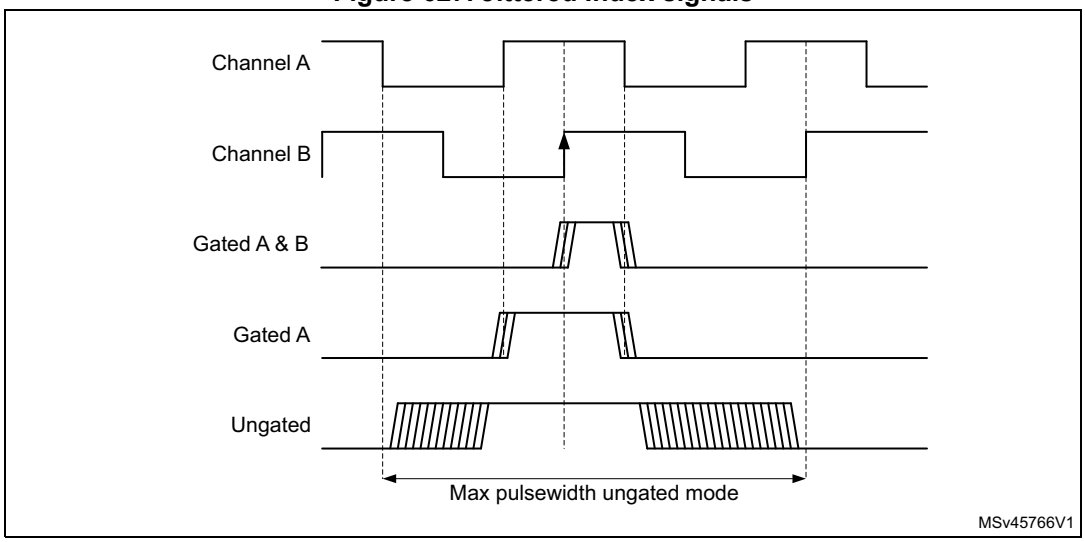
Figure 626. Index gating options



The circuitry tolerates jitter on index signal, whatever the gating mode, as shown on *Figure 627*.

In ungated mode, the signal must be strictly below two encoder periods. If the pulse width is greater or equal to two encoder period, the counter is reset multiple times.

Figure 627. Jittered Index signals



The timer supports the three gating options identically, without any specific programming needed. It is only necessary to define on which encoder state (for example channel A and channel B state combination) the index must be synchronized, using the IPOS[1:0] bitfield in the TIMx_ECR register.

The index detection event acts differently depending on counting direction to ensure symmetrical operation during speed reversal:

- The counter is reset during up-counting (DIR bit = 0).
- The counter is set to TIMx_ARR when down-counting.

This allows the index to be generated on the very same mechanical angular position whatever the counting direction. *Figure 628* shows at which position is the index generated, for a simplistic example (an encoder providing four edges par mechanical rotation).

Figure 628. Index generation for IPOS[1:0] = 11

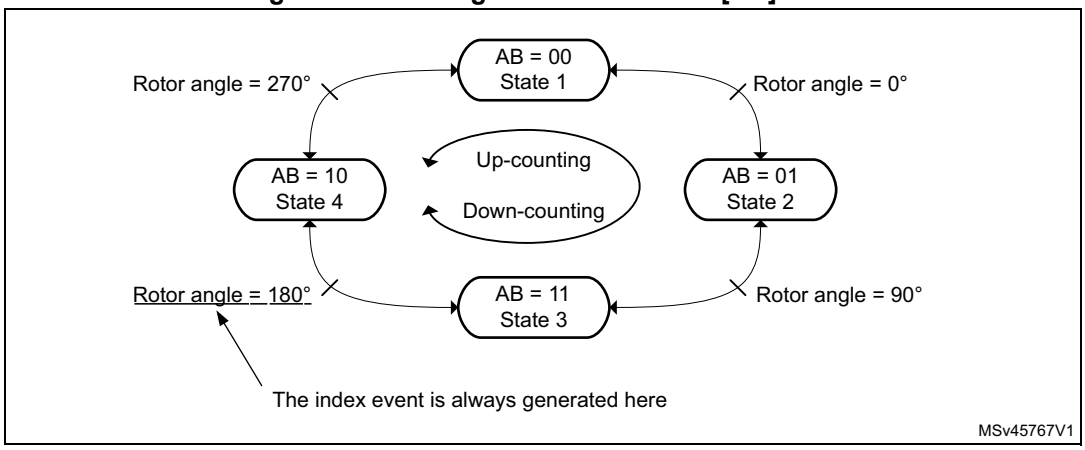


Figure 629 presents waveforms and corresponding values for IPOS[1:0] = 11. It shows that the instant at which the counter value is forced is automatically adjusted depending on the counting direction:

- Counter set to 0 when encoder state is 11 (ChA = 1, ChB = 1), when up-counting (DIR bit = 0).
- Counter set to TIMx_ARR when exiting the 11 state, when down-counting (DIR bit = 1).

An interrupt can be issued upon index detection event.

The arrows are indicating on which transition is the index event interrupt generated.

Figure 629. Counter reading with index gated on channel A (IPOS[1:0] = 11)

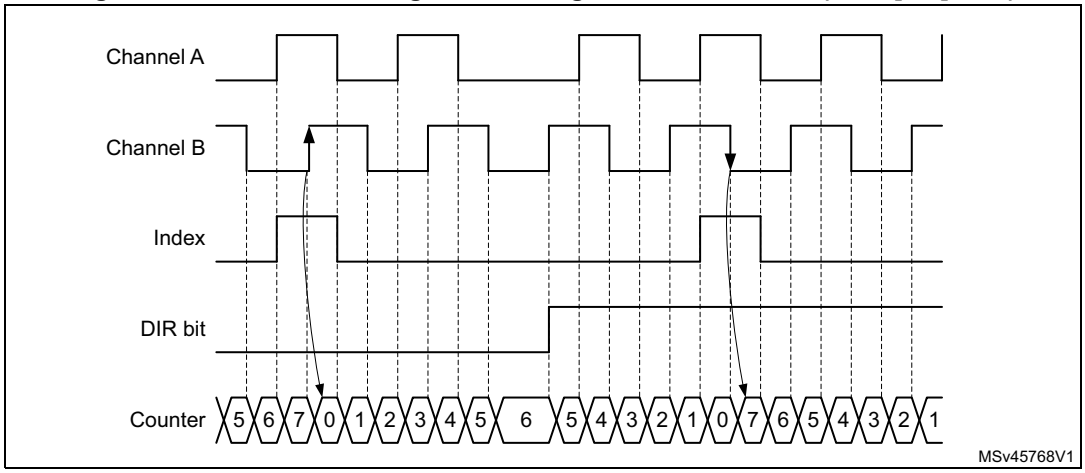


Figure 630 presents waveforms and corresponding values for the ungated mode. The arrows are indicating on which transition is the index event generated.

Figure 630. Counter reading with index ungated (IPOS[1:0] = 00)

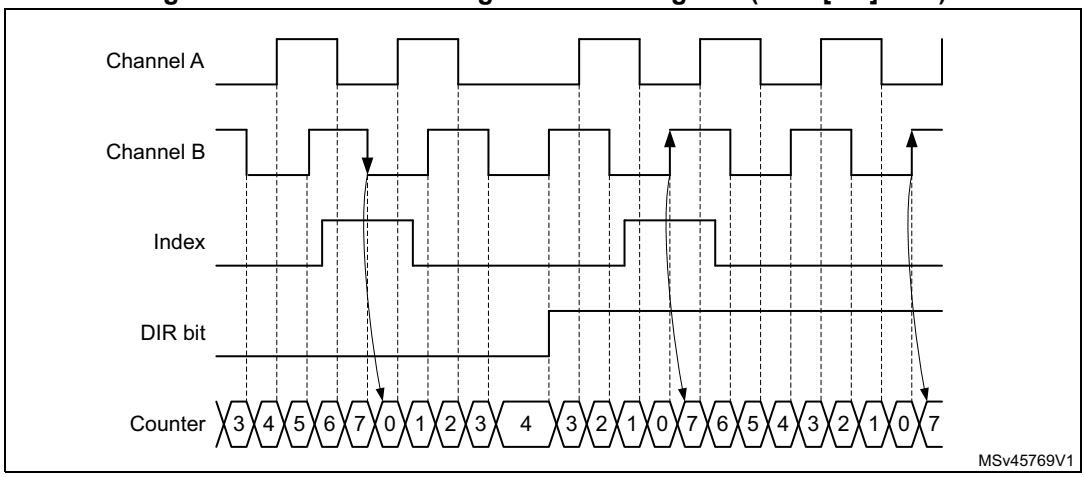


Figure 631 shows how the gated on A & B mode is handled, for various pulse alignment scenarios. The arrows are indicating on which transition is the index event generated.

Figure 631. Counter reading with index gated on channel A and B

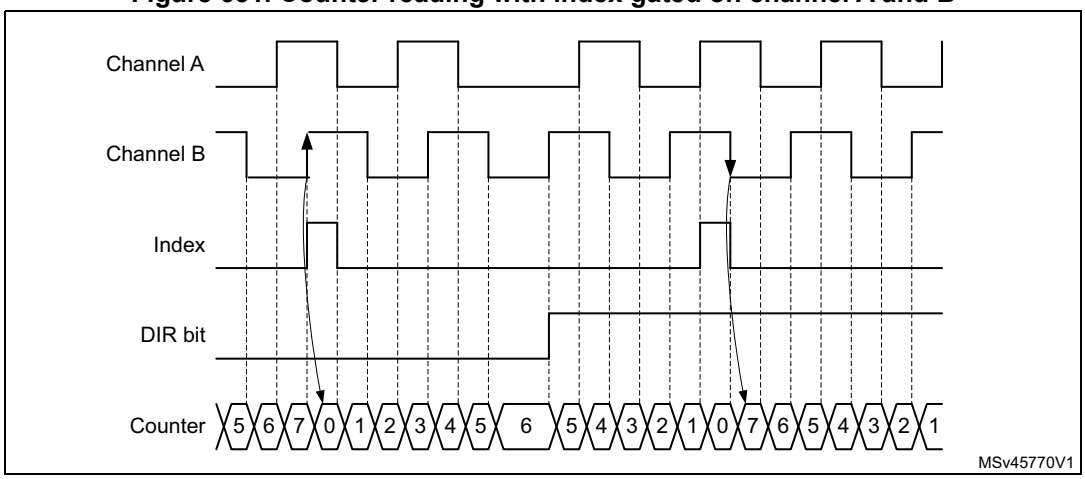


Figure 632 and *Figure 633* detail the case where the subsequent index pulse may be narrower than one quarter of the encoder clock period.

Figure 632. Encoder mode behavior in case of narrow index pulse (IPOS[1:0] = 11)

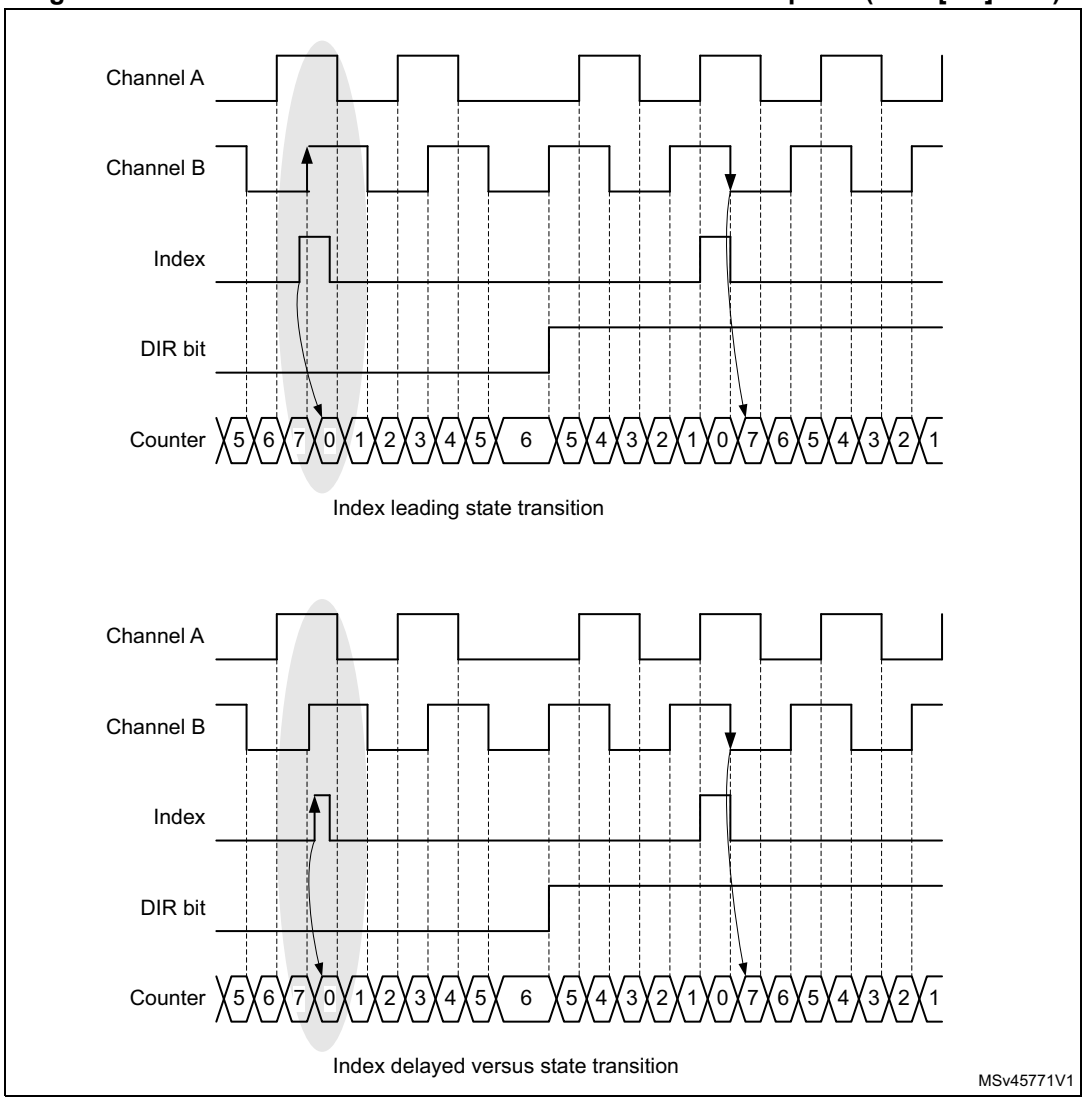


Figure 633. Counter reset Narrow index pulse (closer view, ARR = 0x07)

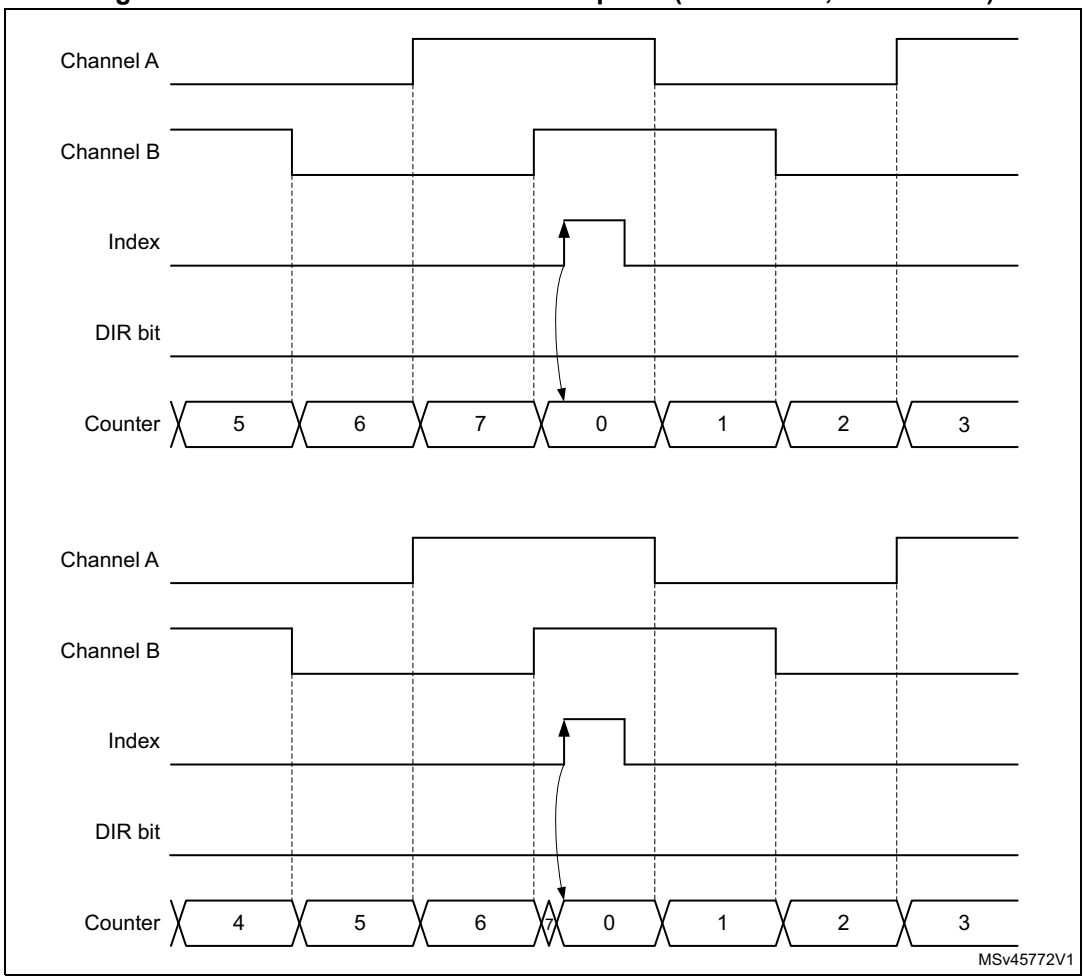
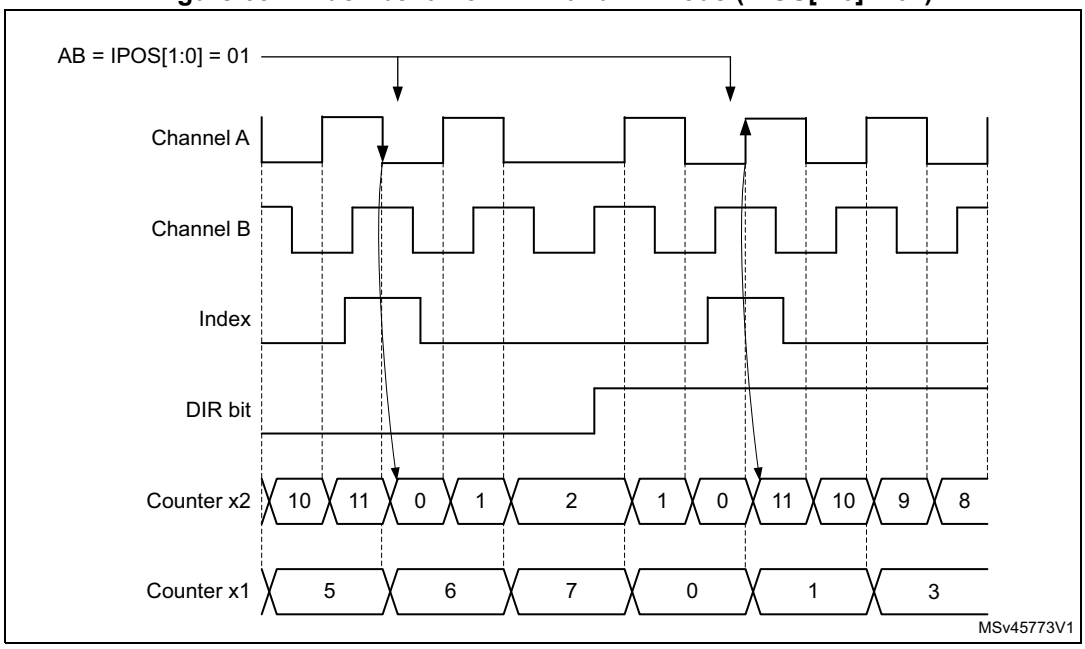


Figure 634 shows how the index is managed in x1 and x2 modes.

Figure 634. Index behavior in x1 and x2 mode (IPOS[1:0] = 01)

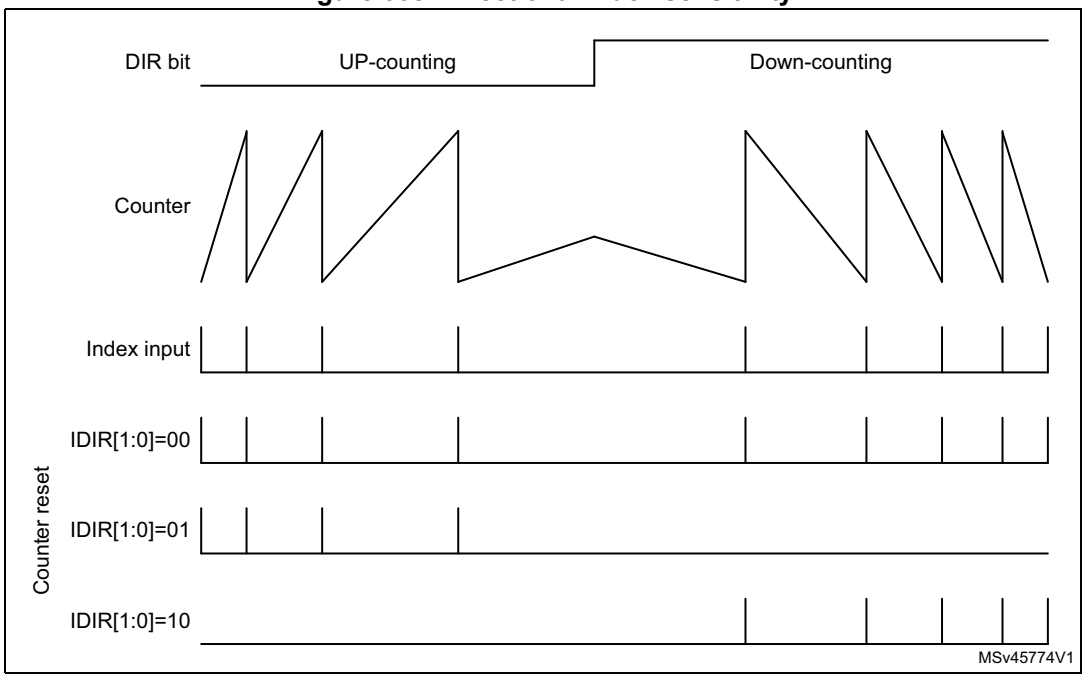


Directional index sensitivity

The IDIR[1:0] bitfield in the TIMx_ECR register allows the index to be active only in a selected counting direction.

Figure 635 shows the relationship between index and counter reset events, depending on IDIR[1:0] value.

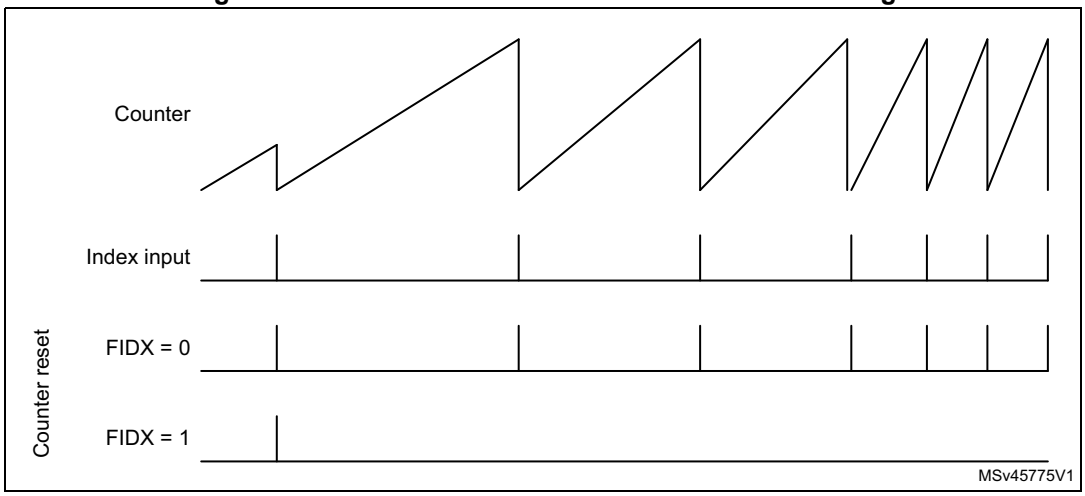
Figure 635. Directional index sensitivity



Special first index event management

The FIDX bit in the TIMx_ECR register allows the index to be taken only once, as shown on *Figure 636*. Once the first index has arrived, any subsequent index is ignored. If needed, the circuitry can be rearmed by writing the FIDX bit to 0 and setting it again to 1.

Figure 636. Counter reset as function of FIDX bit setting



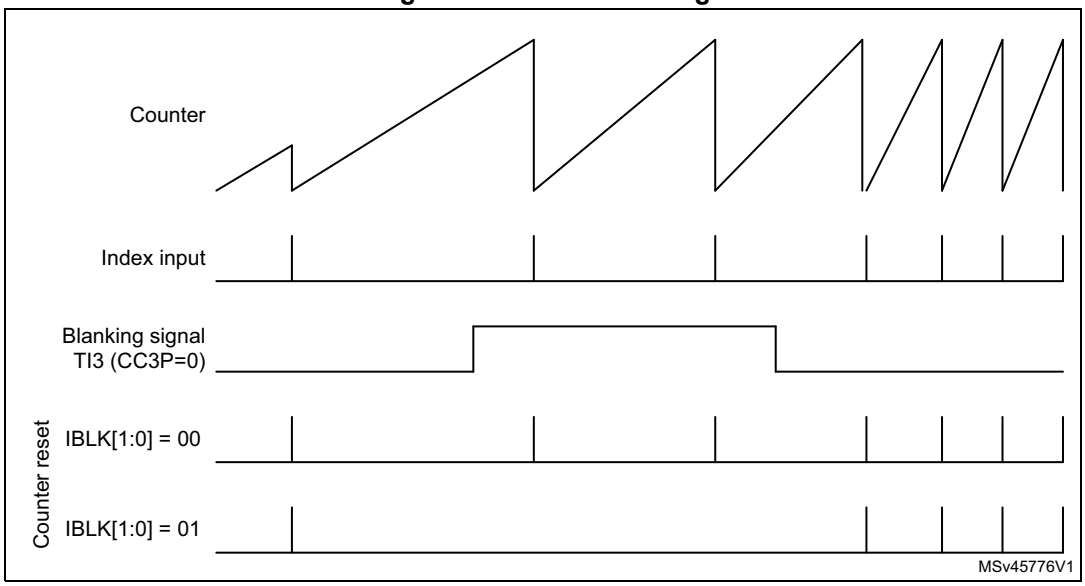
Index blanking

The index event can be blanked using the tim_ti3 or tim_ti4 inputs. During the blanking window, the index events are no longer resetting the counter, as shown on *Figure 637*.

This mode is enabled using the IBLK[1:0] bitfield in the TIMx_ECR register, as following:

- IBLK[1:0] = 00: Index signal always active.
- IBLK[1:0] = 01: Index signal blanking on tim_ti3 input.
- IBLK[1:0] = 10: Index signal blanking on tim_ti4 input.

Figure 637. Index blanking



Index management in nonquadrature mode

Figure 638 and *Figure 639* detail how the index is managed in directional clock mode and clock plus direction mode, when the SMS[3:0] bitfield is equal to 1010, 1011, 1100, 1101.

For both of these modes, the index sensitivity is set with the IPOS[0] bit as following:

- IPOS[0] = 0: Index is detected on clock low level.
- IPOS[0] = 1: Index is detected on clock high level.

The IPOS[1] bit is not-significant.

Figure 638. Index behavior in clock + direction mode, IPOS[0] = 1

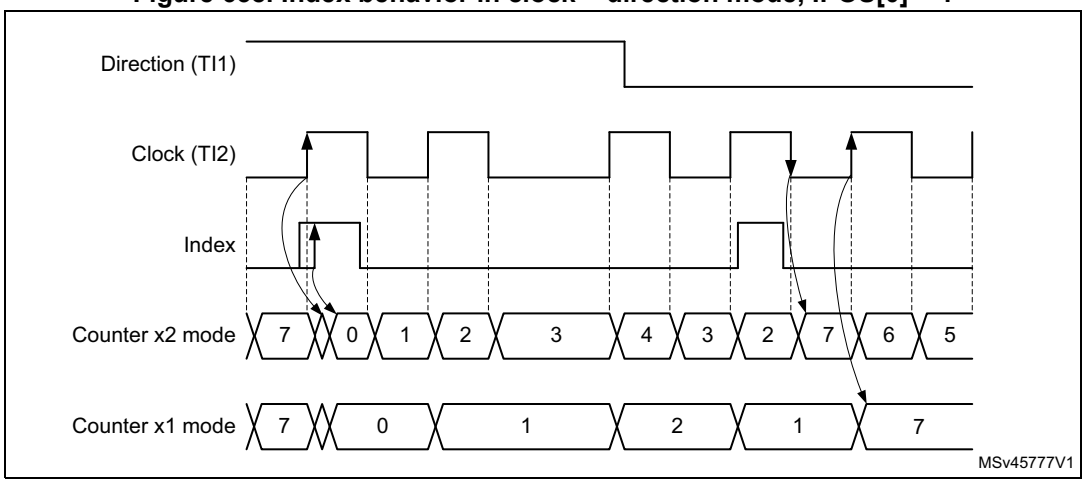
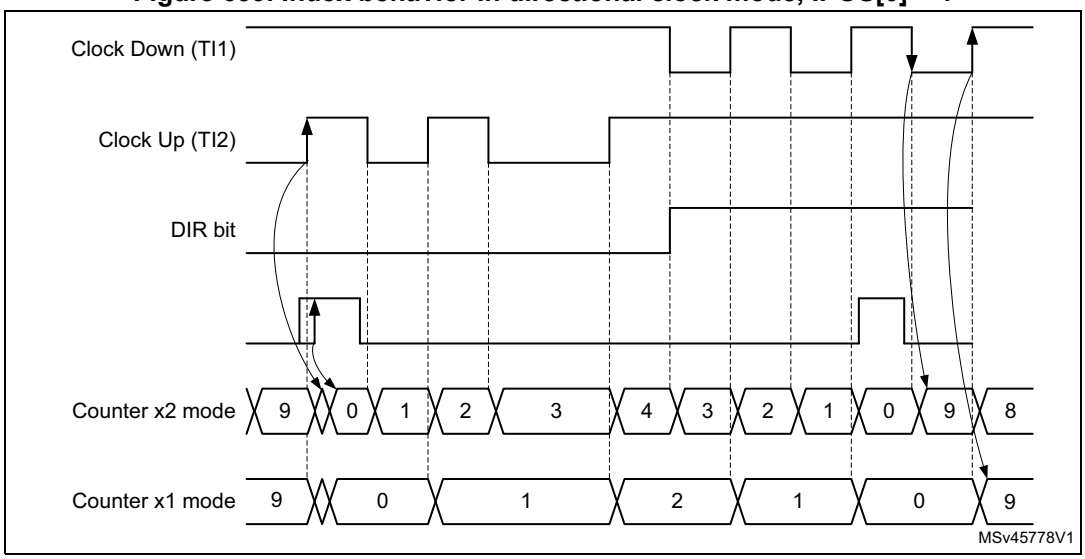


Figure 639. Index behavior in directional clock mode, IPOS[0] = 1

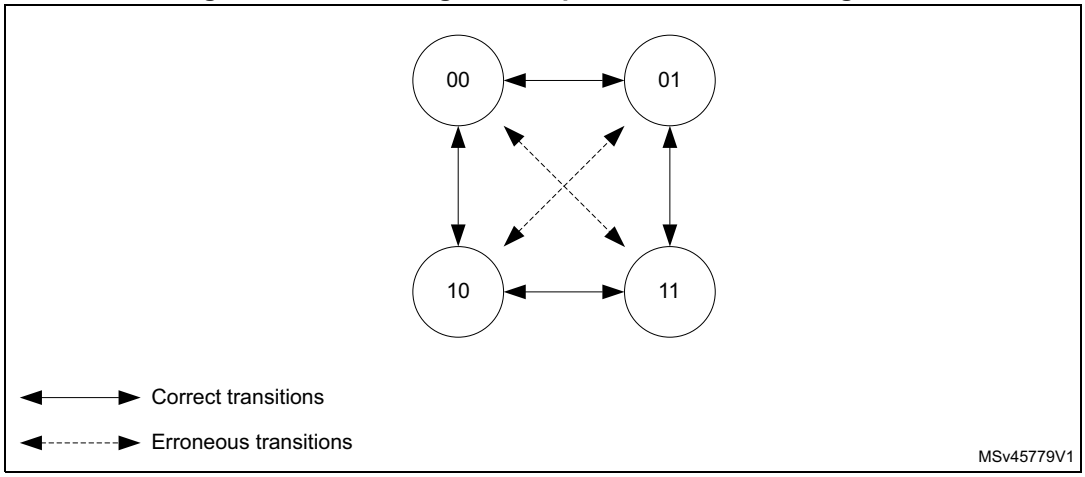


Encoder error management

For encoder configurations where two quadrature signals are available, it is possible to detect transition errors. The reading on the two inputs corresponds to a 2-bit gray code which can be represented as a state diagram, on *Figure 640*. A single bit is expected to change at once. An erroneous transition sets the TERRF interrupt flag in the TIMx_SR

status register. A transition error interrupt is generated if the TERRIE bit is set in the TIMx_DIER register.

Figure 640. State diagram for quadrature encoded signals



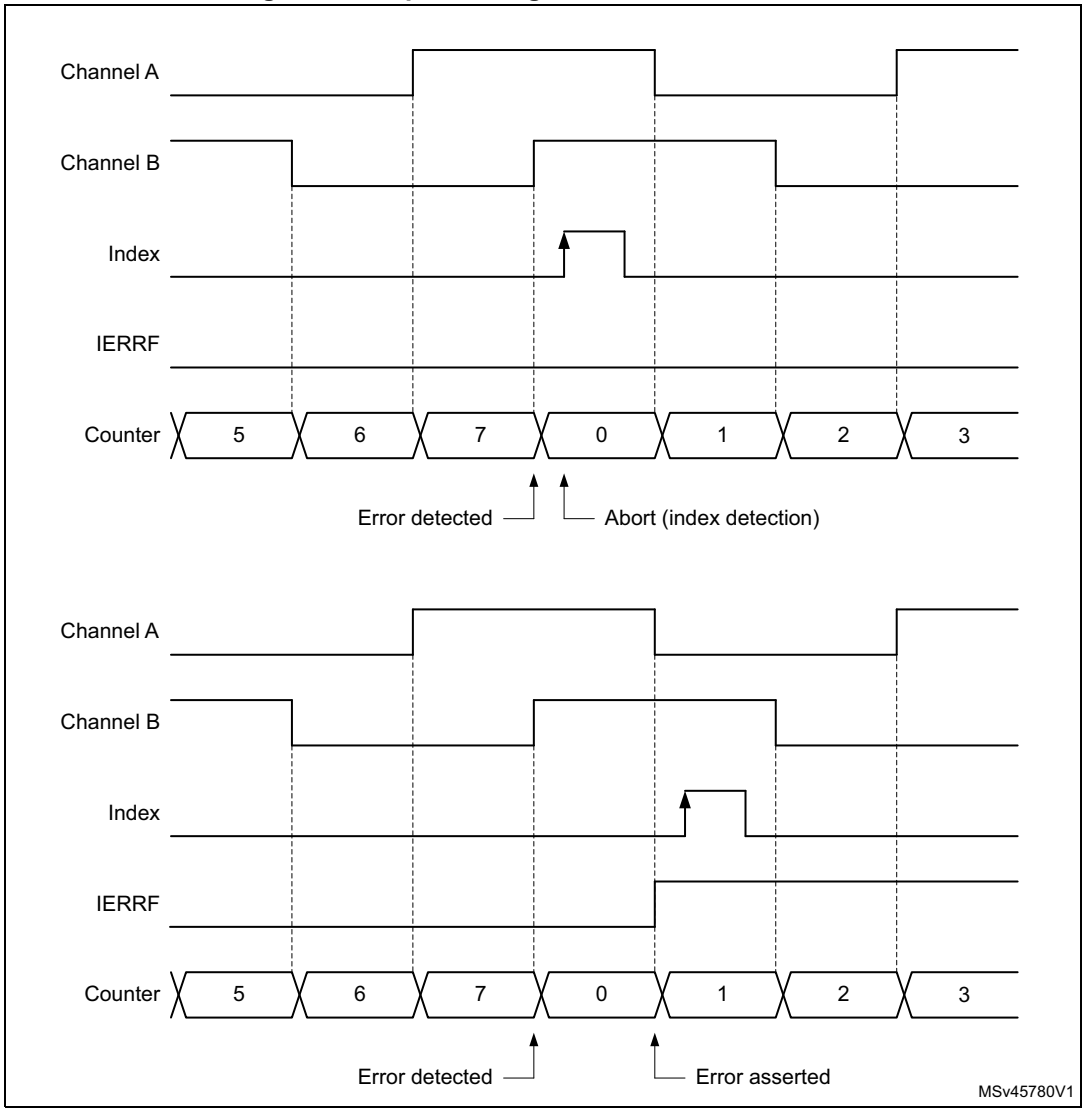
For encoder having an index signal, it is possible to detect abnormal operation resulting in an excess of pulses per revolution. An encoder with N pulses per revolution provides 4xN counts per revolution. The index signal resets the counter every 4xN clock periods.

If the counter value is incremented from TIMx_ARR to 0 or decremented from 0 to TIMx_ARR value without any index event, this is reported as an index position error.

The overflow threshold is programmed using the TIMx_ARR register. A 1000 lines encoder results in a counter value being between 0 and 3999 (in 4x reading mode). The overflow detection threshold must be programmed by setting TIMx_ARR = 3999 + 1 = 4000.

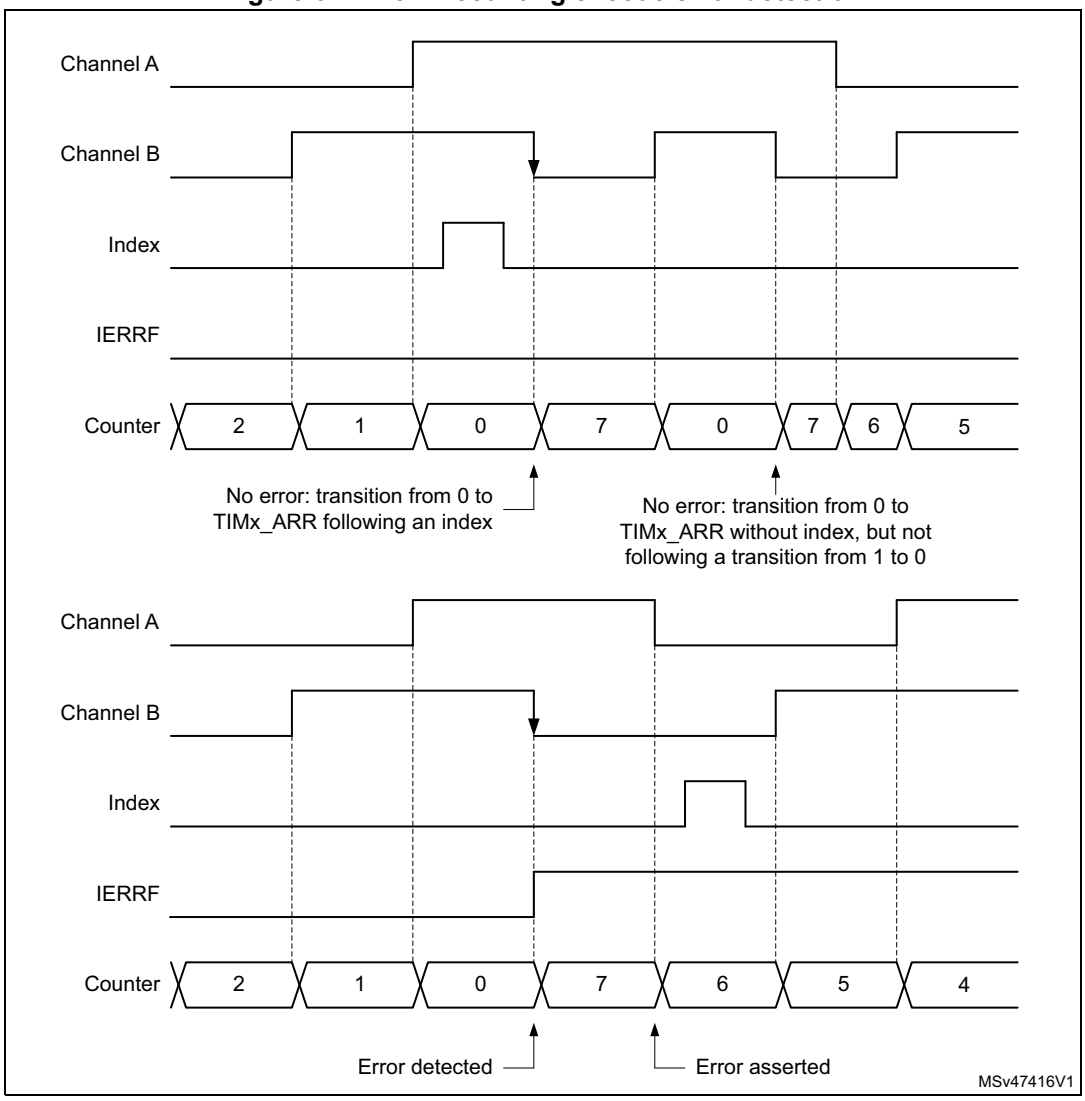
The error assertion is delayed to the transition 0 to 1 when in up-counting. This is to cope with narrow index pulses in gated A and B mode, as shown on *Figure 641*.

Figure 641. Up-counting encoder error detection



In down-counting mode, the detection is conditioned by a preliminary transition from 1 to 0. This is to cope with narrow index pulses in gated A and B mode, as shown on *Figure 642*, to avoid any false error detection in case the encoder dithers between TIMx_ARR and 0 immediately after the index detection.

Figure 642. Down-counting encode error detection



An index error sets the IERRF interrupt flag in the TIMx_SR status register. An index error interrupt is generated if the IERRIE bit is set in the TIMx_DIER register.

Functional encoder interrupts

The following interrupts are also available in encoder mode

- Direction change: any change of the counting direction in encoder mode causes the DIR bit in the TIMx_CR1 register to toggle. The direction change sets the DIRF interrupt flag in the TIMx_SR status register. A direction change interrupt is generated if the DIRIE bit is set in the TIMx_DIER register.
- Index event: the index event sets the IDXF interrupt flag in the TIMx_SR status register. An index interrupt is generated if the IDXIE bit is set in the TIMx_DIER register.

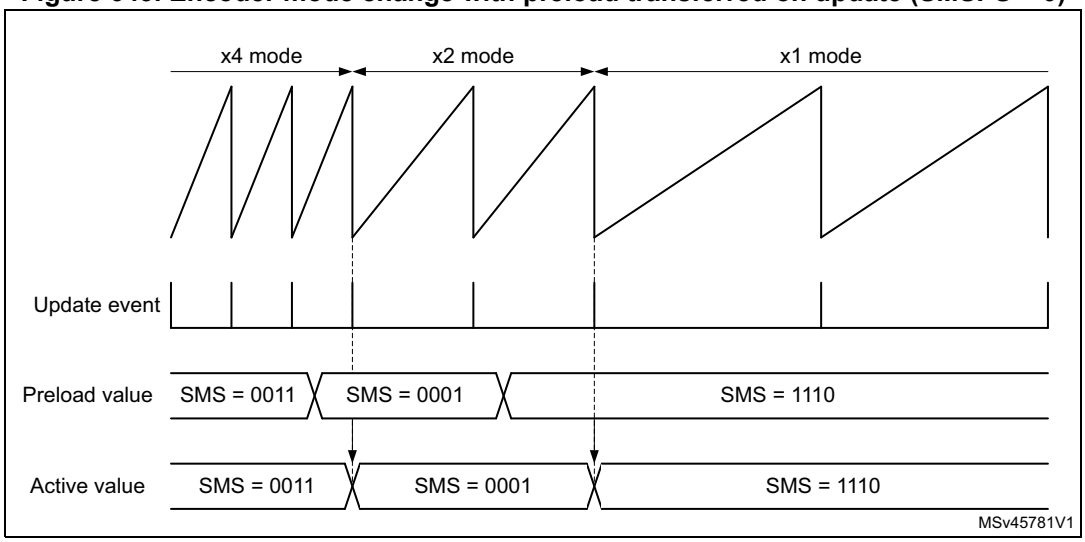
Slave mode selection preload for run-time encoder mode update

It can be necessary to switch from one encoder mode to another during run-time. This is typically done at high-speed to decrease the update interrupt rate, by switching from x4 to x2 to x1 mode, as shown on *Figure 643*.

For this purpose, the SMS[3:0] bit can be preloaded. This is enabled by setting the SMSPE enable bit in the TIMx_SMCR register. The trigger for the transfer from SMS[3:0] preload to active value can be selected with the SMSPS bit in the TIMx_SMCR register.

- SMSPS = 0: the transfer is triggered by the update event (UEV) occurring when the counter overflows when up-counting, and underflows when down-counting.
- SMSPS = 1: the transfer is triggered by the index event.

Figure 643. Encoder mode change with preload transferred on update (SMSPS = 0)



Encoder clock output

The encoder mode operating principle is not perfectly suited for high-resolution velocity measurements, at low speed, as it requires a relatively long integration time to have a sufficient number of clock edges and a precise measurement.

At low speed, a better solution is to do an edge-to-edge clock period measurement. This can be achieved using a slave timer. The timer can output the encoder clock information on the tim_trgo output. The slave timer can then perform a period measurement and provide velocity information for each and every encoder clock edge.

This mode is enabled by setting the MMS[3:0] bitfield to 1000, in the TIMx_CR2 register. It is valid for the following SMS[3:0] values: 0001, 0010, 0011, 1010, 1011, 1100, 1101, 1110, 1111. Any other SMS[3:0] code is not allowed and may lead to unexpected behavior.

50.4.19 Direction bit output

It is possible to output a direction signal out of the timer, on the tim_oc3 and tim_oc4 output signals (copy of the DIR bit in the TIMx_CR1 register). This is achieved by setting the OC3M[3:0] or the OC4M[3:0] bitfield to 1011 in the TIMx_CCMR2 register.

This feature can be used for monitoring the counting direction (or rotation direction) in encoder mode, or to have a signal indicating the up/down phases in center-aligned PWM mode.

50.4.20 UIF bit remapping

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the update interrupt flag (UIF) into bit 31 of the timer counter register's bit 31 (TIMx_CNT[31]). This is used to atomically read both the counter value and a potential roll-over condition signaled by the UIFCPY flag. It eases the calculation of angular speed by avoiding race conditions caused, for instance, by a processing shared between a background task (counter reading) and an interrupt (update interrupt).

There is no latency between the UIF and UIFCPY flag assertions.

In 32-bit timer implementations, when the IUFREMAP bit is set, bit 31 of the counter is overwritten by the UIFCPY flag upon read access (the counter's most significant bit is only accessible in write mode).

50.4.21 Timer input XOR function

The TI1S bit in the TIMx_CR2 register, allows the input filter of channel 1 to be connected to the output of an XOR gate, combining the three input pins tim_ti1, tim_ti2 and tim_ti3.

The XOR output can be used with all the timer input functions such as trigger or input capture.

An example of this feature used to interface Hall sensors is given in *Section 49.3.29: Interfacing with Hall sensors*.

50.4.22 Timers and external trigger synchronization

The TIMx timers can be synchronized with an external trigger in several modes: Reset mode, Gated mode, Trigger mode, Reset + trigger and gated + reset modes.

Slave mode: Reset mode

The counter and its prescaler can be reinitialized in response to an event on a trigger input. Moreover, if the URS bit from the TIMx_CR1 register is low, an update event UEV is generated. Then all the preloaded registers (TIMx_ARR, TIMx_CCRx) are updated.

In the following example, the upcounter is cleared in response to a rising edge on tim_ti1 input:

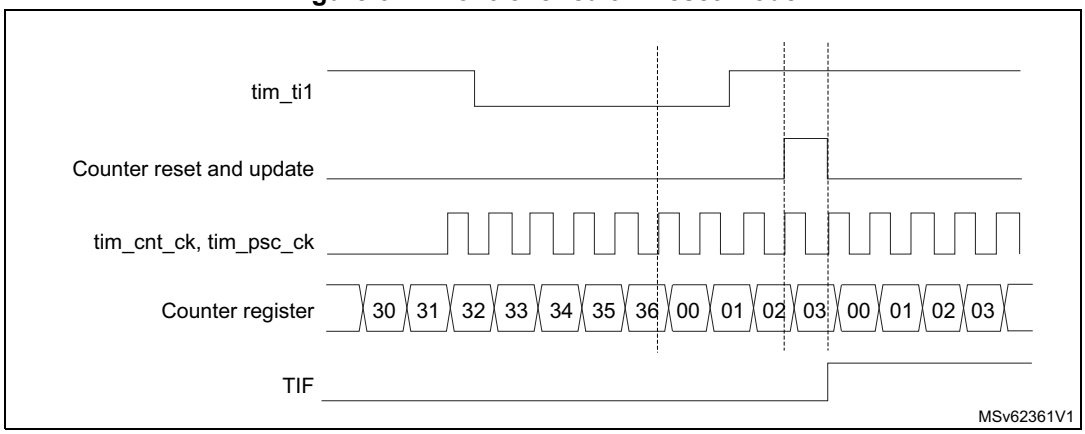
1. Configure the channel 1 to detect rising edges on tim_ti1. Configure the input filter duration (in this example, we do not need any filter, so we keep IC1F = 0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S = 01 in the TIMx_CCMR1 register. Write CC1P = 0 and CC1NP = 0 in TIMx_CCER register to validate the polarity (and detect rising edges only).
2. Configure the timer in reset mode by writing SMS = 100 in TIMx_SMCR register. Select tim_ti1 as the input source by writing TS = 00101 in TIMx_SMCR register.
3. Start the counter by writing CEN = 1 in the TIMx_CR1 register.

The counter starts counting on the internal clock, then behaves normally until tim_ti1 rising edge. When tim_ti1 rises, the counter is cleared and restarts from 0. In the meantime, the

trigger flag is set (TIF bit in the TIMx_SR register) and an interrupt request, or a DMA request can be sent if enabled (depending on the TIE and TDE bits in TIMx_DIER register).

The following figure shows this behavior when the autoreload register TIMx_ARR = 0x36. The delay between the rising edge on tim_ti1 and the actual reset of the counter is due to the resynchronization circuit on tim_ti1 input.

Figure 644. Control circuit in reset mode



Slave mode: Gated mode

The counter can be enabled depending on the level of a selected input.

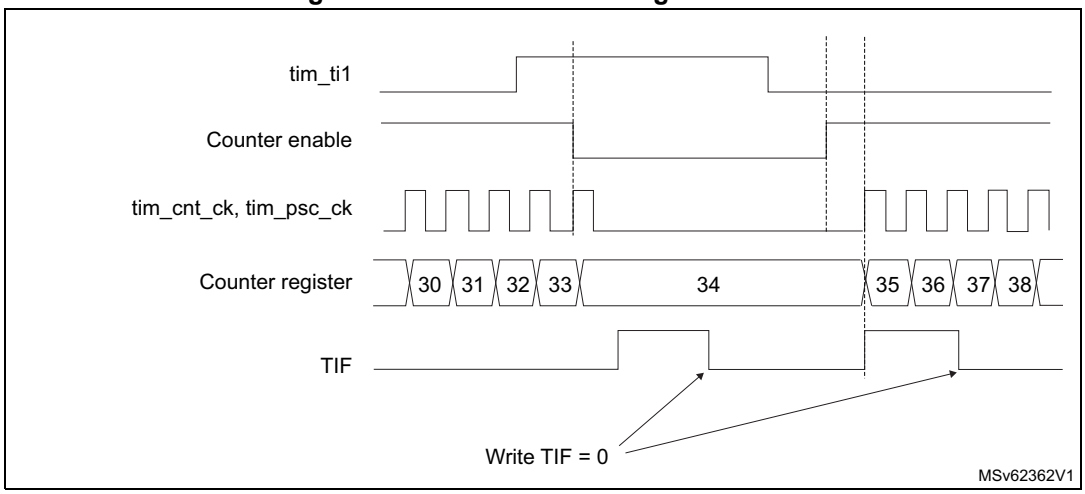
In the following example, the upcounter counts only when tim_ti1 input is low:

1. Configure the channel 1 to detect low levels on tim_ti1. Configure the input filter duration (in this example, we do not need any filter, so we keep IC1F = 0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S = 01 in TIMx_CCMR1 register. Write CC1P = 1 and CC1NP = 0 in TIMx_CCER register to validate the polarity (and detect low level only).
2. Configure the timer in gated mode by writing SMS = 101 in TIMx_SMCR register. Select tim_ti1 as the input source by writing TS = 00101 in TIMx_SMCR register.
3. Enable the counter by writing CEN = 1 in the TIMx_CR1 register (in gated mode, the counter does not start if CEN = 0, whatever is the trigger input level).

The counter starts counting on the internal clock as long as tim_ti1 is low and stops as soon as tim_ti1 becomes high. The TIF flag in the TIMx_SR register is set both when the counter starts or stops.

The delay between the rising edge on tim_ti1 and the actual stop of the counter is due to the resynchronization circuit on tim_ti1 input.

Figure 645. Control circuit in gated mode



Note: The configuration "CCxP = CCxNP = 1" (detection of both rising and falling edges) does not have any effect in gated mode because gated mode acts on a level and not on an edge.

Slave mode: Trigger mode

The counter can start in response to an event on a selected input.

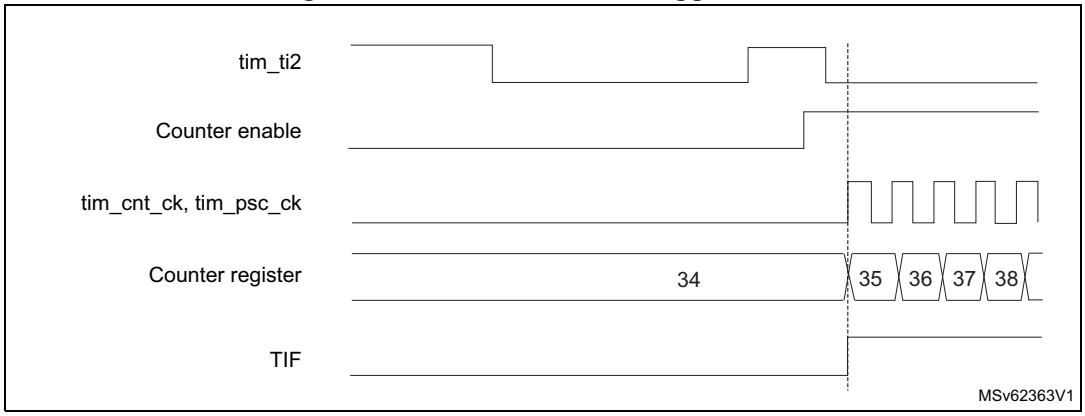
In the following example, the upcounter starts in response to a rising edge on tim_ti2 input:

1. Configure the channel 2 to detect rising edges on tim_ti2. Configure the input filter duration (in this example, we do not need any filter, so we keep IC2F = 0000). The capture prescaler is not used for triggering, so it does not need to be configured. CC2S bits are selecting the input capture source only, CC2S = 01 in TIMx_CCMR1 register. Write CC2P = 1 and CC2NP = 0 in TIMx_CCER register to validate the polarity (and detect low level only).
2. Configure the timer in trigger mode by writing SMS = 110 in TIMx_SMCR register. Select tim_ti2 as the input source by writing TS = 00110 in TIMx_SMCR register.

When a rising edge occurs on tim_ti2, the counter starts counting on the internal clock and the TIF flag is set.

The delay between the rising edge on tim_ti2 and the actual start of the counter is due to the resynchronization circuit on tim_ti2 input.

Figure 646. Control circuit in trigger mode



Slave mode selection preload for run-time encoder mode update

The SMS[3:0] bit can be preloaded. This is enabled by setting the SMSPE enable bit in the TIMx_SMCR register. The trigger for the transfer from SMS[3:0] preload to active value is the update event (UEV) occurring when the counter overflows.

Slave mode – combined reset + trigger mode

In this case, a rising edge of the selected trigger input (tim_trgi) reinitializes the counter, generates an update of the registers, and starts the counter.

This mode is used for one-pulse mode.

Slave mode – combined gated + reset mode

The counter clock is enabled when the trigger input (tim_trgi) is high. The counter stops and is reset as soon as the trigger becomes low. Both start and stop of the counter are controlled.

This mode is used to detect out-of-range PWM signal (duty cycle exceeding a maximum expected value).

Slave mode – external clock mode 2 + trigger mode

The external clock mode 2 can be used in addition to another slave mode (except external clock mode 1 and encoder mode). In this case, the tim_etr_in signal is used as external clock input, and another input can be selected as trigger input when operating in reset mode, gated mode, or trigger mode. It is recommended not to select tim_etr_in as tim_trgi through the TS bits of TIMx_SMCR register.

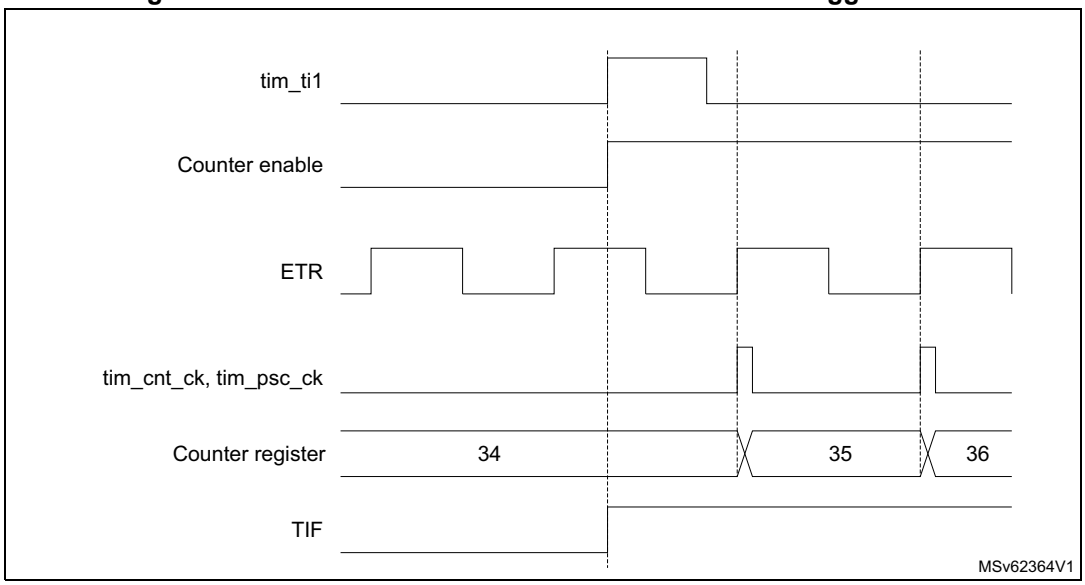
In the following example, the upcounter is incremented at each rising edge of the tim_etr_in signal as soon as a rising edge of tim_ti1 occurs:

1. Configure the external trigger input circuit by programming the TIMx_SMCR register as follows:
   - ETF = 0000: no filter.
   - ETPS = 00: prescaler disabled.
   - ETP = 0: detection of rising edges on tim_etr_in and ECE = 1 to enable the external clock mode 2.
2. Configure the channel 1 as follows, to detect rising edges on TI:
   - IC1F = 0000: no filter.
   - The capture prescaler is not used for triggering and does not need to be configured.
   - CC1S = 01in TIMx_CCMR1 register to select only the input capture source.
   - CC1P = 0 and CC1NP = 0 in TIMx_CCER register to validate the polarity (and detect rising edge only).
3. Configure the timer in trigger mode by writing SMS = 110 in TIMx_SMCR register. Select tim_ti1 as the input source by writing TS = 00101 in TIMx_SMCR register.

A rising edge on tim_ti1 enables the counter and sets the TIF flag. The counter then counts on tim_etr_in rising edges.

The delay between the rising edge of the tim_etr_in signal and the actual reset of the counter is due to the resynchronization circuit on tim_etrp input.

Figure 647. Control circuit in external clock mode 2 + trigger mode



50.4.23 Timer synchronization

The TIMx timers are linked together internally for timer synchronization or chaining. When one timer is configured in Master mode, it can reset, start, stop, or clock the counter of another timer configured in Slave mode.

Figure 648 and *Figure 649* show examples of master/slave timer connections.

Figure 648. Master/Slave timer example

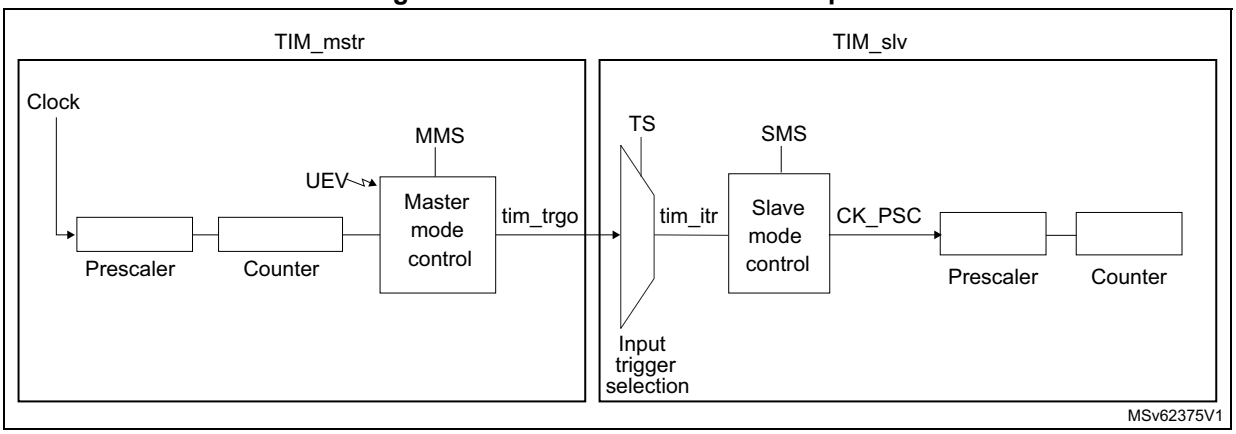
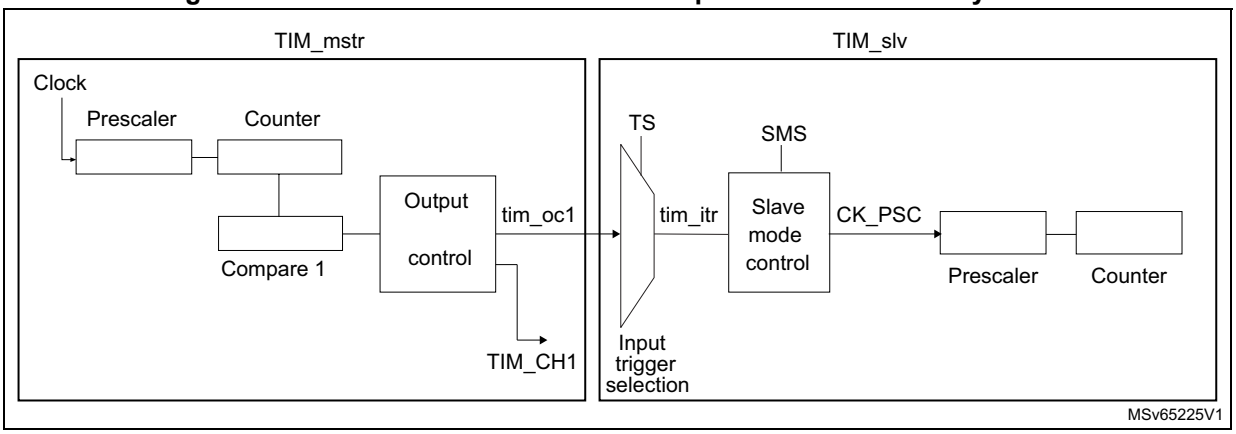


Figure 649. Master/slave connection example with 1 channel only timers



Note: The timers with one channel only (see Figure 649) do not feature a master mode. However, the tim_oc1 output signal can serve as trigger for slave timer (see TIMx internal trigger connection table in Section 50.4.2: TIM2/TIM3/TIM4/TIM5 pins and internal signals).
The tim_oc1 signal pulse width must be programmed to be at least two clock cycles of the destination timer, to make sure the slave timer detects the trigger.
For instance, if the destination timer tim_ker_ck clock is four times slower than the source timer, the OC1 pulse width must be eight clock cycles.

Using one timer as prescaler for another timer

For example, TIM_mstr can be configured to act as a prescaler for TIM_slv. Refer to *Figure 648*. To do this:

1. Configure TIM_mstr in master mode so that it outputs a periodic trigger signal on each update event UEV. If MMS = 010 is written in the TIM_mstr_CR2 register, a rising edge is output on tim_trgo each time an update event is generated.
2. To connect the tim_trgo output of TIM_mstr to TIM_slv, TIM_slv must be configured in slave mode using ITR2 as internal trigger. This is selected through the TS bits in the TIM_slv_SMCR register (writing TS = 00010).
3. Then the slave mode controller must be put in external clock mode 1 (write SMS = 111 in the TIM_slv_SMCR register). This causes TIM_slv to be clocked by the rising edge of the periodic TIM_mstr trigger signal (which correspond to the TIM_mstr counter overflow).
4. Finally both timers must be enabled by setting their respective CEN bits (TIMx_CR1 register).

Note: If tim_ocx is selected on TIM_mstr as the trigger output (MMS = 1xx), its rising edge is used to clock the counter of TIM_slv.

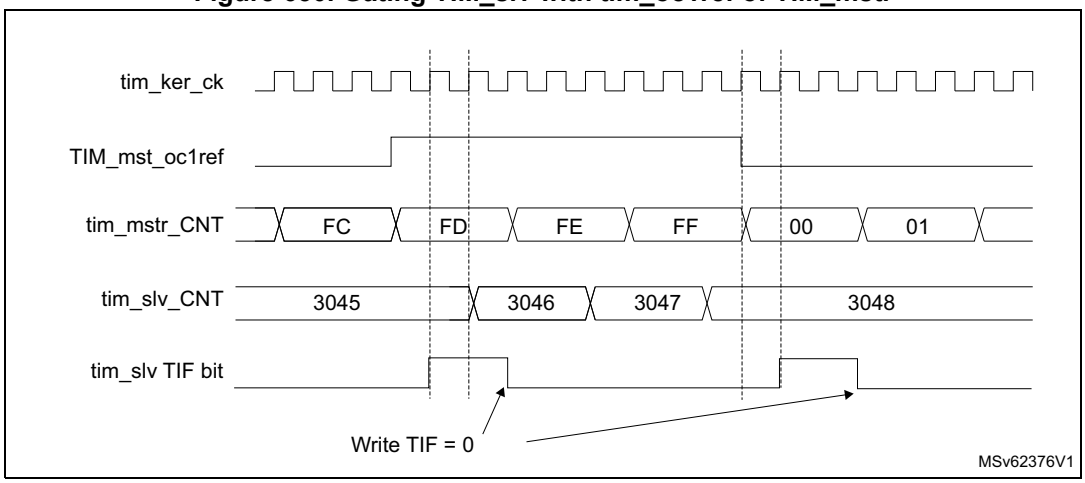
Using one timer to enable another timer

In this example, we control the enable of TIM_slv with the output compare 1 of TIM_mstr. Refer to *Figure 648* for connections. TIM_slv counts on the divided internal clock only when tim_oc1ref of TIM_mstr is high. Both counter clock frequencies are divided by 3 by the prescaler compared to tim_ker_ck ($f_{tim_cnt_ck} = f_{tim_ker_ck}/3$).

1. Configure TIM_mstr master mode to send its output compare 1 reference (tim_oc1ref) signal as trigger output (MMS = 100 in the TIM_mstr_CR2 register).
2. Configure the TIM_mstr tim_oc1ref waveform (TIM_mstr_CCMR1 register).
3. Configure TIM_slv to get the input trigger from TIM_mstr (TS = 00010 in the TIM_slv_SMCR register).
4. Configure TIM_slv in gated mode (SMS = 101 in TIM_slv_SMCR register).
5. Enable TIM_slv by writing 1 in the CEN bit (TIM_slv_CR1 register).
6. Start TIM_mstr by writing 1 in the CEN bit (TIM_mstr_CR1 register).

Note: The slave timer counter clock is not synchronized with the master timer counter clock, this mode only affects the TIM_slv counter enable signal.

Figure 650. Gating TIM_slv with tim_oc1ref of TIM_mstr

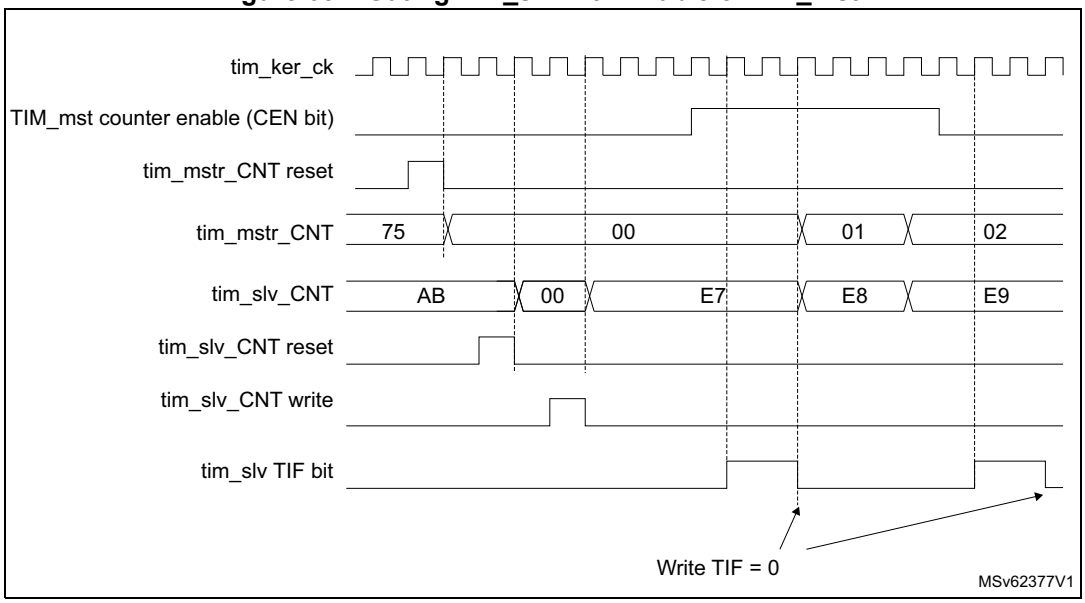


In the example in *Figure 650*, the TIM_slv counter and prescaler are not initialized before being started. So they start counting from their current value. It is possible to start from a given value by resetting both timers before starting TIM_mstr. Then any value can be written in the timer counters. The timers can easily be reset by software using the UG bit in the TIMx_EGR registers.

In the next example (refer to *Figure 651*), we synchronize TIM_mstr and TIM_slv. TIM_mstr is the master and starts from 0. TIM_slv is the slave and starts from 0xE7. The prescaler ratio is the same for both timers. TIM_slv stops when TIM_mstr is disabled by writing 0 to the CEN bit in the TIM_mstr_CR1 register:

1. Configure TIM_mstr master mode to send its output compare 1 reference (tim_oc1ref) signal as trigger output (MMS = 100 in the TIM_mstr_CR2 register).
2. Configure the TIM_mstr tim_oc1ref waveform (TIM_mstr_CCMR1 register).
3. Configure TIM_slv to get the input trigger from TIM_mstr (TS = 00010 in the TIM_slv_SMCR register).
4. Configure TIM_slv in gated mode (SMS = 101 in TIM_slv_SMCR register).
5. Reset TIM_mstr by writing 1 in UG bit (TIM_mstr_EGR register).
6. Reset TIM_slv by writing 1 in UG bit (TIM_slv_EGR register).
7. Initialize TIM_slv to 0xE7 by writing 0xE7 in the TIM_slv counter (TIM_slv_CNT).
8. Enable TIM_slv by writing 1 in the CEN bit (TIM_slv_CR1 register).
9. Start TIM_mstr by writing 1 in the CEN bit (TIM_mstr_CR1 register).
10. Stop TIM_mstr by writing 0 in the CEN bit (TIM_mstr_CR1 register).

Figure 651. Gating TIM_slv with Enable of TIM_mstr

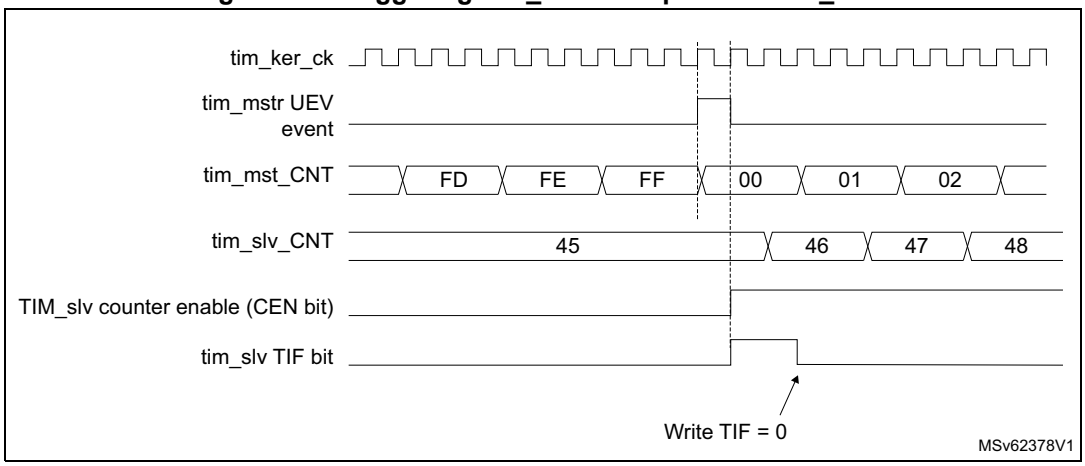


Using one timer to start another timer

In this example, we set the enable of TIM_slv with the update event of TIM_mstr. Refer to *Figure 648* for connections. TIM_slv starts counting from its current value (which can be nonzero) on the divided internal clock as soon as the update event is generated by TIM_mstr. When TIM_slv receives the trigger signal its CEN bit is automatically set and the counter counts until we write 0 to the CEN bit in the TIM_slv_CR1 register. Both counter clock frequencies are divided by 3 by the prescaler compared to tim_ker_ck ($f_{tim_cnt_ck} = f_{tim_ker_ck}/3$).

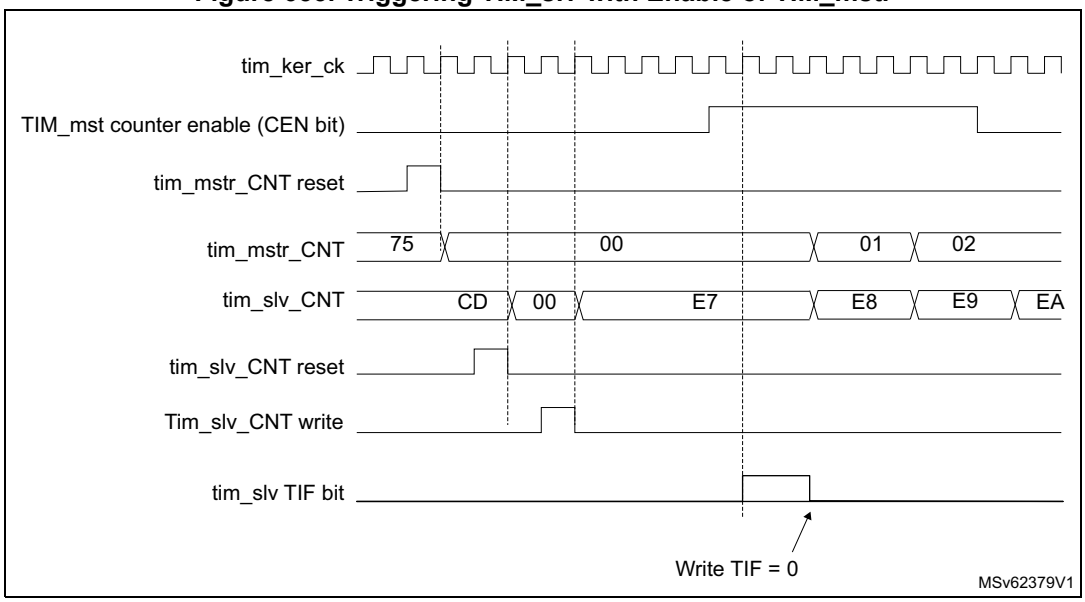
1. Configure TIM_mstr master mode to send its update event (UEV) as trigger output (MMS = 010 in the TIM_mstr_CR2 register).
2. Configure the TIM_mstr period (TIM_mstr_ARR registers).
3. Configure TIM_slv to get the input trigger from TIM_mstr (TS = 00010 in the TIM_slv_SMCR register).
4. Configure TIM_slv in trigger mode (SMS = 110 in TIM_slv_SMCR register).
5. Start TIM_mstr by writing 1 in the CEN bit (TIM_mstr_CR1 register).

Figure 652. Triggering TIM_slv with update of TIM_mstr



As in the previous example, both counters can be initialized before starting counting. *Figure 653* shows the behavior with the same configuration as in *Figure 652* but in trigger mode (SMS = 110 in the TIM_slv_SMCR register) instead of gated mode.

Figure 653. Triggering TIM_slv with Enable of TIM_mstr



Starting two timers synchronously in response to an external trigger

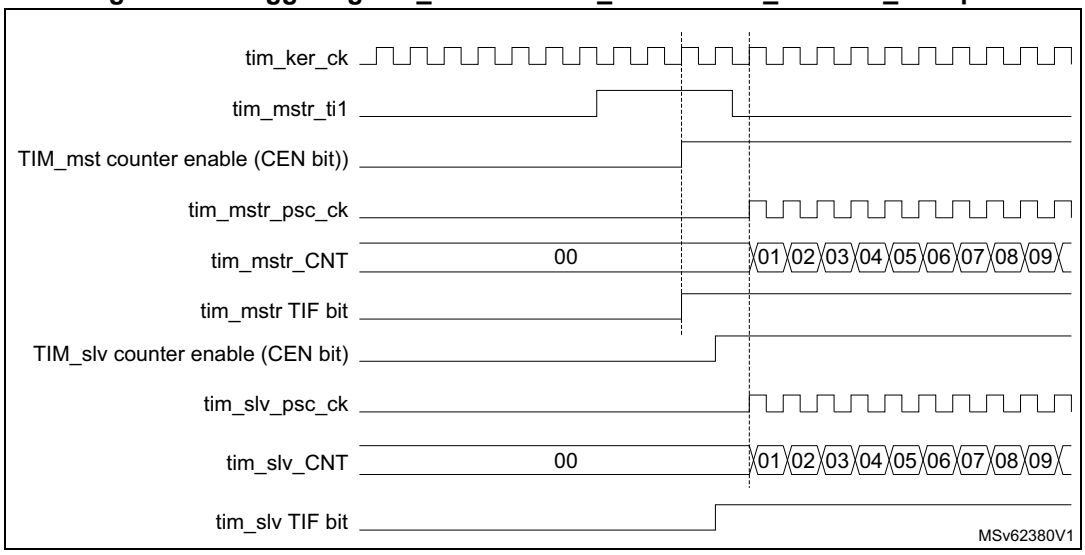
In this example, we set the enable of TIM_mstr when its tim_ti1 input rises, and the enable of TIM_slv with the enable of TIM_mstr. Refer to *Figure 648* for connections. To ensure the counters are aligned, TIM_mstr must be configured in Master/Slave mode (slave with respect to tim_ti1, master with respect to TIM_slv):

1. Configure TIM_mstr master mode to send its enable as trigger output (MMS = 001 in the TIM_mstr_CR2 register).
2. Configure TIM_mstr slave mode to get the input trigger from tim_ti1 (TS = 00100 in the TIM_mstr_SMCR register).
3. Configure TIM_mstr in trigger mode (SMS = 110 in the TIM_mstr_SMCR register).
4. Configure the TIM_mstr in Master/Slave mode by writing MSM = 1 (TIM_mstr_SMCR register).
5. Configure TIM_slv to get the input trigger from TIM_mstr (TS = 00000 in the TIM_slv_SMCR register).
6. Configure TIM_slv in trigger mode (SMS = 110 in the TIM_slv_SMCR register).

When a rising edge occurs on tim_ti1 (TIM_mstr), both counters start counting synchronously on the internal clock and both TIF flags are set.

Note: In this example both timers are initialized before starting (by setting their respective UG bits). Both counters starts from 0, but an offset can easily be inserted between them by writing any of the counter registers (TIMx_CNT). One can see that the master/slave mode inserts a delay between CNT_EN and CK_PSC on TIM_mstr.

Figure 654. Triggering TIM_mstr and TIM_slv with TIM_mstr tim_ti1 input



Note: The clock of the slave peripherals (such as timer, ADC) receiving the tim_trgo signal must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

50.4.24 ADC triggers

The timer can generate an ADC triggering event with various internal signals, such as reset, enable or compare events.

Note: The clock of the slave peripherals (such as timer, ADC) receiving the tim_trgo signal must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

50.4.25 DMA burst mode

The TIMx timers have the capability to generate multiple DMA requests upon a single event. The main purpose is to be able to reprogram part of the timer multiple times without software overhead, but it can also be used to read several registers in a row, at regular intervals.

The DMA controller destination is unique and must point to the virtual register TIMx_DMAR. On a given timer event, the timer launches a sequence of DMA requests (burst). Each write into the TIMx_DMAR register is actually redirected to one of the timer registers.

The DBL[4:0] bits in the TIMx_DCR register set the DMA burst length. The timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address), i.e. the number of transfers (either in half-words or in bytes).

The DBA[4:0] bits in the TIMx_DCR registers define the DMA base address for DMA transfers (when read/write accesses are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register:

Example:

00000: TIMx_CR1

00001: TIMx_CR2

00010: TIMx_SMCR

The DBSS[3:0] bits in the TIMx_DCR register defines the interrupt source that triggers the DMA burst transfers (see *Section 50.5.29: TIMx DMA control register (TIMx_DCR)(x = 2 to 5)* for details).

As an example, the timer DMA burst feature is used to update the contents of the CCRx registers (x = 2, 3, 4) upon an update event, with the DMA transferring half words into the CCRx registers.

This is done in the following steps:

1. Configure the corresponding DMA channel as follows:
   - DMA channel peripheral address is the DMAR register address.
   - DMA channel memory address is the address of the buffer in the RAM containing the data to be transferred by DMA into CCRx registers.
   - Number of data to transfer = 3 (See note below).
   - Circular mode disabled.
2. Configure the DCR register by configuring the DBA and DBL bitfields as follows: DBL = 3 transfers, DBA = 0xE and DBSS = 1.
3. Enable the TIMx update DMA request (set the UDE bit in the DIER register).
4. Enable TIMx.
5. Enable the DMA channel.

This example is for the case where every CCRx register has to be updated once. If every CCRx register is to be updated twice for example, the number of data to transfer must be 6. Let's take the example of a buffer in the RAM containing data1, data2, data3, data4, data5,

and data6. The data is transferred to the CCRx registers as follows: on the first update DMA request, data1 is transferred to CCR2, data2 is transferred to CCR3, data3 is transferred to CCR4 and on the second update DMA request, data4 is transferred to CCR2, data5 is transferred to CCR3, and data6 is transferred to CCR4.

Note: A null value can be written to the reserved registers.

50.4.26 TIM2/TIM3/TIM4/TIM5 DMA requests

The TIM2/TIM3/TIM4/TIM5 can generate a DMA requests, as shown in *Table 546*.

Table 546. DMA request

DMA request signal	DMA request	Enable control bit
tim_upd_dma	Update	UDE
tim_cc1_dma	Capture/compare 1	CC1DE
tim_cc2_dma	Capture/compare 2	CC2DE
tim_cc3_dma	Capture/compare 3	CC3DE
tim_cc4_dma	Capture/compare 4	CC4DE
tim_trgi_dma	Trigger	TDE

Note: Some timer's DMA requests may not be connected to the DMA controller. Refer to the DMA section(s) for more details.

50.4.27 Debug mode

When the microcontroller enters debug mode (Cortex®-M33 core halted), the TIMx counter can either continue to work normally or stops.

The behavior in debug mode can be programmed with a dedicated configuration bit per timer in the Debug support (DBG) module.

For more details, refer to section Debug support (DBG).

50.4.28 TIM2/TIM3/TIM4/TIM5 low-power modes

Table 547. Effect of low-power modes on TIM2/TIM3/TIM4/TIM5

Mode	Description
Sleep	No effect, peripheral is active. The interrupts can cause the device to exit from Sleep mode.
Stop	The timer operation is stopped and the register content is kept. No interrupt can be generated.
Standby	The timer is powered-down and must be reinitialized after exiting the Standby mode.

50.4.29 TIM2/TIM3/TIM4/TIM5 interrupts

The TIM2/TIM3/TIM4/TIM5 can generate multiple interrupts, as shown in *Table 548*.

Table 548. Interrupt requests

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop and Standby mode
TIM_UP	Update	UIF	UIE	write 0 in UIF	Yes	No
TIM_CC	Capture/compare 1	CC1IF	CC1IE	write 0 in CC1IF	Yes	No
	Capture/compare 2	CC2IF	CC2IE	write 0 in CC2IF	Yes	No
	Capture/compare 3	CC3IF	CC3IE	write 0 in CC3IF	Yes	No
	Capture/compare 4	CC4IF	CC4IE	write 0 in CC4IF	Yes	No
TIM_TRG	Trigger	TIF	TIE	write 0 in TIF	Yes	No
TIM_DIR_IDX	Index	IDXF	IDXIE	write 0 in IDXF	Yes	No
	Direction	DIRF	DIRIE	write 0 in DIRF	Yes	No
TIM_IERR	Index Error	IERRF	IERRIE	write 0 in IERRF	Yes	No
TIM_TER	Transition Error	TERRF	TERRIE	write 0 in TERRF	Yes	No

50.5 TIM2/TIM3/TIM4/TIM5 registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by half-words (16-bit) or words (32-bit).

50.5.1 TIMx control register 1 (TIMx_CR1)(x = 2 to 5)

Address offset: 0x000

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DITHEN	UIFREMAP	Res.	CKD[1:0]		ARPE	CMS[1:0]		DIR	OPM	URS	UDIS	CEN
			rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **DITHEN**: Dithering Enable

0: Dithering disabled

1: Dithering enabled

Note: The DITHEN bit can only be modified when CEN bit is reset.

Bit 11 **UIFREMAP**: UIF status bit remapping

0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.

1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bit 10 Reserved, must be kept at reset value.

Bits 9:8 **CKD[1:0]**: Clock division

This bitfield indicates the division ratio between the timer clock (tim_ker_ck) frequency and sampling clock used by the digital filters (tim_etr_in, tim_tix),

00: $t_{DTS} = t_{tim_ker_ck}$

01: $t_{DTS} = 2 \times t_{tim_ker_ck}$

10: $t_{DTS} = 4 \times t_{tim_ker_ck}$

11: Reserved

Bit 7 **ARPE**: Autoreload preload enable

0: TIMx_ARR register is not buffered

1: TIMx_ARR register is buffered

Bits 6:5 **CMS[1:0]**: Center-aligned mode selection

00: Edge-aligned mode. The counter counts up or down depending on the direction bit (DIR).

01: Center-aligned mode 1. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS = 00 in TIMx_CCMRx register) are set only when the counter is counting down.

10: Center-aligned mode 2. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS = 00 in TIMx_CCMRx register) are set only when the counter is counting up.

11: Center-aligned mode 3. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS = 00 in TIMx_CCMRx register) are set both when the counter is counting up or down.

Note: It is not allowed to switch from edge-aligned mode to center-aligned mode as long as the counter is enabled (CEN = 1)

Bit 4 **DIR**: Direction

0: Counter used as upcounter

1: Counter used as downcounter

Note: This bit is read only when the timer is configured in Center-aligned mode or Encoder mode.

Bit 3 **OPM**: One-pulse mode

0: Counter is not stopped at update event

1: Counter stops counting at the next update event (clearing the bit CEN)

Bit 2 **URS**: Update request source

This bit is set and cleared by software to select the UEV event sources.

0: Any of the following events generate an update interrupt or DMA request if enabled. These events can be:

- Counter overflow/underflow
- Setting the UG bit
- Update generation through the slave mode controller

1: Only counter overflow/underflow generates an update interrupt or DMA request if enabled.

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable UEV event generation.

0: UEV enabled. The Update (UEV) event is generated by one of the following events:

- Counter overflow/underflow
- Setting the UG bit
- Update generation through the slave mode controller

Buffered registers are then loaded with their preload values.

1: UEV disabled. The Update event is not generated, shadow registers keep their value (ARR, PSC, CCRx). However the counter and the prescaler are reinitialized if the UG bit is set or if a hardware reset is received from the slave mode controller.

Bit 0 **CEN**: Counter enable

0: Counter disabled

1: Counter enabled

Note: External clock, gated mode and encoder mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

CEN is cleared automatically in one-pulse mode, when an update event occurs.

50.5.2 TIMx control register 2 (TIMx_CR2)(x = 2 to 5)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	MMS[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw									
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1S	MMS[2:0]			CCDS	Res.	Res.	Res.
								rw	rw	rw	rw	rw			

Bits 31:26 Reserved, must be kept at reset value.

Bits 24:8 Reserved, must be kept at reset value.

Bit 7 **TI1S**: tim_ti1 selection

0: The tim_ti1_in[15:0] multiplexer output is to tim_ti1 input
1: The tim_ti1_in[15:0], tim_ti2_in[15:0] and tim_ti3_in[15:0] multiplexers outputs are XORed and connected to the tim_ti1 input. See also *Section 49.3.29: Interfacing with Hall sensors*.

Bits 25, 6, 5, 4 **MMS[3:0]**: Master mode selection

These bits are used to select the information to be sent in master mode to slave timers for synchronization (tim_trgo). The combination is as follows:

0000: **Reset** - the UG bit from the TIMx_EGR register is used as trigger output (tim_trgo). If the reset is generated by the trigger input (slave mode controller configured in reset mode) then the signal on tim_trgo is delayed compared to the actual reset.

0001: **Enable** - the Counter enable signal, CNT_EN, is used as trigger output (tim_trgo). It is useful to start several timers at the same time or to control a window in which a slave timer is enabled. The Counter Enable signal is generated by a logic AND between CEN control bit and the trigger input when configured in gated mode.
When the Counter Enable signal is controlled by the trigger input, there is a delay on tim_trgo, except if the master/slave mode is selected (see the MSM bit description in TIMx_SMCR register).

0010: **Update** - The update event is selected as trigger output (tim_trgo). For instance a master timer can then be used as a prescaler for a slave timer.

0011: **Compare Pulse** - The trigger output send a positive pulse when the CC1IF flag is to be set (even if it was already high), as soon as a capture or a compare match occurred (tim_trgo).

0100: **Compare** - tim_oc1refc signal is used as trigger output (tim_trgo)

0101: **Compare** - tim_oc2refc signal is used as trigger output (tim_trgo)

0110: **Compare** - tim_oc3refc signal is used as trigger output (tim_trgo)

0111: **Compare** - tim_oc4refc signal is used as trigger output (tim_trgo)

1000: **Encoder clock output** - The encoder clock signal is used as trigger output (tim_trgo). This code is valid for the following SMS[3:0] values: 0001, 0010, 0011, 1010, 1011, 1100, 1101, 1110, 1111. Any other SMS[3:0] code is not allowed and may lead to unexpected behavior.

Others: Reserved

Note: The clock of the slave timer or ADC must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the master timer.

Bit 3 **CCDS**: Capture/compare DMA selection

0: CCx DMA request sent when CCx event occurs
1: CCx DMA requests sent when update event occurs

Bits 2:0 Reserved, must be kept at reset value.

50.5.3 TIMx slave mode control register (TIMx_SMCR)(x = 2 to 5)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	SMSPS	SMSPE	Res.	Res.	TS[4:3]		Res.	Res.	Res.	SMS[3]
						rw	rw			rw	rw				rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETP	ECE	ETPS[1:0]		ETF[3:0]				MSM	TS[2:0]			OCCS	SMS[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **SMSPS**: SMS preload source

This bit selects whether the events that triggers the SMS[3:0] bitfield transfer from preload to active

0: The transfer is triggered by the Timer's Update event

1: The transfer is triggered by the Index event

Bit 24 **SMSPE**: SMS preload enable

This bit selects whether the SMS[3:0] bitfield is preloaded

0: SMS[3:0] bitfield is not preloaded

1: SMS[3:0] preload is enabled

Bits 23:22 Reserved, must be kept at reset value.

Bits 19:17 Reserved, must be kept at reset value.

Bit 15 **ETP**: External trigger polarity

This bit selects whether tim_etr_in or $\overline{\text{tim_etr_in}}$ is used for trigger operations

0: tim_etr_in is non-inverted, active at high level or rising edge

1: tim_etr_in is inverted, active at low level or falling edge

Bit 14 **ECE**: External clock enable

This bit enables External clock mode 2.

0: External clock mode 2 disabled

1: External clock mode 2 enabled. The counter is clocked by any active edge on the tim_etrf signal.

Note: Setting the ECE bit has the same effect as selecting external clock mode 1 with tim_trgi connected to tim_etrf (SMS = 111 and TS = 00111).
It is possible to simultaneously use external clock mode 2 with the following slave modes: reset mode, gated mode and trigger mode. Nevertheless, tim_trgi must not be connected to tim_etrf in this case (TS bits must not be 00111).
If external clock mode 1 and external clock mode 2 are enabled at the same time, the external clock input is tim_etrf.

Bits 13:12 **ETPS[1:0]**: External trigger prescaler

External trigger signal tim_etrp frequency must be at most 1/4 of tim_ker_ck frequency. A prescaler can be enabled to reduce tim_etrp frequency. It is useful when inputting fast external clocks on tim_etr_in.

00: Prescaler OFF

01: tim_etrp frequency divided by 2

10: tim_etrp frequency divided by 4

11: tim_etrp frequency divided by 8

Bits 11:8 **ETF[3:0]**: External trigger filter

This bitfield then defines the frequency used to sample tim_etrp signal and the length of the digital filter applied to tim_etrp. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}
0001: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 2
0010: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 4
0011: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 8
0100: $f_{SAMPLING} = f_{DTS}/2$, N = 6
0101: $f_{SAMPLING} = f_{DTS}/2$, N = 8
0110: $f_{SAMPLING} = f_{DTS}/4$, N = 6
0111: $f_{SAMPLING} = f_{DTS}/4$, N = 8
1000: $f_{SAMPLING} = f_{DTS}/8$, N = 6
1001: $f_{SAMPLING} = f_{DTS}/8$, N = 8
1010: $f_{SAMPLING} = f_{DTS}/16$, N = 5
1011: $f_{SAMPLING} = f_{DTS}/16$, N = 6
1100: $f_{SAMPLING} = f_{DTS}/16$, N = 8
1101: $f_{SAMPLING} = f_{DTS}/32$, N = 5
1110: $f_{SAMPLING} = f_{DTS}/32$, N = 6
1111: $f_{SAMPLING} = f_{DTS}/32$, N = 8

Bit 7 **MSM**: Master/Slave mode

0: No action
1: The effect of an event on the trigger input (tim_trgi) is delayed to allow a perfect synchronization between the current timer and its slaves (through tim_trgo). It is useful if we want to synchronize several timers on a single external event.

Bits 21, 20, 6, 5, 4 **TS[4:0]**: Trigger selection

This bitfield selects the trigger input to be used to synchronize the counter.

00000: Internal trigger 0 (tim_itr0)
00001: Internal trigger 1 (tim_itr1)
00010: Internal trigger 2 (tim_itr2)
00011: Internal trigger 3 (tim_itr3)
00100: tim_ti1 edge detector (tim_ti1f_ed)
00101: Filtered timer input 1 (tim_ti1fp1)
00110: Filtered timer input 2 (tim_ti2fp2)
00111: External trigger input (tim_etrf)
01000: Internal trigger 4 (tim_itr4)
01001: Internal trigger 5 (tim_itr5)
01010: Internal trigger 6 (tim_itr6)
01011: Internal trigger 7 (tim_itr7)
01100: Internal trigger 8 (tim_itr8)
01101: Internal trigger 9 (tim_itr9)
01110: Internal trigger 10 (tim_itr10)
01111: Internal trigger 11 (tim_itr11)
10000: Internal trigger 12 (tim_itr12)
10001: Internal trigger 13 (tim_itr13)
10010: Internal trigger 14 (tim_itr14)
10011: Internal trigger 15 (tim_itr15)
Others: Reserved

See *Section 50.4.2: TIM2/TIM3/TIM4/TIM5 pins and internal signals* for product specific implementation details.

Note: These bits must be changed only when they are not used (for example when SMS = 000) to avoid wrong edge detections at the transition.

Bit 3 **OCCS**: OCREF clear selection

This bit is used to select the OCREF clear source
0: tim_ocref_clr_int is connected to the tim_ocref_clr input
1: tim_ocref_clr_int is connected to tim_etrf

Note: If the OCREF clear selection feature is not supported, this bit is reserved and forced by hardware to 0. Section 50.3: TIM2/TIM3/TIM4/TIM5 implementation.

Bits 16, 2, 1, 0 **SMS[3:0]**: Slave mode selection

When external signals are selected the active edge of the trigger signal (tim_trgi) is linked to the polarity selected on the external input (refer to ETP bit in TIMx_SMCR for tim_etr_in and CCxP/CCxNP bits in TIMx_CCER register for tim_ti1fp1 and tim_ti2fp2).

0000: Slave mode disabled - if CEN = 1 then the prescaler is clocked directly by the internal clock.

0001: Encoder mode 1 - Counter counts up/down on tim_ti1fp1 edge depending on tim_ti2fp2 level.

0010: Encoder mode 2 - Counter counts up/down on tim_ti2fp2 edge depending on tim_ti1fp1 level.

0011: Encoder mode 3 - Counter counts up/down on both tim_ti1fp1 and tim_ti2fp2 edges depending on the level of the other input.

0100: Reset mode - Rising edge of the selected trigger input (tim_trgi) reinitializes the counter and generates an update of the registers.

0101: Gated mode - The counter clock is enabled when the trigger input (tim_trgi) is high. The counter stops (but is not reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

0110: Trigger mode - The counter starts at a rising edge of the trigger tim_trgi (but it is not reset). Only the start of the counter is controlled.

0111: External clock mode 1 - Rising edges of the selected trigger (tim_trgi) clock the counter.

1000: Combined reset + trigger mode - Rising edge of the selected trigger input (tim_trgi) reinitializes the counter, generates an update of the registers and starts the counter.

1001: Combined gated + reset mode - The counter clock is enabled when the trigger input (tim_trgi) is high. The counter stops and is reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

1010: Encoder mode: Clock plus direction, x2 mode.

1011: Encoder mode: Clock plus direction, x1 mode, tim_ti2fp2 edge sensitivity is set by CC2P.

1100: Encoder mode: Directional clock, x2 mode.

1101: Encoder mode: Directional clock, x1 mode, tim_ti1fp1 and tim_ti2fp2 edge sensitivity is set by CC1P and CC2P.

1110: Quadrature encoder mode: x1 mode, counting on tim_ti1fp1 edges only, edge sensitivity is set by CC1P.

1111: Quadrature encoder mode: x1 mode, counting on tim_ti2fp2 edges only, edge sensitivity is set by CC2P.

Note: The gated mode must not be used if tim_ti1f_ed is selected as the trigger input (TS = 00100). Indeed, tim_ti1f_ed outputs 1 pulse for each transition on tim_ti1f, whereas the gated mode checks the level of the trigger signal.

Note: The clock of the slave peripherals (such as timer, ADC) receiving the tim_trgo signal must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

50.5.4 TIMx DMA/Interrupt enable register (TIMx_DIER)(x = 2 to 5)

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TERRIE	IERRIE	DIRIE	IDXIE	Res.	Res.	Res.	Res.
								rw	rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TDE	Res.	CC4DE	CC3DE	CC2DE	CC1DE	UDE	Res.	TIE	Res.	CC4IE	CC3IE	CC2IE	CC1IE	UIE
	rw		rw	rw	rw	rw	rw		rw		rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **TERRIE**: Transition error interrupt enable
0: Transition error interrupt disabled
1: Transition error interrupt enabled

Bit 22 **IERRIE**: Index error interrupt enable
0: Index error interrupt disabled
1: Index error interrupt enabled

Bit 21 **DIRIE**: Direction change interrupt enable
0: Direction change interrupt disabled
1: Direction change interrupt enabled

Bit 20 **IDXIE**: Index interrupt enable
0: Index interrupt disabled
1: Index interrupt enabled

Bits 19:15 Reserved, must be kept at reset value.

Bit 14 **TDE**: Trigger DMA request enable
0: Trigger DMA request disabled.
1: Trigger DMA request enabled.

Bit 13 Reserved, must be kept at reset value.

Bit 12 **CC4DE**: Capture/Compare 4 DMA request enable
0: CC4 DMA request disabled.
1: CC4 DMA request enabled.

Bit 11 **CC3DE**: Capture/Compare 3 DMA request enable
0: CC3 DMA request disabled.
1: CC3 DMA request enabled.

Bit 10 **CC2DE**: Capture/Compare 2 DMA request enable
0: CC2 DMA request disabled.
1: CC2 DMA request enabled.

Bit 9 **CC1DE**: Capture/Compare 1 DMA request enable
0: CC1 DMA request disabled.
1: CC1 DMA request enabled.

Bit 8 **UDE**: Update DMA request enable
0: Update DMA request disabled.
1: Update DMA request enabled.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **TIE**: Trigger interrupt enable
0: Trigger interrupt disabled.
1: Trigger interrupt enabled.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **CC4IE**: Capture/Compare 4 interrupt enable
0: CC4 interrupt disabled.
1: CC4 interrupt enabled.

Bit 3 **CC3IE**: Capture/Compare 3 interrupt enable
0: CC3 interrupt disabled.
1: CC3 interrupt enabled.

Bit 2 **CC2IE**: Capture/Compare 2 interrupt enable
0: CC2 interrupt disabled.
1: CC2 interrupt enabled.

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable
0: CC1 interrupt disabled.
1: CC1 interrupt enabled.

Bit 0 **UIE**: Update interrupt enable
0: Update interrupt disabled.
1: Update interrupt enabled.

50.5.5 TIMx status register (TIMx_SR)(x = 2 to 5)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TERRF	IERRF	DIRF	IDXF	Res.	Res.	Res.	Res.
								rc_w0	rc_w0	rc_w0	rc_w0				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	CC4OF	CC3OF	CC2OF	CC1OF	Res.	Res.	TIF	Res.	CC4IF	CC3IF	CC2IF	CC1IF	UIF
			rc_w0	rc_w0	rc_w0	rc_w0			rc_w0		rc_w0	rc_w0	rc_w0	rc_w0	rc_w0

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **TERRF**: Transition error interrupt flag
This flag is set by hardware when a transition error is detected in encoder mode. It is cleared by software by writing it to 0.
0: No encoder transition error has been detected.
1: An encoder transition error has been detected

Bit 22 **IERRF**: Index error interrupt flag
This flag is set by hardware when an index error is detected. It is cleared by software by writing it to 0.
0: No index error has been detected.
1: An index error has been detected

Bit 21 **DIRF**: Direction change interrupt flag
This flag is set by hardware when the direction changes in encoder mode (DIR bit value in TIMx_CR is changing). It is cleared by software by writing it to 0.
0: No direction change
1: Direction change

Bit 20 **IDXF**: Index interrupt flag
This flag is set by hardware when an index event is detected. It is cleared by software by writing it to 0.
0: No index event occurred.
1: An index event has occurred

Bits 19:13 Reserved, must be kept at reset value.

Bit 12 **CC4OF**: Capture/Compare 4 overcapture flag
refer to CC1OF description

Bit 11 **CC3OF**: Capture/Compare 3 overcapture flag
refer to CC1OF description

Bit 10 **CC2OF**: Capture/compare 2 overcapture flag
refer to CC1OF description

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag
This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to 0.
0: No overcapture has been detected.
1: The counter value has been captured in TIMx_CCR1 register while CC1IF flag was already set

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **TIF**: Trigger interrupt flag
This flag is set by hardware on the TRG trigger event (active edge detected on tim_trgi input) when the slave mode controller is enabled in all modes but gated mode. It is set when the counter starts or stops when gated mode is selected. It is cleared by software.
0: No trigger event occurred.
1: Trigger interrupt pending.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **CC4IF**: Capture/Compare 4 interrupt flag
Refer to CC1IF description

Bit 3 **CC3IF**: Capture/Compare 3 interrupt flag
Refer to CC1IF description

Bit 2 **CC2IF**: Capture/Compare 2 interrupt flag
Refer to CC1IF description

Bit 1 **CC1IF**: Capture/compare 1 interrupt flag
This flag is set by hardware. It is cleared by software (input capture or output compare mode) or by reading the TIMx_CCR1 register (input capture mode only).
0: No compare match / No input capture occurred
1: A compare match or an input capture occurred
If channel CC1 is configured as output: this flag is set when the content of the counter TIMx_CNT matches the content of the TIMx_CCR1 register. When the content of TIMx_CCR1 is greater than the content of TIMx_ARR, the CC1IF bit goes high on the counter overflow (in up-counting and up/down-counting modes) or underflow (in down-counting mode). There are three possible options for flag setting in center-aligned mode, refer to the CMS bits in the TIMx_CR1 register for the full description.
If channel CC1 is configured as input: this bit is set when counter value has been captured in TIMx_CCR1 register (an edge has been detected on IC1, as per the edge sensitivity defined with the CC1P and CC1NP bits setting, in TIMx_CCER).

Bit 0 **UIF**: Update interrupt flag
This bit is set by hardware on an update event. It is cleared by software.
0: No update occurred
1: Update interrupt pending. This bit is set by hardware when the registers are updated:
At overflow or underflow and if UDIS = 0 in the TIMx_CR1 register.
When CNT is reinitialized by software using the UG bit in TIMx_EGR register, if URS = 0 and UDIS = 0 in the TIMx_CR1 register.
When CNT is reinitialized by a trigger event (refer to the synchro control register description), if URS = 0 and UDIS = 0 in the TIMx_CR1 register.

50.5.6 TIMx event generation register (TIMx_EGR)(x = 2 to 5)

Address offset: 0x014

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TG	Res.	CC4G	CC3G	CC2G	CC1G	UG
									w		w	w	w	w	w

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **TG**: Trigger generation
This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action
1: The TIF flag is set in TIMx_SR register. Related interrupt or DMA transfer can occur if enabled.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **CC4G**: Capture/compare 4 generation
Refer to CC1G description

Bit 3 **CC3G**: Capture/compare 3 generation
Refer to CC1G description

Bit 2 **CC2G**: Capture/compare 2 generation
Refer to CC1G description

Bit 1 **CC1G**: Capture/compare 1 generation
This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action
1: A capture/compare event is generated on channel 1:
If channel CC1 is configured as output:
CC1IF flag is set, Corresponding interrupt or DMA request is sent if enabled.
If channel CC1 is configured as input:
The current value of the counter is captured in TIMx_CCR1 register. The CC1IF flag is set, the corresponding interrupt or DMA request is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation
This bit can be set by software, it is automatically cleared by hardware.
0: No action
1: Re-initialize the counter and generates an update of the registers. Note that the prescaler counter is cleared too (anyway the prescaler ratio is not affected). The counter is cleared if the center-aligned mode is selected or if DIR = 0 (up-counting), else it takes the autoreload value (TIMx_ARR) if DIR = 1 (down-counting).

50.5.7 TIMx capture/compare mode register 1 (TIMx_CCMR1)(x = 2 to 5)

Address offset: 0x018

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (for example channel 1 in input capture mode and channel 2 in output compare mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IC2F[3:0]				IC2PSC[1:0]		CC2S[1:0]		IC1F[3:0]				IC1PSC[1:0]		CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Input capture mode

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **IC2F[3:0]**: Input capture 2 filter

Bits 11:10 **IC2PSC[1:0]**: Input capture 2 prescaler

Bits 9:8 **CC2S[1:0]**: Capture/compare 2 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC2 channel is configured as output.
01: CC2 channel is configured as input, tim_ic2 is mapped on tim_ti2.
10: CC2 channel is configured as input, tim_ic2 is mapped on tim_ti1.
11: CC2 channel is configured as input, tim_ic2 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx_CCER).

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bitfield defines the frequency used to sample tim_ti1 input and the length of the digital filter applied to tim_ti1. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:
0000: No filter, sampling is done at f_{DTS}
0001: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 2
0010: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 4
0011: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 8
0100: $f_{SAMPLING} = f_{DTS}/2$, N = 6
0101: $f_{SAMPLING} = f_{DTS}/2$, N = 8
0110: $f_{SAMPLING} = f_{DTS}/4$, N = 6
0111: $f_{SAMPLING} = f_{DTS}/4$, N = 8
1000: $f_{SAMPLING} = f_{DTS}/8$, N = 6
1001: $f_{SAMPLING} = f_{DTS}/8$, N = 8
1010: $f_{SAMPLING} = f_{DTS}/16$, N = 5
1011: $f_{SAMPLING} = f_{DTS}/16$, N = 6
1100: $f_{SAMPLING} = f_{DTS}/16$, N = 8
1101: $f_{SAMPLING} = f_{DTS}/32$, N = 5
1110: $f_{SAMPLING} = f_{DTS}/32$, N = 6
1111: $f_{SAMPLING} = f_{DTS}/32$, N = 8

Bits 3:2 **IC1PSC[1:0]**: Input capture 1 prescaler

This bitfield defines the ratio of the prescaler acting on CC1 input (tim_ic1). The prescaler is reset as soon as CC1E = 0 (TIMx_CCER register).
00: no prescaler, capture is done each time an edge is detected on the capture input
01: capture is done once every 2 events
10: capture is done once every 4 events
11: capture is done once every 8 events

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC1 channel is configured as output
01: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti1
10: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti2
11: CC1 channel is configured as input, tim_ic1 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

50.5.8 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 2 to 5)

Address offset: 0x018

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (for example channel 1 in input capture mode and channel 2 in output compare mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M [3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M [3]
							rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC2CE	OC2M[2:0]			OC2PE	OC2FE	CC2S[1:0]		OC1CE	OC1M[2:0]			OC1PE	OC1FE	CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Output compare mode

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 **OC2CE**: Output compare 2 clear enable

Bits 24, 14:12 **OC2M[3:0]**: Output compare 2 mode
refer to OC1M description on bits 6:4

Bit 11 **OC2PE**: Output compare 2 preload enable

Bit 10 **OC2FE**: Output compare 2 fast enable

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection
This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC2 channel is configured as output
01: CC2 channel is configured as input, tim_ic2 is mapped on tim_ti2
10: CC2 channel is configured as input, tim_ic2 is mapped on tim_ti1
11: CC2 channel is configured as input, tim_ic2 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through the TS bit (TIMx_SMCR register)
Note: CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx_CCER).

Bit 7 **OC1CE**: Output compare 1 clear enable
0: tim_oc1ref is not affected by the tim_ocref_clr_int input
1: tim_oc1ref is cleared as soon as a High level is detected on tim_ocref_clr_int input

Bits 16, 6:4 **OC1M[3:0]**: Output compare 1 mode

These bits define the behavior of the output reference signal tim_oc1ref from which tim_oc1 is derived. tim_oc1ref is active high whereas tim_oc1 active level depends on CC1P bit.

0000: Frozen - The comparison between the output compare register TIMx_CCR1 and the counter TIMx_CNT has no effect on the outputs. This mode can be used when the timer serves as a software timebase. When the frozen mode is enabled during timer operation, the ouput keeps the state (active or inactive) it had before entering the frozen state.

0001: Set channel 1 to active level on match. tim_oc1ref signal is forced high when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0010: Set channel 1 to inactive level on match. tim_oc1ref signal is forced low when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0011: Toggle - tim_oc1ref toggles when TIMx_CNT = TIMx_CCR1.

0100: Force inactive level - tim_oc1ref is forced low.

0101: Force active level - tim_oc1ref is forced high.

0110: PWM mode 1 - In up-counting, channel 1 is active as long as TIMx_CNT<TIMx_CCR1 else inactive. In down-counting, channel 1 is inactive (tim_oc1ref = 0) as long as TIMx_CNT>TIMx_CCR1 else active (tim_oc1ref = 1).

0111: PWM mode 2 - In up-counting, channel 1 is inactive as long as TIMx_CNT<TIMx_CCR1 else active. In down-counting, channel 1 is active as long as TIMx_CNT>TIMx_CCR1 else inactive.

1000: Retriggerable OPM mode 1 - In up-counting mode, the channel is active until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes inactive again at the next update. In down-counting mode, the channel is inactive until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes inactive again at the next update.

1001: Retriggerable OPM mode 2 - In up-counting mode, the channel is inactive until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 2 and the channels becomes inactive again at the next update. In down-counting mode, the channel is active until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update.

1010: Reserved.

1011: Reserved.

1100: Combined PWM mode 1 - tim_oc1ref has the same behavior as in PWM mode 1. tim_oc1refc is the logical OR between tim_oc1ref and tim_oc2ref.

1101: Combined PWM mode 2 - tim_oc1ref has the same behavior as in PWM mode 2. tim_oc1refc is the logical AND between tim_oc1ref and tim_oc2ref.

1110: Asymmetric PWM mode 1 - tim_oc1ref has the same behavior as in PWM mode 1. tim_oc1refc outputs tim_oc1ref when the counter is counting up, tim_oc2ref when it is counting down.

1111: Asymmetric PWM mode 2 - tim_oc1ref has the same behavior as in PWM mode 2. tim_oc1refc outputs tim_oc1ref when the counter is counting up, tim_oc2ref when it is counting down.

Note: In PWM mode, the OCREF level changes when the result of the comparison changes, when the output compare mode switches from “frozen” mode to “PWM” mode and when the output compare mode switches from “force active/inactive” mode to “PWM” mode.

Bit 3 **OC1PE**: Output compare 1 preload enable

0: Preload register on TIMx_CCR1 disabled. TIMx_CCR1 can be written at anytime, the new value is taken in account immediately.
1: Preload register on TIMx_CCR1 enabled. Read/Write operations access the preload register. TIMx_CCR1 preload value is loaded in the active register at each update event.

Bit 2 **OC1FE**: Output compare 1 fast enable

This bit decreases the latency between a trigger event and a transition on the timer output. It must be used in one-pulse mode (OPM bit set in TIMx_CR1 register), to have the output pulse starting as soon as possible after the starting trigger.
0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.
1: An active edge on the trigger input acts like a compare match on CC1 output. Then, OC is set to the compare level independently from the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to three clock cycles. OCFE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC1 channel is configured as output.
01: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti1.
10: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti2.
11: CC1 channel is configured as input, tim_ic1 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

50.5.9 TIMx capture/compare mode register 2 (TIMx_CCMR2)(x = 2 to 5)

Address offset: 0x01C

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (for example channel 1 in input capture mode and channel 2 in output compare mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IC4F[3:0]				IC4PSC[1:0]		CC4S[1:0]		IC3F[3:0]				IC3PSC[1:0]		CC3S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Input capture mode

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **IC4F[3:0]**: Input capture 4 filter

Bits 11:10 **IC4PSC[1:0]**: Input capture 4 prescaler

Bits 9:8 **CC4S[1:0]**: Capture/Compare 4 selection
This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC4 channel is configured as output
01: CC4 channel is configured as input, tim_ic4 is mapped on tim_ti4
10: CC4 channel is configured as input, tim_ic4 is mapped on tim_ti3
11: CC4 channel is configured as input, tim_ic4 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)
Note: CC4S bits are writable only when the channel is OFF (CC4E = 0 in TIMx_CCER).

Bits 7:4 **IC3F[3:0]**: Input capture 3 filter

Bits 3:2 **IC3PSC[1:0]**: Input capture 3 prescaler

Bits 1:0 **CC3S[1:0]**: Capture/Compare 3 selection
This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC3 channel is configured as output
01: CC3 channel is configured as input, tim_ic3 is mapped on tim_ti3
10: CC3 channel is configured as input, tim_ic3 is mapped on tim_ti4
11: CC3 channel is configured as input, tim_ic3 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)
Note: CC3S bits are writable only when the channel is OFF (CC3E = 0 in TIMx_CCER).

50.5.10 TIMx capture/compare mode register 2 [alternate] (TIMx_CCMR2)(x = 2 to 5)

Address offset: 0x01C

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (for example channel 1 in input capture mode and channel 2 in output compare mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC4M [3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC3M [3]
							rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC4CE	OC4M[2:0]			OC4PE	OC4FE	CC4S[1:0]		OC3CE	OC3M[2:0]			OC3PE	OC3FE	CC3S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Output compare mode

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 **OC4CE**: Output compare 4 clear enable

Bits 24, 14:12 **OC4M[3:0]**: Output compare 4 mode
Refer to OC3M[3:0]

Bit 11 **OC4PE**: Output compare 4 preload enable

Bit 10 **OC4FE**: Output compare 4 fast enable

Bits 9:8 **CC4S[1:0]**: Capture/Compare 4 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC4 channel is configured as output

01: CC4 channel is configured as input, tim_ic4 is mapped on tim_ti4

10: CC4 channel is configured as input, tim_ic4 is mapped on tim_ti3

11: CC4 channel is configured as input, tim_ic4 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC4S bits are writable only when the channel is OFF (CC4E = 0 in TIMx_CCER).

Bit 7 **OC3CE**: Output compare 3 clear enable

Bits 16, 6:4 **OC3M[3:0]**: Output compare 3 mode

These bits define the behavior of the output reference signal tim_oc3ref from which tim_oc3 and tim_oc3n are derived. tim_oc3ref is active high whereas tim_oc3 and tim_oc3n active level depends on CC3P and CC3NP bits.

0000: Frozen - The comparison between the output compare register TIMx_CCR3 and the counter TIMx_CNT has no effect on the outputs.(this mode is used to generate a timing base).

0001: Set channel 3 to active level on match. tim_oc3ref signal is forced high when the counter TIMx_CNT matches the capture/compare register 3 (TIMx_CCR3).

0010: Set channel 3 to inactive level on match. tim_oc3ref signal is forced low when the counter TIMx_CNT matches the capture/compare register 3 (TIMx_CCR3).

0011: Toggle - tim_oc3ref toggles when TIMx_CNT = TIMx_CCR3.

0100: Force inactive level - tim_oc3ref is forced low.

0101: Force active level - tim_oc3ref is forced high.

0110: PWM mode 1 - In up-counting, channel 3 is active as long as TIMx_CNT<TIMx_CCR3 else inactive. In down-counting, channel 3 is inactive (tim_oc3ref = 0) as long as TIMx_CNT>TIMx_CCR3 else active (tim_oc3ref = 1).

0111: PWM mode 2 - In up-counting, channel 3 is inactive as long as TIMx_CNT<TIMx_CCR3 else active. In down-counting, channel 3 is active as long as TIMx_CNT>TIMx_CCR3 else inactive.

1000: Retrigerrable OPM mode 1 - In up-counting mode, the channel is active until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update. In down-counting mode, the channel is inactive until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes inactive again at the next update.

1001: Retrigerrable OPM mode 2 - In up-counting mode, the channel is inactive until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 2 and the channels becomes inactive again at the next update. In down-counting mode, the channel is active until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update.

1010: Pulse on compare: a pulse is generated on tim_oc3ref upon CCR3 match event, as per PWPRSC[2:0] and PW[7:0] bitfields programming in TIMx_ECR.

1011: Direction output. The tim_oc3ref signal is overridden by a copy of the DIR bit.

1100: Combined PWM mode 1 - tim_oc3ref has the same behavior as in PWM mode 1. tim_oc3refc is the logical OR between tim_oc3ref and tim_oc4ref.

1101: Combined PWM mode 2 - tim_oc3ref has the same behavior as in PWM mode 2. tim_oc3refc is the logical AND between tim_oc3ref and tim_oc4ref.

1110: Asymmetric PWM mode 1 - tim_oc3ref has the same behavior as in PWM mode 1. tim_oc3refc outputs tim_oc3ref when the counter is counting up, tim_oc4ref when it is counting down.

1111: Asymmetric PWM mode 2 - tim_oc3ref has the same behavior as in PWM mode 2. tim_oc3refc outputs tim_oc3ref when the counter is counting up, tim_oc4ref when it is counting down.

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S = 00 (the channel is configured in output).

Note: In PWM mode, the OCREF level changes only when the result of the comparison changes or when the output compare mode switches from “frozen” mode to “PWM” mode.

On channels having a complementary output, this bitfield is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the OC3M active bits take the new value from the preloaded bits only when a COM event is generated.

Bit 3 **OC3PE**: Output compare 3 preload enable

Bit 2 **OC3FE**: Output compare 3 fast enable

Bits 1:0 **CC3S[1:0]**: Capture/Compare 3 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC3 channel is configured as output
01: CC3 channel is configured as input, tim_ic3 is mapped on tim_ti3
10: CC3 channel is configured as input, tim_ic3 is mapped on tim_ti4
11: CC3 channel is configured as input, tim_ic3 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC3S bits are writable only when the channel is OFF (CC3E = 0 in TIMx_CCER).

50.5.11 TIMx capture/compare enable register (TIMx_CCER)(x = 2 to 5)

Address offset: 0x020

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CC4NP	Res.	CC4P	CC4E	CC3NP	Res.	CC3P	CC3E	CC2NP	Res.	CC2P	CC2E	CC1NP	Res.	CC1P	CC1E
rw		rw	rw	rw		rw	rw	rw		rw	rw	rw		rw	rw

Bit 15 **CC4NP**: *Capture/Compare 4 output Polarity.*
Refer to CC1NP description

Bit 14 Reserved, must be kept at reset value.

Bit 13 **CC4P**: *Capture/Compare 4 output Polarity.*
Refer to CC1P description

Bit 12 **CC4E**: *Capture/Compare 4 output enable.*
refer to CC1E description

Bit 11 **CC3NP**: *Capture/Compare 3 output Polarity.*
Refer to CC1NP description

Bit 10 Reserved, must be kept at reset value.

Bit 9 **CC3P**: *Capture/Compare 3 output Polarity.*
Refer to CC1P description

Bit 8 **CC3E**: *Capture/Compare 3 output enable.*
Refer to CC1E description

Bit 7 **CC2NP**: *Capture/Compare 2 output Polarity.*
Refer to CC1NP description

Bit 6 Reserved, must be kept at reset value.

Bit 5 **CC2P**: *Capture/Compare 2 output Polarity.*
refer to CC1P description

Bit 4 **CC2E**: *Capture/Compare 2 output enable.*
Refer to CC1E description

Bit 3 **CC1NP**: *Capture/Compare 1 output Polarity.*

CC1 channel configured as output: CC1NP must be kept cleared in this case.

CC1 channel configured as input: This bit is used in conjunction with CC1P to define tim_ti1fp1/tim_ti2fp1 polarity. refer to CC1P description.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CC1P**: *Capture/Compare 1 output Polarity.*

0: OC1 active high (output mode) / Edge sensitivity selection (input mode, see below)

1: OC1 active low (output mode) / Edge sensitivity selection (input mode, see below)

When CC1 channel is configured as input, both CC1NP/CC1P bits select the active polarity of TI1FP1 and TI2FP1 for trigger or capture operations.

CC1NP = 0, CC1P = 0: non-inverted/rising edge. The circuit is sensitive to TIxFP1 rising edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode or encoder mode).

CC1NP = 0, CC1P = 1: inverted/falling edge. The circuit is sensitive to TIxFP1 falling edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is inverted (trigger operation in gated mode or encoder mode).

CC1NP = 1, CC1P = 1: non-inverted/both edges. The circuit is sensitive to both TIxFP1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), TIxFP1is not inverted (trigger operation in gated mode). This configuration must not be used in encoder mode.

CC1NP = 1, CC1P = 0: this configuration is reserved, it must not be used.

Bit 0 **CC1E**: *Capture/Compare 1 output enable.*

0: Capture mode disabled / OC1 is not active

1: Capture mode enabled / OC1 signal is output on the corresponding output pin

Table 549. Output control bit for standard tim_ocx channels

CCxE bit	tim_ocx output state
0	Output disabled (not driven by the timer: Hi-Z)
1	Output enabled (tim_ocx = tim_ocxref + Polarity)

Note: The state of the external IO pins connected to the standard tim_ocx channels depends only on the GPIO registers when CCxE = 0.

50.5.12 TIMx counter (TIMx_CNT)(x = 3, 4)

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: Value depends on IUFREMAP in TIMx_CR1.
If UIFREMAP = 0
Reserved
If UIFREMAP = 1
UIFCPY: UIF Copy
This bit is a read-only copy of the UIF bit of the TIMx_ISR register

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value
Non-dithering mode (DITHEN = 0)
The register holds the counter value.
Dithering mode (DITHEN = 1)
The register holds the non-dithered part in CNT[15:0]. The fractional part is not available.

50.5.13 TIMx counter (TIMx_CNT)(x = 2, 5)

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIFCPY_CNT[31]	CNT[30:16]														
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY_CNT[31]**: Value depends on IUFREMAP in TIMx_CR1.
If UIFREMAP = 0
CNT[31]: Most significant bit of counter value
If UIFREMAP = 1
UIFCPY: UIF Copy
This bit is a read-only copy of the UIF bit of the TIMx_ISR register

Bits 30:0 **CNT[30:0]**: Least significant part of counter value
Non-dithering mode (DITHEN = 0)
The register holds the counter value.
Dithering mode (DITHEN = 1)
The register holds the non-dithered part in CNT[30:0]. The fractional part is not available.

50.5.14 TIMx prescaler (TIMx_PSC)(x = 2 to 5)

Address offset: 0x028

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency tim_cnt_ck is equal to $f_{tim_psc_ck}$ / (PSC[15:0] + 1).
PSC contains the value to be loaded in the active prescaler register at each update event (including when the counter is cleared through UG bit of TIMx_EGR register or through trigger controller when configured in “reset mode”).

50.5.15 TIMx autoreload register (TIMx_ARR)(x = 3, 4)

Address offset: 0x02C

Reset value: 0x0000 FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **ARR[19:0]**: Low autoreload value

ARR is the value to be loaded in the actual autoreload register.
Refer to the *Section 50.4.3: Time-base unit* for more details about ARR update and behavior.
The counter is blocked while the autoreload value is null.
Non-dithering mode (DITHEN = 0)
The register holds the autoreload value.
Dithering mode (DITHEN = 1)
The register holds the integer part in ARR[19:4]. The ARR[3:0] bitfield contains the dithered part.

50.5.16 TIMx autoreload register (TIMx_ARR)(x = 2, 5)

Address offset: 0x02C

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ARR[31:0]**: Autoreload value

ARR is the value to be loaded in the actual autoreload register.

Refer to the *Section 50.4.3: Time-base unit* for more details about ARR update and behavior.

The counter is blocked while the autoreload value is null.

Non-dithering mode (DITHEN = 0)

The register holds the autoreload value.

Dithering mode (DITHEN = 1)

The register holds the integer part in ARR[31:4]. The ARR[3:0] bitfield contains the dithered part.

50.5.17 TIMx capture/compare register 1 (TIMx_CCR1)(x = 3, 4)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR1[19:0]**: Capture/compare 1 value

If channel CC1 is configured as output:

CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc1 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value in CCR1[15:0]. The CCR1[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR1[19:4]. The CCR1[3:0] bitfield contains the dithered part.

If channel CC1 is configured as input:

CCR1 is the counter value transferred by the last input capture 1 event (tim_ic1). The TIMx_CCR1 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The CCR1[15:0] bits hold the capture value. The CCR1[19:16] bits are reserved.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR1[19:0]. The CCR1[3:0] bits are reset.

50.5.18 TIMx capture/compare register 1 (TIMx_CCR1)(x = 2, 5)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CCR1[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CCR1[31:0]**: Capture/compare 1 value

If channel CC1 is configured as output:

CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc1 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR1[31:4]. The CCR1[3:0] bitfield contains the dithered part.

If channel CC1 is configured as input:

CCR1 is the counter value transferred by the last input capture 1 event (tim_ic1). The TIMx_CCR1 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The register holds the capture value.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR1[31:0]. The CCR1[3:0] bits are reset.

50.5.19 TIMx capture/compare register 2 (TIMx_CCR2)(x = 3, 4)

Address offset: 0x038

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR2[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR2[19:0]**: Capture/compare 1 value

If channel CC2 is configured as output:

CCR2 is the value to be loaded in the actual capture/compare 2 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx_CCMR2 register (bit OC2PE). Else the preload value is copied in the active capture/compare 2 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc2 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value in CCR2[15:0]. The CCR2[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR2[19:4]. The CCR2[3:0] bitfield contains the dithered part.

If channel CC2 is configured as input:

CCR2 is the counter value transferred by the last input capture 2 event (tim_ic2). The TIMx_CCR2 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The CCR2[15:0] bits hold the capture value. The CCR2[19:16] bits are reserved.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR2[19:0]. The CCR2[3:0] bits are reset.

50.5.20 TIMx capture/compare register 2 (TIMx_CCR2)(x = 2, 5)

Address offset: 0x038

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CCR2[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CCR2[31:0]**: Capture/compare 2 value

If channel CC2 is configured as output:

CCR2 is the value to be loaded in the actual capture/compare 2 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx_CCMR2 register (bit OC2PE). Else the preload value is copied in the active capture/compare 2 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc2 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR2[31:4]. The CCR2[3:0] bitfield contains the dithered part.

If channel CC2 is configured as input:

CCR2 is the counter value transferred by the last input capture 2 event (tim_ic2). The TIMx_CCR2 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The register holds the capture value.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR2[31:0]. The CCR2[3:0] bits are reset.

50.5.21 TIMx capture/compare register 3 (TIMx_CCR3)(x = 3, 4)

Address offset: 0x03C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR3[19:16]			
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR3[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR3[19:0]**: Capture/compare 3 value

If channel CC3 is configured as output:

CCR3 is the value to be loaded in the actual capture/compare 3 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx_CCMR3 register (bit OC3PE). Else the preload value is copied in the active capture/compare 3 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc3 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value in CCR3[15:0]. The CCR3[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR3[19:4]. The CCR3[3:0] bitfield contains the dithered part.

If channel CC3 is configured as input:

CCR3 is the counter value transferred by the last input capture 3 event (tim_ic3). The TIMx_CCR3 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The CCR3[15:0] bits hold the capture value. The CCR3[19:16] bits are reserved.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR3[19:0]. The CCR3[3:0] bits are reset.

50.5.22 TIMx capture/compare register 3 (TIMx_CCR3)(x = 2, 5)

Address offset: 0x03C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CCR3[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR3[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CCR3[31:0]**: Capture/compare 3 value

If channel CC3 is configured as output:

CCR3 is the value to be loaded in the actual capture/compare 3 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx_CCMR3 register (bit OC3PE). Else the preload value is copied in the active capture/compare 3 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc3 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR3[31:4]. The CCR3[3:0] bitfield contains the dithered part.

If channel CC3 is configured as input:

CCR3 is the counter value transferred by the last input capture 3 event (tim_ic3). The TIMx_CCR3 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The register holds the capture value.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR3[31:0]. The CCR3[3:0] bits are reset.

50.5.23 TIMx capture/compare register 4 (TIMx_CCR4)(x = 3, 4)

Address offset: 0x040

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR4[19:16]			
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR4[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR4[19:0]**: Capture/compare 4 value

If channel CC4 is configured as output:

CCR4 is the value to be loaded in the actual capture/compare 4 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx_CCMR4 register (bit OC4PE). Else the preload value is copied in the active capture/compare 4 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc4 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value in CCR4[15:0]. The CCR4[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR4[19:4]. The CCR4[3:0] bitfield contains the dithered part.

If channel CC4 is configured as input:

CCR4 is the counter value transferred by the last input capture 4 event (tim_ic4). The TIMx_CCR4 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The CCR4[15:0] bits hold the capture value. The CCR4[19:16] bits are reserved.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR4[19:0]. The CCR4[3:0] bits are reset.

50.5.24 TIMx capture/compare register 4 (TIMx_CCR4)(x = 2, 5)

Address offset: 0x040

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CCR4[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR4[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CCR4[31:0]**: Capture/compare 4 value

If channel CC4 is configured as output:

CCR4 is the value to be loaded in the actual capture/compare 4 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx_CCMR4 register (bit OC4PE). Else the preload value is copied in the active capture/compare 4 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc4 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR4[31:4]. The CCR4[3:0] bitfield contains the dithered part.

If channel CC4 is configured as input:

CCR4 is the counter value transferred by the last input capture 4 event (tim_ic4). The TIMx_CCR4 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The register holds the capture value.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR4[31:0]. The CCR4[3:0] bits are reset.

50.5.25 TIMx timer encoder control register (TIMx_ECR)(x = 2 to 5)

Address offset: 0x058

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	PWPRSC[2:0]			PW[7:0]							
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IPOS[1:0]		FIDX	IBLK[1:0]		IDIR[1:0]		IE
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bits 26:24 **PWPRSC[2:0]**: Pulse width prescaler

This bitfield sets the clock prescaler for the pulse generator, as following:

$t_{PWG} = (2^{(PWPRSC[2:0])}) \times t_{tim_ker_ck}$

Bits 23:16 **PW[7:0]**: Pulse width

This bitfield defines the pulse duration, as following:

$t_{PW} = PW[7:0] \times t_{PWG}$

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:6 **IPOS[1:0]**: Index positioning

In quadrature encoder mode (SMS[3:0] = 0001, 0010, 0011, 1110, 1111), this bit indicates in which AB input configuration the Index event resets the counter.

00: Index resets the counter when AB = 00
01: Index resets the counter when AB = 01
10: Index resets the counter when AB = 10
11: Index resets the counter when AB = 11

In directional clock mode or clock plus direction mode (SMS[3:0] = 1010, 1011, 1100, 1101), these bits indicates on which level the Index event resets the counter. In bidirectional clock mode, this applies for both clock inputs.

x0: Index resets the counter when clock is 0
x1: Index resets the counter when clock is 1

Note: IPOS[1] bit is not significant

Bit 5 **FIDX**: First index

This bit indicates if the first index only is taken into account

0: Index is always active
1: the first Index only resets the counter

Bits 4:3 **IBLK[1:0]**: Index blanking

This bit indicates if the Index event is conditioned by the tim_ti3 input

00: Index always active
01: Index disabled hen tim_ti3 input is active, as per CC3P bitfield
10: Index disabled when tim_ti4 input is active, as per CC4P bitfield
11: Reserved

Bits 2:1 **IDIR[1:0]**: Index direction

This bit indicates in which direction the Index event resets the counter.

00: Index resets the counter whatever the direction
01: Index resets the counter when up-counting only
10: Index resets the counter when down-counting only
11: Reserved

Bit 0 **IE**: Index enable

This bit indicates if the Index event resets the counter.

0: Index disabled
1: Index enabled

50.5.26 TIMx timer input selection register (TIMx_TISEL)(x = 2 to 5)

Address offset: 0x05C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **TI4SEL[3:0]**: Selects tim_ti4[15:0] input
0000: tim_ti4_in0: TIMx_CH4
0001: tim_ti4_in1
...
1111: tim_ti4_in15
Refer to *Section 50.4.2: TIM2/TIM3/TIM4/TIM5 pins and internal signals* for product specific implementation.

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **TI3SEL[3:0]**: Selects tim_ti3[15:0] input
0000: tim_ti3_in0: TIMx_CH3
0001: tim_ti3_in1
...
1111: tim_ti3_in15
Refer to *Section 50.4.2: TIM2/TIM3/TIM4/TIM5 pins and internal signals* for product specific implementation.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: Selects tim_ti2[15:0] input
0000: tim_ti2_in0: TIMx_CH2
0001: tim_ti2_in1
...
1111: tim_ti2_in15
Refer to *Section 50.4.2: TIM2/TIM3/TIM4/TIM5 pins and internal signals* for product specific implementation.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: Selects tim_ti1[15:0] input
0000: tim_ti1_in0: TIMx_CH1
0001: tim_ti1_in1
...
1111: tim_ti1_in15
Refer to *Section 50.4.2: TIM2/TIM3/TIM4/TIM5 pins and internal signals* for product specific implementation.

50.5.27 TIMx alternate function register 1 (TIMx_AF1)(x = 2 to 5)

Address offset: 0x060

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL[3:2]	
														rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETRSEL[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw														

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:14 **ETRSEL[3:0]**: etr_in source selection
These bits select the etr_in input source.
0000: tim_etr0: TIMx_ETR input
0001: tim_etr1
...
1111: tim_etr15
Refer to *Section 50.4.2: TIM2/TIM3/TIM4/TIM5 pins and internal signals* for product specific implementation.

Bits 13:0 Reserved, must be kept at reset value.

50.5.28 TIMx alternate function register 2 (TIMx_AF2)(x = 2 to 5)

Address offset: 0x064

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCRSEL[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **OCRSEL[2:0]**: ocref_clr source selection
These bits select the ocref_clr input source.
000: tim_ocref_clr0
001: tim_ocref_clr1
...
111: tim_ocref_clr7
Refer to *Section 50.4.2: TIM2/TIM3/TIM4/TIM5 pins and internal signals* for product specific implementation.

Bits 15:0 Reserved, must be kept at reset value.

50.5.29 TIMx DMA control register (TIMx_DCR)(x = 2 to 5)

Address offset: 0x3DC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBSS[3:0]			
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:16 **DBSS[3:0]**: DMA burst source selection

This bitfield defines the interrupt source that triggers the DMA burst transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address).

0000: Reserved
0001: Update
0010: CC1
0011: CC2
0100: CC3
0101: CC4
0110: COM
0111: Trigger
Others: reserved

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **DBL[4:0]**: DMA burst length

This 5-bit vector defines the length of DMA transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address), i.e. the number of transfers. Transfers can be in half-words or in bytes (see example below).

00000: 1 transfer
00001: 2 transfers
00010: 3 transfers
...
11010: 26 transfers

Example: Let us consider the following transfer: DBL = 7 bytes & DBA = TIM2_CR1.

–If DBL = 7 bytes and DBA = TIM2_CR1 represents the address of the byte to be transferred, the address of the transfer is given by the following equation:

(TIMx_CR1 address) + DBA + (DMA index), where DMA index = DBL

In this example, 7 bytes are added to (TIMx_CR1 address) + DBA, which gives us the address from/to which the data are copied. In this case, the transfer is done to 7 registers starting from the following address: (TIMx_CR1 address) + DBA

According to the configuration of the DMA Data Size, several cases may occur:

–If the DMA Data Size is configured in half-words, 16-bit data are transferred to each of the 7 registers.

–If the DMA Data Size is configured in bytes, the data are also transferred to 7 registers: the first register contains the first MSB byte, the second register, the first LSB byte and so on. So with the transfer Timer, one also has to specify the size of data transferred by DMA.

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **DBA[4:0]**: DMA base address

This 5-bits vector defines the base-address for DMA transfers (when read/write access are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register.

Example:
00000: TIMx_CR1,
00001: TIMx_CR2,
00010: TIMx_SMCR,
...

50.5.30 TIMx DMA address for full transfer (TIMx_DMAR)(x = 2 to 5)

Address offset: 0x3E0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMAB[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAB[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DMAB[31:0]**: DMA register for burst accesses

A read or write operation to the DMAR register accesses the register located at the address

(TIMx_CR1 address) + (DBA + DMA index) x 4

where TIMx_CR1 address is the address of the control register 1, DBA is the DMA base address configured in TIMx_DCR register, DMA index is automatically controlled by the DMA transfer, and ranges from 0 to DBL (DBL configured in TIMx_DCR).

50.5.31 TIMx register map

TIMx registers are mapped as described in the table below.

Table 550. TIM2/TIM3/TIM4/TIM5 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	TIMx_CR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DITHEN	UIFREMA	Res.	CKD [1:0]		ARPE	CMS [1:0]		DIR	OPM	URS	UDIS	CEN
	Reset value																				0	0		0	0	0	0	0	0	0	0	0	0
0x004	TIMx_CR2	Res.	Res.	Res.	Res.	Res.	Res.	MMS[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1S	MMS[2:0]			CCDS	Res.	Res.	Res.
	Reset value							0																		0	0	0	0	0			
0x008	TIMx_SMCR	Res.	Res.	Res.	Res.	Res.	Res.	SMSPS	SMSPE	Res.	Res.	TS [4:3]		Res.	Res.	Res.	SMS[3]	ETP	ECE	ETPS [1:0]		ETF[3:0]				MSM	TS[2:0]			Res.	SMS[2:0]		
	Reset value							0	0			0	0				0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
0x00C	TIMx_DIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TERRIE	IERRIE	DIRIE	IDXIE	Res.	Res.	Res.	Res.	Res.	Res.	TDE	Res.	CC4DE	CC3DE	CC2DE	CC1DE	UDE	Res.	TIE	Res.	CC4IE	CC3IE	CC2IE	CC1IE	UIE
	Reset value								0	0	0	0							0		0	0	0	0	0		0		0	0	0	0	0
0x010	TIMx_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TERRF	IERRF	DIRF	IDXF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC4OF	CC3OF	CC2OF	CC1OF	Res.	Res.	TIF	Res.	CC4IF	CC3IF	CC2IF	CC1IF	UIF
	Reset value								0	0	0	0									0	0	0	0			0		0	0	0	0	0
0x014	TIMx_EGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TG	Res.	CC4G	CC3G	CC2G	CC1G	UG
	Reset value																										0		0	0	0	0	0
0x018	TIMx_CCMR1 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC2F[3:0]				IC2 PSC [1:0]		CC2S [1:0]		IC1F[3:0]				IC1 PSC [1:0]		CC1S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TIMx_CCMR1 Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]	OC2CE	OC2M [2:0]			OC2PE	OC2FE	CC2S [1:0]		OC1CE	OC1M [2:0]			OC1PE	OC1FE	CC1S [1:0]	
	Reset value								0								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x01C	TIMx_CCMR2 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC4F[3:0]				IC4 PSC [1:0]		CC4S [1:0]		IC3F[3:0]				IC3 PSC [1:0]		CC3S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TIMx_CCMR2 Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC4M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC3M[3]	O24CE	OC4M [2:0]			OC4PE	OC4FE	CC4S [1:0]		OC3CE	OC3M [2:0]			OC3PE	OC3FE	CC3S [1:0]	
	Reset value								0								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 550. TIM2/TIM3/TIM4/TIM5 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x020	TIMx_CCER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC4NP	Res.	CC4P	CC4E	CC3NP	Res.	CC3P	CC3E	CC2NP	Res.	CC2P	CC2E	CC1NP	Res.	CC1P	CC1E
	Reset value																	0		0	0	0		0	0	0		0	0	0		0	0
0x024	TIMx_CNT	UIFCPY_CNT[31]	CNT[30:16] (CNT[31:16] on 32-bit timers only)															CNT[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x028	TIMx_PSC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x02C	TIMx_ARR (x = 3, 4)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:0]																			
	Reset value													0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x02C	TIMx_ARR (x = 2, 5)	ARR[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x030	Reserved	Reserved																															
0x034	TIMx_CCR1	CCR1[31:20] (32-bit timers only)												CCR1[19:0]																			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x038	TIMx_CCR2	CCR2[31:20] (32-bit timers only)												CCR2[19:0]																			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x03C	TIMx_CCR3	CCR3[31:20] (32-bit timers only)												CCR3[19:0]																			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x040	TIMx_CCR4	CCR4[31:20] (32-bit timers only)												CCR4[19:0]																			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x044.. 0x054	Reserved	Res.																															
0x058	TIMx_ECR	Res.	Res.	Res.	Res.	Res.	PWPRSC [2:0]			PW[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IPOS [1:0]		FIDX	IBLK [1:0]		IDIR [1:0]		IE
	Reset value						0	0	0	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0	0
0x05C	TIMx_TISEL	Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]				Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value					0	0	0	0					0	0	0	0					0	0	0	0					0	0	0	0
0x060	TIMx_AF1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL [3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value															0	0	0	0														
0x064	TIMx_AF2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCRSEL[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value														0	0	0																
0x068.. 0x3D8	Reserved	Res.																															

Table 550. TIM2/TIM3/TIM4/TIM5 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x3DC	TIMx_DCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBSS[3:0]				Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
	Reset value													0	0	0	0				0	0	0	0	0				0	0	0	0	0
0x3E0	TIMx_DMAR	DMAB[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

51 Basic timers (TIM6/TIM7)

51.1 TIM6/TIM7 introduction

The basic timers TIM6/TIM7 consist in a 16-bit autoreload counter driven by a programmable prescaler.

They can be used as generic timers for time-base generation.

The basic timer can also be used for triggering the digital-to-analog converter. This is done with the trigger output of the timer.

The timers are completely independent, and do not share any resources.

51.2 TIM6/TIM7 main features

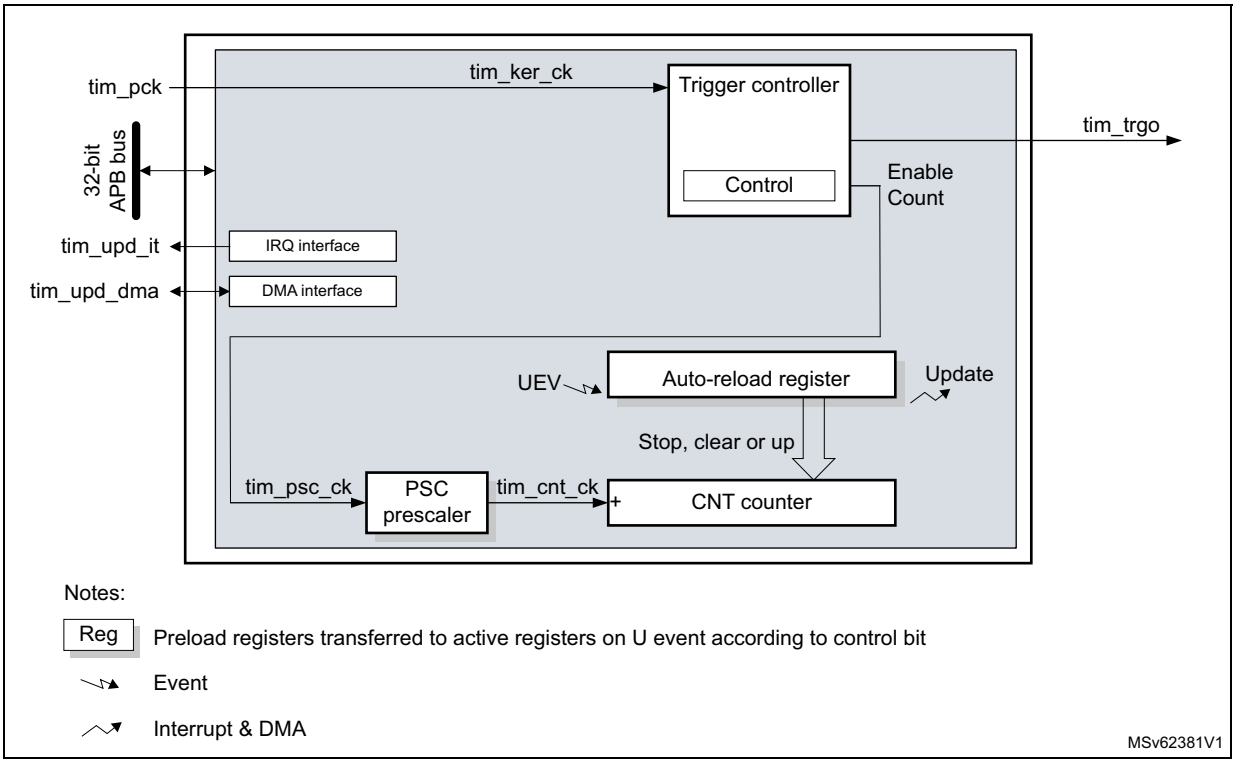
Basic timer (TIM6/TIM7) features include:

- 16-bit autoreload upcounter.
- 16-bit programmable prescaler used to divide (also “on the fly”) the counter clock frequency by any factor between 1 and 65535.
- Synchronization circuit to trigger the DAC.
- Interrupt/DMA generation on the update event: counter overflow.

51.3 TIM6/TIM7 functional description

51.3.1 TIM6/TIM7 block diagram

Figure 655. Basic timer block diagram



51.3.2 TIM6/TIM7 internal signals

The table in this section summarizes the TIM inputs and outputs.

Table 551. TIM internal input/output signals

Internal signal name	Signal type	Description
tim_pclk	Input	Timer APB clock
tim_ker_ck	Input	Timer kernel clock. This clock must be synchronous with tim_pclk (derived from the same source). The clock ratio tim_ker_ck/tim_pclk must be an integer: 1, 2, 3,..., 16 (maximum value)
tim_trgo	Output	Internal trigger output. This trigger can trigger other on-chip peripherals (DAC).
tim_upd_it	Output	Timer update event interrupt
tim_upd_dma	Output	Timer update dma request

51.3.3 TIM6/TIM7 clocks

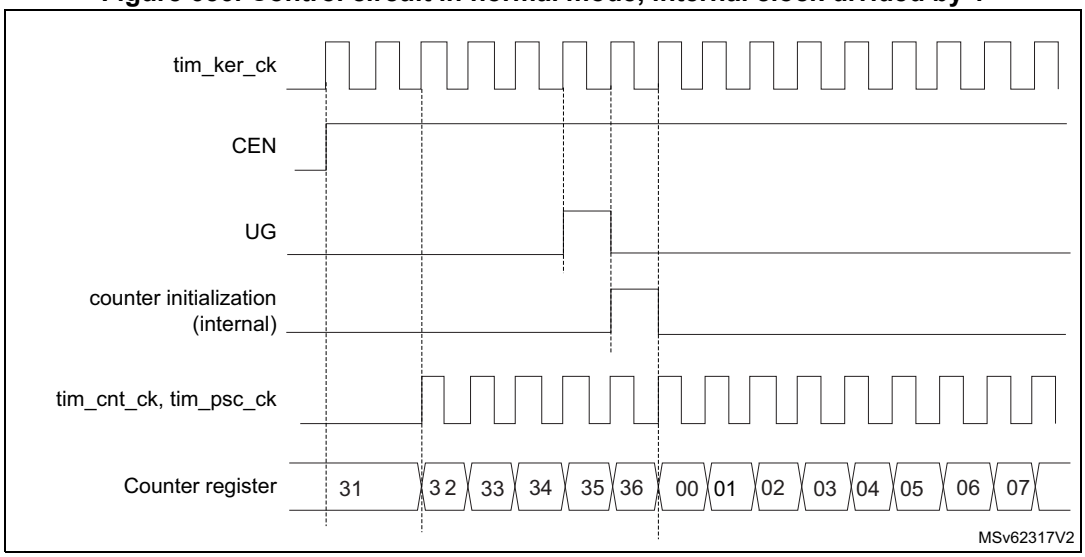
The timer bus interface is clocked by the tim_pclk APB clock.

The counter clock tim_ker_ck is connected to the tim_pclk input.

The CEN (in the TIMx_CR1 register) and UG bits (in the TIMx_EGR register) are actual control bits and can be changed only by software (except for UG that remains cleared automatically). As soon as the CEN bit is written to 1, the prescaler is clocked by the internal clock tim_ker_ck.

Figure 656 shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

Figure 656. Control circuit in normal mode, internal clock divided by 1



51.3.4 Time-base unit

The main block of the programmable timer is a 16-bit upcounter with its related autoreload register. The counter clock can be divided by a prescaler.

The counter, the autoreload register and the prescaler register can be written or read by software. This is true even when the counter is running.

The time-base unit includes:

- Counter register (TIMx_CNT)
- Prescaler register (TIMx_PSC)
- Auto-Reload register (TIMx_ARR).

The autoreload register is preloaded. The preload register is accessed each time an attempt is made to write or read the autoreload register. The contents of the preload register are transferred into the shadow register permanently or at each update event UEV, depending on the autoreload preload enable bit (ARPE) in the TIMx_CR1 register. The update event is sent when the counter reaches the overflow value and if the UDIS bit equals 0 in the TIMx_CR1 register. It can also be generated by software. The generation of the update event is described in detail for each configuration.

The counter is clocked by the prescaler output tim_cnt_ck, which is enabled only when the counter enable bit (CEN) in the TIMx_CR1 register is set.

Note that the actual counter enable signal tim_cnt_en is set one clock cycle after CEN bit set.

Prescaler description

The prescaler can divide the counter clock frequency by any factor between 1 and 65536. It is based on a 16-bit counter controlled through a 16-bit register (in the TIMx_PSC register). It can be changed on the fly as the TIMx_PSC control register is buffered. The new prescaler ratio is taken into account at the next update event.

Figure 657 and *Figure 658* give some examples of the counter behavior when the prescaler ratio is changed on the fly.

Figure 657. Counter timing diagram with prescaler division change from 1 to 2

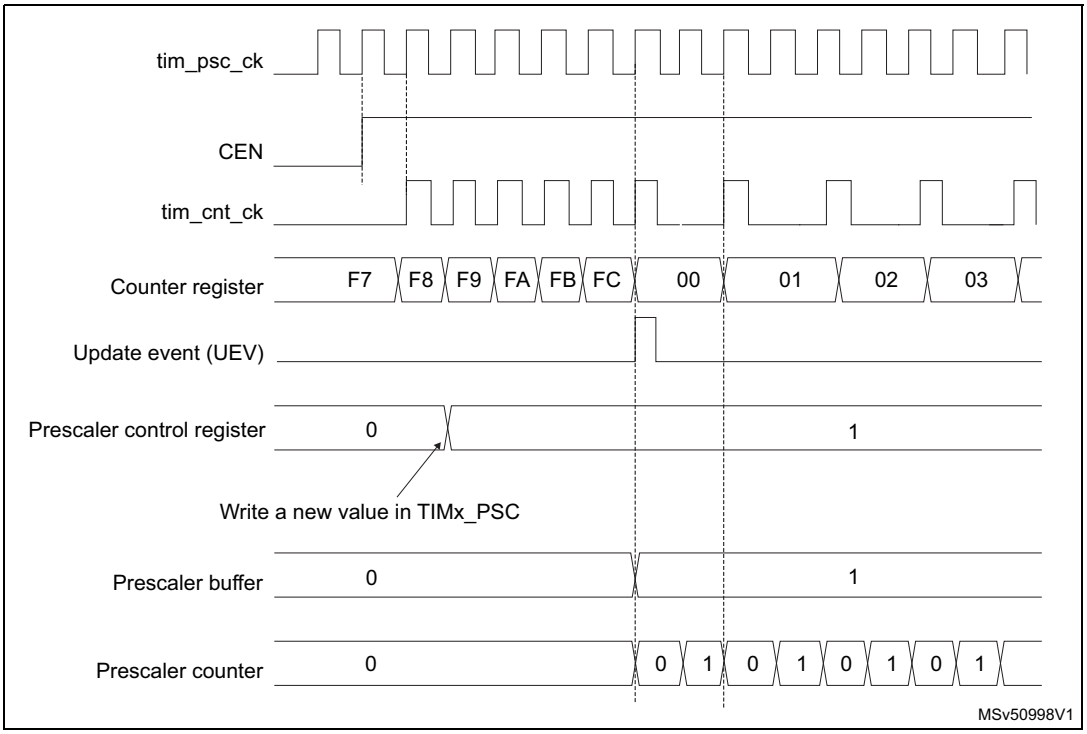
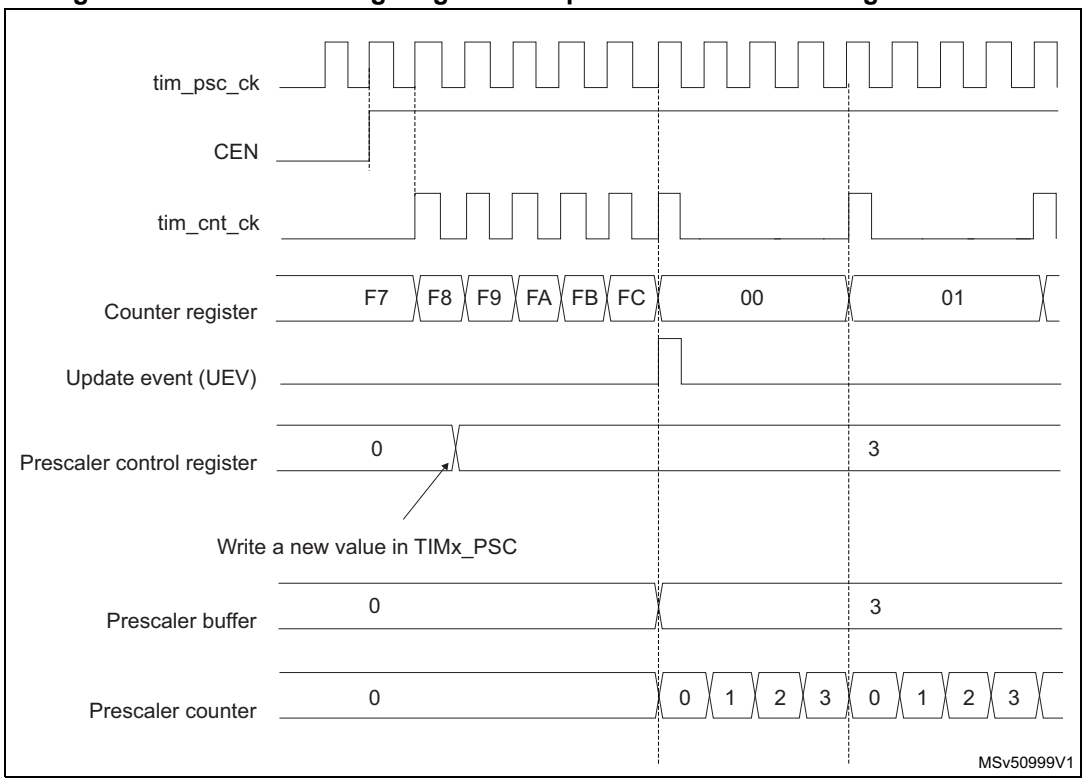


Figure 658. Counter timing diagram with prescaler division change from 1 to 4



51.3.5 Counting mode

The counter counts from 0 to the autoreload value (contents of the TIMx_ARR register), then restarts from 0 and generates a counter overflow event.

An update event can be generate at each counter overflow or by setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller).

The UEV event can be disabled by software by setting the UDIS bit in the TIMx_CR1 register. This avoids updating the shadow registers while writing new values into the preload registers. In this way, no update event occurs until the UDIS bit has been written to 0, however, the counter and the prescaler counter both restart from 0 (but the prescale rate does not change). In addition, if the URS (update request selection) bit in the TIMx_CR1 register is set, setting the UG bit generates an update event UEV, but the UIF flag is not set (so no interrupt or DMA request is sent).

When an update event occurs, all the registers are updated and the update flag (UIF bit in the TIMx_SR register) is set (depending on the URS bit):

- The buffer of the prescaler is reloaded with the preload value (contents of the TIMx_PSC register).
- The autoreload shadow register is updated with the preload value (TIMx_ARR).

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR = 0x36.

Figure 659. Counter timing diagram, internal clock divided by 1

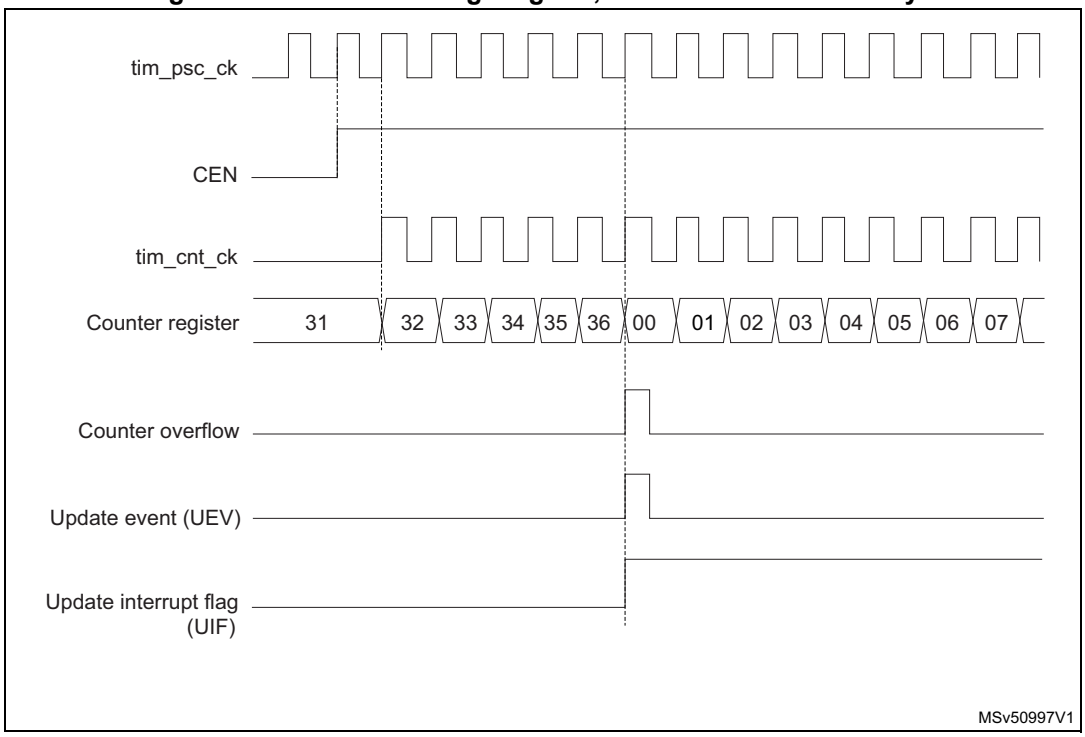


Figure 660. Counter timing diagram, internal clock divided by 2

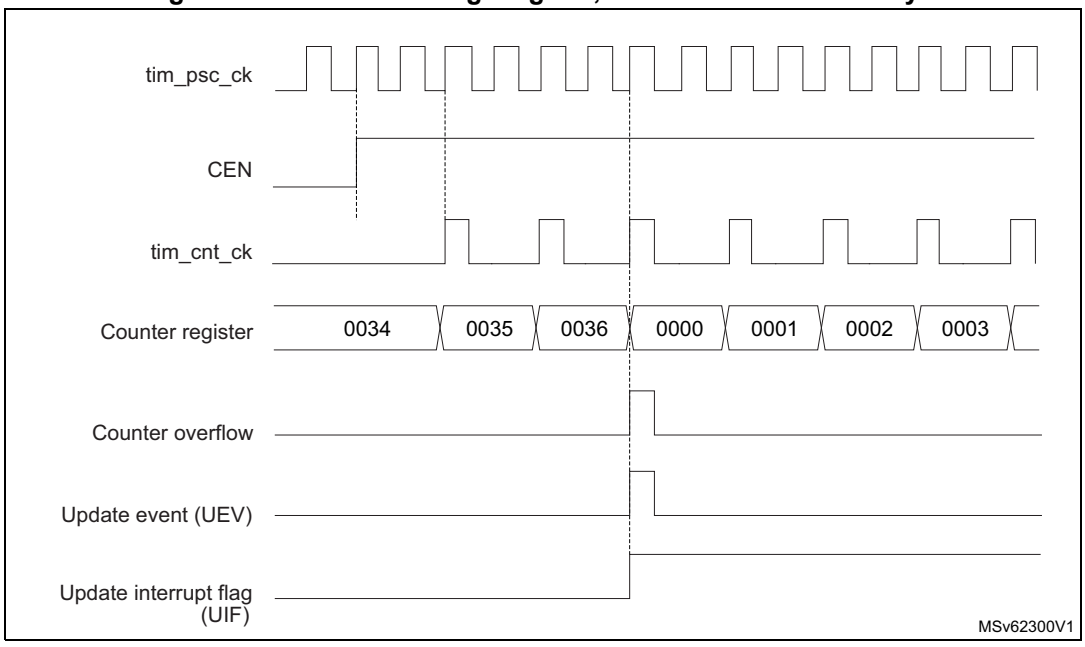


Figure 661. Counter timing diagram, internal clock divided by 4

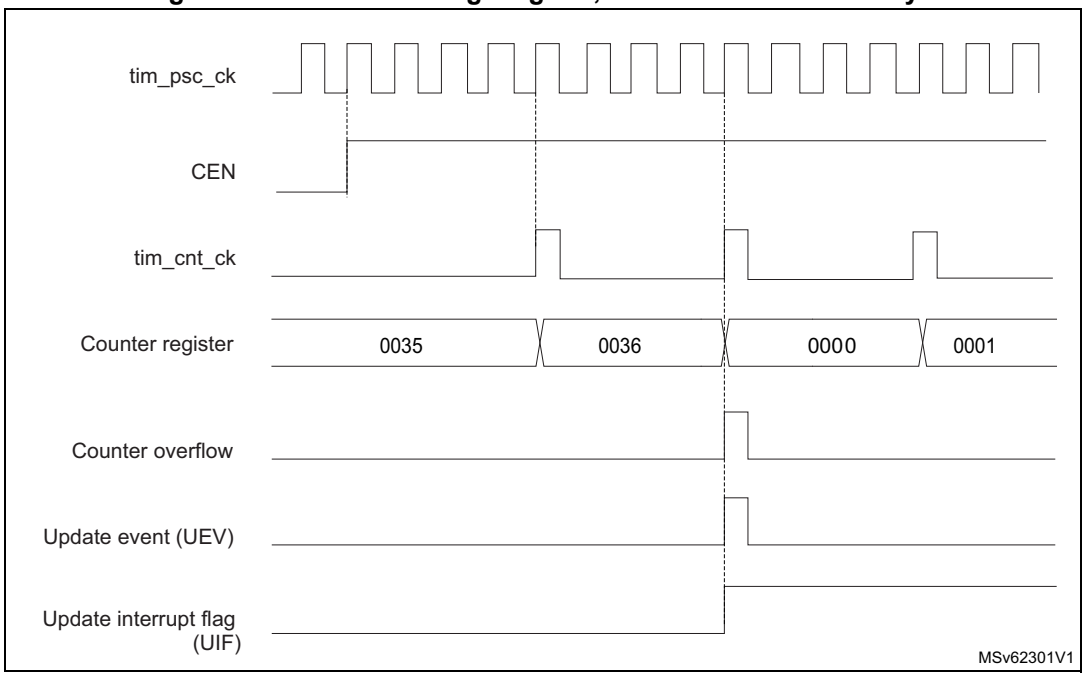


Figure 662. Counter timing diagram, internal clock divided by N

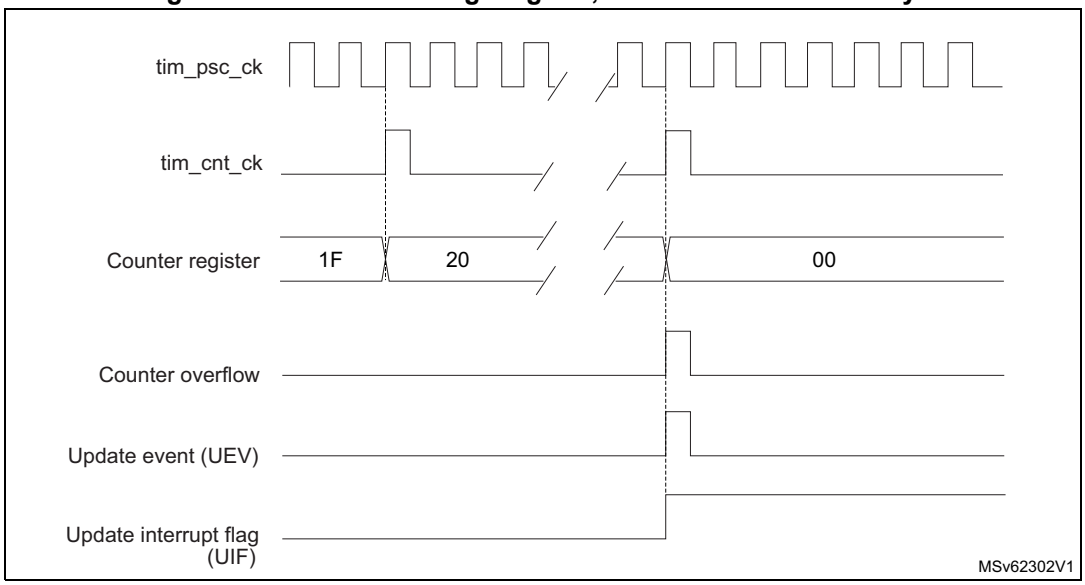


Figure 663. Counter timing diagram, update event when ARPE = 0 (TIMx_ARR not preloaded)

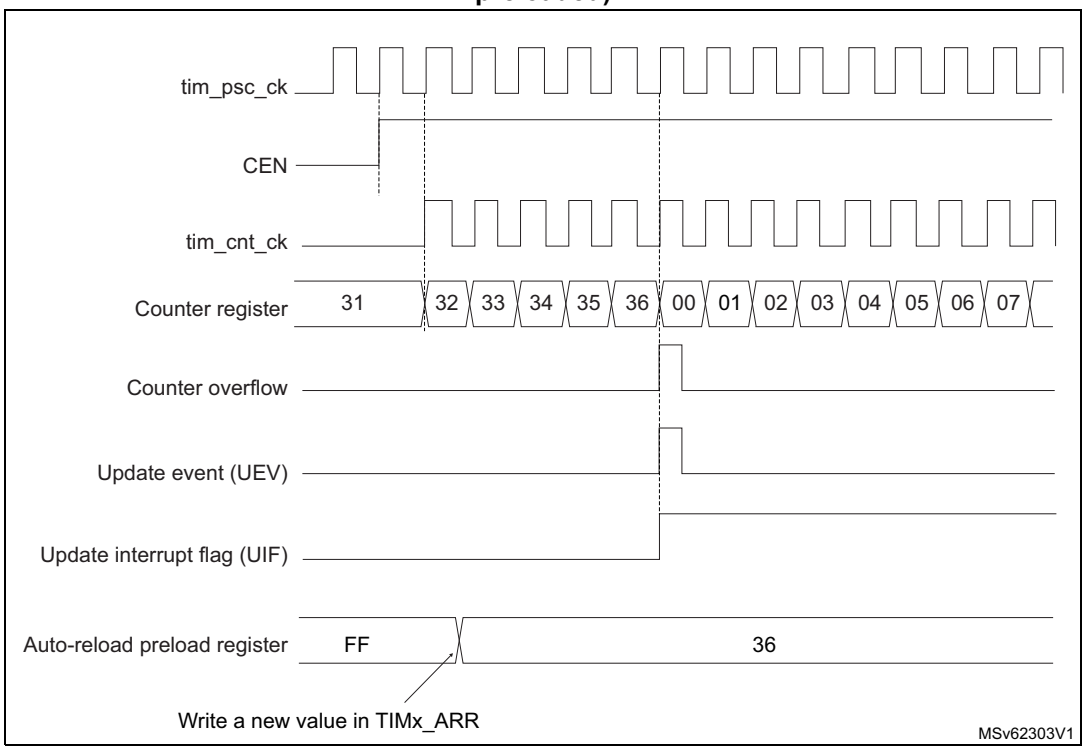
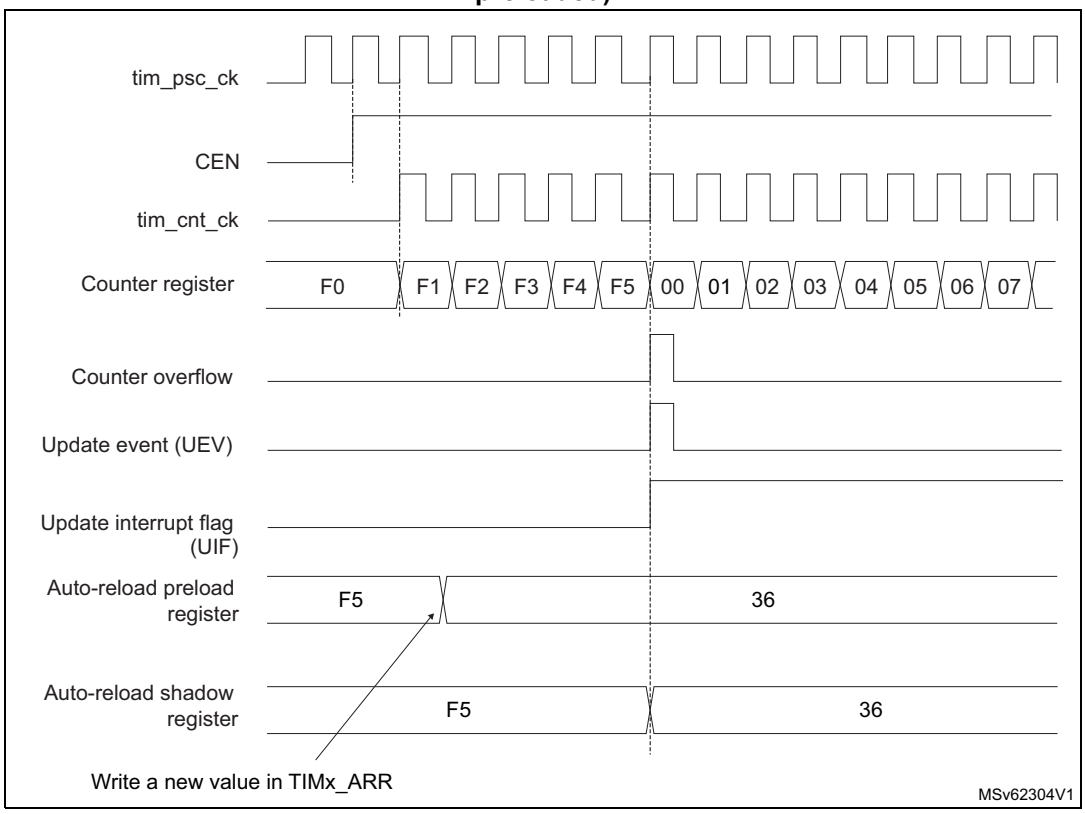


Figure 664. Counter timing diagram, update event when ARPE = 1 (TIMx_ARR preloaded)



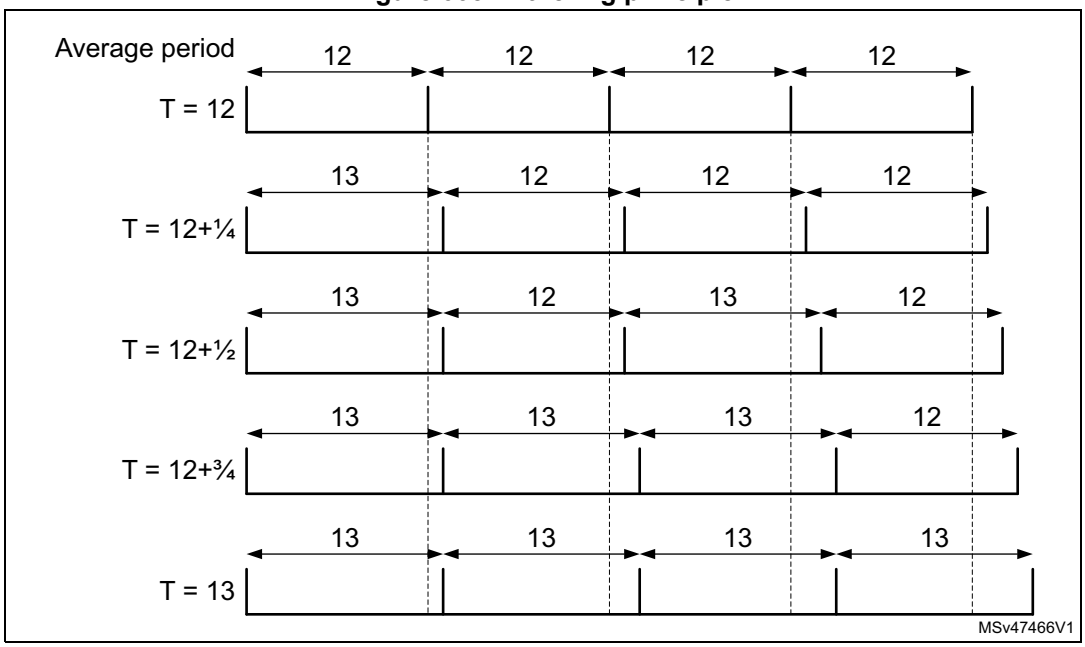
Dithering mode

The time base effective resolution can be increased by enabling the dithering mode, using the DITHEN bit in the TIMx_CR1 register. This affects the way the TIMx_ARR is behaving, and is useful for adjusting the average counter period when the timer is used as a trigger (typically for a DAC).

The operating principle is to have the actual ARR value slightly changed (adding or not one timer clock period) over 16 consecutive counting periods, with predefined patterns. This allows a 16-fold resolution increase, considering the average counting period.

Figure 665 presents the dithering principle applied to four consecutive counting periods.

Figure 665. Dithering principle

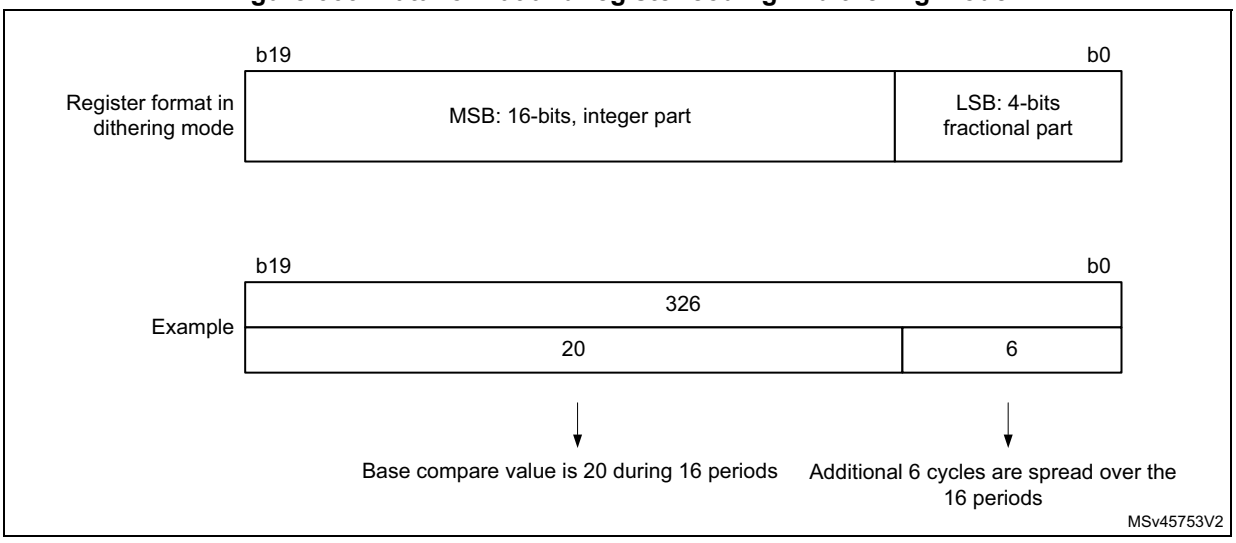


When the dithering mode is enabled, the register coding is changed as follows (see *Figure 666* for example):

- The four LSBs are coding for the enhanced resolution part (fractional part).
- The MSBs are left-shifted to the bits 19:4 and are coding for the base value.

Note: The following sequence must be followed when resetting the DITHEN bit:
1. CEN and ARPE bits must be reset
2. The DITHEN bit must be reset
3. The CEN bit can be set (eventually with ARPE = 1).

Figure 666. Data format and register coding in dithering mode



The minimum frequency is given by the following formula:

$$\text{Resolution} = \frac{F_{Tim}}{F_{pwm}} \Rightarrow F_{pwmMin} = \frac{F_{Tim}}{Max_{Resolution}}$$

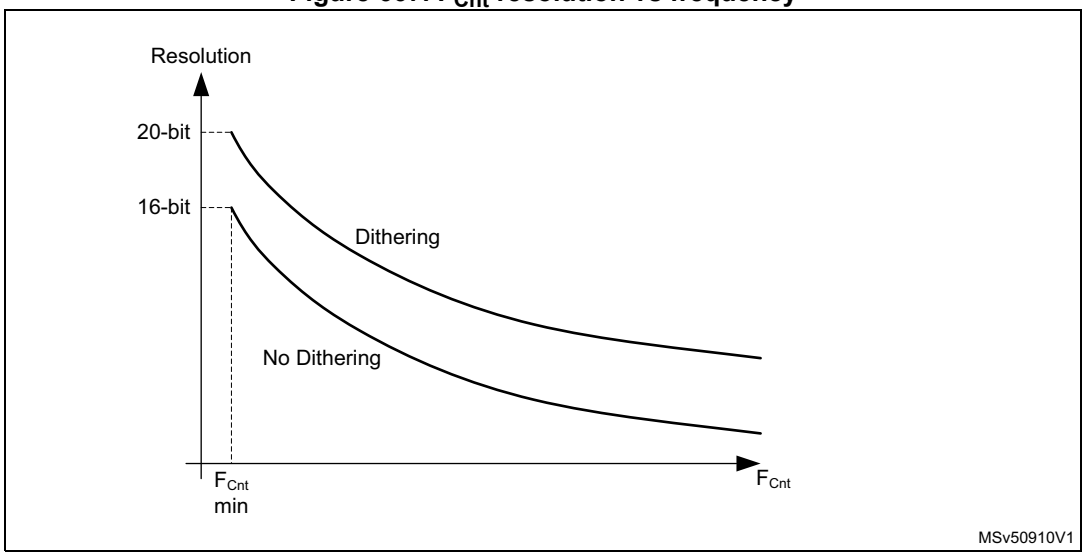
$$\text{Dithering mode disabled: } F_{pwmMin} = \frac{F_{Tim}}{65536}$$

$$\text{Dithering mode enabled: } F_{pwmMin} = \frac{F_{Tim}}{65535 + \frac{15}{16}}$$

Note: The maximum TIMx_ARR value is limited to 0xFFFEF in dithering mode (corresponds to 65534 for the integer part and 15 for the dithered part).

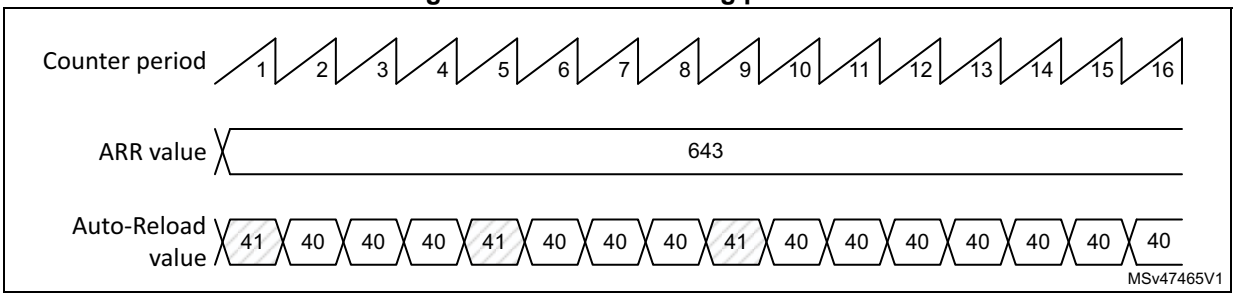
As shown on *Figure 667*, the dithering mode is used to increase the PWM resolution whatever the PWM frequency.

Figure 667. F_{Cnt} resolution vs frequency



The period changes are spread over 16 consecutive periods, as described in *Figure 668*.

Figure 668. PWM dithering pattern



The autoreload and compare values increments are spread following the specific patterns described in *Table 552*. The dithering sequence is done to have increments distributed as evenly as possible and minimize the overall ripple.

Table 552. TIMx_ARR register change dithering pattern

-	PWM period															
LSB value	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
0000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0001	+1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0010	+1	-	-	-	-	-	-	-	+1	-	-	-	-	-	-	-
0011	+1	-	-	-	+1	-	-	-	+1	-	-	-	-	-	-	-
0100	+1	-	-	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0101	+1	-	+1	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0110	+1	-	+1	-	+1	-	-	-	+1	-	+1	-	+1	-	-	-
0111	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	-	-
1000	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1001	+1	+1	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1010	+1	+1	+1	-	+1	-	+1	-	+1	+1	+1	-	+1	-	+1	-
1011	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	-	+1	-
1100	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-
1101	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-
1110	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	+1	+1	+1	+1	-
1111	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	-

51.3.6 UIF bit remapping

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the update interrupt flag UIF into the timer counter register's bit 31 (TIMxCNT[31]). This is used to atomically read both the counter value and a potential roll-over condition signaled by the UIFCPY flag. In particular cases, it can ease the calculations by avoiding race conditions caused for instance by a processing shared between a background task (counter reading) and an interrupt (update interrupt).

There is no latency between the assertions of the UIF and UIFCPY flags.

51.3.7 ADC triggers

The timer can generate an ADC triggering event with various internal signals, such as reset, enable or compare events.

Note: The clock of the slave peripherals (such as timer, ADC) receiving the tim_trgo signal must be enabled prior to receiving events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

51.3.8 TIM6/TIM7 DMA requests

The TIM6/TIM7 can generate a single DMA request, as shown in *Table 553*.

Table 553. DMA request

DMA acronym	DMA request	Enable control bit
tim_upd_dma	Update	UDE

51.3.9 Debug mode

When the microcontroller enters debug mode (Cortex®-M33 core halted), the TIMx counter can either continue to work normally or be stopped.

The behavior in debug mode can be programmed with a dedicated configuration bit per timer in the Debug support (DBG) module.

For more details, refer to section Debug support (DBG).

51.3.10 TIM6/TIM7 low-power modes

Table 554. Effect of low-power modes on TIM6/TIM7

Mode	Description
Sleep	No effect, peripheral is active. The interrupts can cause the device to exit from Sleep mode.
Stop	The timer operation is stopped and the register content is kept. No interrupt can be generated.
Standby	The timer is powered-down and must be reinitialized after exiting the Standby mode.

51.3.11 TIM6/TIM7 interrupts

The TIM6/TIM7 can generate a single interrupt, as shown in *Table 555*.

Table 555. Interrupt request

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop and Standby mode
TIM6 TIM7	Update	UIF	UIE	write 0 in UIF	Yes	No

51.4 TIM6/TIM7 registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by half-words (16-bit) or words (32-bit).

51.4.1 TIMx control register 1 (TIMx_CR1)(x = 6 to 7)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DITHEN	UIFREMAP	Res.	Res.	Res.	ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
			rw	rw				rw				rw	rw	rw	rw

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **DITHEN**: Dithering enable
0: Dithering disabled
1: Dithering enabled
Note: The DITHEN bit can only be modified when CEN bit is reset.

Bit 11 **UIFREMAP**: UIF status bit remapping
0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bits 10:8 Reserved, must be kept at reset value.

Bit 7 **ARPE**: Auto-reload preload enable
0: TIMx_ARR register is not buffered.
1: TIMx_ARR register is buffered.

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **OPM**: One-pulse mode
0: Counter is not stopped at update event
1: Counter stops counting at the next update event (clearing the CEN bit).

Bit 2 **URS**: Update request source

This bit is set and cleared by software to select the UEV event sources.

0: Any of the following events generates an update interrupt or DMA request if enabled. These events can be:

- Counter overflow/underflow
- Setting the UG bit
- Update generation through the slave mode controller

1: Only counter overflow/underflow generates an update interrupt or DMA request if enabled.

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable UEV event generation.

0: UEV enabled. The Update (UEV) event is generated by one of the following events:

- Counter overflow/underflow
- Setting the UG bit
- Update generation through the slave mode controller

Buffered registers are then loaded with their preload values.

1: UEV disabled. The Update event is not generated, shadow registers keep their value (ARR, PSC). However the counter and the prescaler are reinitialized if the UG bit is set or if a hardware reset is received from the slave mode controller.

Bit 0 **CEN**: Counter enable

0: Counter disabled

1: Counter enabled

CEN is cleared automatically in one-pulse mode, when an update event occurs.

51.4.2 TIMx control register 2 (TIMx_CR2)(x = 6 to 7)

Address offset: 0x04

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MMS[2:0]			Res.	Res.	Res.	Res.
									rw	rw	rw				

Bits 15:7 Reserved, must be kept at reset value.

Bits 6:4 **MMS[2:0]**: Master mode selection

These bits are used to select the information to be sent in master mode to slave timers for synchronization (TRGO). The combination is as follows:

000:**Reset** - the UG bit from the TIMx_EGR register is used as a trigger output (tim_trgo).

001:**Enable** - the Counter enable signal, tim_cnt_en, is used as a trigger output (tim_trgo). It is useful to start several timers at the same time or to control a window in which a slave timer is enabled. The Counter Enable signal is generated when the CEN control bit is written.

010:**Update** - The update event is selected as a trigger output (tim_trgo). For instance a master timer can then be used as a prescaler for a slave timer.

Note: The clock of the slave timer or he peripheral receiving the tim_trgo must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the master timer.

Bits 3:0 Reserved, must be kept at reset value.

51.4.3 TIMx DMA/Interrupt enable register (TIMx_DIER)(x = 6 to 7)

Address offset: 0x0C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	UDE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIE
							rw								rw

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **UDE**: Update DMA request enable

0: Update DMA request disabled.
1: Update DMA request enabled.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **UIE**: Update interrupt enable

0: Update interrupt disabled.
1: Update interrupt enabled.

51.4.4 TIMx status register (TIMx_SR)(x = 6 to 7)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIF
															rc_w0

Bits 15:1 Reserved, must be kept at reset value.

Bit 0 **UIF**: Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.

0: No update occurred.

1: Update interrupt pending. This bit is set by hardware when the registers are updated:

–On counter overflow if UDIS = 0 in the TIMx_CR1 register.

–When CNT is reinitialized by software using the UG bit in the TIMx_EGR register, if URS = 0 and UDIS = 0 in the TIMx_CR1 register.

51.4.5 TIMx event generation register (TIMx_EGR)(x = 6 to 7)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UG
															w

Bits 15:1 Reserved, must be kept at reset value.

Bit 0 **UG**: Update generation

This bit can be set by software, it is automatically cleared by hardware.

0: No action.

1: Re-initializes the timer counter and generates an update of the registers. Note that the prescaler counter is cleared too (but the prescaler ratio is not affected).

51.4.6 TIMx counter (TIMx_CNT)(x = 6 to 7)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF copy

This bit is a read-only copy of the UIF bit of the TIMx_ISR register. If the UIFREMAP bit in TIMx_CR1 is reset, bit 31 is reserved and read as 0.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value

Non-dithering mode (DITHEN = 0)

The register holds the counter value.

Dithering mode (DITHEN = 1)

The register only holds the non-dithered part in CNT[15:0]. The fractional part is not available.

51.4.7 TIMx prescaler (TIMx_PSC)(x = 6 to 7)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency $f_{tim_cnt_ck}$ is equal to $f_{tim_psc_ck}$ / (PSC[15:0] + 1).

PSC contains the value to be loaded into the active prescaler register at each update event. (including when the counter is cleared through UG bit of TIMx_EGR register.

51.4.8 TIMx autoreload register (TIMx_ARR)(x = 6 to 7)

Address offset: 0x2C

Reset value: 0x0000 FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:16]			
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **ARR[19:0]**: Auto-reload value

ARR is the value to be loaded into the actual auto-reload register.

Refer to *Section 51.3.4: Time-base unit* for more details about ARR update and behavior.

The counter is blocked while the auto-reload value is null.

Non-dithering mode (DITHEN = 0)

The register holds the auto-reload value in ARR[15:0]. The ARR[19:16] bits are reserved.

Dithering mode (DITHEN = 1)

The register holds the integer part in ARR[19:4]. The ARR[3:0] bitfield contains the dithered part.

51.4.9 TIMx register map

TIMx registers are mapped as 16-bit addressable registers as described in the table below:

Table 556. TIMx register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	TIMx_CR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DITHEN	UIFREMA	Res.	Res.	Res.	ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
	Reset value																				0	0				0				0	0	0	0
0x04	TIMx_CR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MMS [2:0]			Res.	Res.	Res.	Res.
	Reset value																										0	0	0				
0x08	Reserved																																
0x0C	TIMx_DIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UDE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIE
	Reset value																								0								0
0x10	TIMx_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIF
	Reset value																																0
0x14	TIMx_EGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UG
	Reset value																																0
0x18-0x20	Reserved																																
0x24	TIMx_CNT	UIFCPY or Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	TIMx_PSC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	TIMx_ARR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:0]																			
	Reset value													0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

52 General-purpose timers (TIM12/TIM13/TIM14)

52.1 TIM12/TIM13/TIM14 introduction

The TIM12/TIM13/TIM14 general-purpose timers consist in a 16-bit autoreload counter driven by a programmable prescaler.

They may be used for a variety of purposes, including measuring the pulse lengths of input signals (input capture) or generating output waveforms (output compare, PWM).

Pulse lengths and waveform periods can be modulated from a few microseconds to several milliseconds using the timer prescaler and the RCC clock controller prescalers.

The TIM12/TIM13/TIM14 timers are completely independent, and do not share any resources. They can be synchronized together as described in *Section 52.4.20: Timer synchronization (TIM12 only)*.

52.2 TIM12 main features

The features of the TIM12 general-purpose timer include:

- 16-bit autoreload upcounter
- 16-bit programmable prescaler used to divide the counter clock frequency by any factor between 1 and 65536 (can be changed “on the fly”)
- Up to two independent channels for:
  - Input capture
  - Output compare
  - PWM generation (edge-aligned mode)
  - One-pulse mode output
- Synchronization circuit to control the timer with external signals and to interconnect several timers together
- Interrupt generation on the following events:
  - Update: counter overflow, counter initialization (by software or internal trigger)
  - Trigger event (counter start, stop, initialization, or count by internal trigger)
  - Input capture
  - Output compare

52.3 TIM13/TIM14 main features

The features of general-purpose timers TIM13/TIM14 include:

- 16-bit autoreload upcounter
- 16-bit programmable prescaler used to divide the counter clock frequency by any factor between 1 and 65536 (can be changed “on the fly”)
- Independent channel for:
  - Input capture
  - Output compare
  - PWM generation (edge-aligned mode)
  - One-pulse mode output
- Interrupt generation on the following events:
  - Update: counter overflow, counter initialization (by software)
  - Input capture
  - Output compare

52.4 TIM12/TIM13/TIM14 functional description

52.4.1 Block diagram

Figure 669. General-purpose timer block diagram (TIM12)

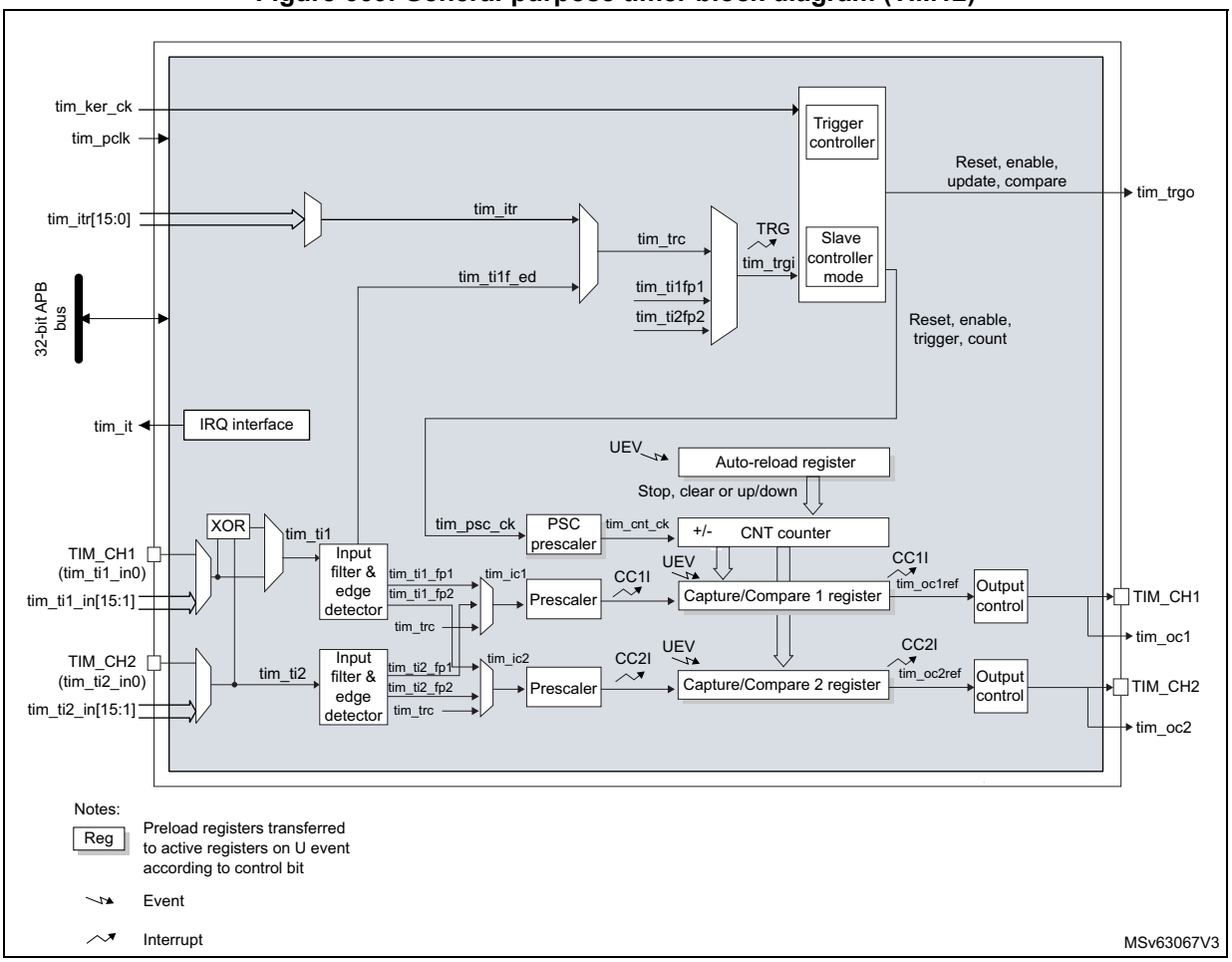
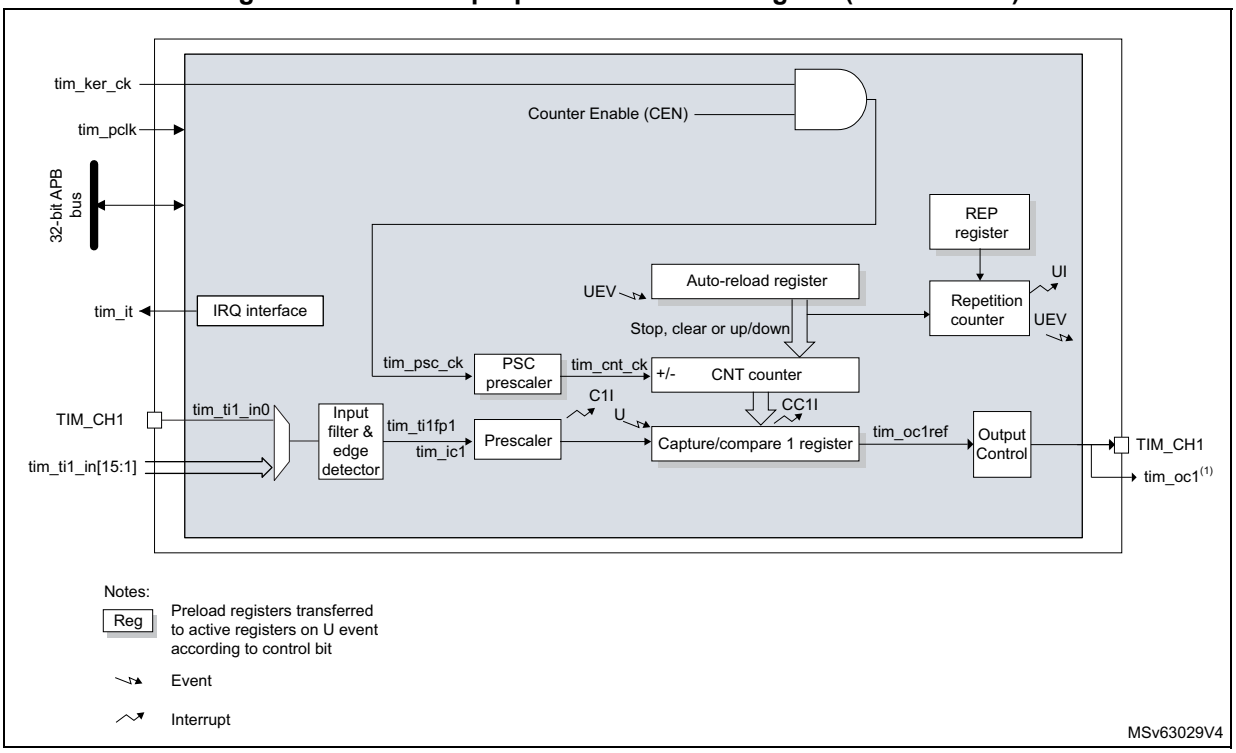


Figure 670. General-purpose timer block diagram (TIM13/TIM14)



1. This signal can be used as trigger for some slave timer (see internal trigger connection table in next section). See *Section 52.4.21: Using timer output as trigger for other timers (TIM13/TIM14 only)* for details.

52.4.2 TIM12/TIM13/TIM14 pins and internal signals

Table 557 and *Table 558* in this section summarize the TIM inputs and outputs.

Table 557. TIM input/output pins

Pin name	Signal type	Description
TIM_CH1 TIM_CH2(1)	Input/Output	Timer multi-purpose channels. Each channel be used for capture, compare, or PWM. TIM_CH1 and TIM_CH2 can also be used as external clock (below 1/4 of the tim_ker_ck clock) and external trigger inputs.

1. Available for TIM12 only.

Table 558. TIM internal input/output signals

Internal signal name	Signal type	Description
tim_ti1_in[15:0] tim_ti2_in[15:0](1)	Input	Internal timer inputs bus. These inputs can be used for capture or as external clock (below 1/4 of the tim_ker_ck clock).
tim_itr[15:0](1)	Input	Internal trigger input bus. These inputs can be used for the slave mode controller or as a input clock (below 1/4 of the tim_ker_ck clock).
tim_oc1 tim_oc2(1)	Output	Internal timer output. Can be used for triggering other timers or the ADC(s).

Table 558. TIM internal input/output signals (continued)

Internal signal name	Signal type	Description
tim_trgo(1)	Output	Internal trigger output. This trigger can trigger other on-chip peripherals.
tim_pclk	Input	Timer APB clock
tim_ker_ck	Input	Timer kernel clock. This clock must be synchronous with tim_pclk (derived from the same source). The clock ratio tim_ker_ck/tim_pclk must be an integer:1, 2, 3,..., 16 (maximum value)
tim_it	Output	Global Timer interrupt, gathering capture/compare, update, break trigger and commutation requests

1. Available for TIM12 only.

Table 559 and *Table 560* list the sources connected to the tim_ti[2:1] input multiplexers.

Table 559. Interconnect to the tim_ti1 input multiplexer

tim_ti1 inputs	Sources		
	TIM12	TIM13	TIM14
tim_ti1_in0	TIM12_CH1	TIM13_CH1	TIM14_CH1
tim_ti1_in1	Reserved	i3c1_ibiack	i3c2_ibiack
tim_ti1_in2	comp1_out	comp1_out	comp1_out
tim_ti1_in3	comp2_out	comp2_out	comp2_out
tim_ti1_in4	HSI/1024	Reserved	
tim_ti1_in5	CSI/128		
tim_ti1_in[15:6]	Reserved		

Table 560. Interconnect to the tim_ti2 input multiplexer

tim_ti2 inputs	Sources
	TIM12
tim_ti2_in0	TIM12_CH2
tim_ti2_in1	comp2_out
tim_ti2_in[15:2]	Reserved

Table 561 lists the internal sources connected to the tim_itr input multiplexer.

Table 561. TIMx internal trigger connection

TIMx	TIM12
tim_itr0	tim1_trgo
tim_itr1	tim2_trgo
tim_itr2	tim3_trgo
tim_itr3	tim4_trgo
tim_itr4	tim5_trgo
tim_itr5	tim8_trgo
tim_itr6	Reserved
tim_itr7	tim13_oc1
tim_itr8	tim14_oc1
tim_itr9	tim15_trgo
tim_itr10	tim16_oc1
tim_itr11	tim17_oc1
tim_itr[15:12]	Reserved

52.4.3 Time-base unit

The main block of the timer is a 16-bit up-counter with its related autoreload register. The counter clock can be divided by a prescaler.

The counter, the autoreload register and the prescaler register can be written or read by software. This is true even when the counter is running.

The time-base unit includes:

- Counter register (TIMx_CNT)
- Prescaler register (TIMx_PSC)
- Autoreload register (TIMx_ARR).

The autoreload register is preloaded. Writing to or reading from the auto-reload register accesses the preload register. The content of the preload register is transferred into the shadow register permanently or at each update event (UEV), depending on the autoreload preload enable bit (ARPE) in TIMx_CR1 register. The update event is sent when the counter reaches the overflow and if the UDIS bit equals 0 in the TIMx_CR1 register. It can also be generated by software. The generation of the update event is described in details for each configuration.

The counter is clocked by the prescaler output tim_cnt_ck, which is enabled only when the counter enable bit (CEN) in TIMx_CR1 register is set (refer also to the slave mode controller description to get more details on counter enabling).

Note that the counter starts counting one clock cycle after setting the CEN bit in the TIMx_CR1 register.

Prescaler description

The prescaler can divide the counter clock frequency by any factor between 1 and 65536. It is based on a 16-bit counter controlled through a 16-bit register (in the TIMx_PSC register). It can be changed on the fly as this control register is buffered. The new prescaler ratio is taken into account at the next update event.

Figure 671 and *Figure 672* give some examples of the counter behavior when the prescaler ratio is changed on the fly.

Figure 671. Counter timing diagram with prescaler division change from 1 to 2

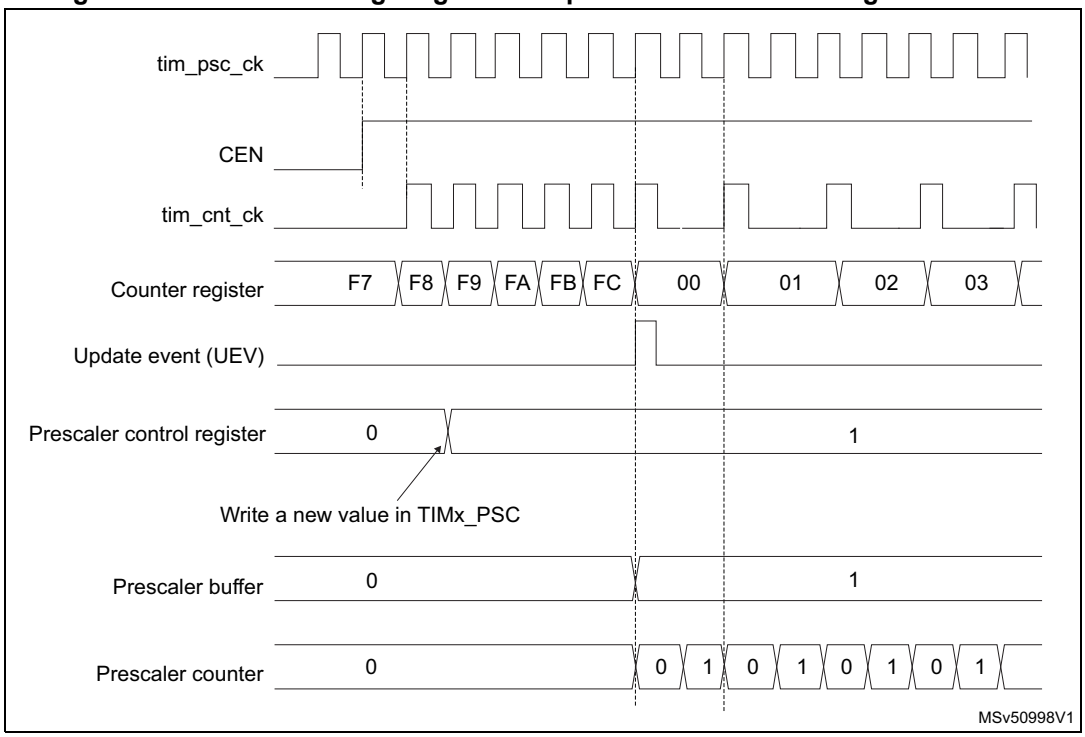
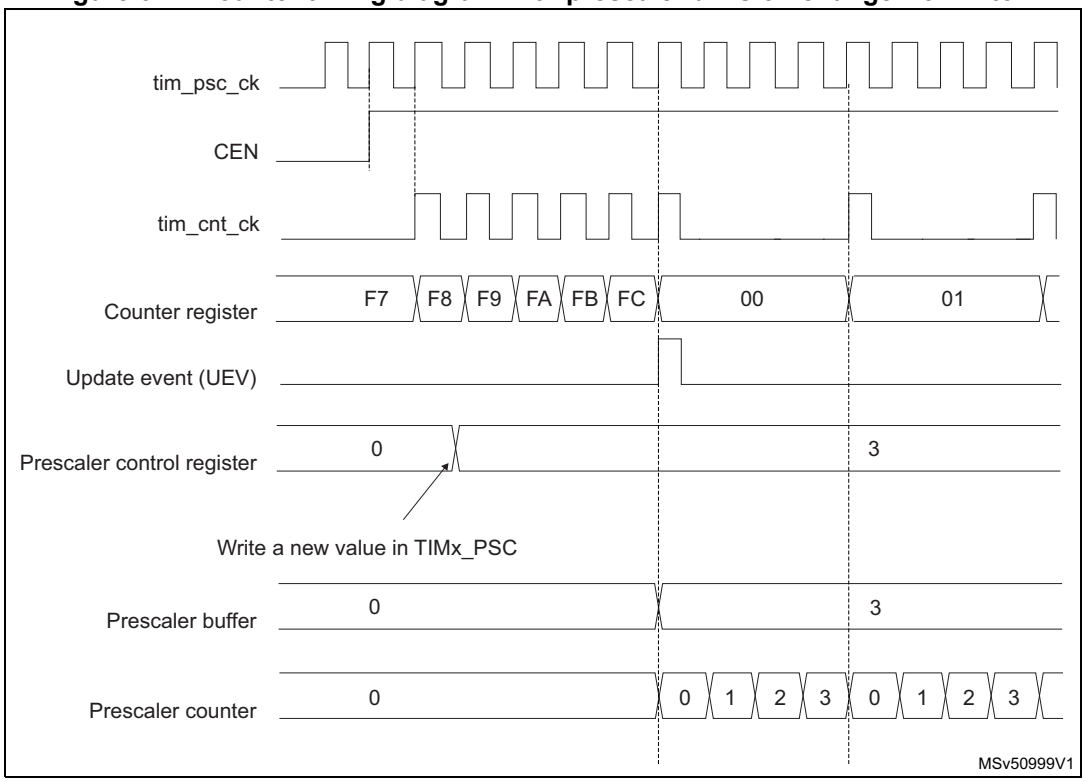


Figure 672. Counter timing diagram with prescaler division change from 1 to 4



52.4.4 Counter modes

Upcounting mode

In upcounting mode, the counter counts from 0 to the autoreload value (content of the TIMx_ARR register), then restarts from 0 and generates a counter overflow event.

Setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller on TIM12) also generates an update event.

The UEV event can be disabled by software by setting the UDIS bit in the TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter restarts from 0, as well as the counter of the prescaler (but the prescale rate does not change). In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The autoreload shadow register is updated with the preload value (TIMx_ARR).
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR = 0x36.

Figure 673. Counter timing diagram, internal clock divided by 1

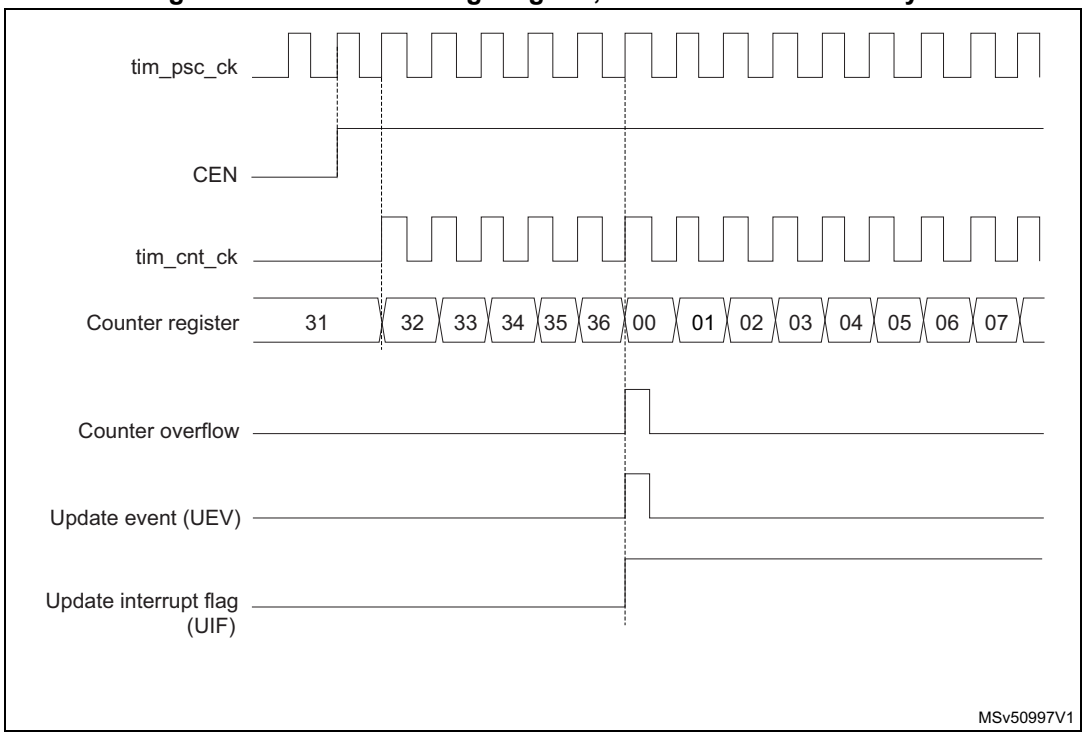


Figure 674. Counter timing diagram, internal clock divided by 2

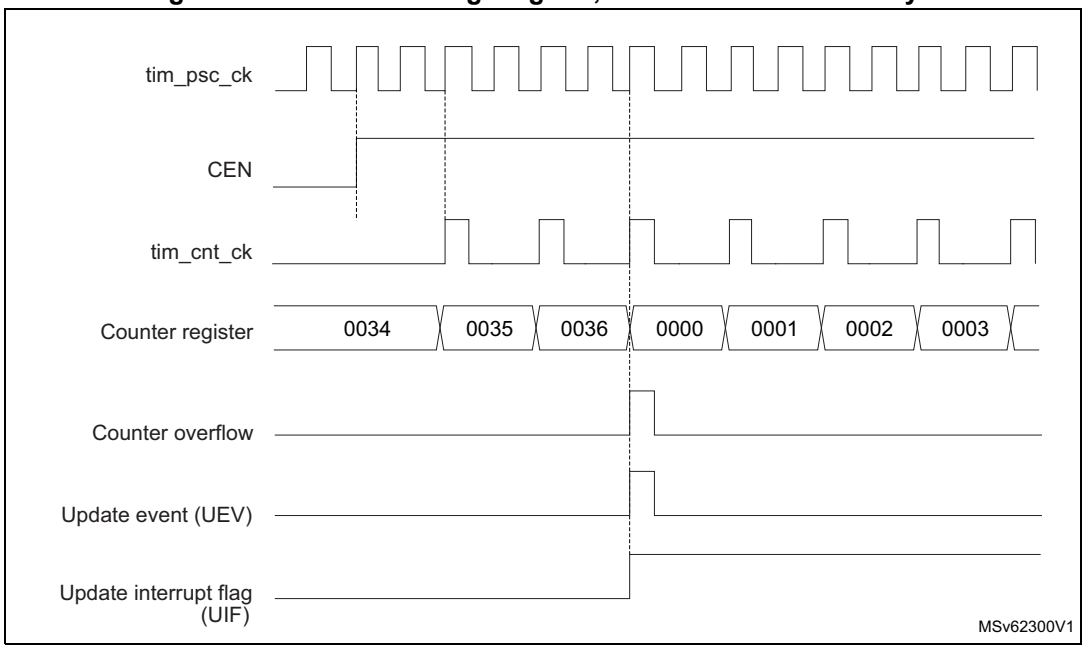


Figure 675. Counter timing diagram, internal clock divided by 4

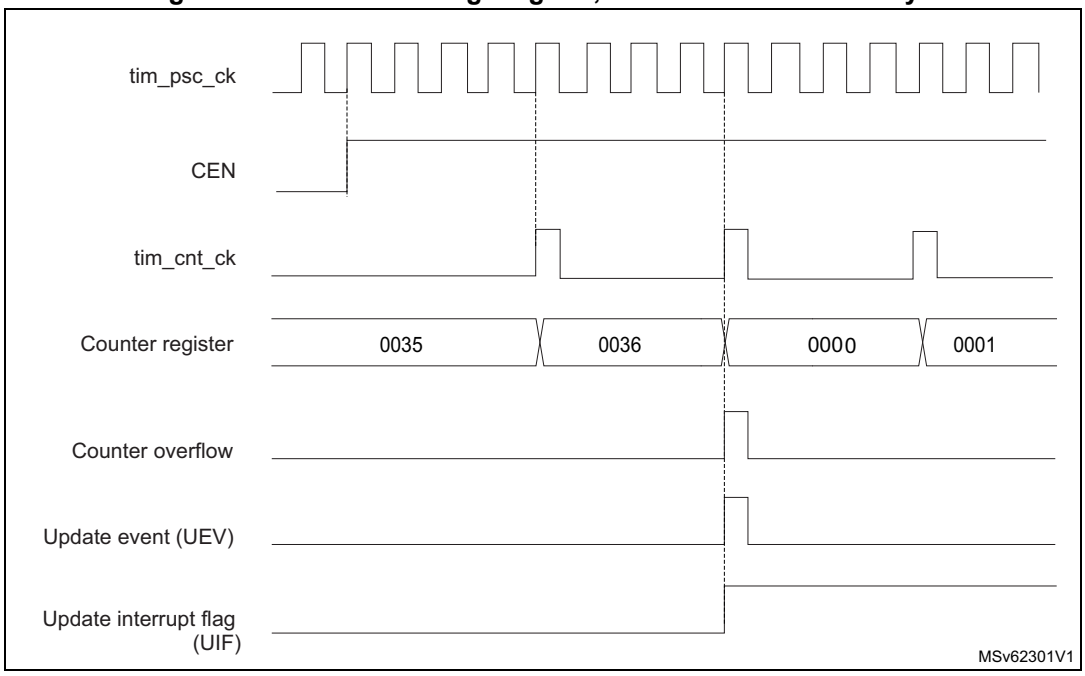


Figure 676. Counter timing diagram, internal clock divided by N

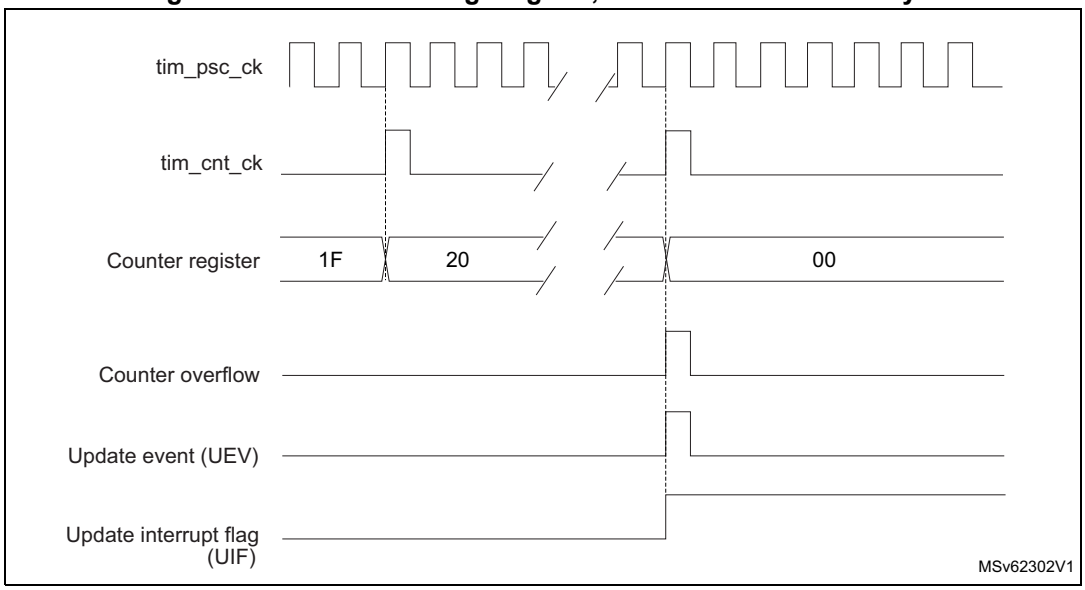


Figure 677. Counter timing diagram, update event when ARPE = 0 (TIMx_ARR not preloaded)

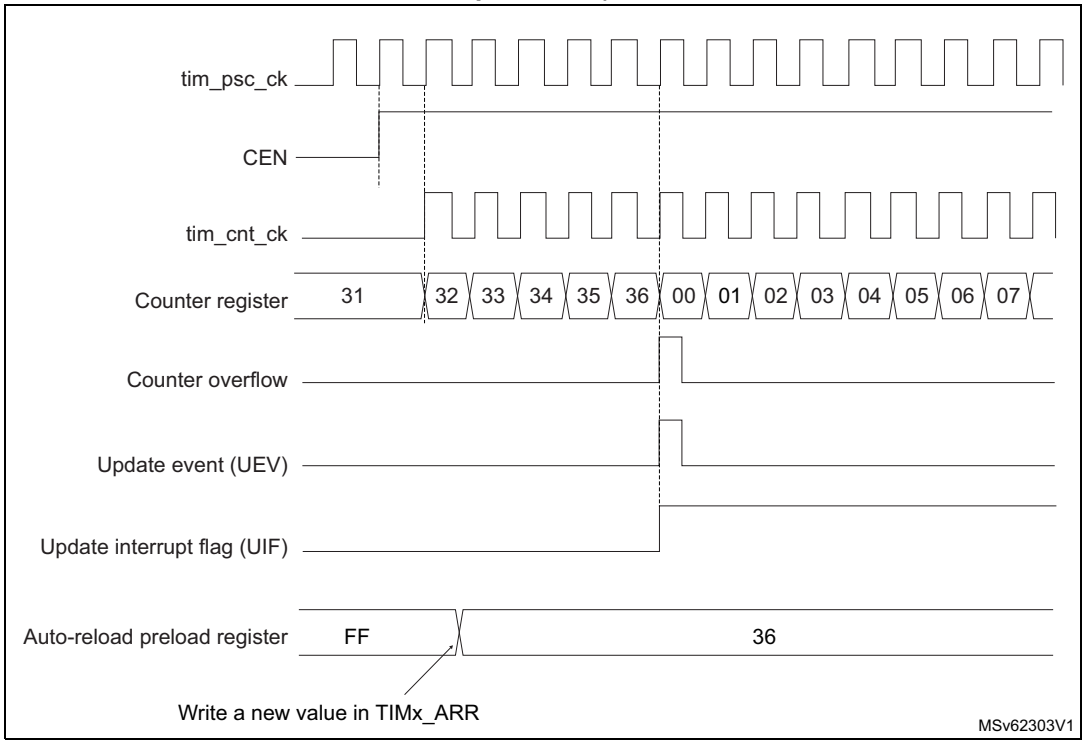
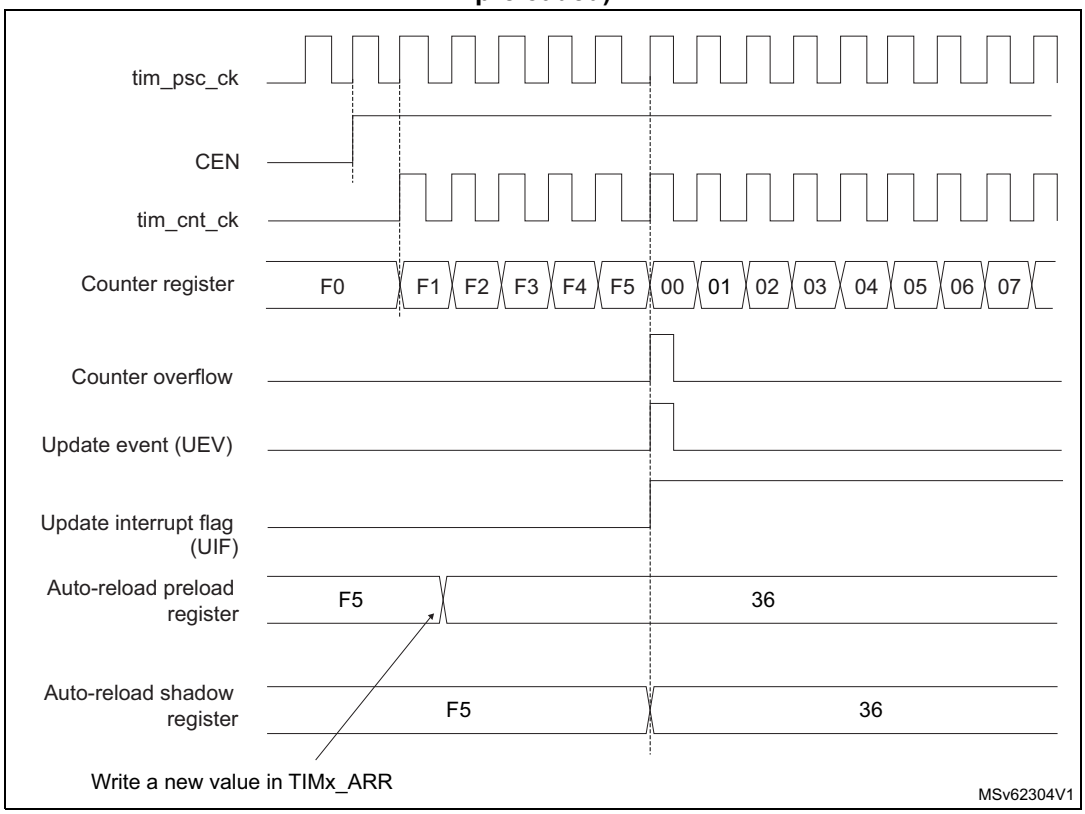


Figure 678. Counter timing diagram, update event when ARPE = 1 (TIMx_ARR preloaded)



52.4.5 Clock selection

The counter clock can be provided by the following clock sources:

- Internal clock (tim_ker_ck)
- External clock mode1 (for TIM12): external input pin (tim_ti1 or tim_ti2, if available)
- Internal trigger inputs (tim_itrx) (for TIM12): connecting the trigger output from another timer. For instance, another timer can be configured as a prescaler for TIM12. Refer to *Section : Using one timer as prescaler for another timer* for more details.

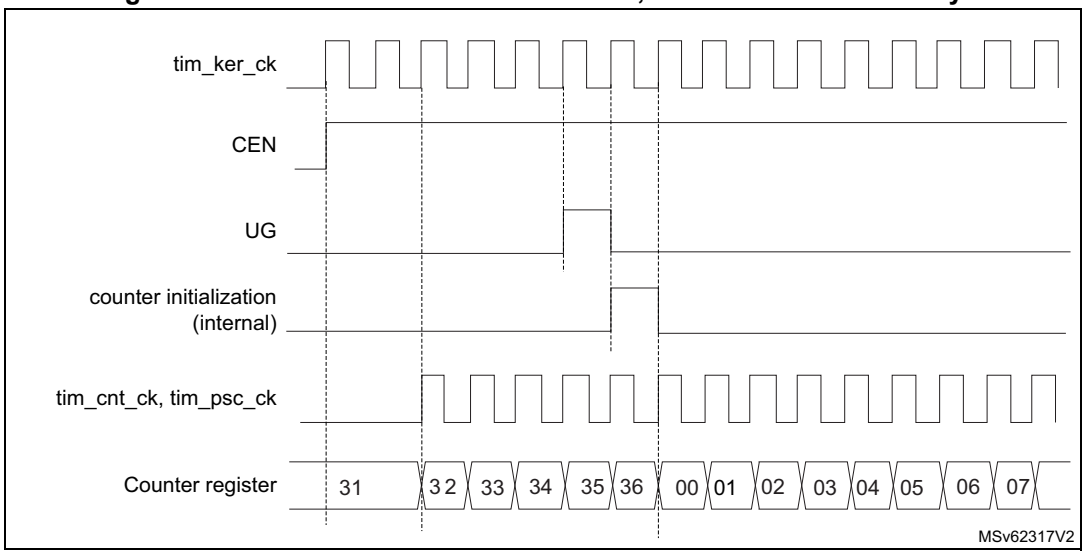
Internal clock source (tim_ker_ck)

The internal clock source is the default clock source for TIM13/TIM14.

For TIM12, the internal clock source is selected when the slave mode controller is disabled (SMS = 000). The CEN bit in the TIMx_CR1 register and the UG bit in the TIMx_EGR register are then used as control bits and can be changed only by software (except for UG which remains cleared). As soon as the CEN bit is programmed to 1, the prescaler is clocked by the internal clock tim_ker_ck.

Figure 679 shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

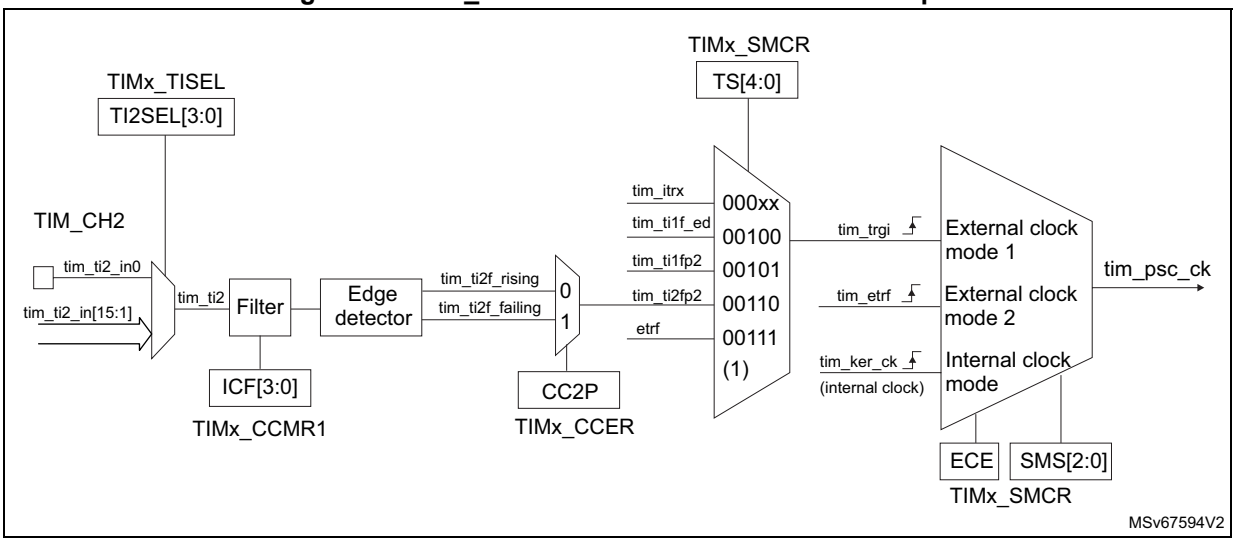
Figure 679. Control circuit in normal mode, internal clock divided by 1



External clock source mode 1

This mode is selected when SMS = 111 in the TIMx_SMCR register. The counter can count at each rising or falling edge on a selected input.

Figure 680. tim_ti2 external clock connection example



For example, to configure the upcounter to count in response to a rising edge on the tim_ti2 input, use the following procedure:

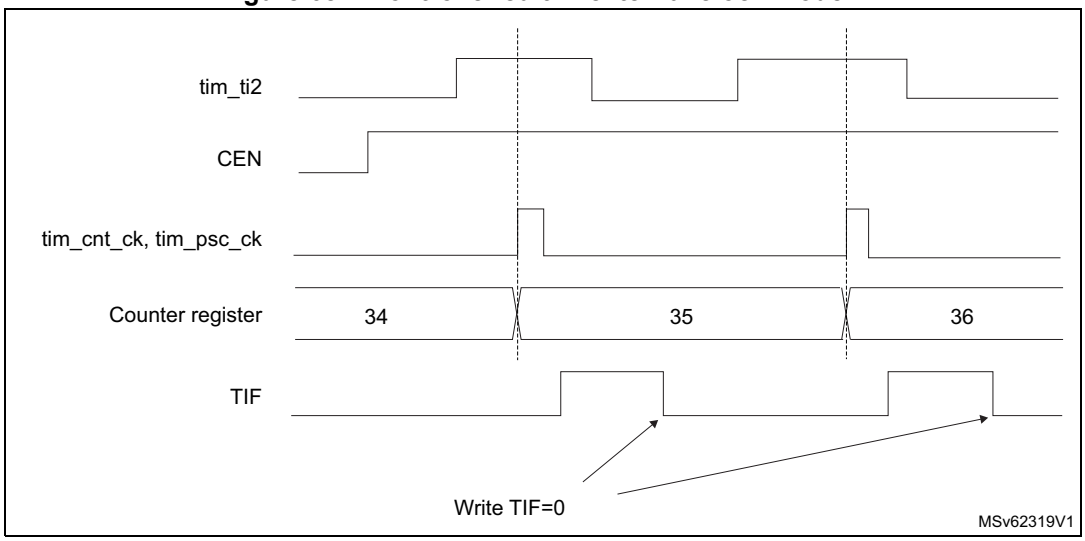
1. Select the proper tim_ti2_in[15:0] source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Configure channel 2 to detect rising edges on the tim_ti2 input by writing CC2S = 01 in the TIMx_CCMR1 register.
3. Configure the input filter duration by writing the IC2F[3:0] bits in the TIMx_CCMR1 register (if no filter is needed, keep IC2F = 0000).
4. Select the rising edge polarity by writing CC2P = 0 and CC2NP = 0 in the TIMx_CCER register.
5. Configure the timer in external clock mode 1 by writing SMS = 111 in the TIMx_SMCR register.
6. Select tim_ti2 as the trigger input source by writing TS = 110 in the TIMx_SMCR register.
7. Enable the counter by writing CEN = 1 in the TIMx_CR1 register.

Note: The capture prescaler is not used for triggering, it is not necessary to configure it.

When a rising edge occurs on tim_ti2, the counter counts once and the TIF flag is set.

The delay between the rising edge on tim_ti2 and the actual clock of the counter is due to the resynchronization circuit on tim_ti2 input.

Figure 681. Control circuit in external clock mode 1



52.4.6 Capture/compare channels

Each Capture/Compare channel is built around a capture/compare register (including a shadow register), an input stage for capture (with digital filter, multiplexing and prescaler), and an output stage (with comparator and output control).

Figure 682, *Figure 683*, *Figure 684* and *Figure 685* give an overview of a capture/compare channel.

The input stage samples the corresponding tim_tix input to generate a filtered signal tim_tixf. Then, an edge detector with polarity selection generates a signal (tim_tixfpy) which

can be used as trigger input by the slave mode controller or as the capture command. It is prescaled before the capture register (ICxPS).

Figure 682. Capture/compare channel 1 input stage (TIM13/TIM14)

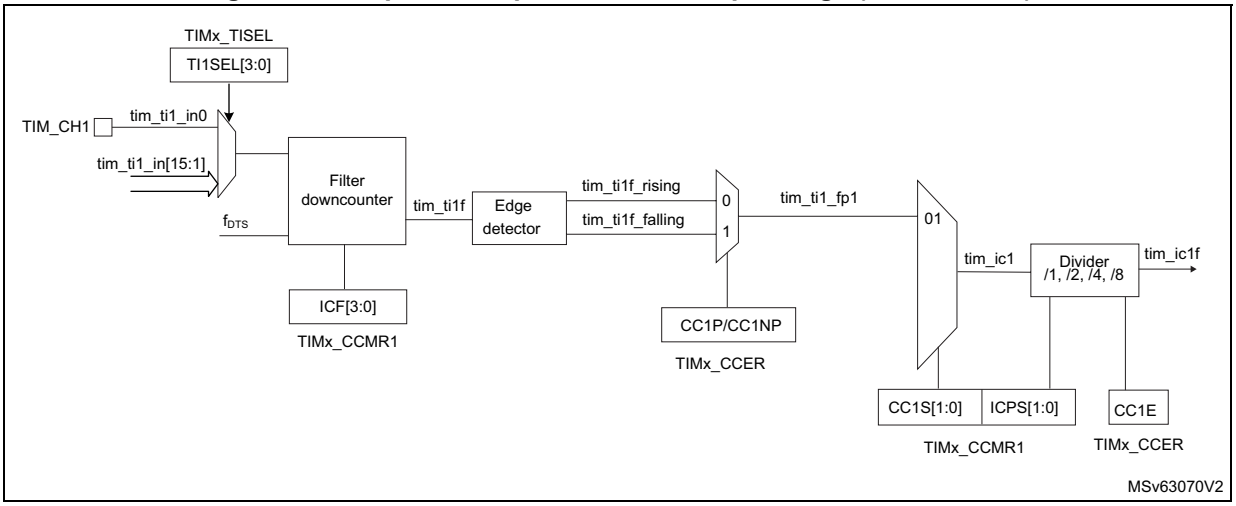
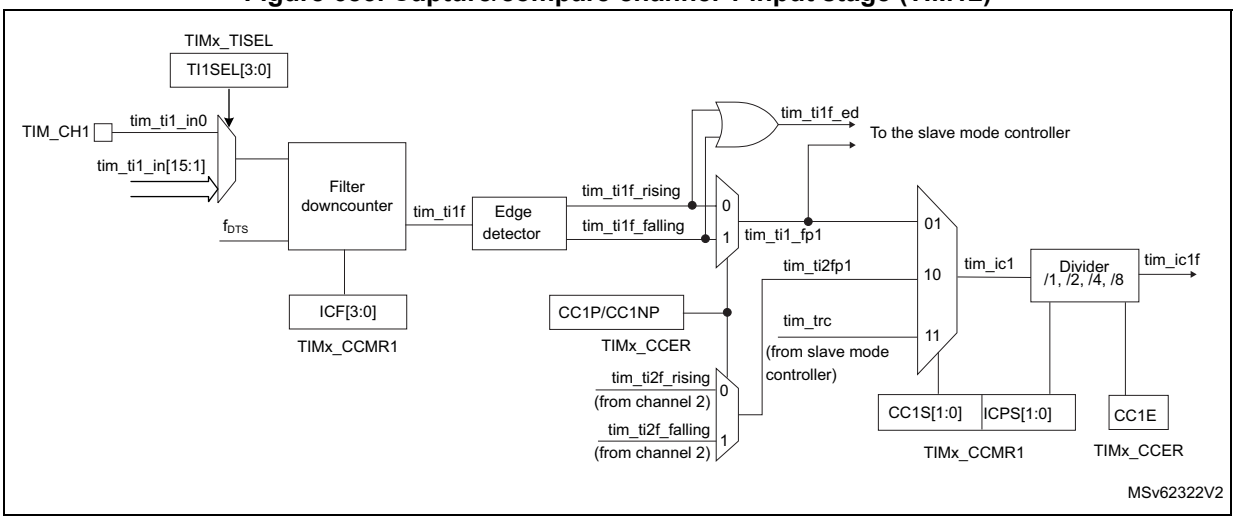


Figure 683. Capture/compare channel 1 input stage (TIM12)



The output stage generates an intermediate waveform which is then used for reference: tim_ocxref (active high). The polarity acts at the end of the chain.

Figure 684. Capture/compare channel 1 main circuit

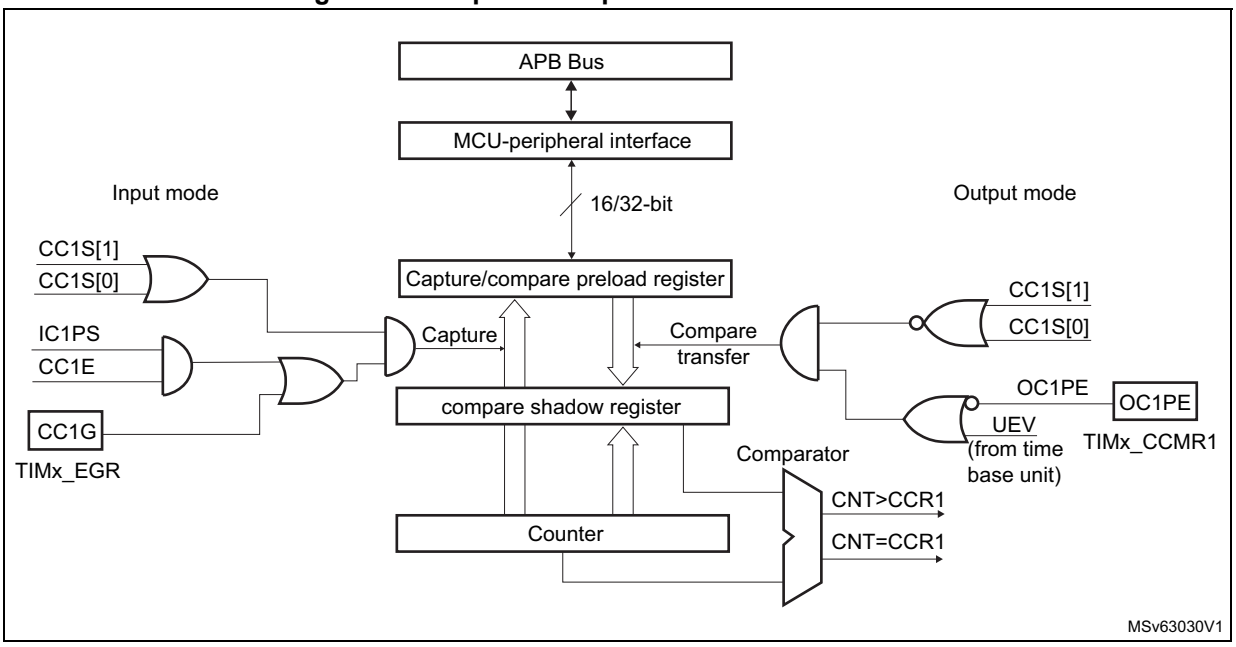
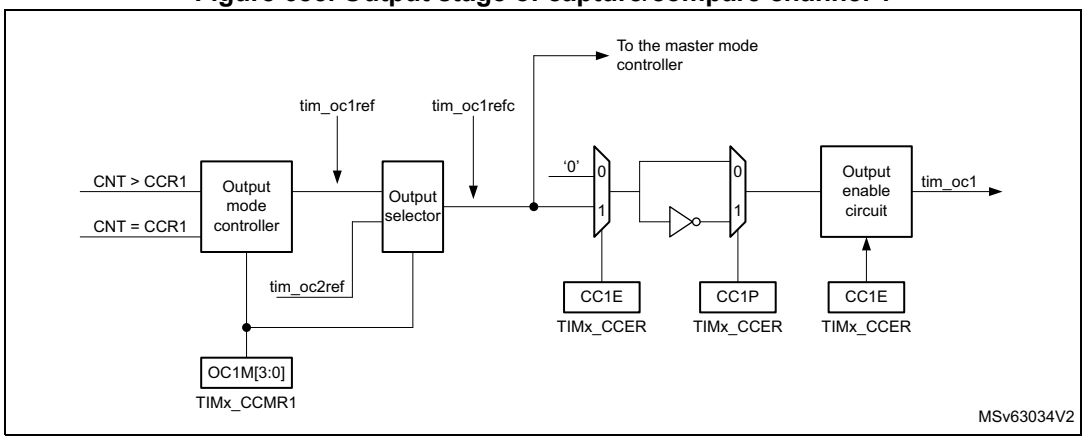


Figure 685. Output stage of capture/compare channel 1



The capture/compare block is made of one preload register and one shadow register. Write and read always access the preload register.

In capture mode, captures are actually done in the shadow register, which is copied into the preload register.

In compare mode, the content of the preload register is copied into the shadow register which is compared to the counter.

52.4.7 Input capture mode

In Input capture mode, the capture/compare registers (TIMx_CCRx) are used to latch the value of the counter after a transition detected by the corresponding tim_icx signal. When a capture occurs, the corresponding CCXIF flag (TIMx_SR register) is set and an interrupt request can be sent if they are enabled. If a capture occurs while the CCxIF flag was already high, then the overcapture flag CCxOF (TIMx_SR register) is set. CCxIF can be

cleared by software by writing it to 0 or by reading the captured data stored in the TIMx_CCRx register. CCxOF is cleared when it is written with 0.

The following example shows how to capture the counter value in TIMx_CCR1 when tim_ti1 input rises. To do this, use the following procedure:

1. Select the proper tim_ti1_in[15:0] source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input: TIMx_CCR1 must be linked to the tim_ti1 input, so write the CC1S bits to 01 in the TIMx_CCMR1 register. As soon as CC1S becomes different from 00, the channel is configured in input mode, and the TIMx_CCR1 register becomes read-only.
3. Program the appropriate input filter duration in relation with the signal connected to the timer (by programming the ICxF bits in the TIMx_CCMRx register if the input is one of the tim_tix inputs). Let's imagine that, when toggling, the input signal is not stable during at most five internal clock cycles. The user must program a filter duration longer than these five clock cycles. The user can validate a transition on tim_ti1 when eight consecutive samples with the new level have been detected (sampled at f_{DTS} frequency). Then write IC1F bits to 0011 in the TIMx_CCMR1 register.
4. Select the edge of the active transition on the tim_ti1 channel by programming CC1P and CC1NP bits to 00 in the TIMx_CCER register (rising edge in this case).
5. Program the input prescaler. In this example, the user wishes the capture to be performed at each valid transition, so the prescaler is disabled (write IC1PS bits to 00 in the TIMx_CCMR1 register).
6. Enable capture from the counter into the capture register by setting the CC1E bit in the TIMx_CCER register.
7. If needed, enable the related interrupt request by setting the CC1IE bit in the TIMx_DIER register.

When an input capture occurs:

- The TIMx_CCR1 register gets the value of the counter on the active transition.
- CC1IF flag is set (interrupt flag). CC1OF is also set if at least two consecutive captures occurred whereas the flag was not cleared.
- An interrupt is generated depending on the CC1IE bit.

In order to handle the overcapture, it is recommended to read the data before the overcapture flag. This is to avoid missing an overcapture which may happen after reading the flag and before reading the data.

Note: IC interrupt requests can be generated by software by setting the corresponding CCxG bit in the TIMx_EGR register.

52.4.8 PWM input mode (TIM12 only)

This mode is used to measure both the period and the duty cycle of a PWM signal connected to single tim_tix input:

- The TIMx_CCR1 register holds the period value (interval between two consecutive rising edges).
- The TIM_CCR2 register holds the pulse width (interval between two consecutive rising and falling edges.

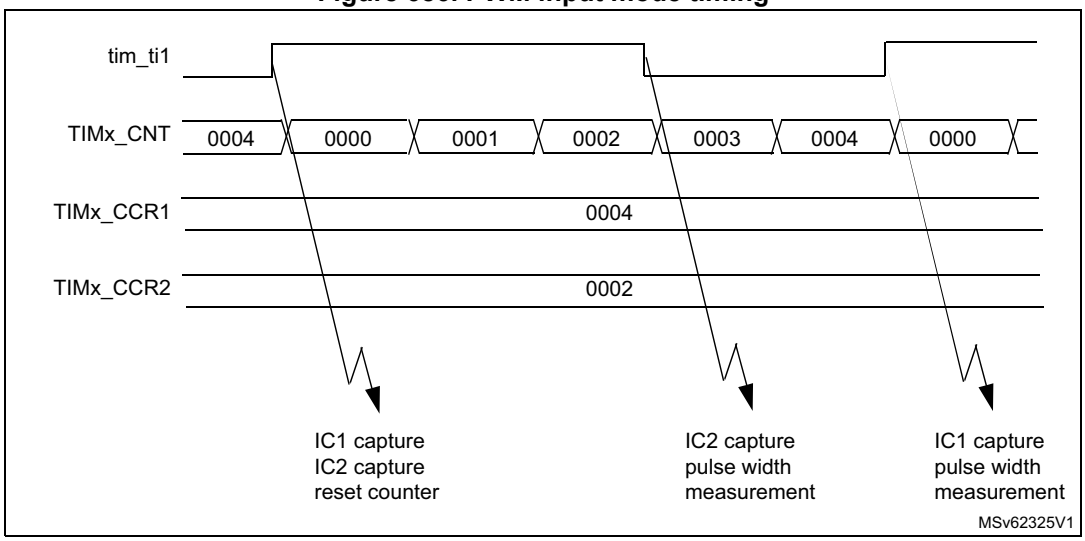
This mode is a particular case of input capture mode. The set-up procedure is similar with the following differences:

- Two tim_icx signals are mapped on the same tim_tix input.
- These two tim_icx signals are active on edges with opposite polarity.
- One of the two tim_tixfpy signals is selected as trigger input and the slave mode controller is configured in reset mode.

For example, one can measure the period (in TIMx_CCR1 register) and the duty cycle (in TIMx_CCR2 register) of the PWM applied on tim_ti1 using the following procedure (depending on tim_ker_ck frequency and prescaler value):

1. Select the proper tim_ti1_in[15:0] source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input for TIMx_CCR1: write the CC1S bits to 01 in the TIMx_CCMR1 register (tim_ti1 selected).
3. Select the active polarity for tim_ti1fp1 (used both for capture in TIMx_CCR1 and counter clear): program the CC1P and CC1NP bits to 00 (active on rising edge).
4. Select the active input for TIMx_CCR2: write the CC2S bits to 10 in the TIMx_CCMR1 register (tim_ti1 selected).
5. Select the active polarity for tim_ti1fp2 (used for capture in TIMx_CCR2): program the CC2P and CC2NP bits to 10 (active on falling edge).
6. Select the valid trigger input: write the TS bits to 00101 in the TIMx_SMCR register (tim_ti1fp1 selected).
7. Configure the slave mode controller in reset mode: write the SMS bits to 100 in the TIMx_SMCR register.
8. Enable the captures: write the CC1E and CC2E bits to 1 in the TIMx_CCER register.

Figure 686. PWM input mode timing



52.4.9 Forced output mode

In output mode (CCxS bits = 00 in the TIMx_CCMRx register), each output compare signal (tim_ocxref and then tim_ocx) can be forced to active or inactive level directly by software, independently of any comparison between the output compare register and the counter.

To force an output compare signal (tim_ocxref/tim_ocx) to its active level, one just needs to write 0101 in the OCxM bits in the corresponding TIMx_CCMRx register. Thus tim_ocxref is forced high (tim_ocxref is always active high) and tim_ocx get opposite value to CCxP polarity bit.

For example: CCxP = 0 (tim_ocx active high) => tim_ocx is forced to high level.

The tim_ocxref signal can be forced low by writing the OCxM bits to 0100 in the TIMx_CCMRx register.

Anyway, the comparison between the TIMx_CCRx shadow register and the counter is still performed and allows the flag to be set. Interrupt requests can be sent accordingly. This is described in the output compare mode section below.

52.4.10 Output compare mode

This function is used to control an output waveform or indicating when a period of time has elapsed.

When a match is found between the capture/compare register and the counter, the output compare function:

1. Assigns the corresponding output pin to a programmable value defined by the output compare mode (OCxM bits in the TIMx_CCMRx register) and the output polarity (CCxP bit in the TIMx_CCER register). The output pin can keep its level (OCxM = 0000), be set active (OCxM = 0001), be set inactive (OCxM = 0010) or can toggle (OCxM = 0011) on match.
2. Sets a flag in the interrupt status register (CCxIF bit in the TIMx_SR register).
3. Generates an interrupt if the corresponding interrupt mask is set (CCXIE bit in the TIMx_DIER register).

The TIMx_CCRx registers can be programmed with or without preload registers using the OCxPE bit in the TIMx_CCMRx register.

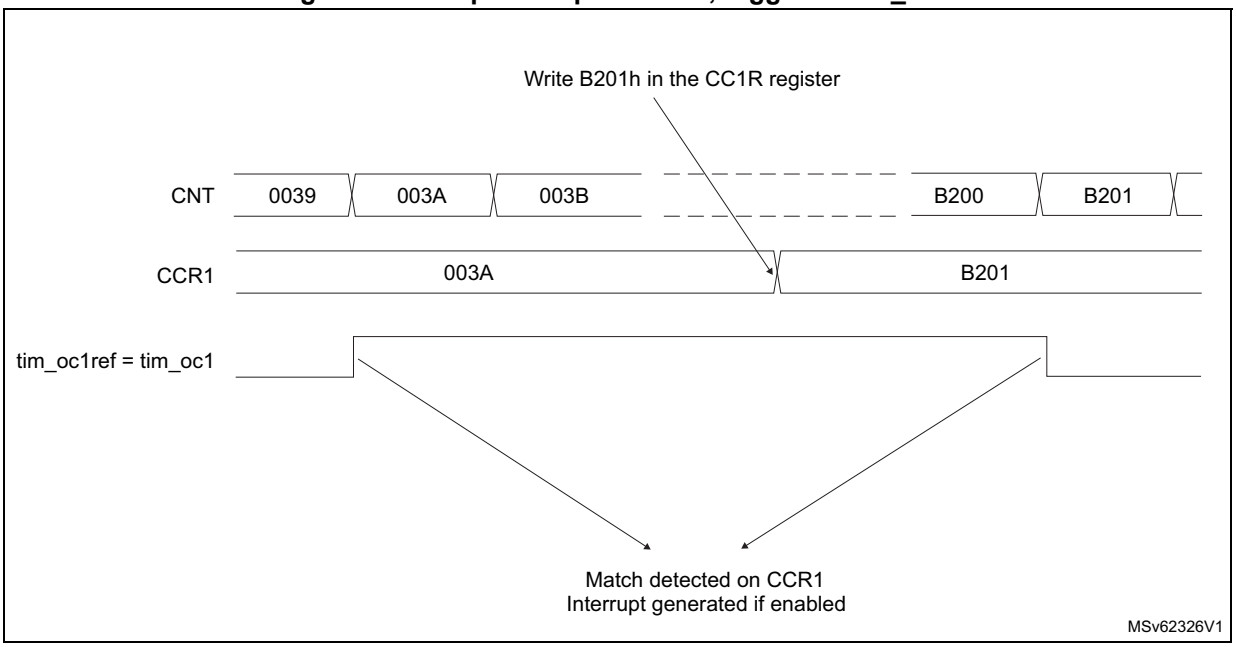
In output compare mode, the update event UEV has no effect on tim_ocxref and tim_ocx output. The timing resolution is one count of the counter. Output compare mode can also be used to output a single pulse (in One-pulse mode).

Procedure:

1. Select the counter clock (internal, external, prescaler).
2. Write the desired data in the TIMx_ARR and TIMx_CCRx registers.
3. Set the CCxIE bit if an interrupt request is to be generated.
4. Select the output mode. For example:
   - Write OCxM = 0011 to toggle tim_ocx output pin when CNT matches CCRx
   - Write OCxPE = 0 to disable preload register
   - Write CCxP = 0 to select active high polarity
   - Write CCxE = 1 to enable the output
5. Enable the counter by setting the CEN bit in the TIMx_CR1 register.

The TIMx_CCRx register can be updated at any time by software to control the output waveform, provided that the preload register is not enabled (OCxPE = 0, else TIMx_CCRx shadow register is updated only at the next update event UEV). An example is given in *Figure 687*.

Figure 687. Output compare mode, toggle on tim_oc1.



52.4.11 PWM mode

Pulse width modulation mode is used to generate a signal with a frequency determined by the value of the TIMx_ARR register and a duty cycle determined by the value of the TIMx_CCRx register.

The PWM mode can be selected independently on each channel (one PWM per tim_ocx output) by writing 0110 (PWM mode 1) or 0111 (PWM mode 2) in the OCxM bits in the TIMx_CCMRx register. The corresponding preload register must be enabled by setting the OCxPE bit in the TIMx_CCMRx register, and eventually the autoreload preload register (in upcounting or center-aligned modes) by setting the ARPE bit in the TIMx_CR1 register.

As the preload registers are transferred to the shadow registers only when an update event occurs, before starting the counter, all registers must be initialized by setting the UG bit in the TIMx_EGR register.

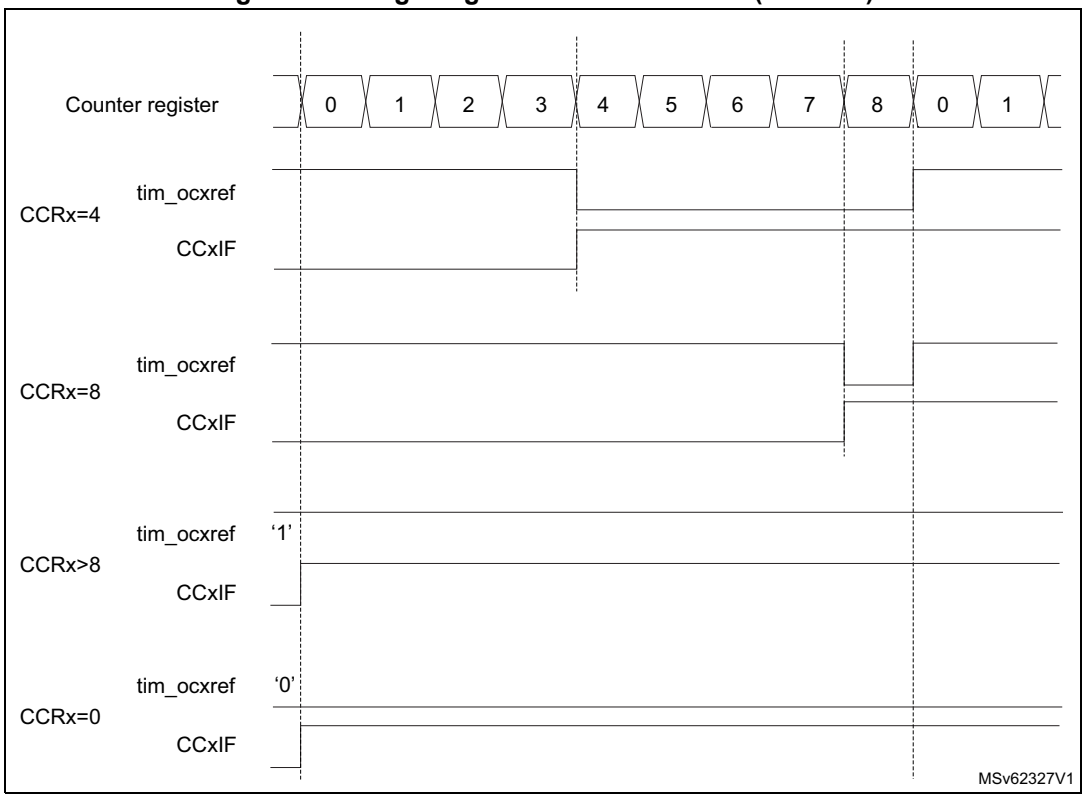
The tim_ocx polarity is software programmable using the CCxP bit in the TIMx_CCER register. It can be programmed as active high or active low. The tim_ocx output is enabled by the CCxE bit in the TIMx_CCER register. Refer to the TIMx_CCERx register description for more details.

In PWM mode (1 or 2), TIMx_CNT and TIMx_CCRx are always compared to determine whether TIMx_CNT ≤ TIMx_CCRx.

The timer is able to generate PWM in edge-aligned mode only since the counter is upcounting.

In the following example, the user considers PWM mode 1. The reference PWM signal tim_ocxref is high as long as TIMx_CNT < TIMx_CCRx else it becomes low. If the compare value in TIMx_CCRx is greater than the autoreload value (in TIMx_ARR) then tim_ocxref is held at 1. If the compare value is 0 then tim_ocxref is held at 0. *Figure 688* shows some edge-aligned PWM waveforms in an example where TIMx_ARR = 8.

Figure 688. Edge-aligned PWM waveforms (ARR = 8)

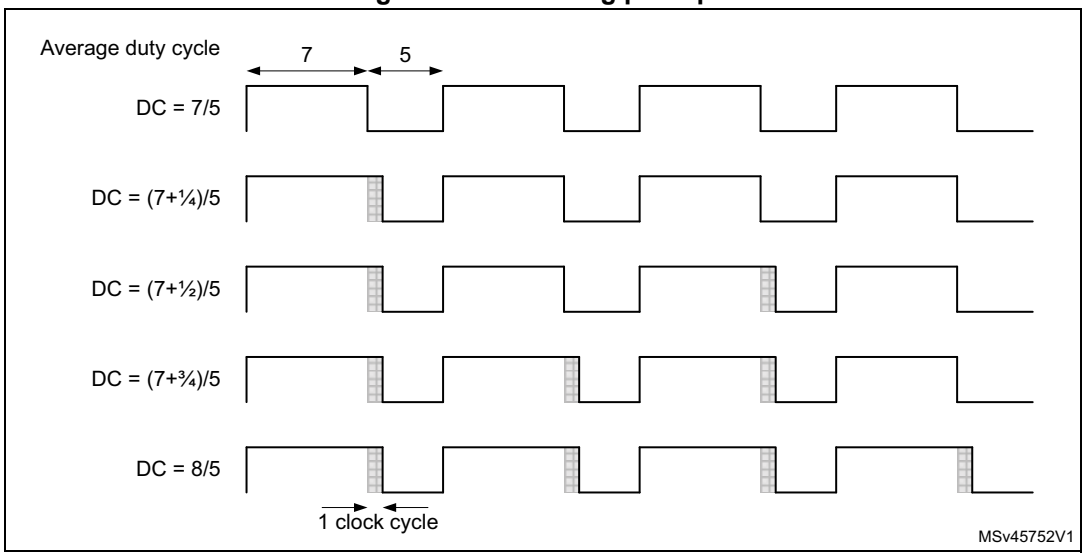


Dithering mode

The PWM mode effective resolution can be increased by enabling the dithering mode, using the DITHEN bit in the TIMx_CR1 register. This applies to both the CCR (for duty cycle resolution increase) and ARR (for PWM frequency resolution increase).

The operating principle is to have the actual CCR (or ARR) value slightly changed (adding or not one timer clock period) over 16 consecutive PWM periods, with predefined patterns. This allows a 16-fold resolution increase, considering the average duty cycle or PWM period. *Figure 689* presents the dithering principle applied to four consecutive PWM cycles.

Figure 689. Dithering principle

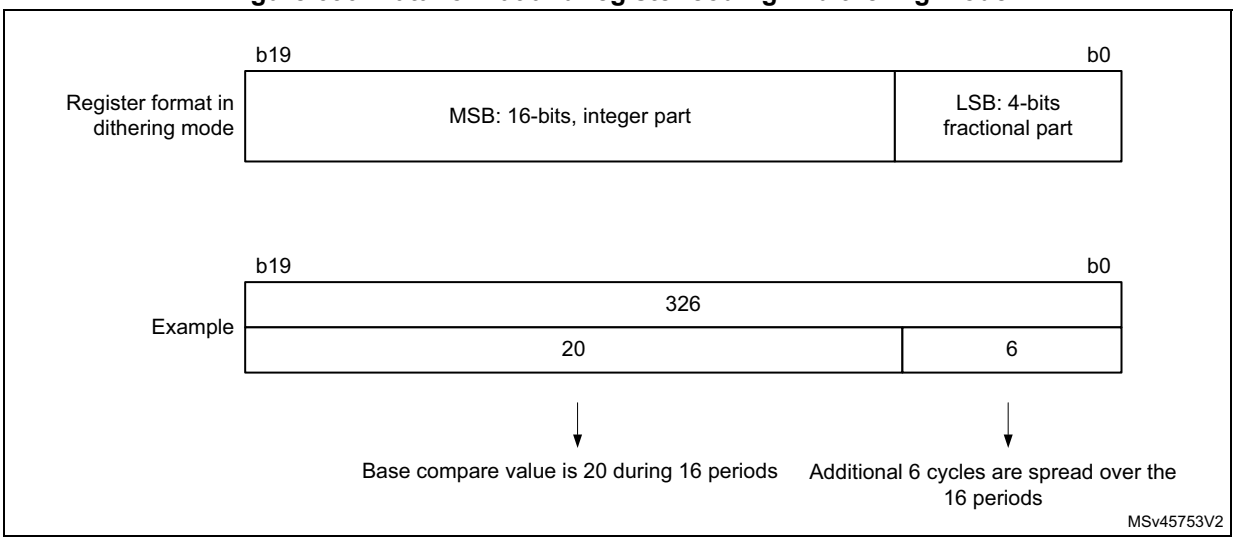


When the dithering mode is enabled, the register coding is changed as follows (see *Figure 690* for example):

- The four LSBs are coding for the enhanced resolution part (fractional part).
- The MSBs are left-shifted to the bits 19:4 and are coding for the base value.

Note: The following sequence must be followed when resetting the DITHEN bit:
1. CEN and ARPE bits must be reset
2. The DITHEN bit must be reset
3. The CCIF flags must be cleared
4. The CEN bit can be set (eventually with ARPE = 1).

Figure 690. Data format and register coding in dithering mode



The minimum frequency is given by the following formula:

$$\text{Resolution} = \frac{F_{Tim}}{F_{pwm}} \Rightarrow F_{pwmMin} = \frac{F_{Tim}}{Max_{Resolution}}$$

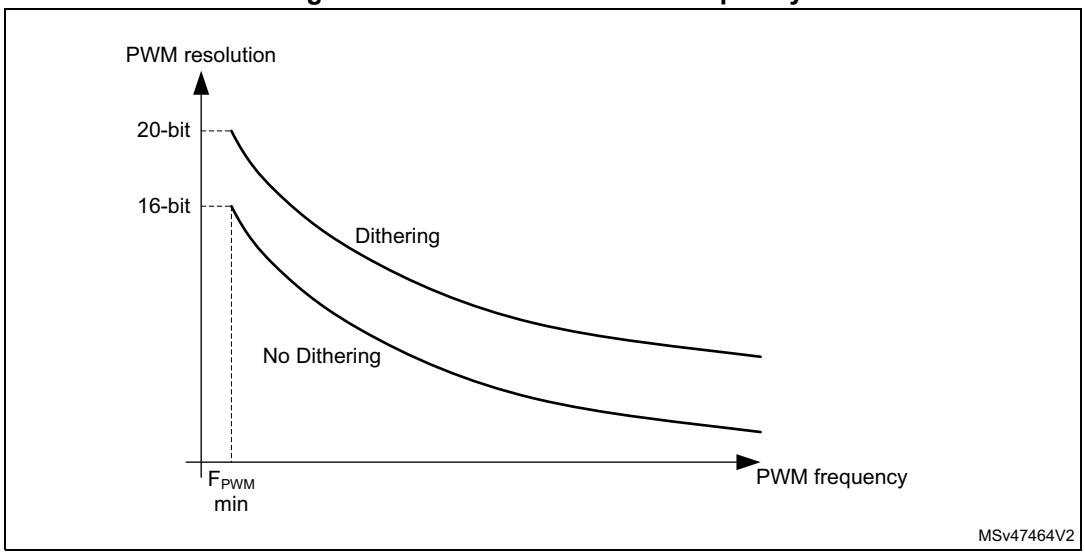
$$\text{Dithering mode disabled: } F_{pwmMin} = \frac{F_{Tim}}{65536}$$

$$\text{Dithering mode enabled: } F_{pwmMin} = \frac{F_{Tim}}{65535 + \frac{15}{16}}$$

Note: The maximum TIMx_ARR and TIMxCCRy values are limited to 0xFFFEF in dithering mode (corresponds to 65534 for the integer part and 15 for the dithered part).

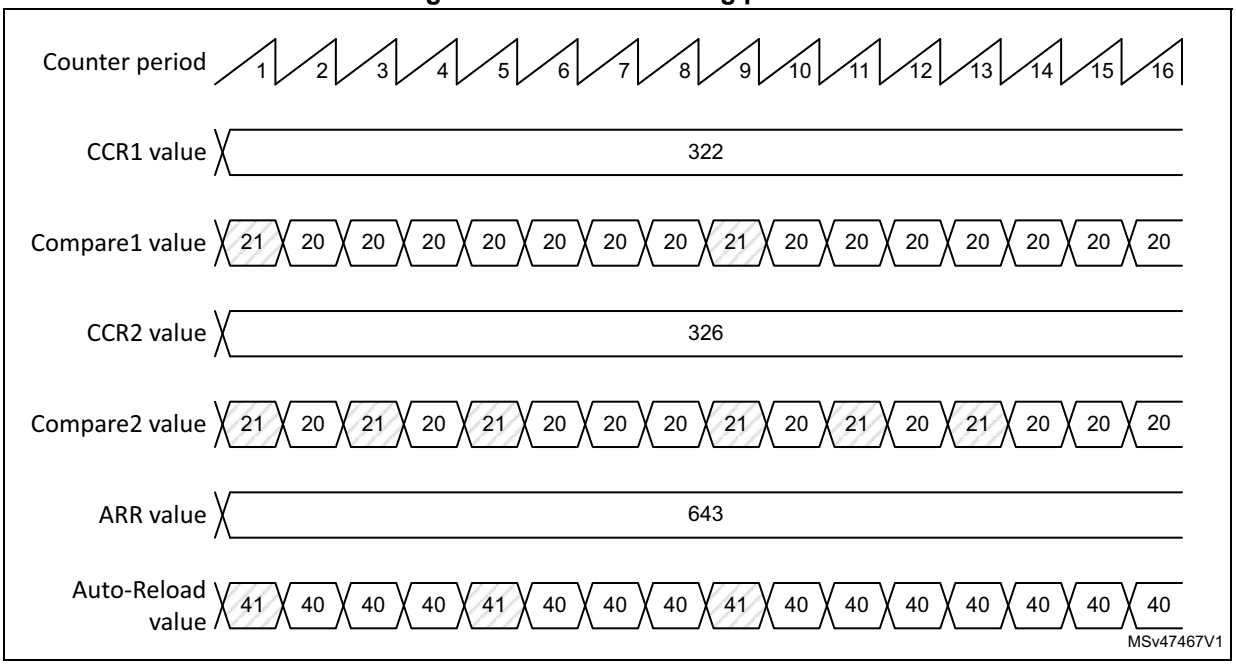
As shown on *Figure 691*, the dithering mode is used to increase the PWM resolution whatever the PWM frequency.

Figure 691. PWM resolution vs frequency



The duty cycle and/or period changes are spread over 16 consecutive periods, as described in *Figure 692*.

Figure 692. PWM dithering pattern



The autoreload and compare values increments are spread following specific patterns described in *Table 562*. The dithering sequence is done to have increments distributed as evenly as possible and minimize the overall ripple.

Table 562. CCR and ARR register change dithering pattern

-	PWM period															
LSB value	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
0000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0001	+1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0010	+1	-	-	-	-	-	-	-	+1	-	-	-	-	-	-	-
0011	+1	-	-	-	+1	-	-	-	+1	-	-	-	-	-	-	-
0100	+1	-	-	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0101	+1	-	+1	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0110	+1	-	+1	-	+1	-	-	-	+1	-	+1	-	+1	-	-	-
0111	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	-	-
1000	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1001	+1	+1	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1010	+1	+1	+1	-	+1	-	+1	-	+1	+1	+1	-	+1	-	+1	-
1011	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	-	+1	-
1100	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-
1101	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-

Table 562. CCR and ARR register change dithering pattern (continued)

-	PWM period															
LSB value	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1110	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	+1	+1	+1	+1	-
1111	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	-

52.4.12 Combined PWM mode (TIM12 only)

Combined PWM mode allows two edge or center-aligned PWM signals to be generated with programmable delay and phase shift between respective pulses. While the frequency is determined by the value of the TIMx_ARR register, the duty cycle and delay are determined by the two TIMx_CCRx registers. The resulting signals, tim_ocxrefc, are made of an OR or AND logical combination of two reference PWMs:

- tim_oc1refc (or tim_oc2refc) is controlled by the TIMx_CCR1 and TIMx_CCR2 registers.

Combined PWM mode can be selected independently on two channels (one tim_ocx output per pair of CCR registers) by writing 1100 (Combined PWM mode 1) or 1101 (Combined PWM mode 2) in the OCxM bits in the TIMx_CCMRx register.

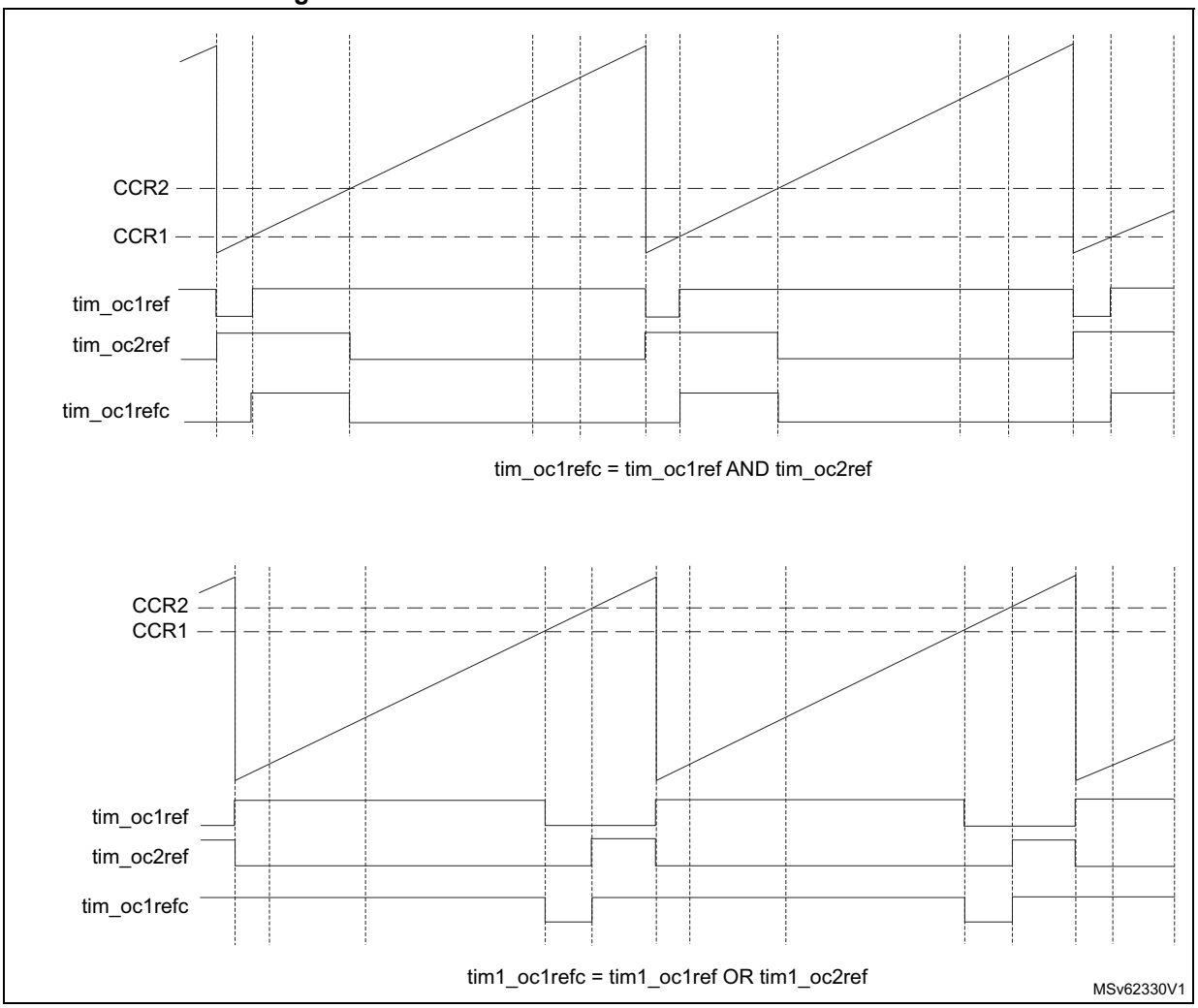
When a given channel is used as a combined PWM channel, its complementary channel must be configured in the opposite PWM mode (for instance, one in Combined PWM mode 1 and the other in combined PWM mode 2).

Note: The OCxM[3:0] bitfield is split into two parts for compatibility reasons, the most significant bit is not contiguous with the three least significant ones.

Figure 693 represents an example of signals that can be generated using combined PWM mode, obtained with the following configuration:

- Channel 1 is configured in combined PWM mode 2.
- Channel 2 is configured in PWM mode 1.

Figure 693. Combined PWM mode on channel 1 and 2



52.4.13 One-pulse mode

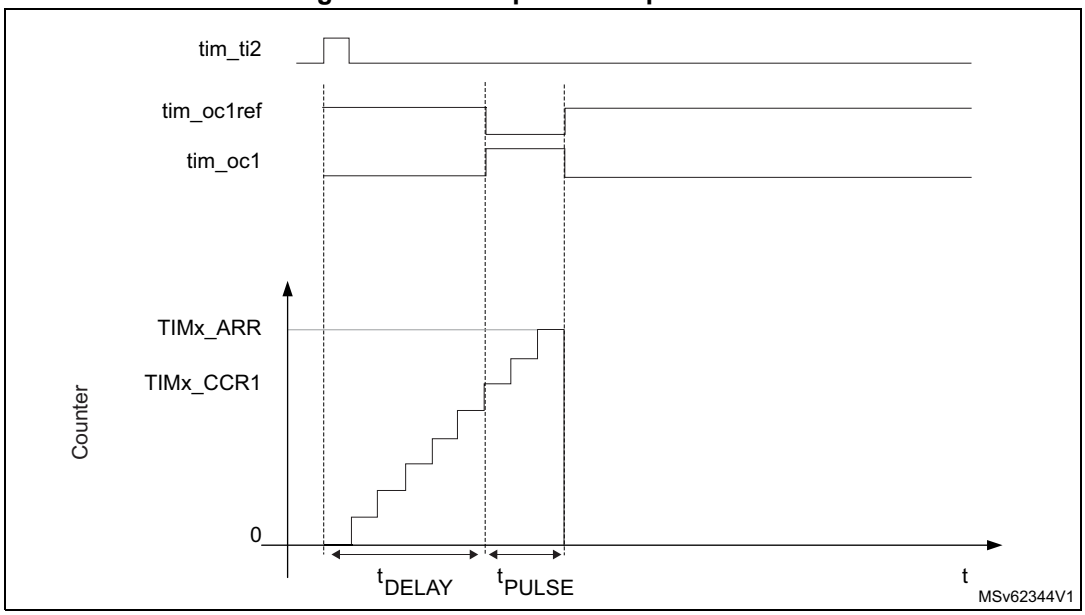
One-pulse mode (OPM) is a particular case of the previous modes. It allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length after a programmable delay.

Starting the counter can be controlled through the slave mode controller. Generating the waveform can be done in output compare mode or PWM mode. One-pulse mode is selected by setting the OPM bit in the TIMx_CR1 register. This makes the counter stop automatically at the next update event UEV.

A pulse can be correctly generated only if the compare value is different from the counter initial value. Before starting (when the timer is waiting for the trigger), the configuration must be as follows:

CNT < CCRx ≤ ARR (in particular, 0 < CCRx)

Figure 694. Example of one pulse mode



For example one may want to generate a positive pulse on tim_oc1 with a length of tPULSE and after a delay of tDELAY as soon as a positive edge is detected on the tim_ti2 input pin.

Use tim_ti2fp2 as trigger 1:

1. Select the proper tim_ti2_in[15:0] source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Map tim_ti2fp2 to tim_ti2 by writing CC2S = 01 in the TIMx_CCMR1 register.
3. tim_ti2fp2 must detect a rising edge, write CC2P = 0 and CC2NP = 0 in the TIMx_CCER register.
4. Configure tim_ti2fp2 as trigger for the slave mode controller (tim_trgi) by writing TS = 00110 in the TIMx_SMCR register.
5. tim_ti2fp2 is used to start the counter by writing SMS to 110 in the TIMx_SMCR register (trigger mode).

The OPM waveform is defined by writing the compare registers (taking into account the clock frequency and the counter prescaler).

- The t_{DELAY} is defined by the value written in the TIMx_CCR1 register.
- The t_{PULSE} is defined by the difference between the autoreload value and the compare value (TIMx_ARR - TIMx_CCR1).
- Assuming the user wants to build a waveform with a transition from 0 to 1 when a compare match occurs and a transition from 1 to 0 when the counter reaches the autoreload value. To do this PWM mode 2 must be enabled by writing OC1M = 0111 in the TIMx_CCMR1 register. Optionally the preload registers can be enabled by writing OC1PE = 1 in the TIMx_CCMR1 register and ARPE in the TIMx_CR1 register. In this case one has to write the compare value in the TIMx_CCR1 register, the autoreload value in the TIMx_ARR register, generate an update by setting the UG bit and wait for external trigger event on tim_ti2. CC1P is written to 0 in this example.

Since only one pulse (Single mode) is needed, a 1 must be written in the OPM bit in the TIMx_CR1 register to stop the counter at the next update event (when the counter rolls over

from the autoreload value back to 0). When OPM bit in the TIMx_CR1 register is set to 0, so the Repetitive mode is selected.

Particular case: tim_ocx fast enable

In One-pulse mode, the edge detection on tim_tix input set the CEN bit which enables the counter. Then the comparison between the counter and the compare value makes the output toggle. But several clock cycles are needed for these operations and it limits the minimum delay t_{DELAY} min that can be obtained.

If one wants to output a waveform with the minimum delay, the OCxFE bit can be set in the TIMx_CCMRx register. Then tim_ocxref (and tim_ocx) are forced in response to the stimulus, without taking in account the comparison. Its new level is the same as if a compare match had occurred. OCxFE acts only if the channel is configured in PWM1 or PWM2 mode.

52.4.14 Retriggerable one pulse mode (TIM12 only)

This mode allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length, but with the following differences with nonretriggerable one pulse mode described in *Section 52.4.13: One-pulse mode*:

- The pulse starts as soon as the trigger occurs (no programmable delay).
- The pulse is extended if a new trigger occurs before the previous one is completed.

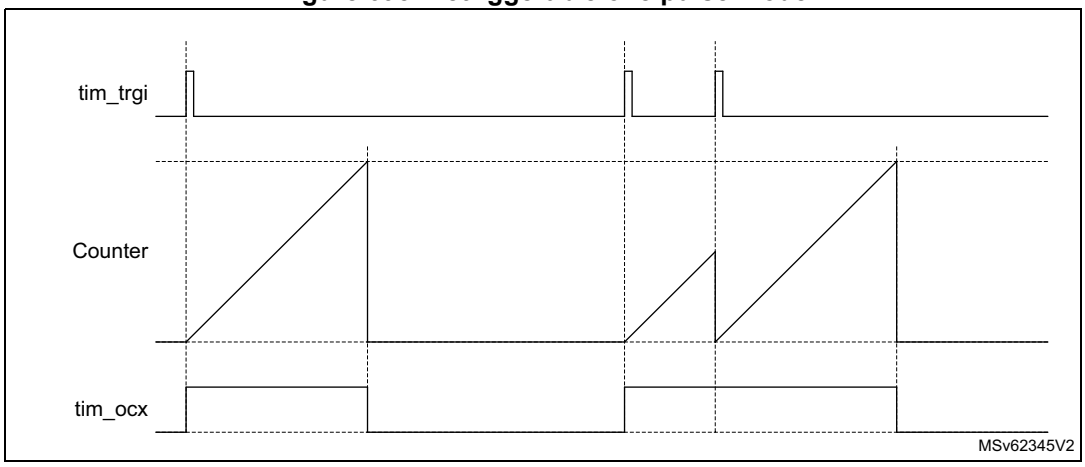
The timer must be in Slave mode, with the bits SMS[3:0] = 1000 (Combined reset + trigger mode) in the TIMx_SMCR register, and the OCxM[3:0] bits set to 1000 or 1001 for retriggerable OPM mode 1 or 2.

If the timer is configured in up-counting mode, the corresponding CCRx must be set to 0 (the ARR register sets the pulse length). If the timer is configured in down-counting mode, CCRx must be above or equal to ARR.

Note: The OCxM[3:0] and SMS[3:0] bit fields are split into two parts for compatibility reasons, the most significant bit are not contiguous with the three least significant ones.

This mode must not be used with center-aligned PWM modes. It is mandatory to have CMS[1:0] = 00 in TIMx_CR1.

Figure 695. Retriggerable one pulse mode



52.4.15 UIF bit remapping

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the update interrupt flag UIF into bit 31 of the timer counter register (TIMxCNT[31]). This is used to atomically read both the counter value and a potential roll-over condition signaled by the UIFCPY flag. In particular cases, it can ease the calculations by avoiding race conditions caused for instance by a processing shared between a background task (counter reading) and an interrupt (update interrupt).

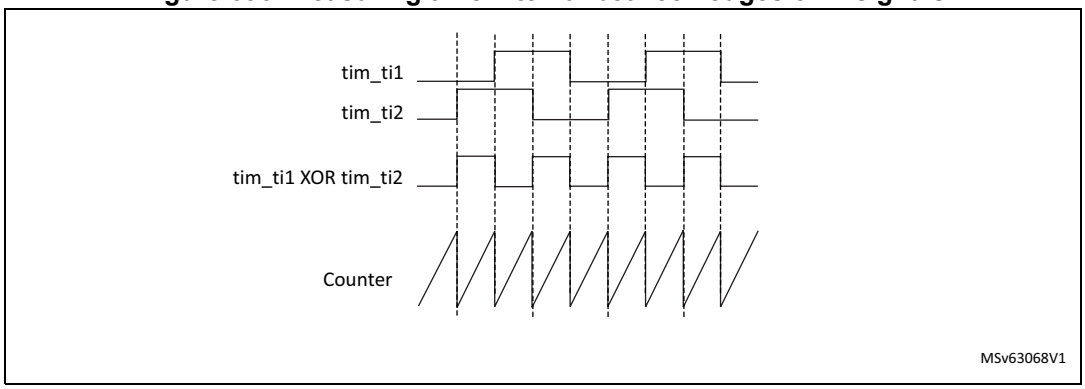
There is no latency between the assertions of the UIF and UIFCPY flags.

52.4.16 Timer input XOR function

The TI1S bit in the TIMx_CR2 register, allows the input filter of channel 1 to be connected to the output of an XOR gate, combining the two input pins tim_ti1 and tim_ti2.

The XOR output can be used with all the timer input functions such as trigger or input capture. It is useful for measuring the interval between the edges on two input signals, as shown in *Figure 696*.

Figure 696. Measuring time interval between edges on 2 signals



52.4.17 TIM12 external trigger synchronization

The TIM12 timer can be synchronized with an external trigger in several modes: Reset mode, Gated mode, Trigger mode, Reset + trigger, and Gated + reset mode.

Slave mode: Reset mode

The counter and its prescaler can be reinitialized in response to an event on a trigger input. Moreover, if the URS bit from the TIMx_CR1 register is low, an update event UEV is generated. Then all the preloaded registers (TIMx_ARR, TIMx_CCRx) are updated.

In the following example, the upcounter is cleared in response to a rising edge on tim_ti1 input:

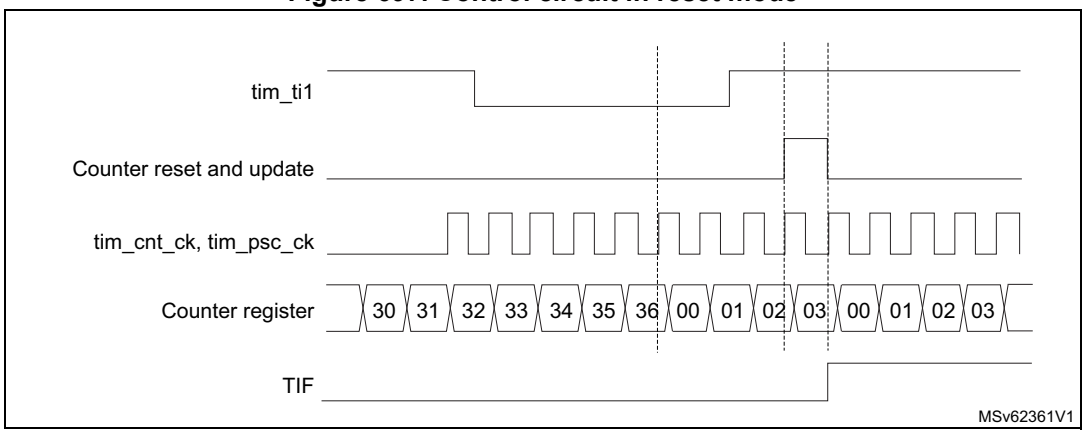
1. Configure the channel 1 to detect rising edges on tim_ti1. Configure the input filter duration (in this example, the user does not need any filter, so the user keeps IC1F = 0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S = 01 in the TIMx_CCMR1 register. Program CC1P and CC1NP to 00 in TIMx_CCER register to validate the polarity (and detect rising edges only).

2. Configure the timer in reset mode by writing SMS = 100 in TIMx_SMCR register. Select tim_ti1 as the input source by writing TS = 00101 in TIMx_SMCR register.
3. Start the counter by writing CEN = 1 in the TIMx_CR1 register.

The counter starts counting on the internal clock, then behaves normally until tim_ti1 rising edge. When tim_ti1 rises, the counter is cleared and restarts from 0. In the meantime, the trigger flag is set (TIF bit in the TIMx_SR register) and an interrupt request can be sent if enabled (depending on the TIE bit in TIMx_DIER register).

The following figure shows this behavior when the autoreload register TIMx_ARR = 0x36. The delay between the rising edge on tim_ti1 and the actual reset of the counter is due to the resynchronization circuit on tim_ti1 input.

Figure 697. Control circuit in reset mode



Slave mode: Gated mode

The counter can be enabled depending on the level of a selected input.

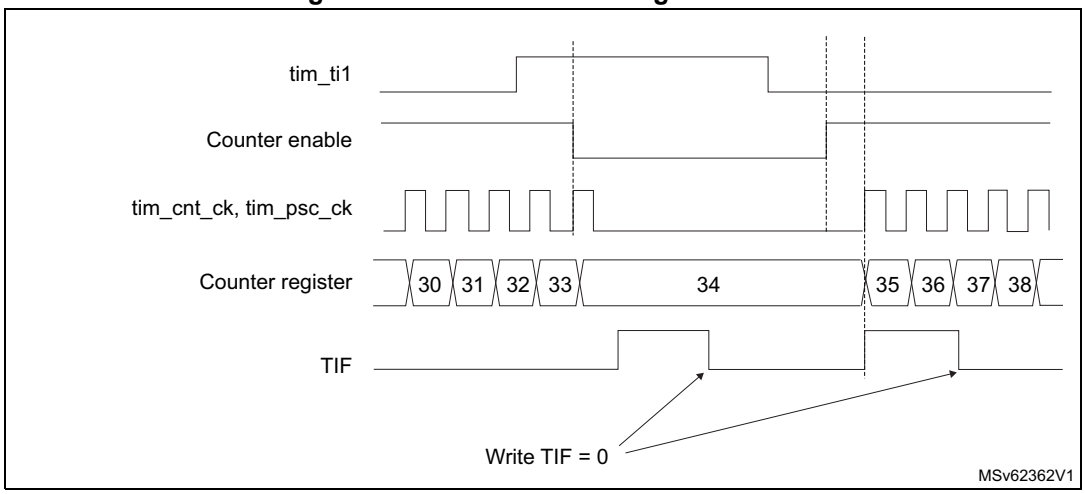
In the following example, the upcounter counts only when tim_ti1 input is low:

1. Configure the channel 1 to detect low levels on tim_ti1. Configure the input filter duration (in this example, the user does not need any filter, so the user keeps IC1F = 0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S = 01 in TIMx_CCMR1 register. Program CC1P = 1 and CC1NP = 0 in TIMx_CCER register to validate the polarity (and detect low level only).
2. Configure the timer in gated mode by writing SMS = 101 in TIMx_SMCR register. Select tim_ti1 as the input source by writing TS = 00101 in TIMx_SMCR register.
3. Enable the counter by writing CEN = 1 in the TIMx_CR1 register (in gated mode, the counter does not start if CEN = 0, whatever is the trigger input level).

The counter starts counting on the internal clock as long as tim_ti1 is low and stops as soon as tim_ti1 becomes high. The TIF flag in the TIMx_SR register is set both when the counter starts or stops.

The delay between the rising edge on tim_ti1 and the actual stop of the counter is due to the resynchronization circuit on tim_ti1 input.

Figure 698. Control circuit in gated mode



Slave mode: Trigger mode

The counter can start in response to an event on a selected input.

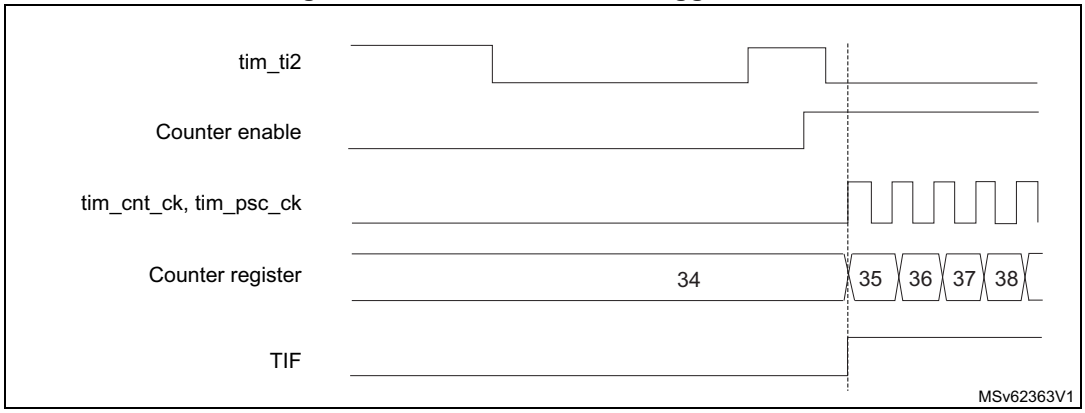
In the following example, the upcounter starts in response to a rising edge on tim_ti2 input:

1. Configure the channel 2 to detect rising edges on tim_ti2. Configure the input filter duration (in this example, the user does not need any filter, so the user keeps IC2F = 0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC2S bits are configured to select the input capture source only, CC2S = 01 in TIMx_CCMR1 register. Program CC2P = 1 and CC2NP = 0 in TIMx_CCER register to validate the polarity (and detect low level only).
2. Configure the timer in trigger mode by writing SMS = 110 in TIMx_SMCR register. Select tim_ti2 as the input source by writing TS = 00110 in TIMx_SMCR register.

When a rising edge occurs on tim_ti2, the counter starts counting on the internal clock and the TIF flag is set.

The delay between the rising edge on tim_ti2 and the actual start of the counter is due to the resynchronization circuit on tim_ti2 input.

Figure 699. Control circuit in trigger mode



52.4.18 Slave mode – combined reset + trigger mode

In this case, a rising edge of the selected trigger input (tim_trgi) reinitializes the counter, generates an update of the registers, and starts the counter.

This mode is used for one-pulse mode.

52.4.19 Slave mode – combined reset + gated mode

The counter clock is enabled when the trigger input (tim_trgi) is high. The counter stops and is reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

52.4.20 Timer synchronization (TIM12 only)

The TIMx timers are linked together internally for timer synchronization or chaining. Refer to *Section 50.4.23: Timer synchronization* for details.

Note: The clock of the slave timer must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the master timer.

52.4.21 Using timer output as trigger for other timers (TIM13/TIM14 only)

The timers with one channel only do not feature a master mode. However, the OC1 output signal can be used to trigger some other timers (including timers described in other sections of this document). Check the “TIMx internal trigger connection” table of any timer on the device to identify which timers can be targeted as slave.

The OC1 signal pulse width must be programmed to be at least two clock cycles of the destination timer, to make sure the slave timer detects the trigger.

For instance, if the destination's timer CK_INT clock is four times slower than the source timer, the OC1 pulse width must be eight clock cycles.

52.4.22 ADC triggers (TIM12 only)

The timer can generate an ADC triggering event with various internal signals, such as reset, enable or compare events.

Note: The clock of the slave peripherals (such as timer, ADC) receiving the tim_trgo signal must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

52.4.23 Debug mode

When the microcontroller enters debug mode (Cortex®-M33 core halted), the TIMx counter can either continue to work normally or stop.

The behavior in debug mode can be programmed with a dedicated configuration bit per timer in the Debug support (DBG) module.

For more details, refer to the Debug section.

52.5 TIM12/TIM13/TIM14 low-power modes

Table 563. Effect of low-power modes on TIM12/TIM13/TIM14

Mode	Description
Sleep	No effect, peripheral is active. The interrupts can cause the device to exit from Sleep mode.
Stop	The timer operation is stopped and the register content is kept. No interrupt can be generated.
Standby	The timer is powered-down and must be reinitialized after exiting the Standby mode.

52.6 TIM12/TIM13/TIM14 interrupts

The TIM12/TIM13/TIM14 can generate multiple interrupts, as shown in *Table 564*.

Table 564. Interrupt requests

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop and Standby mode
TIM	Update	UIF	UIE	write 0 in UIF	Yes	No
	Capture/compare 1	CC1IF	CC1IE	write 0 in CC1IF	Yes	No
TIM	Capture/compare 2(1)	CC2IF	CC2IE	write 0 in CC2IF	Yes	No
	Trigger(1)	TIF	TIE	write 0 in TIF	Yes	No

1. Available for TIM12 only.

52.7 TIM12 registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The peripheral registers have to be written by half-words (16 bits) or words (32 bits). Read accesses can be done by bytes (8 bits), half-words (16 bits), or words (32 bits).

52.7.1 TIM12 control register 1 (TIM12_CR1)

Address offset: 0x000

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DITHEN	UIFREMAP	Res.	CKD[1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
			rw	rw		rw	rw	rw				rw	rw	rw	rw

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **DITHEN**: Dithering enable
0: Dithering disabled
1: Dithering enabled
Note: The DITHEN bit can only be modified when CEN bit is reset.

Bit 11 **UIFREMAP**: UIF status bit remapping
0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bit 10 Reserved, must be kept at reset value.

Bits 9:8 **CKD[1:0]**: Clock division
This bitfield indicates the division ratio between the timer clock (tim_ker_ck) frequency and sampling clock used by the digital filters (tim_tix),
00: $t_{DTS} = t_{tim_ker_ck}$
01: $t_{DTS} = 2 \times t_{tim_ker_ck}$
10: $t_{DTS} = 4 \times t_{tim_ker_ck}$
11: Reserved

Bit 7 **ARPE**: Auto-reload preload enable
0: TIMx_ARR register is not buffered.
1: TIMx_ARR register is buffered.

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **OPM**: One-pulse mode
0: Counter is not stopped on the update event
1: Counter stops counting on the next update event (clearing the CEN bit).

Bit 2 **URS**: Update request source
This bit is set and cleared by software to select the UEV event sources.
0: Any of the following events generates an update interrupt if enabled. These events can be:
– Counter overflow
– Setting the UG bit
– Update generation through the slave mode controller
1: Only counter overflow generates an update interrupt if enabled.

Bit 1 **UDIS**: Update disable
This bit is set and cleared by software to enable/disable update event (UEV) generation.
0: UEV enabled. An UEV is generated by one of the following events:
– Counter overflow
– Setting the UG bit
Buffered registers are then loaded with their preload values.
1: UEV disabled. No UEV is generated, shadow registers keep their value (ARR, PSC, CCRx). The counter and the prescaler are reinitialized if the UG bit is set.

Bit 0 **CEN**: Counter enable
0: Counter disabled
1: Counter enabled
CEN is cleared automatically in one-pulse mode, when an update event occurs.
Note: External clock and gated mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

52.7.2 TIM12 control register 2 (TIM12_CR2)

Address offset: 0x004

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1S	MMS[2:0]			Res.	Res.	Res.	Res.
								rw	rw	rw	rw				

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **TI1S**: tim_ti1 selection

0: The tim_ti1_in[15:0] multiplexer output is connected to tim_ti1 input

1: The tim_ti1_in[15:0] and tim_ti2_in[15:0] multiplexers output are connected to the tim_ti1 input (XOR combination)

Bits 6:4 **MMS[2:0]**: Master mode selection

These bits allow to select the information to be sent in master mode to slave timers for synchronization (tim_trgo). The combination is as follows:

000: Reset - the UG bit from the TIMx_EGR register is used as trigger output (tim_trgo). If the reset is generated by the trigger input (slave mode controller configured in reset mode) then the signal on tim_trgo is delayed compared to the actual reset.

001: Enable - the Counter Enable signal CNT_EN is used as trigger output (tim_trgo). It is useful to start several timers at the same time or to control a window in which a slave timer is enable. The Counter Enable signal is generated by a logic AND between CEN control bit and the trigger input when configured in gated mode. When the Counter Enable signal is controlled by the trigger input, there is a delay on tim_trgo, except if the master/slave mode is selected (see the MSM bit description in TIMx_SMCR register).

010: Update - The update event is selected as trigger output (tim_trgo). For instance a master timer can then be used as a prescaler for a slave timer.

011: Compare Pulse - The trigger output send a positive pulse when the CC1IF flag is to be set (even if it was already high), as soon as a capture or a compare match occurred (tim_trgo).

100: Compare - tim_oc1refc signal is used as trigger output (tim_trgo).

101: Compare - tim_oc2refc signal is used as trigger output (tim_trgo).

Bits 3:0 Reserved, must be kept at reset value.

52.7.3 TIM12 slave mode control register (TIM12_SMCR)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS[4:3]		Res.	Res.	Res.	SMS[3]
										rw	rw				rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MSM	TS[2:0]			Res.	SMS[2:0]		
								rw	rw	rw	rw		rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 19:17 Reserved, must be kept at reset value.

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **MSM:** Master/Slave mode

0: No action

1: The effect of an event on the trigger input (tim_trgi) is delayed to allow a perfect synchronization between the current timer and its slaves (through tim_trgo). It is useful in order to synchronize several timers on a single external event.

Bits 21, 20, 6, 5, 4 **TS[4:0]:** Trigger selection

This TS[4:0] bitfield selects the trigger input to be used to synchronize the counter.

00000: Internal Trigger 0 (tim_itr0)
00001: Internal Trigger 1 (tim_itr1)
00010: Internal Trigger 2 (tim_itr2)
00011: Internal Trigger 3 (tim_itr3)
00100: tim_ti1 Edge Detector (tim_ti1f_ed)
00101: Filtered Timer Input 1 (tim_ti1fp1)
00110: Filtered Timer Input 2 (tim_ti2fp2)
01000: Internal Trigger 4 (tim_itr4)
01001: Internal Trigger 5 (tim_itr5)
01010: Internal Trigger 6 (tim_itr6)
01011: Internal Trigger 7 (tim_itr7)
01100: Internal Trigger 8 (tim_itr8)
01101: Internal Trigger 9 (tim_itr9)
01110: Internal Trigger 10 (tim_itr10)
01111: Internal Trigger 10 (tim_itr11)
10000: Internal Trigger 10 (tim_itr12)
10001: Internal Trigger 10 (tim_itr13)
10010: Internal Trigger 10 (tim_itr14)
10011: Internal Trigger 10 (tim_itr15)
Others: Reserved

See *Table 561: TIMx internal trigger connection* for more details on the meaning of tim_itrx for each timer.

Note: These bits must be changed only when they are not used (for example when SMS = 000) to avoid wrong edge detections at the transition.

Bit 3 Reserved, must be kept at reset value.

Bits 16, 2, 1, 0 **SMS[3:0]:** Slave mode selection

When external signals are selected the active edge of the trigger signal (tim_trgi) is linked to the polarity selected on the external input (see input control register and control register description.

0000: Slave mode disabled - if CEN = 1 then the prescaler is clocked directly by the internal clock.

0001: Reserved

0010: Reserved

0011: Reserved

0100: Reset mode - Rising edge of the selected trigger input (tim_trgi) reinitializes the counter and generates an update of the registers.

0101: Gated mode - The counter clock is enabled when the trigger input (tim_trgi) is high. The counter stops (but is not reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

0110: Trigger mode - The counter starts at a rising edge of the trigger tim_trgi (but it is not reset). Only the start of the counter is controlled.

0111: External clock mode 1 - Rising edges of the selected trigger (tim_trgi) clock the counter.

1000: Combined reset + trigger mode - Rising edge of the selected trigger input (tim_trgi) reinitializes the counter, generates an update of the registers and starts the counter.

1001: Combined gated + reset mode - The counter clock is enabled when the trigger input (tim_trgi) is high. The counter stops and is reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

Other codes: reserved.

Note: The gated mode (including gated + reset mode) must not be used if tim_ti1f_ed is selected as the trigger input (TS = 00100). Indeed, tim_ti1f_ed outputs 1 pulse for each transition on tim_ti1f, whereas the gated mode checks the level of the trigger signal.

The clock of the slave peripherals (such as timer, ADC) receiving the tim_trgo signals must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the master timer.

52.7.4 TIM12 interrupt enable register (TIM12_DIER)

Address offset: 0x00C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIE	Res.	Res.	Res.	CC2IE	CC1IE	UIE
									rw				rw	rw	rw

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **TIE**: Trigger interrupt enable

0: Trigger interrupt disabled.

1: Trigger interrupt enabled.

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **CC2IE**: Capture/Compare 2 interrupt enable
0: CC2 interrupt disabled.
1: CC2 interrupt enabled.

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable
0: CC1 interrupt disabled.
1: CC1 interrupt enabled.

Bit 0 **UIE**: Update interrupt enable
0: Update interrupt disabled.
1: Update interrupt enabled.

52.7.5 TIM12 status register (TIM12_SR)

Address offset: 0x010

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	CC2OF	CC1OF	Res.	Res.	TIF	Res.	Res.	Res.	CC2IF	CC1IF	UIF
					rc_w0	rc_w0			rc_w0				rc_w0	rc_w0	rc_w0

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **CC2OF**: Capture/compare 2 overcapture flag
refer to CC1OF description

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag
This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to 0.
0: No overcapture has been detected.
1: The counter value has been captured in TIMx_CCR1 register while CC1IF flag was already set

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **TIF**: Trigger interrupt flag
This flag is set by hardware on the TRG trigger event (active edge detected on tim_trgi input when the slave mode controller is enabled in all modes but gated mode. It is set when the counter starts or stops when gated mode is selected. It is cleared by software.
0: No trigger event occurred.
1: Trigger interrupt pending.

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **CC2IF**: Capture/Compare 2 interrupt flag
refer to CC1IF description

Bit 1 **CC1IF**: Capture/compare 1 interrupt flag
This flag is set by hardware. It is cleared by software (input capture or output compare mode) or by reading the TIMx_CCR1 register (input capture mode only).
0: No compare match / No input capture occurred
1: A compare match or an input capture occurred.
If channel CC1 is configured as output: this flag is set when he content of the counter TIMx_CNT matches the content of the TIMx_CCR1 register. When the content of TIMx_CCR1 is greater than the content of TIMx_ARR, the CC1IF bit goes high on the counter overflow (in up-counting and up/down-counting modes) or underflow (in down-counting mode). There are 3 possible options for flag setting in center-aligned mode, refer to the CMS bits in the TIMx_CR1 register for the full description.
If channel CC1 is configured as input: this bit is set when counter value has been captured in TIMx_CCR1 register (an edge has been detected on tim_ic1, as per the edge sensitivity defined with the CC1P and CC1NP bits setting, in TIMx_CCER).

Bit 0 **UIF**: Update interrupt flag
This bit is set by hardware on an update event. It is cleared by software.
0: No update occurred.
1: Update interrupt pending. This bit is set by hardware when the registers are updated:
– At overflow and if UDIS = 0 in the TIMx_CR1 register.
– When CNT is reinitialized by software using the UG bit in TIMx_EGR register, if URS = 0 and UDIS = 0 in the TIMx_CR1 register.
– When CNT is reinitialized by a trigger event (refer to *Section 52.7.3: TIM12 slave mode control register (TIM12_SMCR)*), if URS = 0 and UDIS = 0 in the TIMx_CR1 register.

52.7.6 TIM12 event generation register (TIM12_EGR)

Address offset: 0x014

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TG	Res.	Res.	Res.	CC2G	CC1G	UG
									w				w	w	w

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **TG**: Trigger generation
This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action
1: The TIF flag is set in the TIMx_SR register. Related interrupt can occur if enabled

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **CC2G**: Capture/compare 2 generation
refer to CC1G description

Bit 1 **CC1G**: Capture/compare 1 generation
This bit is set by software to generate an event, it is automatically cleared by hardware.
0: No action
1: A capture/compare event is generated on channel 1:
If channel CC1 is configured as output:
the CC1IF flag is set, the corresponding interrupt is sent if enabled.
If channel CC1 is configured as input:
The current counter value is captured in the TIMx_CCR1 register. The CC1IF flag is set, the corresponding interrupt is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation
This bit can be set by software, it is automatically cleared by hardware.
0: No action
1: Re-initializes the counter and generates an update of the registers. The prescaler counter is also cleared and the prescaler ratio is not affected. The counter is cleared.

52.7.7 TIM12 capture/compare mode register 1 (TIM12_CCMR1)

Address offset: 0x018

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits in this register have different functions in input and output modes.

Input capture mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IC2F[3:0]				IC2PSC[1:0]		CC2S[1:0]		IC1F[3:0]				IC1PSC[1:0]		CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **IC2F[3:0]**: Input capture 2 filter

Bits 11:10 **IC2PSC[1:0]**: Input capture 2 prescaler

Bits 9:8 **CC2S[1:0]**: Capture/compare 2 selection
This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC2 channel is configured as output
01: CC2 channel is configured as input, IC2 is mapped on tim_ti2
10: CC2 channel is configured as input, IC2 is mapped on tim_ti1
11: CC2 channel is configured as input, IC2 is mapped on tim_trc. This mode works only if an internal trigger input is selected through the TS bit (TIMx_SMCR register)
Note: The CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx_CCER).

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bitfield defines the frequency used to sample the tim_ti1 input and the length of the digital filter applied to tim_ti1. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}
0001: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 2
0010: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 4
0011: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 8
0100: $f_{SAMPLING} = f_{DTS}/2$, N = 6
0101: $f_{SAMPLING} = f_{DTS}/2$, N = 8
0110: $f_{SAMPLING} = f_{DTS}/4$, N = 6
0111: $f_{SAMPLING} = f_{DTS}/4$, N = 8
1000: $f_{SAMPLING} = f_{DTS}/8$, N = 6
1001: $f_{SAMPLING} = f_{DTS}/8$, N = 8
1010: $f_{SAMPLING} = f_{DTS}/16$, N = 5
1011: $f_{SAMPLING} = f_{DTS}/16$, N = 6
1100: $f_{SAMPLING} = f_{DTS}/16$, N = 8
1101: $f_{SAMPLING} = f_{DTS}/32$, N = 5
1110: $f_{SAMPLING} = f_{DTS}/32$, N = 6
1111: $f_{SAMPLING} = f_{DTS}/32$, N = 8

Bits 3:2 **IC1PSC[1:0]**: Input capture 1 prescaler

This bitfield defines the ratio of the prescaler acting on the CC1 input (tim_ic1).
The prescaler is reset as soon as CC1E = 0 (TIMx_CCER register).
00: no prescaler, capture is done each time an edge is detected on the capture input
01: capture is done once every 2 events
10: capture is done once every 4 events
11: capture is done once every 8 events

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC1 channel is configured as output
01: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti1
10: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti2
11: CC1 channel is configured as input, tim_ic1 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: The CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

52.7.8 TIM12 capture/compare mode register 1 [alternate] (TIM12_CCMR1)

Address offset: 0x018

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits in this register have different functions in input and output modes.

Output compare mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M [3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M [3]
							rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	OC2M[2:0]			OC2PE	OC2FE	CC2S[1:0]		Res.	OC1M[2:0]			OC1PE	OC1FE	CC1S[1:0]	
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 Reserved, must be kept at reset value.

Bits 24, 14:12 **OC2M[3:0]**: Output compare 2 mode
Refer to OC1M[3:0] for bit description.

Bit 11 **OC2PE**: Output compare 2 preload enable

Bit 10 **OC2FE**: Output compare 2 fast enable

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection
This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC2 channel is configured as output
01: CC2 channel is configured as input, IC2 is mapped on tim_ti2
10: CC2 channel is configured as input, IC2 is mapped on tim_ti1
11: CC2 channel is configured as input, IC2 is mapped on tim_trc. This mode works only if an internal trigger input is selected through the TS bit (TIMx_SMCR register
Note: The CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx_CCER).

Bit 7 Reserved, must be kept at reset value.

Bits 16, 6:4 **OC1M[3:0]**: Output compare 1 mode (refer to bit 16 for OC1M[3])

These bits define the behavior of the output reference signal tim_oc1ref from which tim_oc1 is derived. tim_oc1ref is active high whereas the active level of tim_oc1 depends on the CC1P.

0000: Frozen - The comparison between the output compare register TIMx_CCR1 and the counter TIMx_CNT has no effect on the outputs. This mode can be used when the timer serves as a software timebase. When the frozen mode is enabled during timer operation, the ouput keeps the state (active or inactive) it had before entering the frozen state.

0001: Set channel 1 to active level on match. The tim_oc1ref signal is forced high when the TIMx_CNT counter matches the capture/compare register 1 (TIMx_CCR1).

0010: Set channel 1 to inactive level on match. The tim_oc1ref signal is forced low when the TIMx_CNT counter matches the capture/compare register 1 (TIMx_CCR1).

0011: Toggle - tim_oc1ref toggles when TIMx_CNT = TIMx_CCR1

0100: Force inactive level - tim_oc1ref is forced low

0101: Force active level - tim_oc1ref is forced high

0110: PWM mode 1 - channel 1 is active as long as TIMx_CNT<TIMx_CCR1 else it is inactive

0111: PWM mode 2 - channel 1 is inactive as long as TIMx_CNT<TIMx_CCR1 else it is active

1000: Retrigerrable OPM mode 1 - The channel is active until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update.

1001: Retrigerrable OPM mode 2 - The channel is inactive until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 2 and the channels becomes inactive again at the next update.

1010: Reserved,

1011: Reserved,

1100: Combined PWM mode 1 - tim_oc1ref has the same behavior as in PWM mode 1. tim_oc1refc is the logical OR between tim_oc1ref and tim_oc2ref.

1101: Combined PWM mode 2 - tim_oc1ref has the same behavior as in PWM mode 2. tim_oc1refc is the logical AND between tim_oc1ref and tim_oc2ref.

1110: Reserved,

1111: Reserved

Note: In PWM mode, the OCREF level changes when the result of the comparison changes, when the output compare mode switches from “frozen” mode to “PWM” mode and when the output compare mode switches from “force active/inactive” mode to “PWM” mode.

Bit 3 **OC1PE**: Output compare 1 preload enable

0: Preload register on TIMx_CCR1 disabled. TIMx_CCR1 can be written at anytime, the new value is taken into account immediately

1: Preload register on TIMx_CCR1 enabled. Read/Write operations access the preload register. TIMx_CCR1 preload value is loaded into the active register at each update event

Bit 2 **OC1FE**: Output compare 1 fast enable

This bit is used to accelerate the effect of an event on the trigger in input on the CC output.

0: CC1 behaves normally depending on the counter and CCR1 values even when the trigger is ON. The minimum delay to activate the CC1 output when an edge occurs on the trigger input is 5 clock cycles

1: An active edge on the trigger input acts like a compare match on the CC1 output. Then, OC is set to the compare level independently of the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OC1FE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00:CC1 channel is configured as output

01:CC1 channel is configured as input, tim_ic1 is mapped on tim_ti1

10:CC1 channel is configured as input, tim_ic1 is mapped on tim_ti2

11:CC1 channel is configured as input, tim_ic1 is mapped on tim_trc. This mode works only if an internal trigger input is selected through the TS bit (TIMx_SMCR register)

Note: The CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

52.7.9 TIM12 capture/compare enable register (TIM12_CCER)

Address offset: 0x020

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2NP	Res.	CC2P	CC2E	CC1NP	Res.	CC1P	CC1E
								rw		rw	rw	rw		rw	rw

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **CC2NP**: Capture/Compare 2 output Polarity

Refer to CC1NP description

Bit 6 Reserved, must be kept at reset value.

Bit 5 **CC2P**: Capture/Compare 2 output Polarity

Refer to CC1P description

Bit 4 **CC2E**: Capture/Compare 2 output enable

Refer to CC1E description

Bit 3 **CC1NP**: Capture/Compare 1 complementary output Polarity

CC1 channel configured as output: CC1NP must be kept cleared

CC1 channel configured as input: CC1NP is used in conjunction with CC1P to define tim_ti1fp1/tim_ti2fp1 polarity (refer to CC1P description).

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CC1P**: Capture/Compare 1 output Polarity.

0: tim_oc1 active high (output mode) / Edge sensitivity selection (input mode, see below)

1: tim_oc1 active low (output mode) / Edge sensitivity selection (input mode, see below)

When CC1 channel is configured as input, both CC1NP/CC1P bits select the active polarity of tim_ti1fp1 and tim_ti2fp1 for trigger or capture operations.

CC1NP = 0, CC1P = 0: non-inverted/rising edge. The circuit is sensitive to tim_tixfp1 rising edge (capture or trigger operations in reset, external clock or trigger mode), tim_tixfp1 is not inverted (trigger operation in gated mode).

CC1NP = 0, CC1P = 1: inverted/falling edge. The circuit is sensitive to tim_tixfp1 falling edge (capture or trigger operations in reset, external clock or trigger mode), tim_tixfp1 is inverted (trigger operation in gated mode).

CC1NP = 1, CC1P = 1: non-inverted/both edges/ The circuit is sensitive to both tim_tixfp1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), tim_tixfp1 is not inverted (trigger operation in gated mode).

CC1NP = 1, CC1P = 0: This configuration is reserved, it must not be used.

Bit 0 **CC1E**: Capture/Compare 1 output enable.

0: Capture mode disabled / tim_oc1 is not active

1: Capture mode enabled / tim_oc1 signal is output on the corresponding output pin

Table 565. Output control bit for standard tim_ocx channels

CCxE bit	tim_ocx output state
0	Output disabled (not driven by the timer: Hi-Z)
1	Output enabled (tim_ocx = tim_ocxref + Polarity)

Note: The states of the external I/O pins connected to the standard tim_ocx *channels depend on the state of the* tim_ocx *channel and on the GPIO registers.*

52.7.10 TIM12 counter (TIM12_CNT)

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF Copy
This bit is a read-only copy of the UIF bit in the TIMx_ISR register.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value
Non-dithering mode (DITHEN = 0)
The register holds the counter value.
Dithering mode (DITHEN = 1)
The register only holds the non-dithered part in CNT[15:0]. The fractional part is not available.

52.7.11 TIM12 prescaler (TIM12_PSC)

Address offset: 0x028

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value
The counter clock frequency tim_cnt_ck is equal to $f_{tim_psc_ck}$ / (PSC[15:0] + 1).
PSC contains the value to be loaded into the active prescaler register at each update event. (including when the counter is cleared through UG bit of TIMx_EGR register or through trigger controller when configured in “reset mode”).

52.7.12 TIM12 autoreload register (TIM12_ARR)

Address offset: 0x02C

Reset value: 0x0000 FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:16]			
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **ARR[19:0]**: Auto-reload value
ARR is the value to be loaded in the actual auto-reload register.
Refer to the *Section 52.4.3: Time-base unit* for more details about ARR update and behavior.
The counter is blocked while the auto-reload value is null.
Non-dithering mode (DITHEN = 0)
The register holds the auto-reload value in ARR[15:0]. The ARR[19:16] bits are reset.
Dithering mode (DITHEN = 1)
The register holds the integer part in ARR[19:4]. The ARR[3:0] bitfield contains the dithered part.

52.7.13 TIM12 capture/compare register 1 (TIM12_CCR1)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR1[19:0]**: Capture/compare 1 value

If channel CC1 is configured as output:

CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc1 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value in CCR1[15:0]. The CCR1[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR1[19:4]. The CCR1[3:0] bitfield contains the dithered part.

If channel CC1 is configured as input:

CR1 is the counter value transferred by the last input capture 1 event (tim_ic1). The TIMx_CCR1 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The register holds the capture value in CCR1[15:0]. The CCR1[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR1[19:4]. The CCR1[3:0] bits are reset.

52.7.14 TIM12 capture/compare register 2 (TIM12_CCR2)

Address offset: 0x038

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR2[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR2[19:0]**: Capture/compare 2 value

If channel CC2 is configured as output:

CCR2 is the value to be loaded in the actual capture/compare 2 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR2 register (bit OC2PE). Else the preload value is copied in the active capture/compare 2 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signalled on tim_oc2 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value in CCR2[15:0]. The CCR2[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR2[19:4]. The CCR2[3:0] bitfield contains the dithered part.

If channel CC2 is configured as input:

CCR2 is the counter value transferred by the last input capture 1 event (tim_ic2). The TIMx_CCR2 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The register holds the capture value in CCR2[15:0]. The CCR2[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR2[19:4]. The CCR2[3:0] bits are reset.

52.7.15 TIM12 timer input selection register (TIM12_TISEL)

Address offset: 0x05C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: selects tim_ti2_in[15:0] input

0000: TIMx_CH2 input (tim_ti2_in0)

0001: tim_ti2_in1

...

0100: tim_ti2_in15

Refer to *Table 560: Interconnect to the tim_ti2 input multiplexer* for interconnects list.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: selects tim_ti1_in[15:0] input

0000: TIMx_CH1 input (tim_ti1_in0)

0001: tim_ti1_in1

...

1111: tim_ti1_in15

Refer to *Table 559: Interconnect to the tim_ti1 input multiplexer* for interconnects list.

52.7.16 TIM12 register map

TIM12 registers are mapped as 16-bit addressable registers as described below:

Table 566. TIM12 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	TIM12_CR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DITHEN	UIFREMA	Res.	CKD [1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
	Reset value																				0	0		0	0	0				0	0	0	0
0x004	TIM12_CR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1S	MMS[2:0]			Res.	Res.	Res.	Res.
	Reset value																									0	0	0	0				
0x008	TIM12_SMCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS [4:3]		Res.	Res.	Res.	SMS[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MSM	TS[2:0]			Res.	SMS[2:0]		
	Reset value											0	0				0									0	0	0	0		0	0	0
0x00C	TIM12_DIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.		TIE	Res.	Res.	Res.	CC2IE	CC1IE	UIE
	Reset value																										0				0	0	0
0x010	TIM12_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2OF	CC1OF	Res.		TIF	Res.	Res.	Res.	CC2IF	CC1IF	UIF
	Reset value																						0	0			0				0	0	0
0x014	TIM12_EGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.		TG	Res.	Res.	Res.	CC2G	CC1G	UG
	Reset value																										0				0	0	0
0x018	TIM12_CCMR1 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC2F[3:0]				IC2 PSC [1:0]		CC2S [1:0]		IC1F[3:0]				IC1 PSC [1:0]		CC1 S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TIM12_CCMR1 Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]	Res.	OC2M [2:0]			OC2PE	OC2FE	CC2S [1:0]		Res.	OC1M [2:0]			OC1PE	OC1FE	CC1 S [1:0]	
	Reset value								0								0		0	0	0	0	0	0	0		0	0	0	0	0	0	0
0x01C	Reserved	Res.																															
0x020	TIM12_CCER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2NP	Res.	CC2P	CC2E	CC1NP	Res.	CC1P	CC1E
	Reset value																									0		0	0	0		0	0
0x024	TIM12_CNT	UIFCPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x028	TIM12_PSC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.															
	Reset value																		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 566. TIM12 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x02C	TIM12_ARR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x030	Reserved	Res.																															
0x034	TIM12_CCR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x038	TIM12_CCR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR2[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x03C to 0x058	Reserved	Res.																															
0x05C	TIM12_TISEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value																					0	0	0	0					0	0	0	0
0x060 - 0x3E8	Reserved	Res.																															

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

52.8 TIM13/TIM14 registers

The peripheral registers have to be written by half-words (16 bits) or words (32 bits). Read accesses can be done by bytes (8 bits), half-words (16 bits), or words (32 bits).

52.8.1 TIMx control register 1 (TIMx_CR1)(x = 13, 14)

Address offset: 0x000

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DITHEN	UIFREMAP	Res.	CKD[1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
			rw	rw		rw	rw	rw				rw	rw	rw	rw

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **DITHEN**: Dithering enable
0: Dithering disabled
1: Dithering enabled
Note: The DITHEN bit can only be modified when CEN bit is reset.

Bit 11 **UIFREMAP**: UIF status bit remapping
0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bit 10 Reserved, must be kept at reset value.

Bits 9:8 **CKD[1:0]**: Clock division
This bitfield indicates the division ratio between the timer clock (tim_ker_ck) frequency and sampling clock used by the digital filters (tim_tix),
00: $t_{DTS} = t_{tim_ker_ck}$
01: $t_{DTS} = 2 \times t_{tim_ker_ck}$
10: $t_{DTS} = 4 \times t_{tim_ker_ck}$
11: Reserved

Bit 7 **ARPE**: Auto-reload preload enable
0: TIMx_ARR register is not buffered
1: TIMx_ARR register is buffered

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **OPM**: One-pulse mode
0: Counter is not stopped on the update event
1: Counter stops counting on the next update event (clearing the CEN bit).

Bit 2 **URS**: Update request source

This bit is set and cleared by software to select the update interrupt (UEV) sources.

0: Any of the following events generate an UEV if enabled:

– Counter overflow

– Setting the UG bit

1: Only counter overflow generates an UEV if enabled.

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable update interrupt (UEV) event generation.

0: UEV enabled. An UEV is generated by one of the following events:

– Counter overflow

– Setting the UG bit.

Buffered registers are then loaded with their preload values.

1: UEV disabled. No UEV is generated, shadow registers keep their value (ARR, PSC, CCRx). The counter and the prescaler are reinitialized if the UG bit is set.

Bit 0 **CEN**: Counter enable

0: Counter disabled

1: Counter enabled

Note: External clock and gated mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

52.8.2 TIMx interrupt enable register (TIMx_DIER)(x = 13, 14)

Address offset: 0x00C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1IE	UIE
														rw	rw

Bits 15:2 Reserved, must be kept at reset value.

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable

0: CC1 interrupt disabled

1: CC1 interrupt enabled

Bit 0 **UIE**: Update interrupt enable

0: Update interrupt disabled

1: Update interrupt enabled

52.8.3 TIMx status register (TIMx_SR)(x = 13, 14)

Address offset: 0x010

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CC1OF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1IF	UIF
						rc_w0								rc_w0	rc_w0

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag

This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to 0.

0: No overcapture has been detected.

1: The counter value has been captured in TIMx_CCR1 register while CC1IF flag was already set

Bits 8:2 Reserved, must be kept at reset value.

Bit 1 **CC1IF**: Capture/compare 1 interrupt flag

This flag is set by hardware. It is cleared by software (input capture or output compare mode) or by reading the TIMx_CCR1 register (input capture mode only).

0: No compare match / No input capture occurred

1: A compare match or an input capture occurred.

If channel CC1 is configured as output: this flag is set when he content of the counter TIMx_CNT matches the content of the TIMx_CCR1 register. When the content of TIMx_CCR1 is greater than the content of TIMx_ARR, the CC1IF bit goes high on the counter overflow (in up-counting and up/down-counting modes) or underflow (in down-counting mode). There are 3 possible options for flag setting in center-aligned mode, refer to the CMS bits in the TIMx_CR1 register for the full description.

If channel CC1 is configured as input: this bit is set when counter value has been captured in TIMx_CCR1 register (an edge has been detected on tim_ic1, as per the edge sensitivity defined with the CC1P and CC1NP bits setting, in TIMx_CCER).

Bit 0 **UIF**: Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.

0: No update occurred.

1: Update interrupt pending. This bit is set by hardware when the registers are updated:

- At overflow and if UDIS = 0 in the TIMx_CR1 register.
- When CNT is reinitialized by software using the UG bit in TIMx_EGR register, if URS = 0 and UDIS = 0 in the TIMx_CR1 register.

52.8.4 TIMx event generation register (TIMx_EGR)(x = 13, 14)

Address offset: 0x014

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1G	UG
														w	w

Bits 15:2 Reserved, must be kept at reset value.

Bit 1 **CC1G**: Capture/compare 1 generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action
1: A capture/compare event is generated on channel 1:
If channel CC1 is configured as output:
CC1IF flag is set, Corresponding interrupt or is sent if enabled.
If channel CC1 is configured as input:
The current value of the counter is captured in TIMx_CCR1 register. The CC1IF flag is set, the corresponding interrupt is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation

This bit can be set by software, it is automatically cleared by hardware.
0: No action
1: Re-initialize the counter and generates an update of the registers. Note that the prescaler counter is cleared too (anyway the prescaler ratio is not affected). The counter is cleared.

52.8.5 TIMx capture/compare mode register 1 (TIMx_CCMR1)(x = 13, 14)

Address offset: 0x018

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode.

Input capture mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC1F[3:0]				IC1PSC[1:0]		CC1S[1:0]	
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bitfield defines the frequency used to sample tim_ti1 input and the length of the digital filter applied to tim_ti1. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}
0001: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 2
0010: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 4
0011: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 8
0100: $f_{SAMPLING} = f_{DTS}/2$, N = 6
0101: $f_{SAMPLING} = f_{DTS}/2$, N = 8
0110: $f_{SAMPLING} = f_{DTS}/4$, N = 6
0111: $f_{SAMPLING} = f_{DTS}/4$, N = 8
1000: $f_{SAMPLING} = f_{DTS}/8$, N = 6
1001: $f_{SAMPLING} = f_{DTS}/8$, N = 8
1010: $f_{SAMPLING} = f_{DTS}/16$, N = 5
1011: $f_{SAMPLING} = f_{DTS}/16$, N = 6
1100: $f_{SAMPLING} = f_{DTS}/16$, N = 8
1101: $f_{SAMPLING} = f_{DTS}/32$, N = 5
1110: $f_{SAMPLING} = f_{DTS}/32$, N = 6
1111: $f_{SAMPLING} = f_{DTS}/32$, N = 8

Bits 3:2 **IC1PSC[1:0]**: Input capture 1 prescaler

This bitfield defines the ratio of the prescaler acting on CC1 input (tim_ic1).
The prescaler is reset as soon as CC1E = 0 (TIMx_CCER register).
00: no prescaler, capture is done each time an edge is detected on the capture input
01: capture is done once every 2 events
10: capture is done once every 4 events
11: capture is done once every 8 events

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC1 channel is configured as output
01: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti1
10: Reserved
11: Reserved

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

52.8.6 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 13, 14)

Address offset: 0x018

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode.

Output compare mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M [3]
															rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[2:0]			OC1PE	OC1FE	CC1S[1:0]	
									rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bits 15:7 Reserved, must be kept at reset value.

Bits 16, 6:4 **OC1M[3:0]**: Output compare 1 mode (refer to bit 16 for OC1M[3])

These bits define the behavior of the output reference signal tim_oc1ref from which tim_oc1 is derived. tim_oc1ref is active high whereas tim_oc1 active level depends on CC1P bit.

0000: Frozen. The comparison between the output compare register TIMx_CCR1 and the counter TIMx_CNT has no effect on the outputs. This mode can be used when the timer serves as a software timebase. When the frozen mode is enabled during timer operation, the output keeps the state (active or inactive) it had before entering the frozen state.

0001: Set channel 1 to active level on match. tim_oc1ref signal is forced high when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0010: Set channel 1 to inactive level on match. tim_oc1ref signal is forced low when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0011: Toggle - tim_oc1ref toggles when TIMx_CNT = TIMx_CCR1.

0100: Force inactive level - tim_oc1ref is forced low.

0101: Force active level - tim_oc1ref is forced high.

0110: PWM mode 1 - Channel 1 is active as long as TIMx_CNT < TIMx_CCR1 else inactive.

0111: PWM mode 2 - Channel 1 is inactive as long as TIMx_CNT < TIMx_CCR1 else active

Others: Reserved

Note: In PWM mode, the OCREF level changes when the result of the comparison changes, when the output compare mode switches from “frozen” mode to “PWM” mode and when the output compare mode switches from “force active/inactive” mode to “PWM” mode.

Bit 3 **OC1PE**: Output compare 1 preload enable

0: Preload register on TIMx_CCR1 disabled. TIMx_CCR1 can be written at anytime, the new value is taken in account immediately.

1: Preload register on TIMx_CCR1 enabled. Read/Write operations access the preload register. TIMx_CCR1 preload value is loaded in the active register at each update event.

Bit 2 **OC1FE**: Output compare 1 fast enable

This bit decreases the latency between a trigger event and a transition on the timer output. It must be used in one-pulse mode (OPM bit set in TIMx_CR1 register), to have the output pulse starting as soon as possible after the starting trigger.

0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.

1: An active edge on the trigger input acts like a compare match on CC1 output. OC is then set to the compare level independently of the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OC1FE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output.

01: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti1.

10: Reserved.

11: Reserved.

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

52.8.7 TIMx capture/compare enable register (TIMx_CCER)(x = 13, 14)

Address offset: 0x020

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1NP	Res.	CC1P	CC1E
												rw		rw	rw

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **CC1NP**: Capture/Compare 1 complementary output Polarity.

CC1 channel configured as output: CC1NP must be kept cleared.

CC1 channel configured as input: CC1NP bit is used in conjunction with CC1P to define tim_ti1fp1 polarity (refer to CC1P description).

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CC1P**: Capture/Compare 1 output Polarity.
0: tim_oc1 active high (output mode) / Edge sensitivity selection (input mode, see below)
1: tim_oc1 active low (output mode) / Edge sensitivity selection (input mode, see below)
When CC1 channel is configured as input, both CC1NP/CC1P bits select the active polarity of tim_ti1fp1 for capture operations.
CC1NP = 0, CC1P = 0: non-inverted/rising edge. The circuit is sensitive to tim_ti1fp1 rising edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode).
CC1NP = 0, CC1P = 1: inverted/falling edge. The circuit is sensitive to tim_ti1fp1 falling edge (capture or trigger operations in reset, external clock or trigger mode), tim_ti1fp1 is inverted (trigger operation in gated mode).
CC1NP = 1, CC1P = 1: non-inverted/both edges/ The circuit is sensitive to both tim_ti1fp1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), tim_ti1fp1 not inverted (trigger operation in gated mode).
CC1NP = 1, CC1P = 0: This configuration is reserved, it must not be used.

Bit 0 **CC1E**: Capture/Compare 1 output enable.
0: Capture mode disabled / tim_oc1 is not active
1: Capture mode enabled / tim_oc1 signal is output on the corresponding output pin

Table 567. Output control bit for standard tim_ocx channels

CCxE bit	tim_ocx output state
0	Output Disabled (tim_ocx = 0)
1	tim_ocx = tim_ocxref + Polarity

Note: The state of the external I/O pins connected to the standard tim_ocx channels depends on the tim_ocx channel state and the GPIO registers.

52.8.8 TIMx counter (TIMx_CNT)(x = 13, 14)

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF Copy

This bit is a read-only copy of the UIF bit in the TIMx_ISR register.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value

Non-dithering mode (DITHEN = 0)

The register holds the counter value.

Dithering mode (DITHEN = 1)

The register only holds the non-dithered part in CNT[15:0]. The fractional part is not available.

52.8.9 TIMx prescaler (TIMx_PSC)(x = 13, 14)

Address offset: 0x028

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency tim_cnt_ck is equal to $f_{tim_psc_ck}$ / (PSC[15:0] + 1).

PSC contains the value to be loaded in the active prescaler register at each update event.

(including when the counter is cleared through UG bit of TIMx_EGR register or through trigger controller when configured in “reset mode”).

52.8.10 TIMx autoreload register (TIMx_ARR)(x = 13, 14)

Address offset: 0x02C

Reset value: 0x0000 FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **ARR[19:0]**: Auto-reload value

ARR is the value to be loaded in the actual auto-reload register.

Refer to the *Section 52.4.3: Time-base unit* for more details about ARR update and behavior.

The counter is blocked while the auto-reload value is null.

Non-dithering mode (DITHEN = 0)

The register holds the auto-reload value in ARR[15:0]. The ARR[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in ARR[19:4]. The ARR[3:0] bitfield contains the dithered part.

52.8.11 TIMx capture/compare register 1 (TIMx_CCR1)(x = 13, 14)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[19:16]			
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR1[19:0]**: Capture/compare 1 value

If channel CC1 is configured as output:

CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc1 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value in CCR1[15:0]. The CCR1[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR1[19:4]. The CCR1[3:0] bitfield contains the dithered part.

If channel CC1 is configured as input:

CR1 is the counter value transferred by the last input capture 1 event (tim_ic1). The TIMx_CCR1 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The register holds the capture value in CCR1[15:0]. The CCR1[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR1[19:4]. The CCR1[3:0] bits are reset.

52.8.12 TIMx timer input selection register (TIMx_TISEL)(x = 13, 14)

Address offset: 0x05C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1SEL[3:0]			
												rw	rw	rw	rw

Bits 15:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: selects tim_ti1_in[15:0] input
0000: TIMx_CH1 input (tim_ti1_in0)
0001: tim_ti1_in1
...
1111: tim_ti1_in15
Refer to *Table 559: Interconnect to the tim_ti1 input multiplexer* for interconnects list.

52.8.13 TIM13/TIM14 register map

TIMx registers are mapped as 16-bit addressable registers as described in the tables below:

Table 568. TIM13/TIM14 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	TIMx_CR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DITHEN	UIFREMA	Res.	CKD [1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
	Reset value																				0	0		0	0	0				0	0	0	0
0x004 to 0x008	Reserved	Res.																															
0x00C	TIMx_DIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1IE	UIE
	Reset value																															0	0
0x010	TIMx_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1OF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1IF	UIF
	Reset value																							0								0	0
0x014	TIMx_EGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1G	UG
	Reset value																															0	0
0x018	TIMx_CCMR1 Output compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M [2:0]			OC1PE	OC1FE	CC1S [1:0]	
	Reset value																										0	0	0	0	0	0	0
	TIMx_CCMR1 Input capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC1F[3:0]				IC1 PSC [1:0]		CC1S [1:0]	
	Reset value																									0	0	0	0	0	0	0	0
0x01C	Reserved	Res.																															
0x020	TIMx_CCER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1NP	Res.	CC1P	CC1E
	Reset value																													0		0	0
0x024	TIMx_CNT	UIFCPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 568. TIM13/TIM14 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x028	TIMx_PSC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x02C	TIMx_ARR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x030	Reserved	Res.																															
0x034	TIMx_CCR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x038 to 0x058	Reserved	Res.																															
0x05C	TIMx_TISEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value																													0	0	0	0
0x060 - 0x3E8	Reserved	Res.																															

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

53 General purpose timers (TIM15/TIM16/TIM17)

53.1 TIM15/TIM16/TIM17 introduction

The TIM15/TIM16/TIM17 timers consist of a 16-bit autoreload counter driven by a programmable prescaler.

They may be used for a variety of purposes, including measuring the pulse lengths of input signals (input capture) or generating output waveforms (output compare, PWM, complementary PWM with dead-time insertion).

Pulse lengths and waveform periods can be modulated from a few microseconds to several milliseconds using the timer prescaler and the RCC clock controller prescalers.

The TIM15/TIM16/TIM17 timers are completely independent, and do not share any resources. TIM15 can be synchronized as described in *Section 53.4.26: Timer synchronization (TIM15 only)*.

53.2 TIM15 main features

TIM15 includes the following features:

- 16-bit autoreload upcounter
- 16-bit programmable prescaler used to divide (also “on the fly”) the counter clock frequency by any factor between 1 and 65535
- Up to two independent channels for:
  - Input capture
  - Output compare
  - PWM generation (edge mode)
  - One-pulse mode output
- Complementary outputs with programmable dead-time (for channel 1 only)
- Synchronization circuit to control the timer with external signals and to interconnect several timers together
- Repetition counter to update the timer registers only after a given number of cycles of the counter
- Break input to put the timer’s output signals in the reset state or a known state
- Interrupt/DMA generation on the following events:
  - Update: counter overflow counter initialization (by software or internal/external trigger)
  - Trigger event (counter start, stop, initialization, or count by internal/external trigger)
  - Input capture
  - Output compare
  - Break input (interrupt request)

53.3 TIM16/TIM17 main features

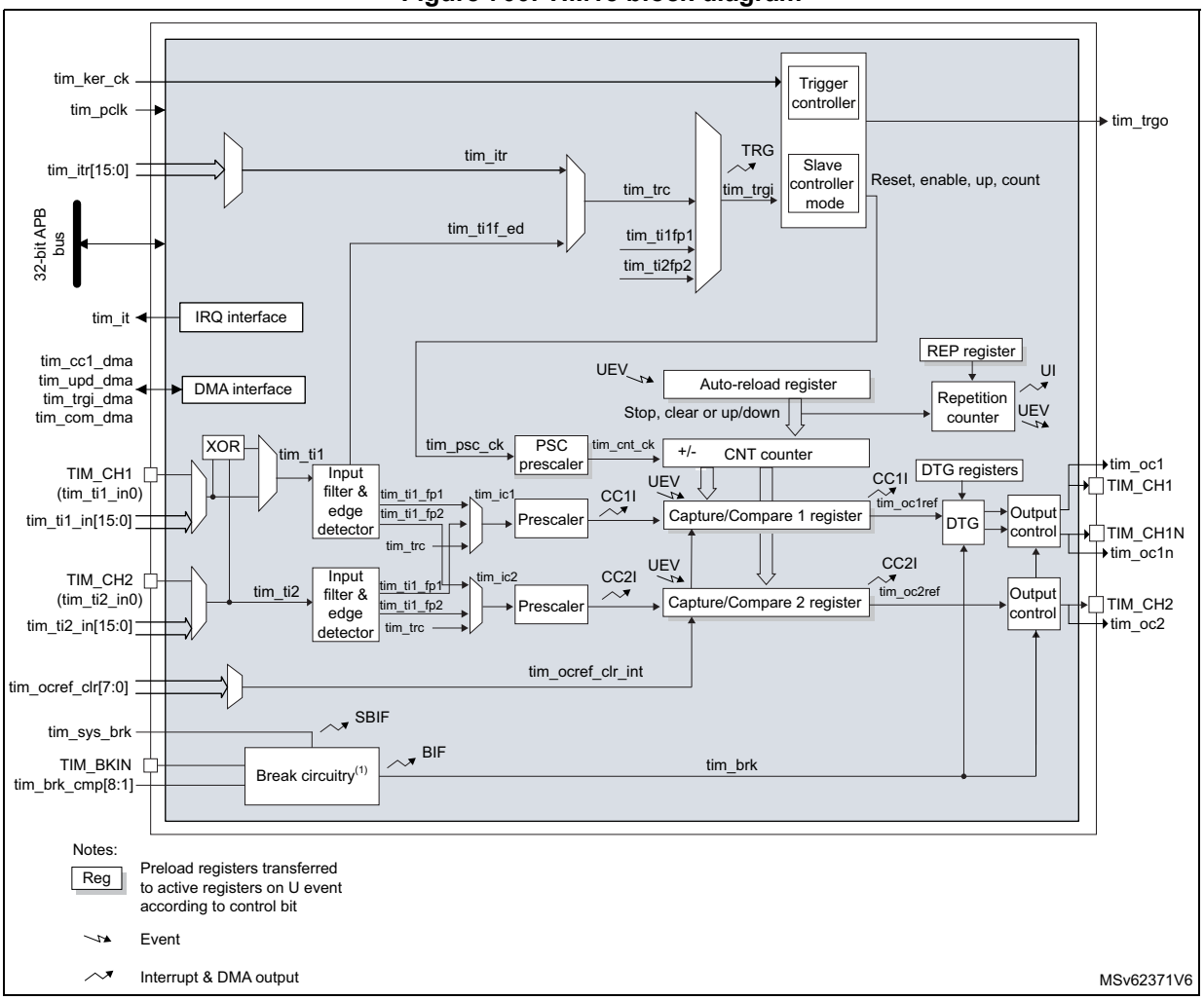
The TIM16/TIM17 timers include the following features:

- 16-bit autoreload upcounter
- 16-bit programmable prescaler used to divide (also “on the fly”) the counter clock frequency by any factor between 1 and 65535
- One channel for:
  - Input capture
  - Output compare
  - PWM generation (edge-aligned mode)
  - One-pulse mode output
- Complementary outputs with programmable dead-time
- Repetition counter to update the timer registers only after a given number of cycles of the counter
- Break input to put the timer’s output signals in the reset state or a known state
- Interrupt/DMA generation on the following events:
  - Update: counter overflow
  - Input capture
  - Output compare
  - Break input

53.4 TIM15/TIM16/TIM17 functional description

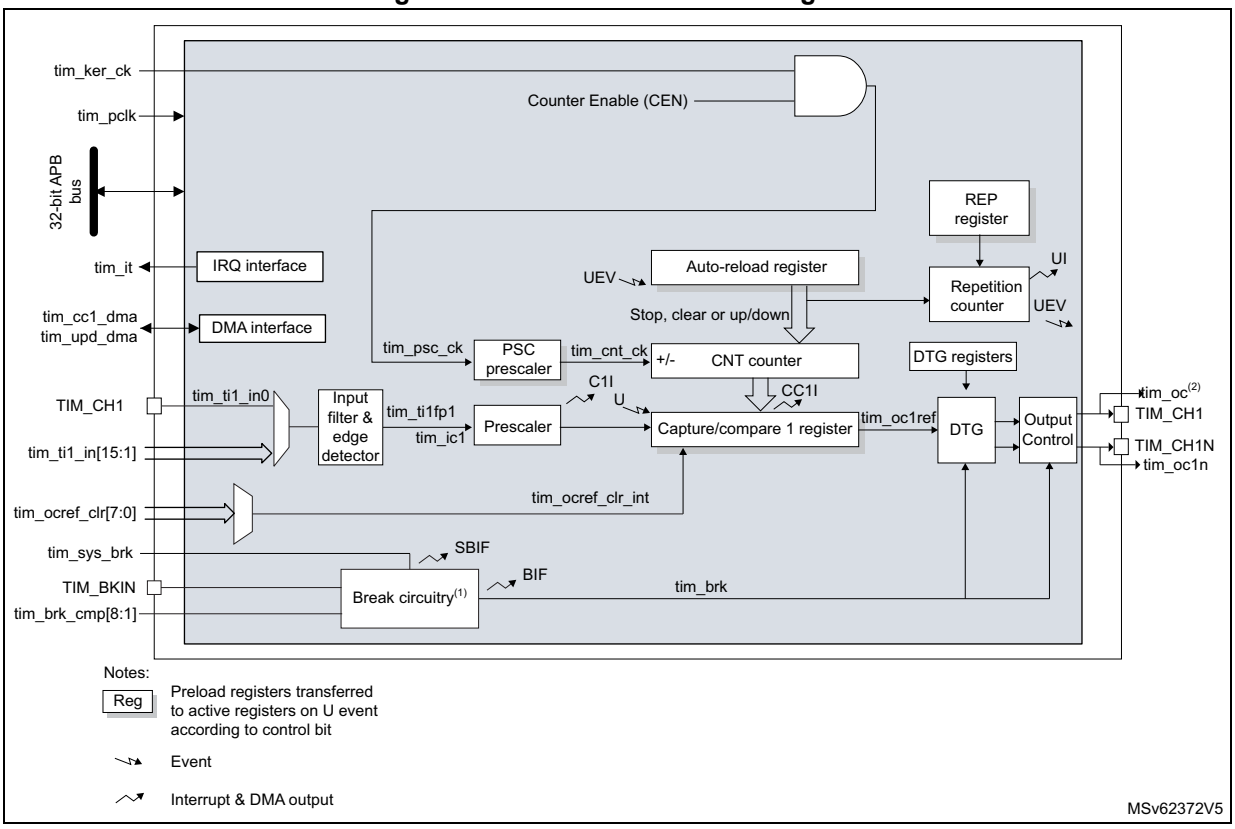
53.4.1 Block diagram

Figure 700. TIM15 block diagram



1. Refer to *Section 53.4.15: Using the break function* for details.

Figure 701. TIM16/TIM17 block diagram



1. Refer to *Section 53.4.15: Using the break function* for details.
2. This signal can be used as trigger for some slave timer (see internal trigger connection table in next section). See *Section 53.4.27: Using timer output as trigger for other timers (TIM16/TIM17 only)* for details.

53.4.2 TIM15/TIM16/TIM17 pins and internal signals

Table 569 and *Table 570* in this section summarize the TIM inputs and outputs.

Table 569. TIM input/output pins

Pin name	Signal type	Description
TIM_CH1 TIM_CH2(1)	Input/Output	Timer multi-purpose channels. Each channel be used for capture, compare, or PWM. TIM_CH1 and TIM_CH2 can also be used as external clock (below 1/4 of the tim_ker_ck clock) and external trigger inputs.
TIM_CH1N	Output	Timer complementary outputs, derived from TIM_CH1 output with the possibility to have deadtime insertion.
TIM_BKIN	Input / Output	Break input. This input can also be configured in bidirectional mode.

1. Available for TIM15 only.

Table 570. TIM internal input/output signals

Internal signal name	Signal type	Description
tim_ti1_in[15:0] tim_ti2_in[15:0](1)	Input	Internal timer inputs bus. These inputs can be used for capture or as external clock (below 1/4 of the tim_ker_ck clock).
tim_itr[15:0](1)	Input	Internal trigger input bus. These inputs can be used for the slave mode controller or as a input clock (below 1/4 of the tim_ker_ck clock).
tim_trgo(1)	Output	Internal trigger output. This trigger can trigger other on-chip peripherals.
tim_ocref_clr[7:0]	Input	Timer tim_ocref_clr input bus. These inputs can be used to clear the tim_ocxref signals, typically for hardware cycle-by-cycle pulsewidth control.
tim_brk_cmp[8:1]	Input	Break input for internal signals
tim_sys_brk[n:0]	Input	System break input. This input gathers the MCU's system level errors.
tim_pclk	Input	Timer APB clock
tim_ker_ck	Input	Timer kernel clock. This clock must be synchronous with tim_pclk (derived from the same source). The clock ratio tim_ker_ck/tim_pclk must be an integer:1, 2, 3,..., 16 (maximum value)
tim_it	Output	Global Timer interrupt, gathering capture/compare, update, break trigger and commutation requests
tim_cc1_dma	Output	Timer capture / compare 1 dma request
tim_upd_dma	Output	Timer update dma request
tim_trgi_dma	Output	Timer trigger dma request
tim_com_dma	Output	Timer commutation dma request

1. Available for TIM15 only.

Table 571 and *Table 572* list the sources connected to the tim_ti[2:1] input multiplexers.

Table 571. Interconnect to the tim_ti1 input multiplexer

tim_ti1 inputs	Sources		
	TIM15	TIM16	TIM17
tim_ti1_in0	TIM15_CH1	TIM16_CH1	TIM17_CH1
tim_ti1_in1	TIM2_CH1	RCC_LSI	Reserved
tim_ti1_in2	TIM3_CH1	RCC_LSE	RCC_HSE_1MHz
tim_ti1_in3	TIM4_CH1	RTC Wake-up	RCC_MCO1
tim_ti1_in4	RCC_LSE	Reserved	Reserved
tim_ti1_in5	RCC_CSI/128		
tim_ti1_in6	RCC_MCO2		
tim_ti1_in7	Reserved		
tim_ti1_in8	comp1_out	comp1_out	comp1_out
tim_ti1_in9	comp2_out	comp2_out	comp2_out
tim_ti1_in[15:10]	Reserved		

Table 572. Interconnect to the tim_ti2 input multiplexer

tim_ti2 inputs	Sources
	TIM15
tim_ti2_in0	TIM15_CH2
tim_ti2_in1	TIM2_CH2
tim_ti2_in2	TIM3_CH2
tim_ti2_in3	TIM4_CH2
tim_ti2_in4	comp1_out
tim_ti2_in5	comp2_out
tim_ti2_in[15:6]	Reserved

Table 573 lists the internal sources connected to the tim_itr input multiplexer.

Table 573. TIMx internal trigger connection

tim_itrx inputs	TIM15
tim_itr0	tim1_trgo
tim_itr1	tim2_trgo
tim_itr2	tim3_trgo
tim_itr3	tim4_trgo
tim_itr4	tim5_trgo

Table 573. TIMx internal trigger connection (continued)

tim_itrx inputs	TIM15
tim_itr5	tim8_trgo
tim_itr6	tim12_trgo
tim_itr7	tim13_oc1
tim_itr8	tim14_oc1
tim_itr9	Reserved
tim_itr10	tim16_oc1
tim_itr11	tim17_oc1
tim_itr[15:12]	Reserved

Table 574 and *Table 575* list the sources connected to the tim_brk input.

Table 574. Timer break interconnect

tim_brk inputs	TIM15	TIM16	TIM17
TIM_BKIN	TIM15_BKIN pin	TIM16_BKIN pin	TIM17_BKIN pin
tim_brk_cmp[1]	comp1_out	comp1_out	comp1_out
tim_brk_cmp[2]	comp2_out	comp2_out	comp2_out
tim_brk_cmp[7:3]	Reserved		
tim_brk_cmp[8]	mdf1_brk0	mdf1_brk1	mdf1_brk2

Table 575. System break interconnect

tim_sys_brk inputs	TIM15/16/17	Enable bit in SBS_CFGR2 register
tim_sys_brk0	FLASH double ECC error	ECCL
tim_sys_brk1	Programmable voltage detector (PVD)	PVDL
tim_sys_brk2	SRAM double ECC error	SEL
tim_sys_brk3	Cortex-M33 LOCKUP	CLL
CSS	Clock security system	None (always enabled)

Table 576 lists the internal sources connected to the tim_ocref_clr input multiplexer.

Table 576. Interconnect to the tim_ocref_clr input multiplexer

Timer OCREF clear signal	Timer OCREF clear signal assignment		
	TIM15	TIM16	TIM17
tim_ocref_clr0	comp1_out	comp1_out	comp1_out

Table 576. Interconnect to the tim_ocref_clr input multiplexer (continued)

Timer OCREF clear signal	Timer OCREF clear signal assignment		
	TIM15	TIM16	TIM17
im_ocref_clr1	comp2_out	comp2_out	comp2_out
tim_ocref_clr[7:2]	Reserved	Reserved	Reserved

53.4.3 Time-base unit

The main block of the programmable advanced-control timer is a 16-bit upcounter with its related autoreload register. The counter clock can be divided by a prescaler.

The counter, the autoreload register and the prescaler register can be written or read by software. This is true even when the counter is running.

The time-base unit includes:

- Counter register (TIMx_CNT)
- Prescaler register (TIMx_PSC)
- Autoreload register (TIMx_ARR)
- Repetition counter register (TIMx_RCR)

The autoreload register is preloaded. Writing to or reading from the autoreload register accesses the preload register. The content of the preload register is transferred into the shadow register permanently or at each update event (UEV), depending on the autoreload preload enable bit (ARPE) in TIMx_CR1 register. The update event is sent when the counter reaches the overflow and if the UDIS bit equals 0 in the TIMx_CR1 register. It can also be generated by software. The generation of the update event is described in detailed for each configuration.

The counter is clocked by the prescaler output tim_cnt_ck, which is enabled only when the counter enable bit (CEN) in TIMx_CR1 register is set (refer also to the slave mode controller description to get more details on counter enabling).

Note that the counter starts counting one clock cycle after setting the CEN bit in the TIMx_CR1 register.

Prescaler description

The prescaler can divide the counter clock frequency by any factor between 1 and 65536. It is based on a 16-bit counter controlled through a 16-bit register (in the TIMx_PSC register). It can be changed on the fly as this control register is buffered. The new prescaler ratio is taken into account at the next update event.

Table 712 and *Table 703* give some examples of the counter behavior when the prescaler ratio is changed on the fly:

Figure 702. Counter timing diagram with prescaler division change from 1 to 2

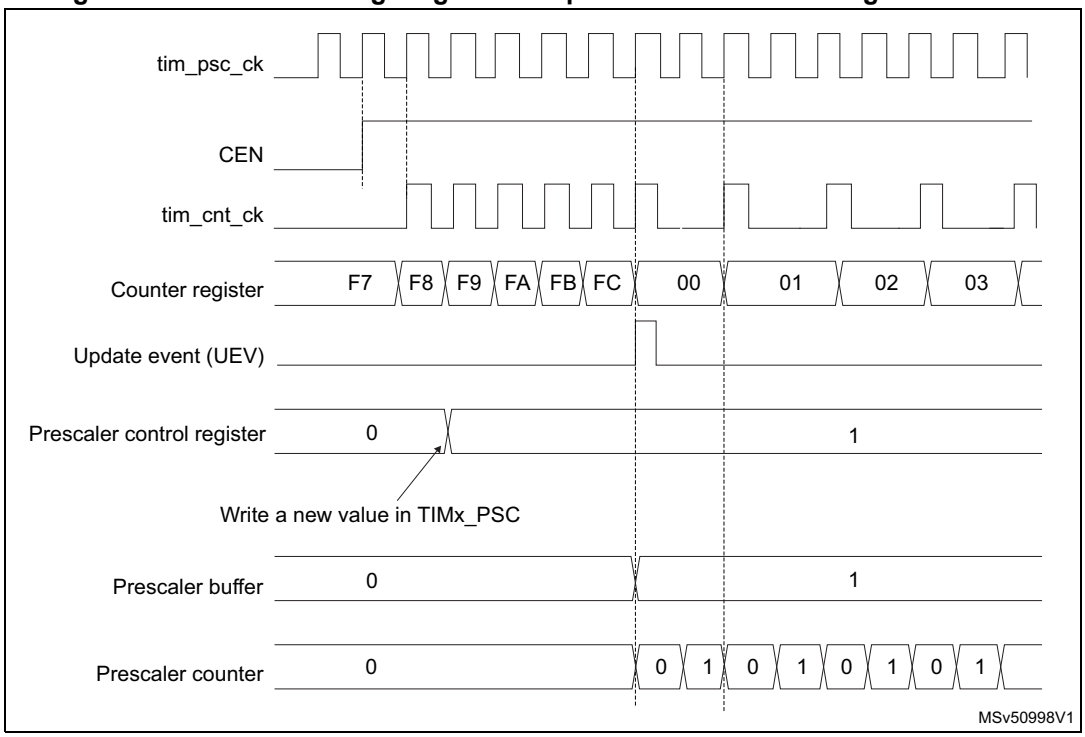
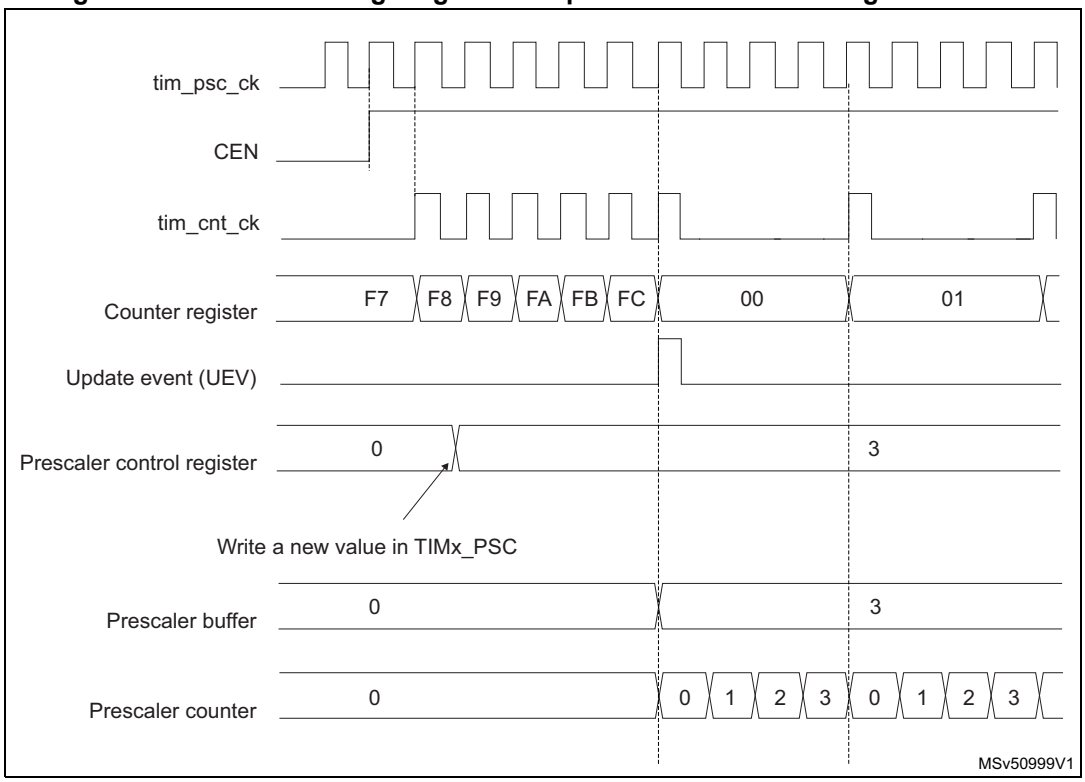


Figure 703. Counter timing diagram with prescaler division change from 1 to 4



53.4.4 Counter modes

Upcounting mode

In upcounting mode, the counter counts from 0 to the autoreload value (content of the TIMx_ARR register), then restarts from 0 and generates a counter overflow event.

If the repetition counter is used, the update event (UEV) is generated after upcounting is repeated for the number of times programmed in the repetition counter register (TIMx_RCR). Else the update event is generated at each counter overflow.

Setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller) also generates an update event.

The UEV event can be disabled by software by setting the UDIS bit in the TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter restarts from 0, as well as the counter of the prescaler (but the prescale rate does not change). In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The repetition counter is reloaded with the content of TIMx_RCR register,
- The autoreload shadow register is updated with the preload value (TIMx_ARR),
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR = 0x36.

Figure 704. Counter timing diagram, internal clock divided by 1

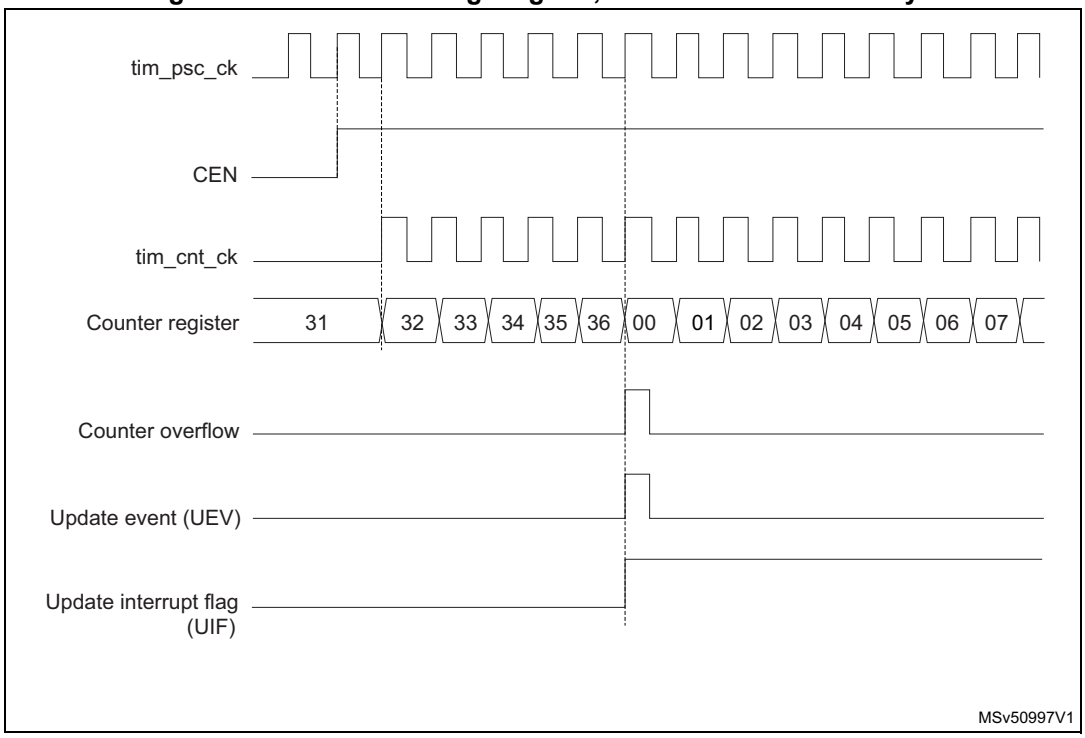


Figure 705. Counter timing diagram, internal clock divided by 2

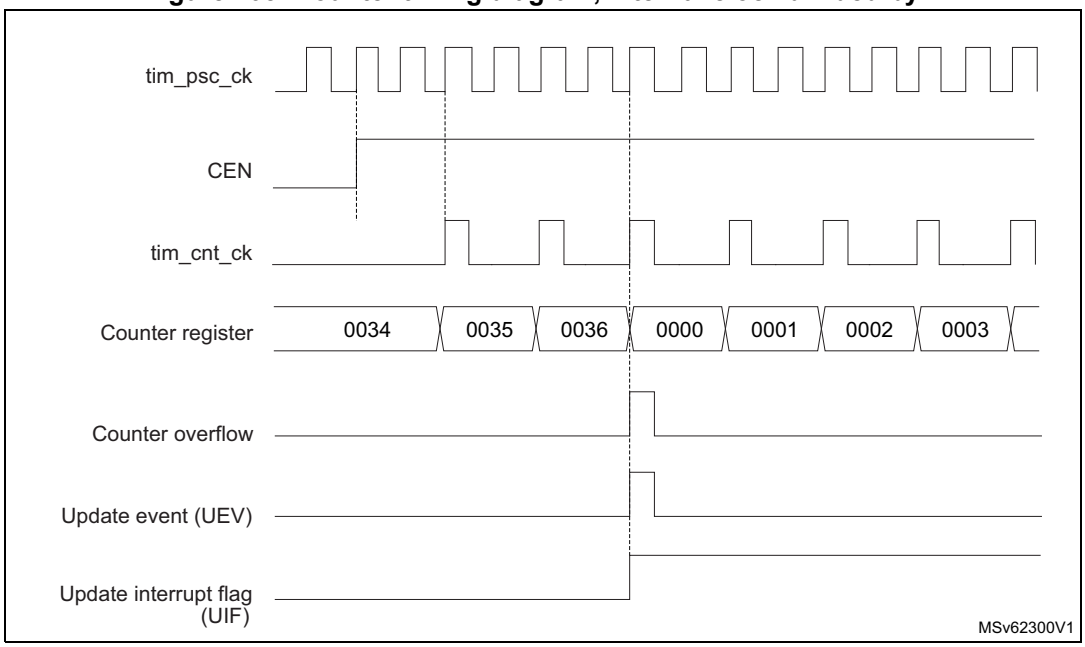


Figure 706. Counter timing diagram, internal clock divided by 4

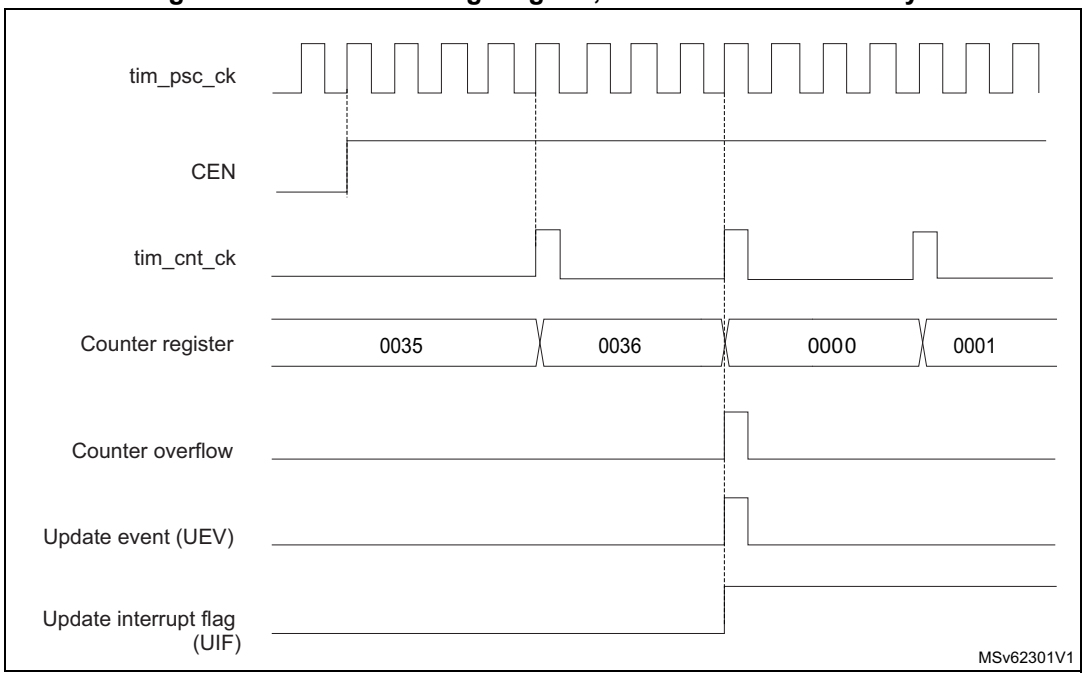


Figure 707. Counter timing diagram, internal clock divided by N

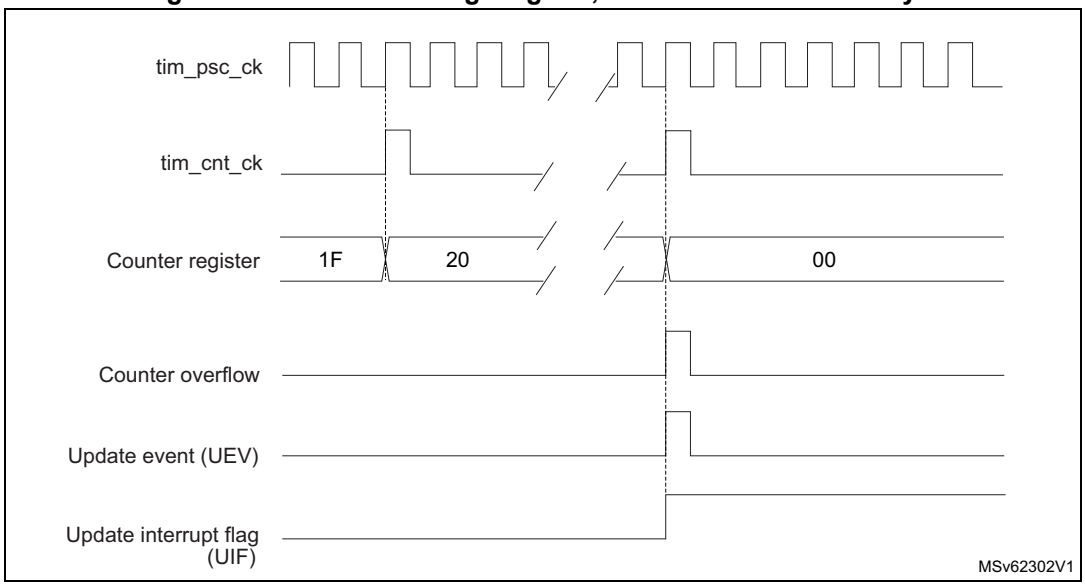


Figure 708. Counter timing diagram, update event when ARPE = 0 (TIMx_ARR not preloaded)

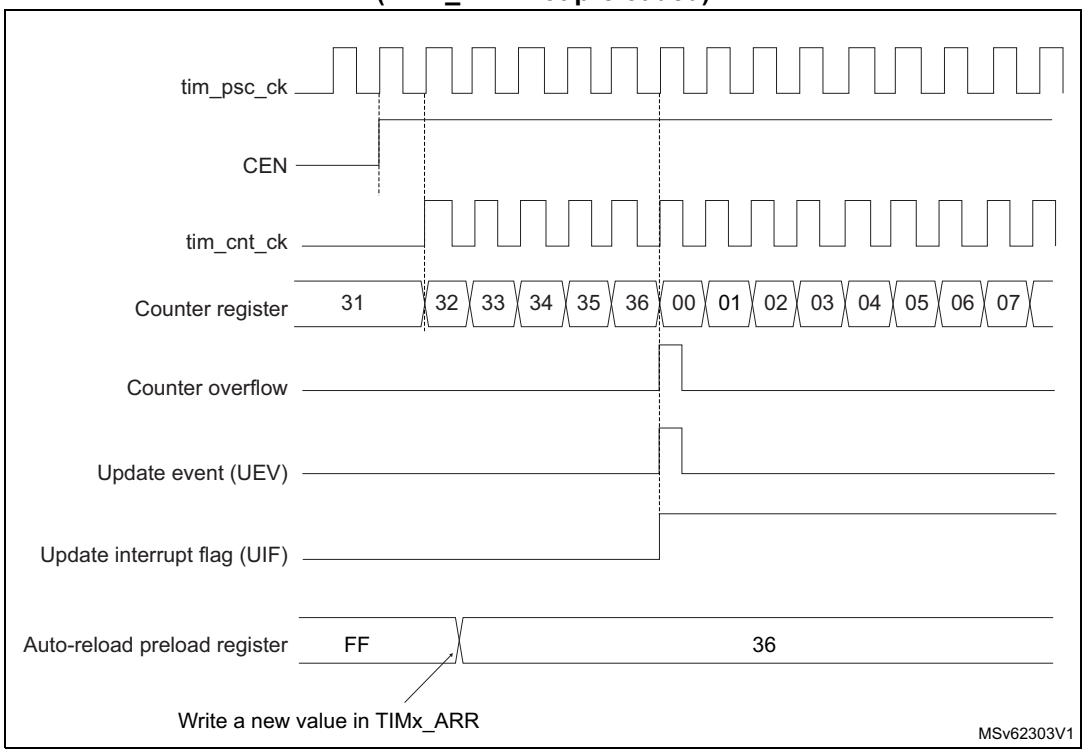
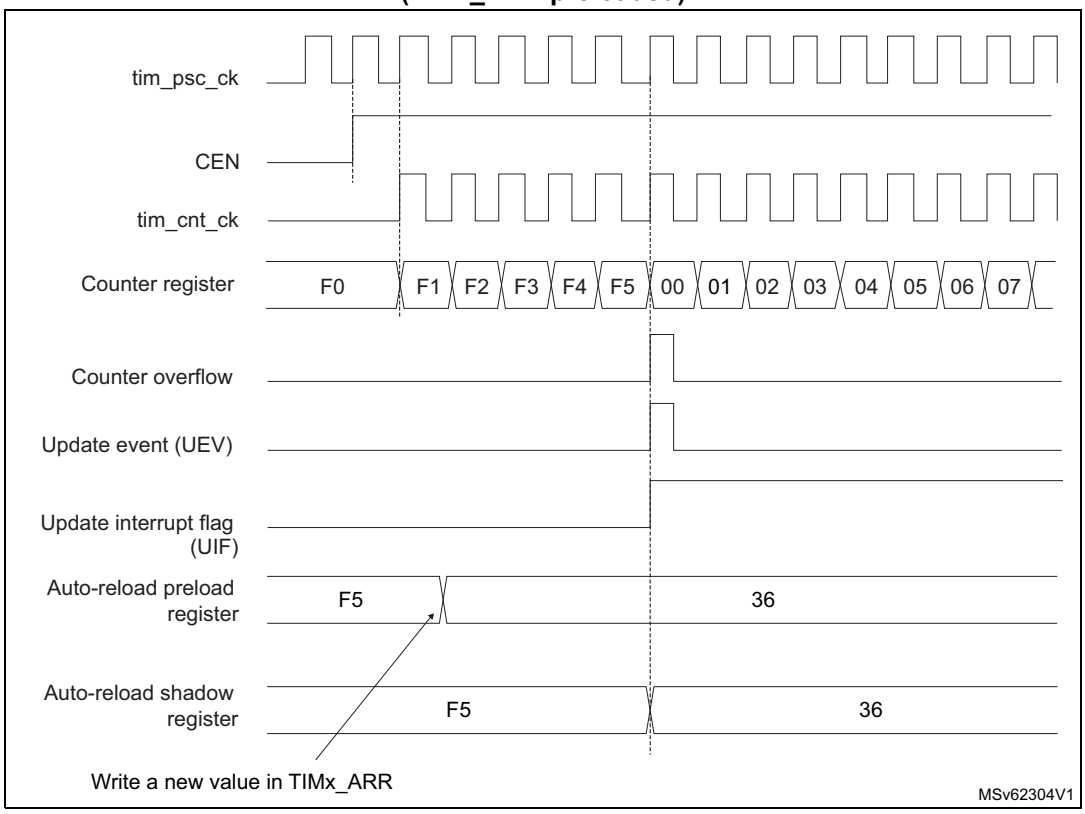


Figure 709. Counter timing diagram, update event when ARPE = 1 (TIMx_ARR preloaded)



53.4.5 Repetition counter

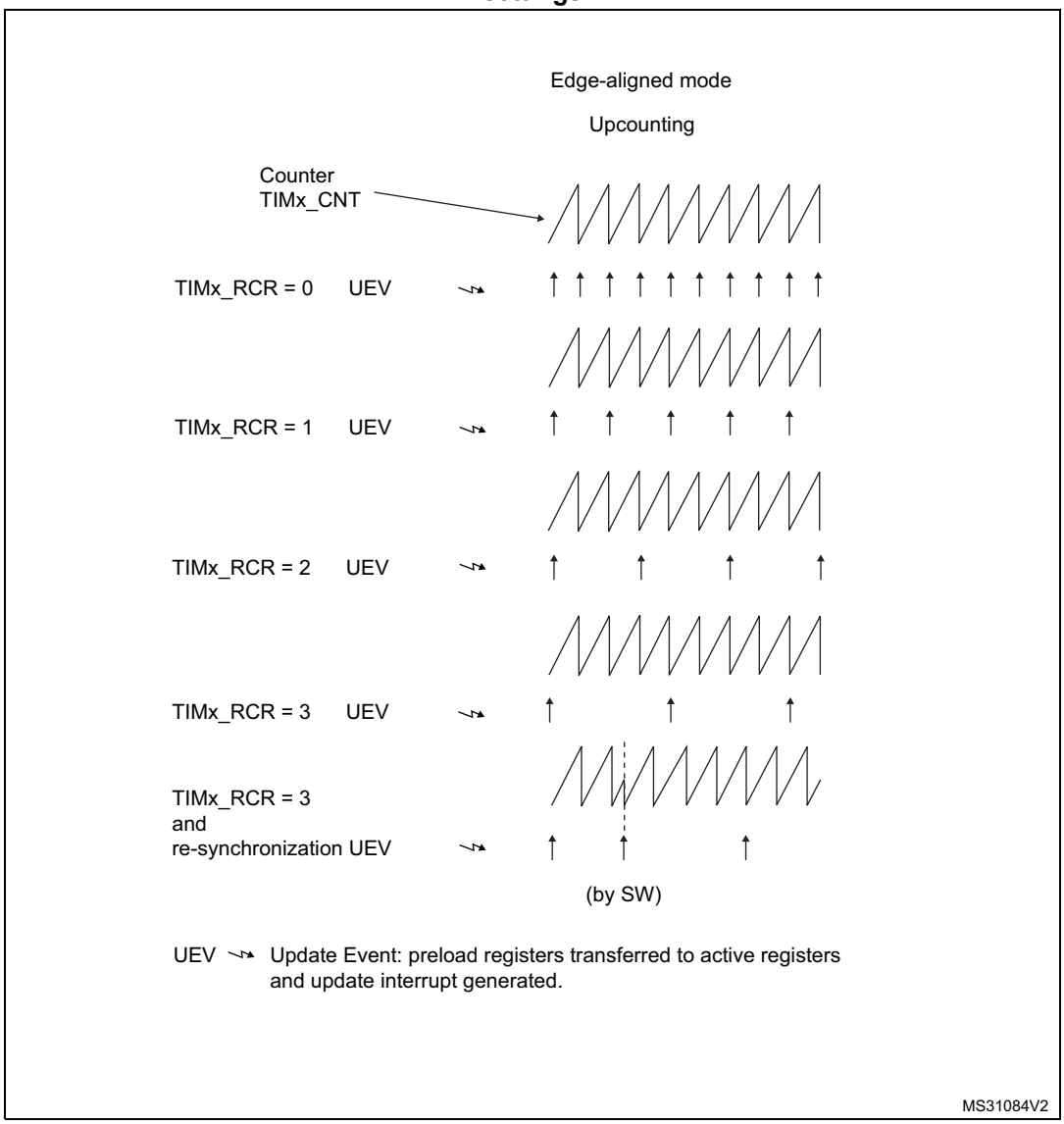
Section 53.4.3: Time-base unit describes how the update event (UEV) is generated with respect to the counter overflows. It is actually generated only when the repetition counter has reached zero. This can be useful when generating PWM signals.

This means that data are transferred from the preload registers to the shadow registers (TIMx_ARR autoreload register, TIMx_PSC prescaler register, but also TIMx_CCRx capture/compare registers in compare mode) every N counter overflows, where N is the value in the TIMx_RCR repetition counter register.

The repetition counter is decremented at each counter overflow.

The repetition counter is an autoreload type; the repetition rate is maintained as defined by the TIMx_RCR register value (refer to *Figure 710*). When the update event is generated by software (by setting the UG bit in TIMx_EGR register) or by hardware through the slave mode controller, it occurs immediately whatever the value of the repetition counter is and the repetition counter is reloaded with the content of the TIMx_RCR register.

Figure 710. Update rate examples depending on mode and TIMx_RCR register settings



53.4.6 Clock selection

The counter clock can be provided by the following clock sources:

- Internal clock (tim_ker_ck)
- External clock mode1: external input pin (tim_ti1 or tim_ti2, if available)
- Internal trigger inputs (tim_itrx) (only for TIM15): using one timer as the prescaler for another timer, for example, TIM1 can be configured to act as a prescaler for TIM15. Refer to *Using one timer as prescaler for another timer* for more details.

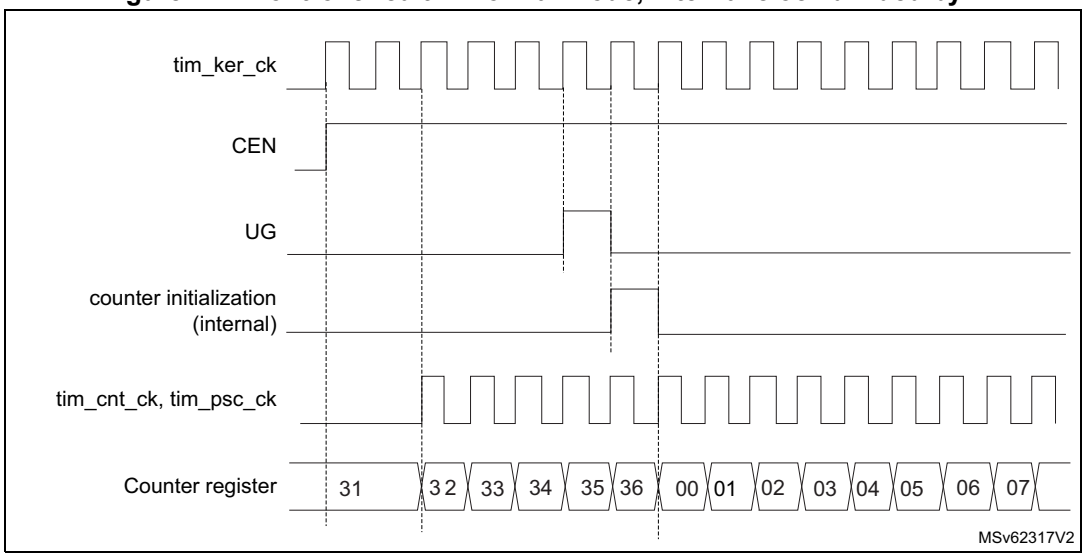
Internal clock source (tim_ker_ck)

If the slave mode controller is disabled (SMS = 000), then the CEN (in the TIMx_CR1 register) and UG bits (in the TIMx_EGR register) are actual control bits and can be changed

only by software (except UG which remains cleared automatically). As soon as the CEN bit is written to 1, the prescaler is clocked by the internal clock tim_ker_ck.

Figure 711 shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

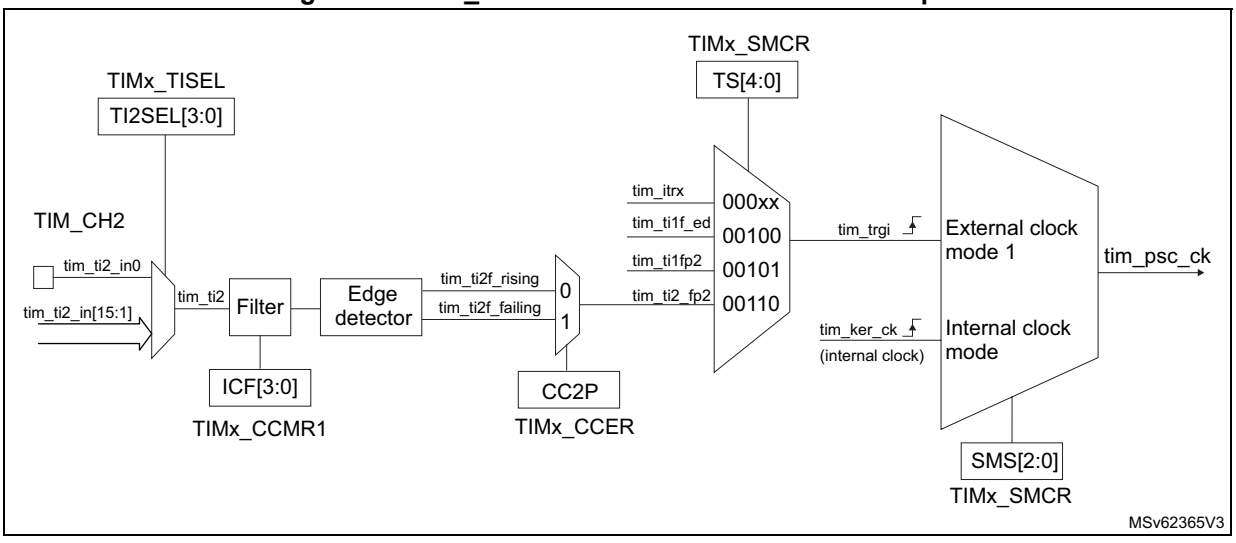
Figure 711. Control circuit in normal mode, internal clock divided by 1



External clock source mode 1

This mode is selected when SMS = 111 in the TIMx_SMCR register. The counter can count at each rising or falling edge on a selected input.

Figure 712. tim_ti2 external clock connection example



For example, to configure the upcounter to count in response to a rising edge on the tim_ti2 input, use the following procedure:

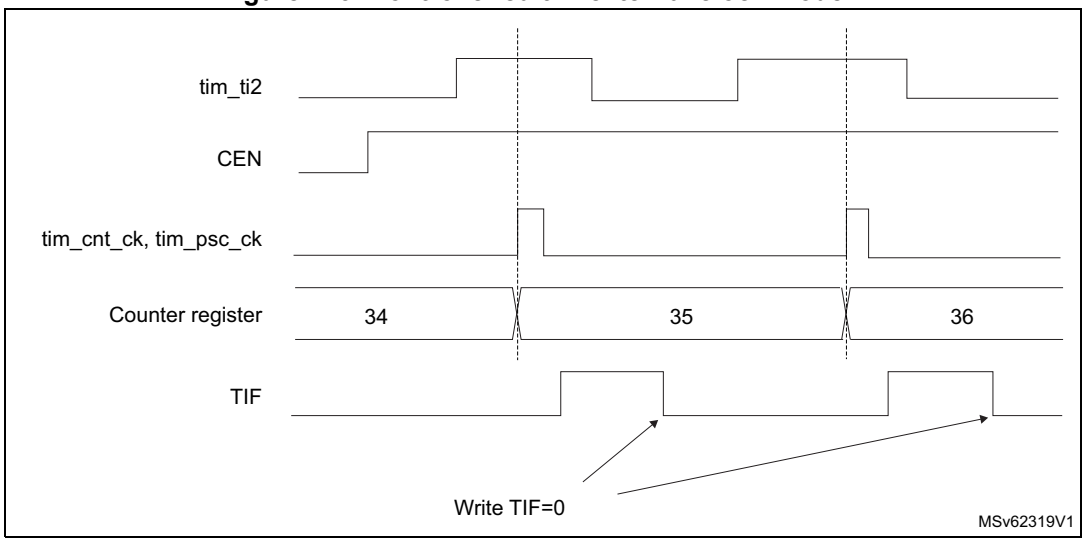
1. Select the proper tim_ti2_in[15:0] source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Configure channel 2 to detect rising edges on the tim_ti2 input by writing CC2S = 01 in the TIMx_CCMR1 register.
3. Configure the input filter duration by writing the IC2F[3:0] bits in the TIMx_CCMR1 register (if no filter is needed, keep IC2F = 0000).
4. Select rising edge polarity by writing CC2P = 0 in the TIMx_CCER register.
5. Configure the timer in external clock mode 1 by writing SMS = 111 in the TIMx_SMCR register.
6. Select tim_ti2 as the trigger input source by writing TS = 00110 in the TIMx_SMCR register.
7. Enable the counter by writing CEN = 1 in the TIMx_CR1 register.

Note: The capture prescaler is not used for triggering, it is not necessary to configure it.

When a rising edge occurs on tim_ti2, the counter counts once and the TIF flag is set.

The delay between the rising edge on tim_ti2 and the actual clock of the counter is due to the resynchronization circuit on tim_ti2 input.

Figure 713. Control circuit in external clock mode 1



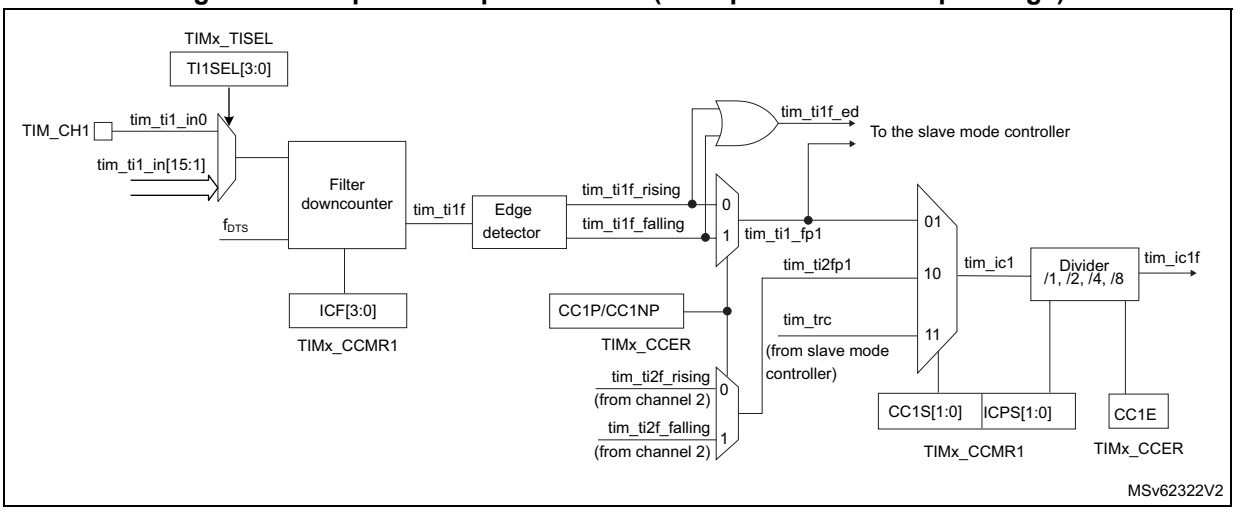
53.4.7 Capture/compare channels

Each Capture/Compare channel is built around a capture/compare register (including a shadow register), a input stage for capture (with digital filter, multiplexing and prescaler) and an output stage (with comparator and output control).

Figure 714 to *Figure 717* give an overview of one Capture/Compare channel.

The input stage samples the corresponding tim_tix input to generate a filtered signal tim_tixf. Then, an edge detector with polarity selection generates a signal (tim_tixfpy) which can be used as trigger input by the slave mode controller or as the capture command. It is prescaled before the capture register (ICxPS).

Figure 714. Capture/compare channel (example: channel 1 input stage)



The output stage generates an intermediate waveform which is then used for reference: tim_ocxref (active high). The polarity acts at the end of the chain.

Figure 715. Capture/compare channel 1 main circuit

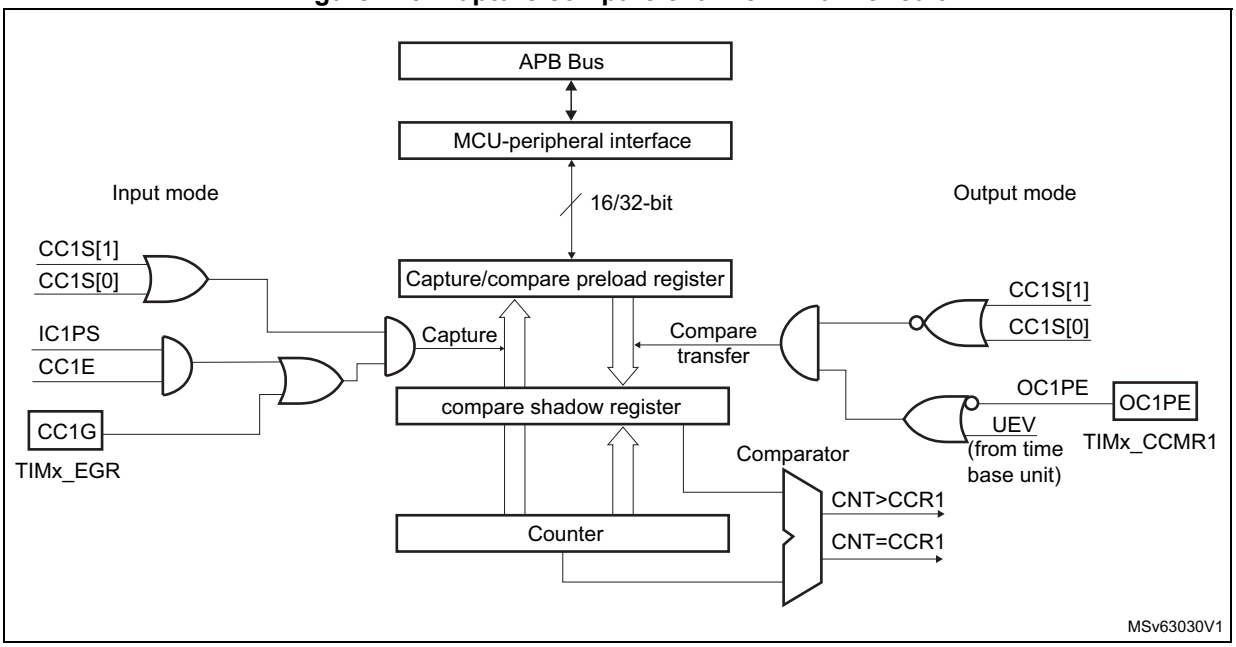


Figure 716. Output stage of capture/compare channel (channel 1)

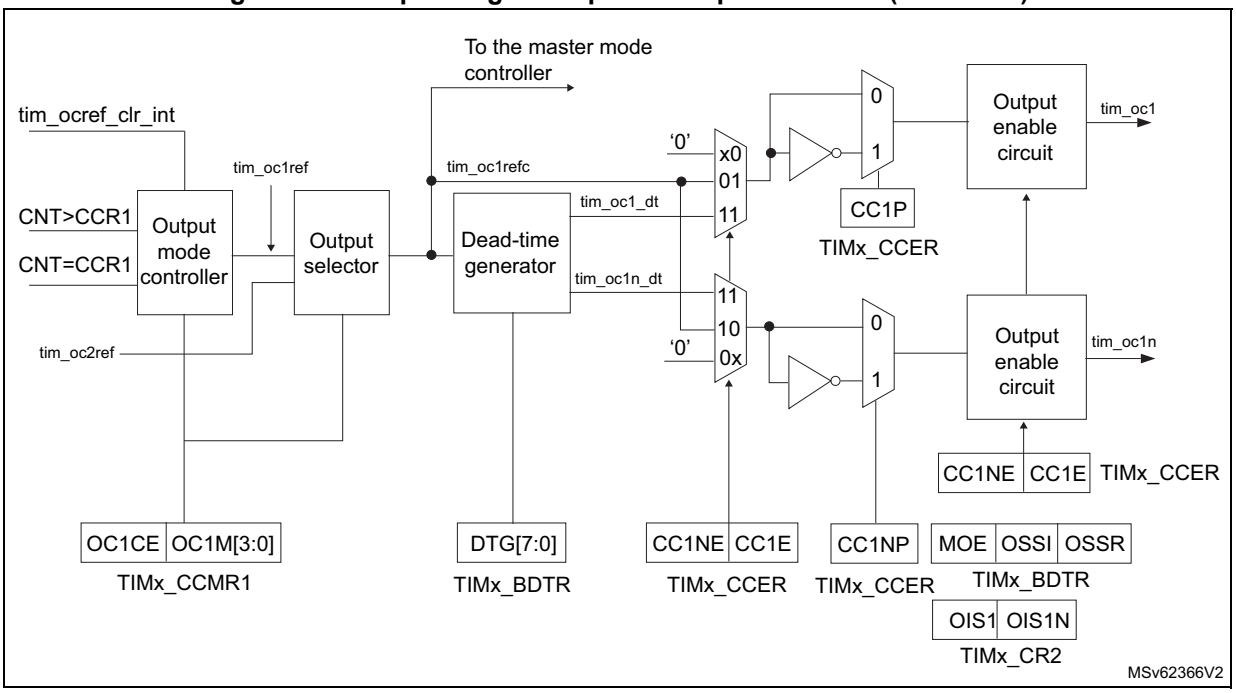
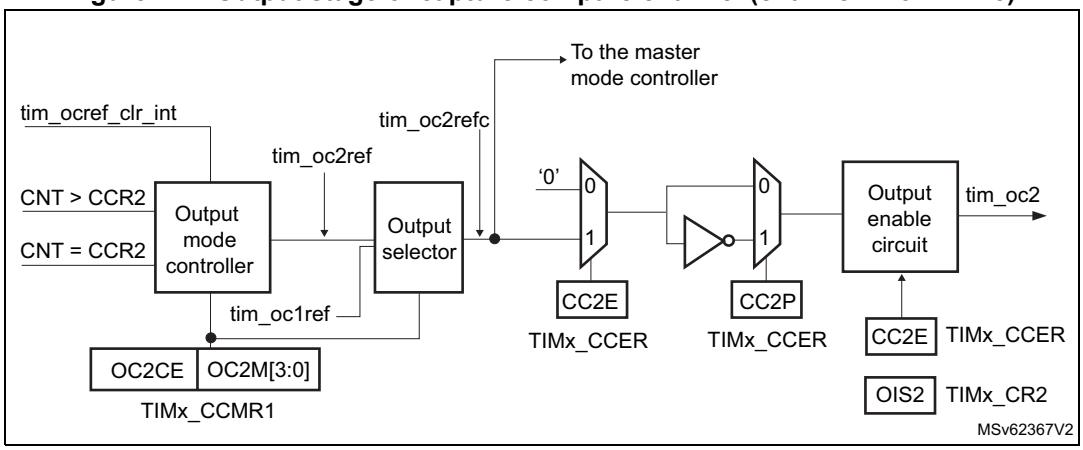


Figure 717. Output stage of capture/compare channel (channel 2 for TIM15)



The capture/compare block is made of one preload register and one shadow register. Write and read always access the preload register.

In capture mode, captures are actually done in the shadow register, which is copied into the preload register.

In compare mode, the content of the preload register is copied into the shadow register which is compared to the counter.

53.4.8 Input capture mode

In Input capture mode, the capture/compare registers (TIMx_CCRx) are used to latch the value of the counter after a transition detected by the corresponding tim_icx signal. When a capture occurs, the corresponding CCXIF flag (TIMx_SR register) is set and an interrupt or a DMA request can be sent if they are enabled. If a capture occurs while the CCxIF flag was

already high, then the overcapture flag CCxOF (TIMx_SR register) is set. CCxIF can be cleared by software by writing it to 0 or by reading the captured data stored in the TIMx_CCRx register. CCxOF is cleared when it is written with 0.

The following example shows how to capture the counter value in TIMx_CCR1 when tim_ti1 input rises. To do this, use the following procedure:

1. Select the proper tim_ti1_in[15:1] source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input: TIMx_CCR1 must be linked to the tim_ti1 input, so write the CC1S bits to 01 in the TIMx_CCMR1 register. As soon as CC1S becomes different from 00, the channel is configured in input, and the TIMx_CCR1 register becomes read-only.
3. Program the appropriate input filter duration in relation with the signal connected to the timer (when the input is one of the tim_tix (ICxF bits in the TIMx_CCMRx register). Let's imagine that, when toggling, the input signal is not stable during at least 5 internal clock cycles. The user must program a filter duration longer than these five clock cycles. The user can validate a transition on tim_ti1 when eight consecutive samples with the new level have been detected (sampled at f_{DTS} frequency). Then write IC1F bits to 0011 in the TIMx_CCMR1 register.
4. Select the edge of the active transition on the tim_ti1 channel by writing CC1P bit to 0 in the TIMx_CCER register (rising edge in this case).
5. Program the input prescaler. In this example, the user wants the capture to be performed at each valid transition, so the prescaler is disabled (write IC1PS bits to 00 in the TIMx_CCMR1 register).
6. Enable capture from the counter into the capture register by setting the CC1E bit in the TIMx_CCER register.
7. If needed, enable the related interrupt request by setting the CC1IE bit in the TIMx_DIER register, and/or the DMA request by setting the CC1DE bit in the TIMx_DIER register.

When an input capture occurs:

- The TIMx_CCR1 register gets the value of the counter on the active transition.
- CC1IF flag is set (interrupt flag). CC1OF is also set if at least two consecutive captures occurred whereas the flag was not cleared.
- An interrupt is generated depending on the CC1IE bit.
- A DMA request is generated depending on the CC1DE bit.

In order to handle the overcapture, it is recommended to read the data before the overcapture flag. This is to avoid missing an overcapture which may happen after reading the flag and before reading the data.

Note: IC interrupt and/or DMA requests can be generated by software by setting the corresponding CCxG bit in the TIMx_EGR register.

53.4.9 PWM input mode (only for TIM15)

This mode is used to measure both the period and the duty cycle of a PWM signal connected to single tim_tix input:

- The TIMx_CCR1 register holds the period value (interval between two consecutive rising edges)
- The TIMx_CCR2 register holds the pulse width (interval between two consecutive rising and falling edges)

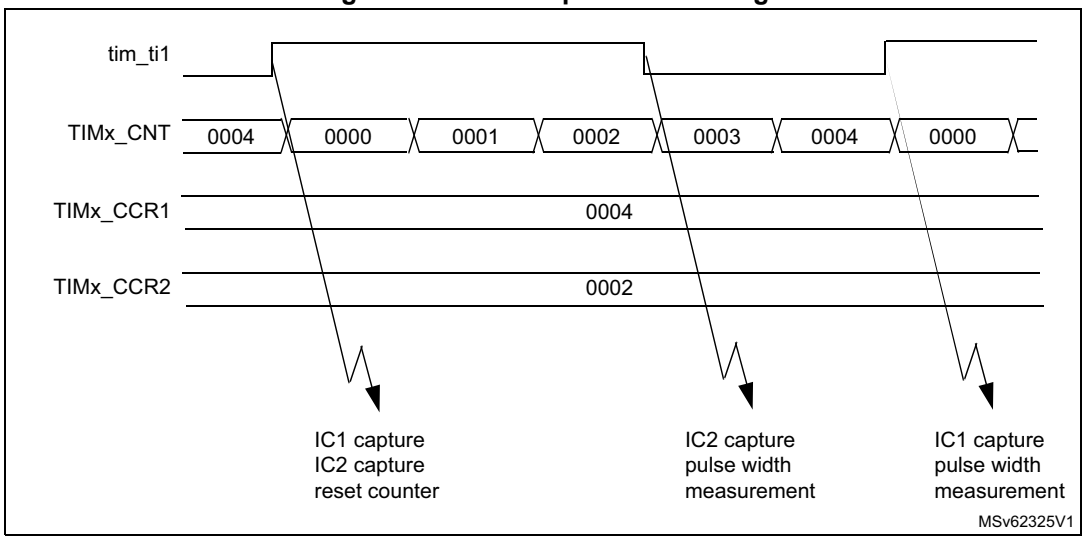
This mode is a particular case of input capture mode. The set-up procedure is similar with the following differences:

- Two tim_icx signals are mapped on the same tim_tix input.
- These two tim_icx signals are active on edges with opposite polarity.
- One of the two tim_tixfpy signals is selected as trigger input and the slave mode controller is configured in reset mode.

For example, one can measure the period (in TIMx_CCR1 register) and the duty cycle (in TIMx_CCR2 register) of the PWM applied on tim_ti1 using the following procedure (depending on tim_ker_ck frequency and prescaler value):

1. Select the proper tim_ti1_in[15:0] source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input for TIMx_CCR1: write the CC1S bits to 01 in the TIMx_CCMR1 register (tim_ti1 selected).
3. Select the active polarity for tim_ti1fp1 (used both for capture in TIMx_CCR1 and counter clear): write the CC1P and CC1NP bits to 0 (active on rising edge).
4. Select the active input for TIMx_CCR2: write the CC2S bits to 10 in the TIMx_CCMR1 register (tim_ti1 selected).
5. Select the active polarity for tim_ti1fp2 (used for capture in TIMx_CCR2): write the CC2P and CC2NP bits to 10 (active on falling edge).
6. Select the valid trigger input: write the TS bits to 00101 in the TIMx_SMCR register (tim_ti1fp1 selected).
7. Configure the slave mode controller in reset mode: write the SMS bits to 100 in the TIMx_SMCR register.
8. Enable the captures: write the CC1E and CC2E bits to 1 in the TIMx_CCER register.

Figure 718. PWM input mode timing



1. The PWM input mode can be used only with the TIMx_CH1/TIMx_CH2 signals due to the fact that only tim_ti1fp1 and tim_ti2fp2 are connected to the slave mode controller.

53.4.10 Forced output mode

In output mode (CCxS bits = 00 in the TIMx_CCMRx register), each output compare signal (tim_ocxref and then tim_ocx/tim_ocxn) can be forced to active or inactive level directly by software, independently of any comparison between the output compare register and the counter.

To force an output compare signal (tim_ocxref/tim_ocx) to its active level, one just needs to write 101 in the OCxM bits in the corresponding TIMx_CCMRx register. Thus tim_ocxref is forced high (tim_ocxref is always active high) and tim_ocx get opposite value to CCxP polarity bit.

For example: CCxP = 0 (tim_ocx active high) → tim_ocx is forced to high level.

The tim_ocxref signal can be forced low by writing the OCxM bits to 100 in the TIMx_CCMRx register.

Anyway, the comparison between the TIMx_CCRx shadow register and the counter is still performed and allows the flag to be set. Interrupt and DMA requests can be sent accordingly. This is described in the output compare mode section below.

53.4.11 Output compare mode

This function is used to control an output waveform or indicating when a period of time has elapsed.

When a match is found between the capture/compare register and the counter, the output compare function:

- Assigns the corresponding output pin to a programmable value defined by the output compare mode (OCxM bits in the TIMx_CCMRx register) and the output polarity (CCxP bit in the TIMx_CCER register). The output pin can keep its level (OCXM = 000), be set

active (OCxM = 001), be set inactive (OCxM = 010) or can toggle (OCxM = 011) on match.

- Sets a flag in the interrupt status register (CCxIF bit in the TIMx_SR register).
- Generates an interrupt if the corresponding interrupt mask is set (CCXIE bit in the TIMx_DIER register).
- Sends a DMA request if the corresponding enable bit is set (CCxDE bit in the TIMx_DIER register, CCDS bit in the TIMx_CR2 register for the DMA request selection).

The TIMx_CCRx registers can be programmed with or without preload registers using the OCxPE bit in the TIMx_CCMRx register.

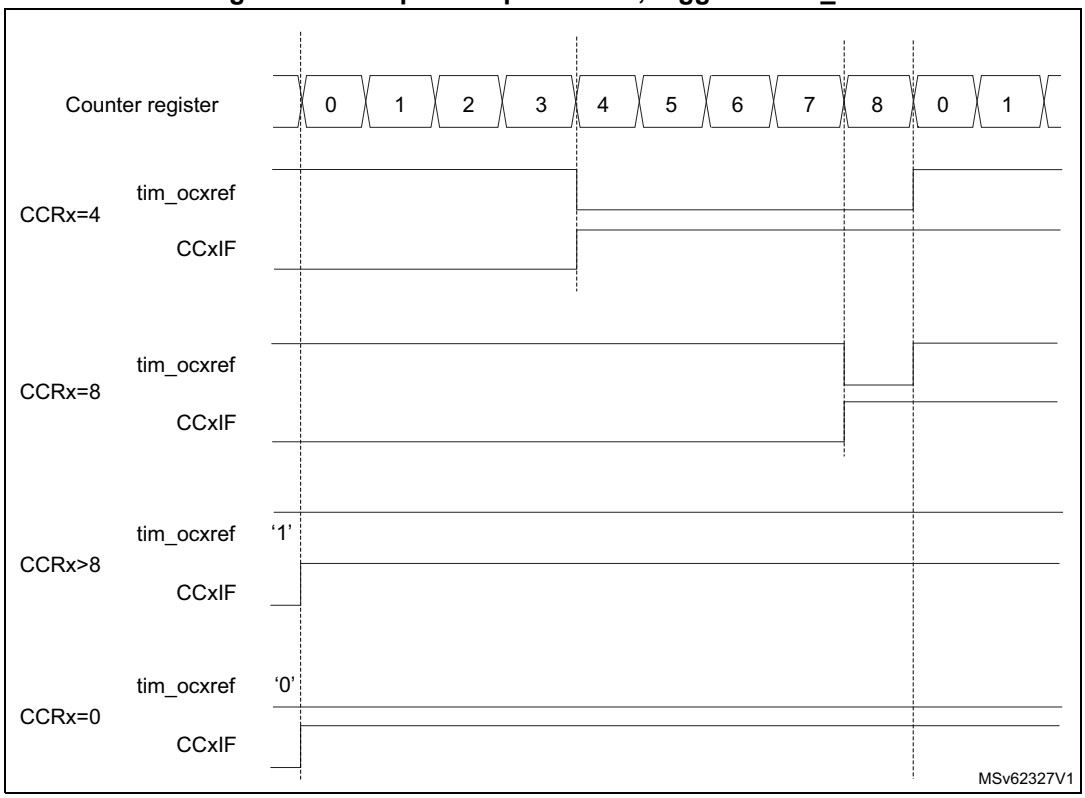
In output compare mode, the update event UEV has no effect on tim_ocxref and tim_ocx output. The timing resolution is one count of the counter. Output compare mode can also be used to output a single pulse (in One-pulse mode).

Procedure

1. Select the counter clock (internal, external, prescaler).
2. Write the desired data in the TIMx_ARR and TIMx_CCRx registers.
3. Set the CCxIE bit if an interrupt request is to be generated.
4. Select the output mode. For example:
   - Write OCxM = 011 to toggle tim_ocx output pin when CNT matches CCRx
   - Write OCxPE = 0 to disable preload register
   - Write CCxP = 0 to select active high polarity
   - Write CCxE = 1 to enable the output
5. Enable the counter by setting the CEN bit in the TIMx_CR1 register.

The TIMx_CCRx register can be updated at any time by software to control the output waveform, provided that the preload register is not enabled (OCxPE = 0, else TIMx_CCRx shadow register is updated only at the next update event UEV). An example is given in *Figure 719*.

Figure 719. Output compare mode, toggle on tim_oc1



53.4.12 PWM mode

Pulse width modulation mode is used to generate a signal with a frequency determined by the value of the TIMx_ARR register and a duty cycle determined by the value of the TIMx_CCRx register.

The PWM mode can be selected independently on each channel (one PWM per tim_ocx output) by writing 110 (PWM mode 1) or 111 (PWM mode 2) in the OCxM bits in the TIMx_CCMRx register. The corresponding preload register must be enabled by setting the OCxPE bit in the TIMx_CCMRx register, and eventually the autoreload preload register (in upcounting or center-aligned modes) by setting the ARPE bit in the TIMx_CR1 register.

As the preload registers are transferred to the shadow registers only when an update event occurs, before starting the counter, all registers must be initialized by setting the UG bit in the TIMx_EGR register.

tim_ocx polarity is software programmable using the CCxP bit in the TIMx_CCER register. It can be programmed as active high or active low. tim_ocx output is enabled by a combination of the CCxE, CCxNE, MOE, OSSI, and OSSR bits (TIMx_CCER and TIMx_BDTR registers). Refer to the TIMx_CCER register description for more details.

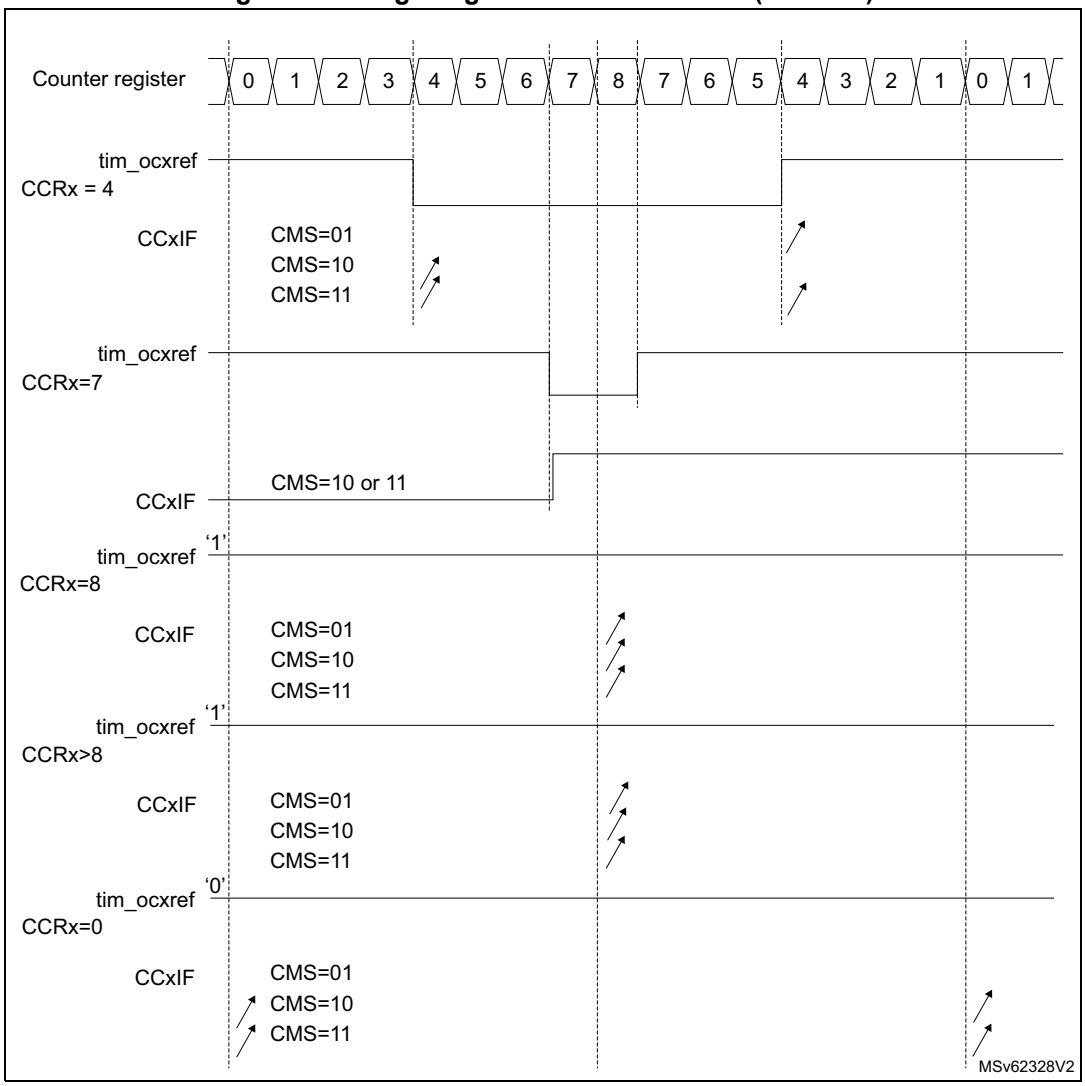
In PWM mode (1 or 2), TIMx_CNT and TIMx_CCRx are always compared to determine whether TIMx_CCRx ≤ TIMx_CNT or TIMx_CNT ≤ TIMx_CCRx (depending on the direction of the counter).

The TIM15/TIM16/TIM17 are capable of upcounting only. Refer to *Upcounting mode*.

In the following example applies to PWM mode 1. The reference PWM signal tim_ocxref is high as long as TIMx_CNT < TIMx_CCRx else it becomes low. If the compare value in

TIMx_CCRx is greater than the autoreload value (in TIMx_ARR) then tim_ocxref is held at 1. If the compare value is 0 then tim_ocxref is held at 0. *Figure 720* shows some edge-aligned PWM waveforms in an example where TIMx_ARR = 8.

Figure 720. Edge-aligned PWM waveforms (ARR = 8)

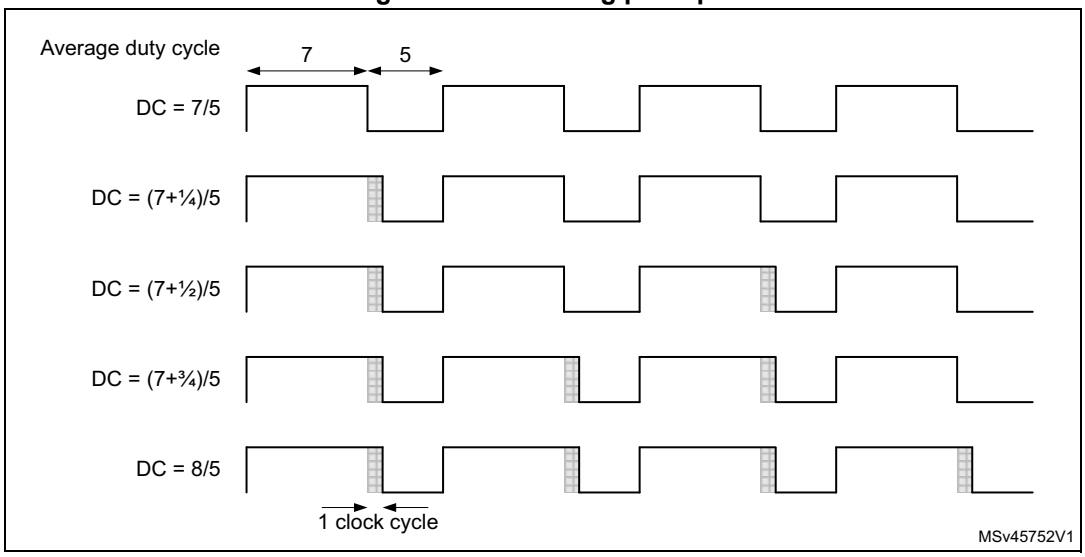


Dithering mode

The PWM mode effective resolution can be increased by enabling the dithering mode, using the DITHEN bit in the TIMx_CR1 register. This applies to both the CCR (for duty cycle resolution increase) and ARR (for PWM frequency resolution increase).

The operating principle is to have the actual CCR (or ARR) value slightly changed (adding or not one timer clock period) over 16 consecutive PWM periods, with predefined patterns. This allows a 16-fold resolution increase, considering the average duty cycle or PWM period. The *Figure 721* below presents the dithering principle applied to four consecutive PWM cycles.

Figure 721. Dithering principle

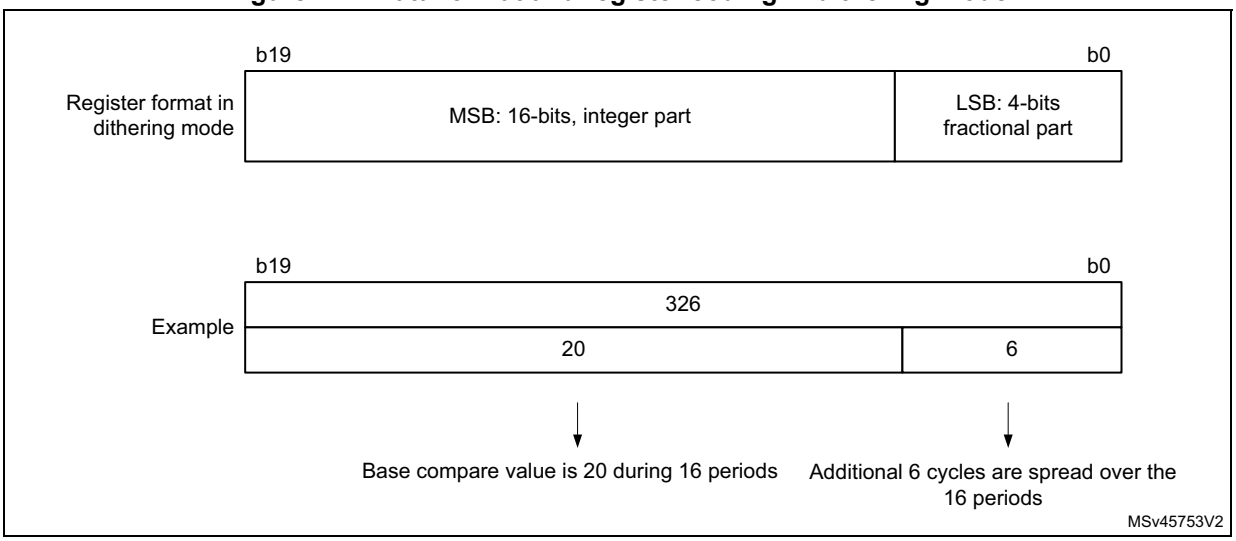


When the dithering mode is enabled, the register coding is changed as follows (see *Figure 722* for example):

- The four LSBs are coding for the enhanced resolution part (fractional part).
- The MSBs are left-shifted to the bits 19:4 and are coding for the base value.

Note: The following sequence must be followed when resetting the DITHEN bit:
1. CEN and ARPE bits must be reset
2. The ARR[3:0] bits must be reset
3. The CCIF flags must be cleared
4. The CEN bit can be set (eventually with ARPE = 1).

Figure 722. Data format and register coding in dithering mode



The minimum frequency is given by the following formula:

$$\text{Resolution} = \frac{F_{Tim}}{F_{pwm}} \Rightarrow F_{pwmMin} = \frac{F_{Tim}}{Max_{Resolution}}$$

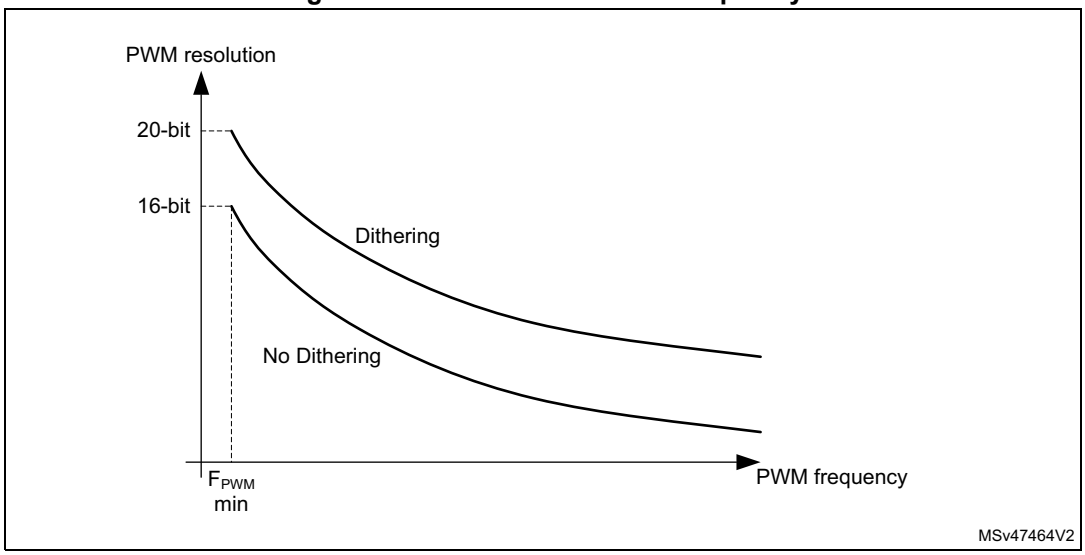
$$\text{Dithering mode disabled: } F_{pwmMin} = \frac{F_{Tim}}{65536}$$

$$\text{Dithering mode enabled: } F_{pwmMin} = \frac{F_{Tim}}{65535 + \frac{15}{16}}$$

Note: The maximum TIMx_ARR and TIMx_CCRy values are limited to 0xFFFEF in dithering mode (corresponds to 65534 for the integer part and 15 for the dithered part).

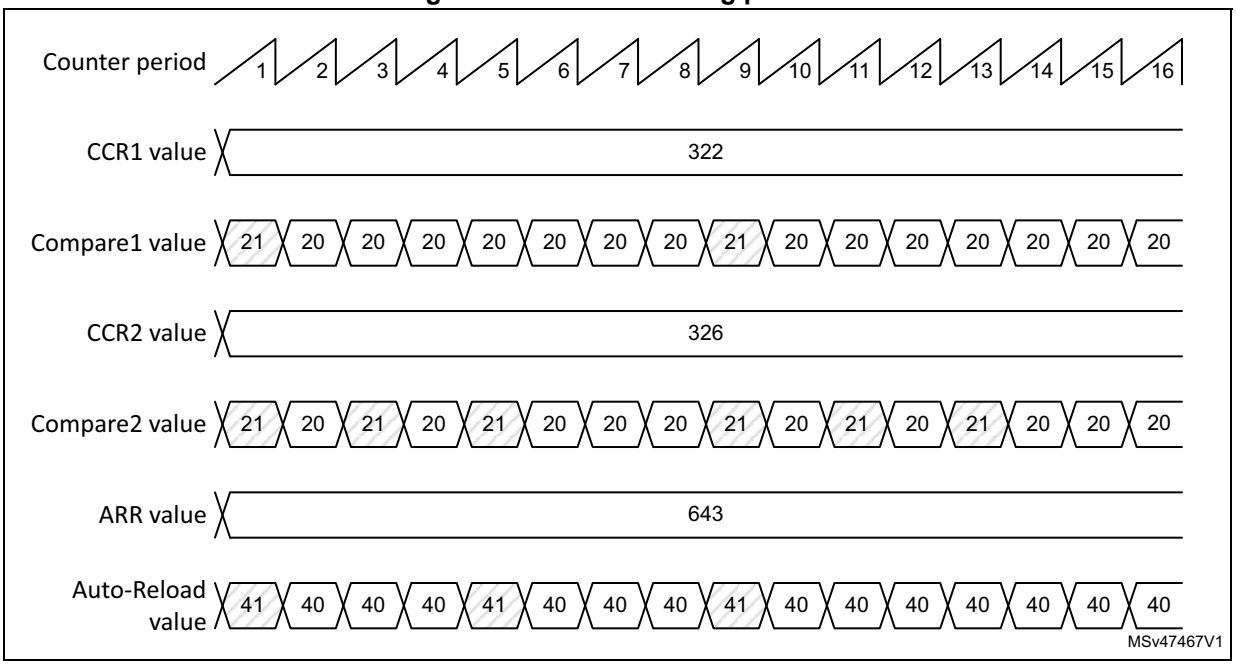
As shown on the *Figure 723* below, the dithering mode is used to increase the PWM resolution whatever the PWM frequency.

Figure 723. PWM resolution vs frequency



The duty cycle and/or period changes are spread over 16 consecutive periods, as described in the *Figure 724* below.

Figure 724. PWM dithering pattern



The autoreload and compare values increments are spread following specific patterns described in the *Table 577* below. The dithering sequence is done to have increments distributed as evenly as possible and minimize the overall ripple.

Table 577. CCR and ARR register change dithering pattern

-	PWM period															
LSB value	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
0000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0001	+1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0010	+1	-	-	-	-	-	-	-	+1	-	-	-	-	-	-	-
0011	+1	-	-	-	+1	-	-	-	+1	-	-	-	-	-	-	-
0100	+1	-	-	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0101	+1	-	+1	-	+1	-	-	-	+1	-	-	-	+1	-	-	-
0110	+1	-	+1	-	+1	-	-	-	+1	-	+1	-	+1	-	-	-
0111	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	-	-
1000	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1001	+1	+1	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
1010	+1	+1	+1	-	+1	-	+1	-	+1	+1	+1	-	+1	-	+1	-
1011	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	-	+1	-
1100	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-
1101	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	-	+1	+1	+1	-

Table 577. CCR and ARR register change dithering pattern (continued)

-	PWM period															
LSB value	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1110	+1	+1	+1	+1	+1	+1	+1	-	+1	+1	+1	+1	+1	+1	+1	-
1111	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	-

53.4.13 Combined PWM mode (TIM15 only)

Combined PWM mode allows two edge or center-aligned PWM signals to be generated with programmable delay and phase shift between respective pulses. While the frequency is determined by the value of the TIMx_ARR register, the duty cycle and delay are determined by the two TIMx_CCRx registers. The resulting signals, tim_ocxrefc, are made of an OR or AND logical combination of two reference PWMs:

- tim_oc1refc (or tim_oc2refc) is controlled by the TIMx_CCR1 and TIMx_CCR2 registers.

Combined PWM mode can be selected independently on two channels (one tim_ocx output per pair of CCR registers) by writing 1100 (Combined PWM mode 1) or 1101 (Combined PWM mode 2) in the OCxM bits in the TIMx_CCMRx register.

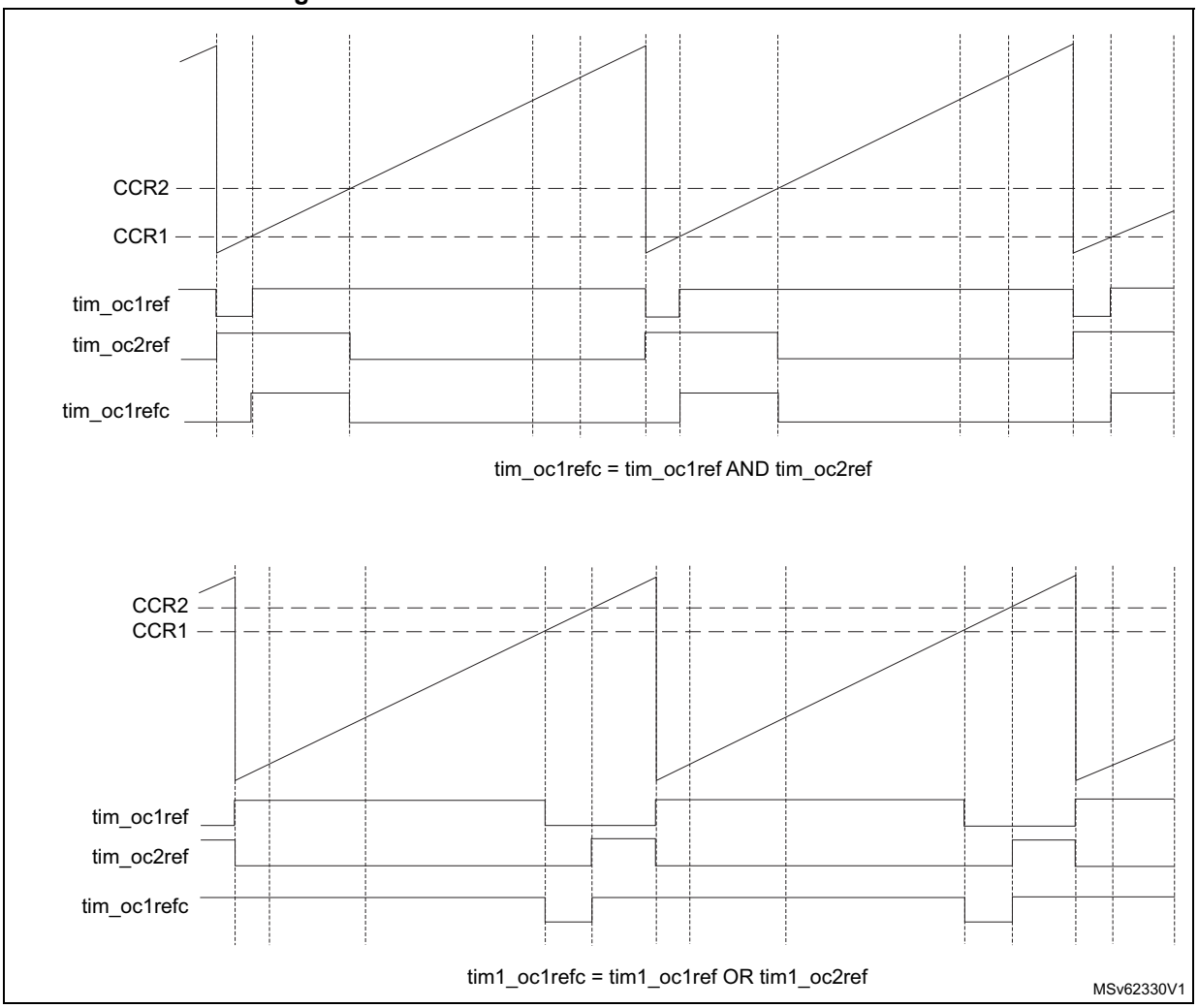
When a given channel is used as a combined PWM channel, its complementary channel must be configured in the opposite PWM mode (for instance, one in Combined PWM mode 1 and the other in Combined PWM mode 2).

Note: The OCxM[3:0] bitfield is split into two parts for compatibility reasons, the most significant bit is not contiguous with the three least significant ones.

Table 725 represents an example of signals that can be generated using Combined PWM mode, obtained with the following configuration:

- Channel 1 is configured in Combined PWM mode 2.
- Channel 2 is configured in PWM mode 1.

Figure 725. Combined PWM mode on channel 1 and 2



53.4.14 Complementary outputs and dead-time insertion

The TIM15/TIM16/TIM17 general-purpose timers can output one complementary signal and manage the switching-off and switching-on of the outputs.

This time is generally known as dead-time and it has to be adjusted depending on the devices that are connected to the outputs and their characteristics (such as intrinsic delays of level-shifters and delays due to power switches)

The polarity of the outputs (main output tim_ocx or complementary tim_ocxn) can be selected independently for each output. This is done by writing to the CCxP and CCxNP bits in the TIMx_CCER register.

The complementary signals tim_ocx and tim_ocxn are activated by a combination of several control bits: the CCxE and CCxNE bits in the TIMx_CCER register and the MOE, OISx, OISxN, OSSI and OSSR bits in the TIMx_BDTR and TIMx_CR2 registers. Refer to *Table 584: Output control bits for complementary tim_oc1 and tim_oc1n channels with break feature (TIM16/TIM17)* for more details. In particular, the dead-time is activated when switching to the idle state (MOE falling down to 0).

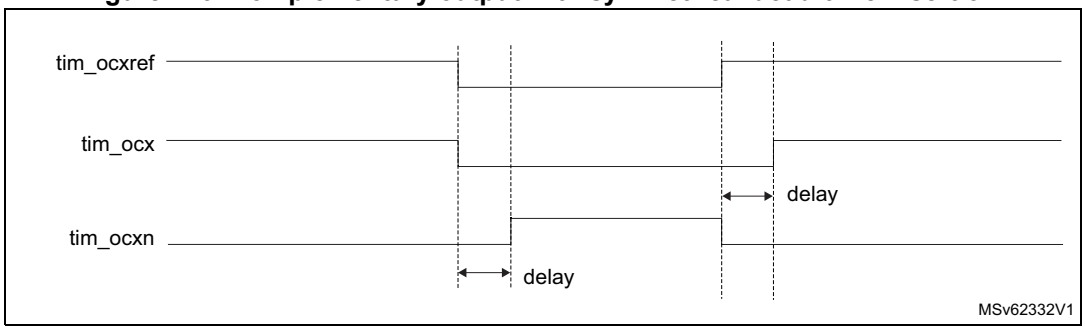
Dead-time insertion is enabled by setting both CCxE and CCxNE bits, and the MOE bit if the break circuit is present. There is one 10-bit dead-time generator for each channel. From a reference waveform tim_ocxref, it generates two outputs tim_ocx and tim_ocxn. If tim_ocx and tim_ocxn are active high:

- The tim_ocx output signal is the same as the reference signal except for the rising edge, which is delayed relative to the reference rising edge.
- The tim_ocxn output signal is the opposite of the reference signal except for the rising edge, which is delayed relative to the reference falling edge.

If the delay is greater than the width of the active output (tim_ocx or tim_ocxn) then the corresponding pulse is not generated.

The following figures show the relationships between the output signals of the dead-time generator and the reference signal tim_ocxref. (in these examples CCxP = 0, CCxNP = 0, MOE = 1, CCxE = 1 and CCxNE = 1)

Figure 726. Complementary output with symmetrical dead-time insertion.



The DTAE bit in the TIMx_DTR2 is used to differentiate the deadtime values for rising and falling edges of the reference signal, as shown on *Figure 727*.

In asymmetrical mode (DTAE = 1), the rising edge-referred deadtime is defined by the DTG[7:0] bitfield in the TIMx_BDTR register, while the falling edge-referred is defined by the DTGF[7:0] bitfield in the TIMx_DTR2 register. The DTAE bit must be written before enabling the counter and must not be modified while CEN = 1.

It is possible to have the deadtime value updated on-the-fly during pwm operation, using a preload mechanism. The deadtime bitfield DTG[7:0] and DTGF[7:0] are preloaded when the DTPE bit is set in the TIMX_DTR2 register. The preload value is loaded in the active register on the next update event.

Note: If the DTPE bit is enabled while the counter is enabled, any new value written since last update is discarded and previous value is used.

Figure 727. Asymmetrical deadtime

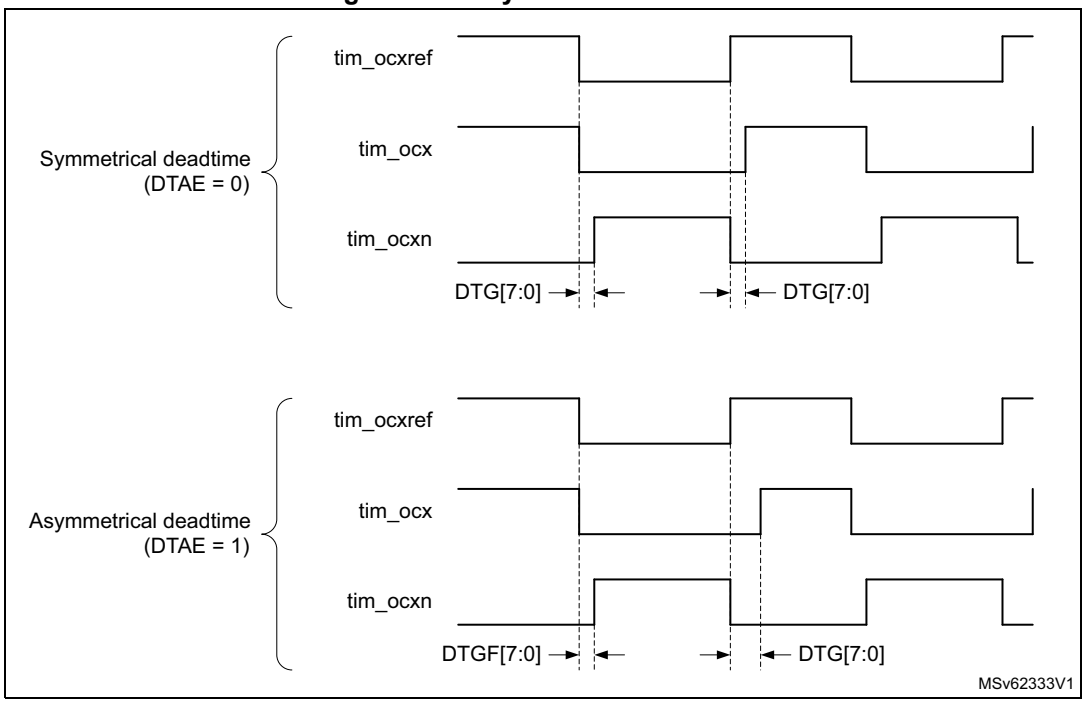


Figure 728. Dead-time waveforms with delay greater than the negative pulse.

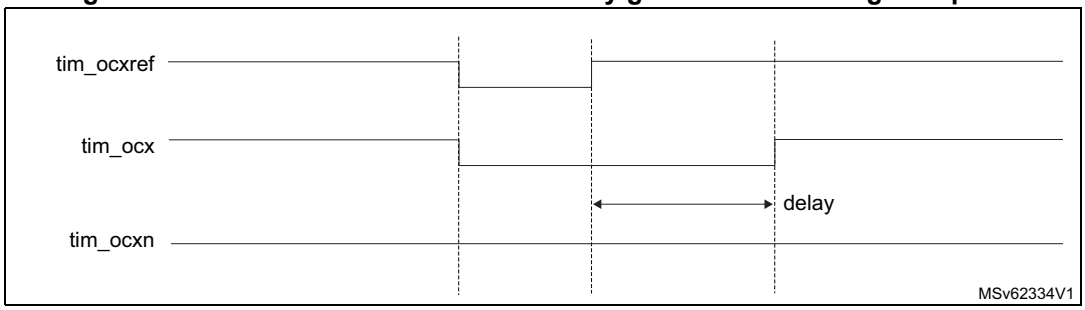
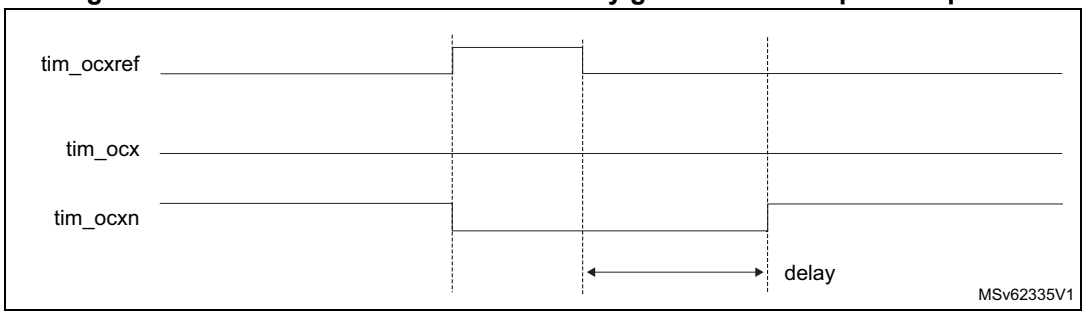


Figure 729. Dead-time waveforms with delay greater than the positive pulse.



The dead-time delay is the same for each of the channels and is programmable with the DTG bits in the TIMx_BDTR register. Refer to *Section 53.8.14: TIMx break and dead-time register (TIMx_BDTR)(x = 16 to 17)* for delay calculation.

Redirecting tim_ocxref to tim_ocx or tim_ocxn

In output mode (forced, output compare or PWM), tim_ocxref can be redirected to the tim_ocx output or to tim_ocxn output by configuring the CCxE and CCxNE bits in the TIMx_CCER register.

This is used to send a specific waveform (such as PWM or static active level) on one output while the complementary remains at its inactive level. Other alternative possibilities are to have both outputs at inactive level or both outputs active and complementary with dead-time.

Note: When only tim_ocxn is enabled (CCxE = 0, CCxNE = 1), it is not complemented and becomes active as soon as tim_ocxref is high. For example, if CCxNP = 0 then tim_ocxn = tim_ocxref. On the other hand, when both tim_ocx and tim_ocxn are enabled (CCxE = CCxNE = 1) tim_ocx becomes active when tim_ocxref is high whereas tim_ocxn is complemented and becomes active when tim_ocxref is low.

53.4.15 Using the break function

The purpose of the break function is to protect power switches driven by PWM signals generated with the timers. The break input is usually connected to fault outputs of power stages and 3-phase inverters. When activated, the break circuitry shuts down the PWM outputs and forces them to a predefined safe state.

The break channel gathers both system-level fault (such as clock failure, ECC/parity, and errors) and application fault (from input pins and built-in comparator), and can force the outputs to a predefined level (either active or inactive) after a deadtime duration.

The output enable signal and output levels during break are depending on several control bits:

- The MOE bit in TIMx_BDTR register is used to enable /disable the outputs by software and is reset in case of break or break2 event.
- The OSSI bit in the TIMx_BDTR register defines whether the timer controls the output in inactive state or releases the control to the GPIO controller (typically to have it in Hi-Z mode).
- The OISx and OISxN bits in the TIMx_CR2 register which are setting the output shut-down level, either active or inactive. The tim_ocx and tim_ocxn outputs cannot be set both to active level at a given time, whatever the OISx and OISxN values. Refer to *Table 584: Output control bits for complementary tim_oc1 and tim_oc1n channels with break feature (TIM16/TIM17)* for more details.

When exiting from reset, the break circuit is disabled and the MOE bit is low. The break function is enabled by setting the BKE bit in the TIMx_BDTR register. The break input polarity can be selected by configuring the BKP bit in the same register. BKE and BKP can be modified at the same time. When the BKE and BKP bits are written, a delay of one APB clock cycle is applied before the writing is effective. Consequently, it is necessary to wait one APB clock period to correctly read back the bit after the write operation.

Because MOE falling edge can be asynchronous, a resynchronization circuit has been inserted between the actual signal (acting on the outputs) and the synchronous control bit (accessed in the TIMx_BDTR register). It results in some delays between the asynchronous and the synchronous signals. In particular, if MOE is set to 1 whereas it was low, a delay must be inserted (dummy instruction) before reading it correctly. This is because the write acts on the asynchronous signal whereas the read reflects the synchronous signal.

The break is generated by the tim_brk inputs which have:

- Programmable polarity (BKP bit in the TIMx_BDTR register).
- Programmable enable bit (BKE bit in the TIMx_BDTR register).
- Programmable filter (BKF[3:0] bits in the TIMx_BDTR register) to avoid spurious events.

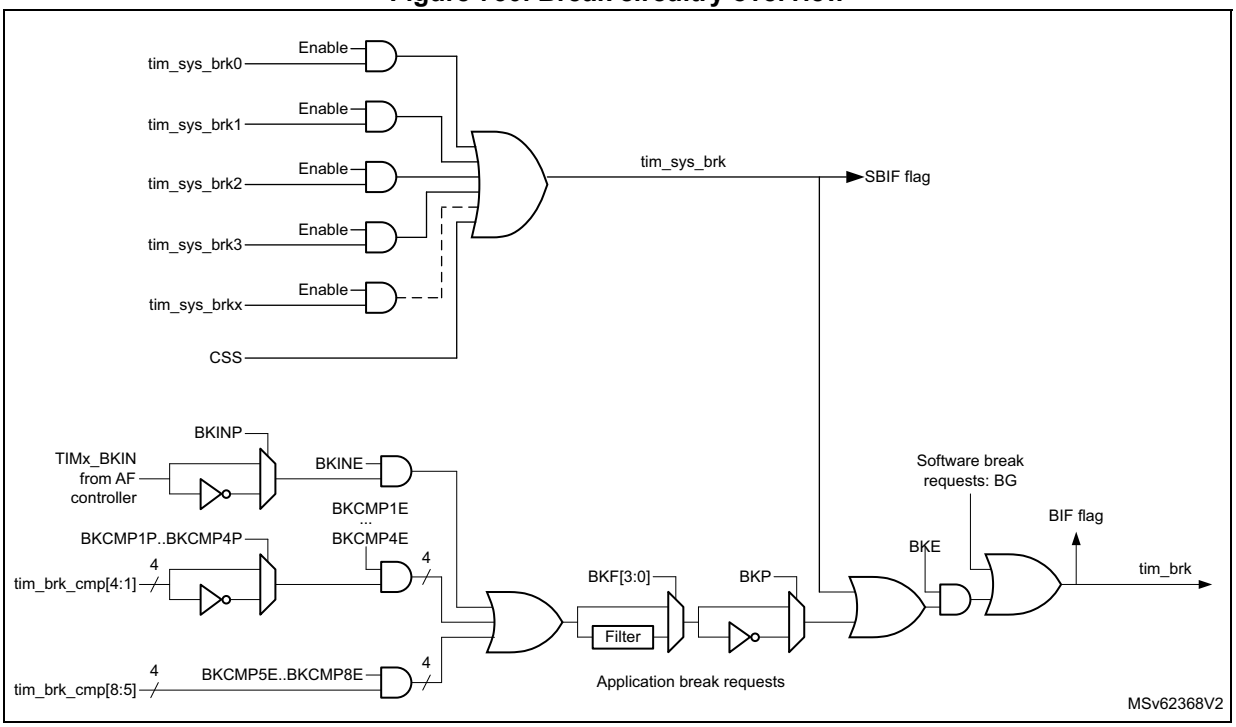
The break can be generated from multiple sources which can be individually enabled and with programmable edge sensitivity, using the TIMx_AF1 register.

The sources for break (tim_brk) channel are:

- External sources connected to one of the TIM_BKIN pins (as per selection done in the GPIO alternate function selection registers), with polarity selection and optional digital filtering.
- Internal sources:
  - Coming from a tim_brk_cmpx input (refer to *Section 53.4.2: TIM15/TIM16/TIM17 pins and internal signals* for product specific implementation).
  - Coming from a system break request on the tim_sys_brk inputs (refer to *Section 53.4.2: TIM15/TIM16/TIM17 pins and internal signals* for product specific implementation).

Break events can also be generated by software using BG bit in the TIMx_EGR register. All sources are ORed before entering the timer tim_brk inputs, as per *Figure 730* below.

Figure 730. Break circuitry overview



Caution: An asynchronous (clockless) operation is only guaranteed when the programmable filter is disabled. If it is enabled, a fail-safe clock mode (for example, using the internal PLL and/or the CSS) must be used to guarantee that break events are handled.

When a break occurs (selected level on the break input):

- The MOE bit is cleared asynchronously, putting the outputs in inactive state, idle state, or even releasing the control to the GPIO (selected by the OSSI bit). This feature functions even if the MCU oscillator is off.
- Each output channel is driven with the level programmed in the OISx bit in the TIMx_CR2 register as soon as MOE = 0. If OSSI = 0, the timer releases the output control (taken over by the GPIO) else the enable output remains high.
- When complementary outputs are used:
  - The outputs are first put in reset state inactive state (depending on the polarity). This is done asynchronously so that it works even if no clock is provided to the timer.
  - If the timer clock is still present, then the dead-time generator is reactivated in order to drive the outputs with the level programmed in the OISx and OISxN bits after a dead-time. Even in this case, tim_ocx and tim_ocxn cannot be driven to their active level together. Note that because of the resynchronization on MOE, the dead-time duration is a bit longer than usual (around 2 tim_ker_ck clock cycles).
  - If OSSI = 0 then the timer releases the enable outputs (taken over by the GPIO which forces a Hi-Z state) else the enable outputs remain or become high as soon as one of the CCxE or CCxNE bits is high.
- The break status flag (BIF bit in the TIMx_SR register) is set. An interrupt can be generated if the BIE bit in the TIMx_DIER register is set. A DMA request can be sent if the BDE bit in the TIMx_DIER register is set.
- If the AOE bit in the TIMx_BDTR register is set, the MOE bit is automatically set again at the next update event UEV. This can be used to perform a regulation, for instance. Else, MOE remains low until it is written with 1 again. In this case, it can be used for security and the break input can be connected to an alarm from power drivers, thermal sensors or any security components.

Note: If the MOE is reset by the CPU while the AOE bit is set, the outputs are in idle state and forced to inactive level or Hi-Z depending on OSSI value. If both the MOE and AOE bits are reset by the CPU, the outputs are in disabled state and driven with the level programmed in the OISx bit in the TIMx_CR2 register.

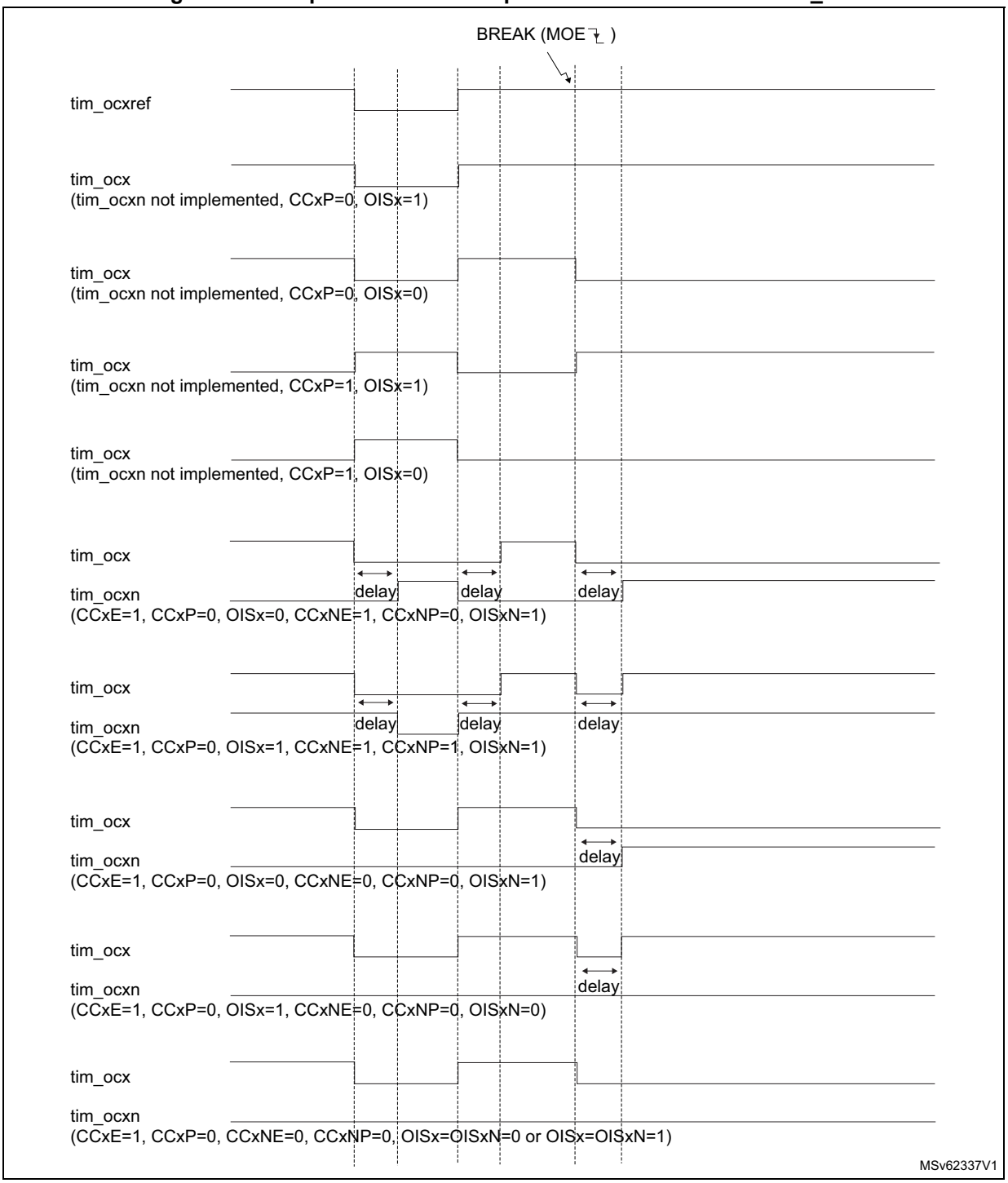
The break inputs are acting on level. Thus, the MOE cannot be set while the break input is active (neither automatically nor by software). In the meantime, the status flag BIF cannot be cleared.

The break can be generated by the tim_brk input which has a programmable polarity and an enable bit BKE in the TIMx_BDTR register.

In addition to the break input and the output management, a write protection has been implemented inside the break circuit to safeguard the application. It is used to freeze the configuration of several parameters (dead-time duration, tim_ocx/tim_ocxn polarities and state when disabled, OCxM configurations, break enable, and polarity). The protection can be selected among 3 levels with the LOCK bits in the TIMx_BDTR register. Refer to *Section 53.8.14: TIMx break and dead-time register (TIMx_BDTR)(x = 16 to 17)*. The LOCK bits can be written only once after an MCU reset.

The *Figure 731* shows an example of behavior for the outputs in response to a break.

Figure 731. Output behavior in response to a break event on tim_brk



53.4.16 Bidirectional break input

The TIM15/TIM16/TIM17 are featuring bidirectional break I/Os, as represented on *Figure 732*.

They are used to have:

- A board-level global break signal available for signaling faults to external MCUs or gate drivers, with a unique pin being both an input and an output status pin.
- Internal break sources and multiple external open drain sources ORed together to trigger a unique break event, when multiple internal and external break sources must be merged.

The tim_brk input is configured in bidirectional mode using the BKBID bit in the TIMx_BDTR register. The BKBID programming bit can be locked in read-only mode using the LOCK bits in the TIMx_BDTR register (in LOCK level 1 or above).

The bidirectional mode requires the I/O to be configured in open-drain mode with active low polarity (using BKINP and BKP bits). Any break request coming either from system (for example CSS), from on-chip peripherals, or from break inputs forces a low level on the break input to signal the fault event. The bidirectional mode is inhibited if the polarity bits are not correctly set (active high polarity), for safety purposes.

The break software event (triggered by setting the BG bit) also causes the break I/O to be forced to '0' to indicate to the external components that the timer has entered in break state. However, this is valid only if the break is enabled (BKE = 1). When a software break event is generated with BKE = 0, the outputs are put in safe state and the break flag is set, but there is no effect on the TIM_BKIN I/O.

A safe disarming mechanism prevents the system to be definitively locked-up (a low level on the break input triggers a break which enforces a low level on the same input).

When the BKDSRM bit is set to 1, this releases the break output to clear a fault signal and to give the possibility to re-arm the system.

At no point the break protection circuitry can be disabled:

- The break input path is always active: a break event is active even if the BKDSRM bit is set and the open drain control is released. This prevents the PWM output to be restarted as long as the break condition is present.
- The BKDSRM bit cannot disarm the break protection as long as the outputs are enabled (MOE bit is set) (see *Table 578*).

Table 578. Break protection disarming conditions

MOE	BKBID	BKDSRM	Break protection state
0	0	X	Armed
0	1	0	Armed
0	1	1	Disarmed
1	X	X	Armed

Arming and rearming break circuitry

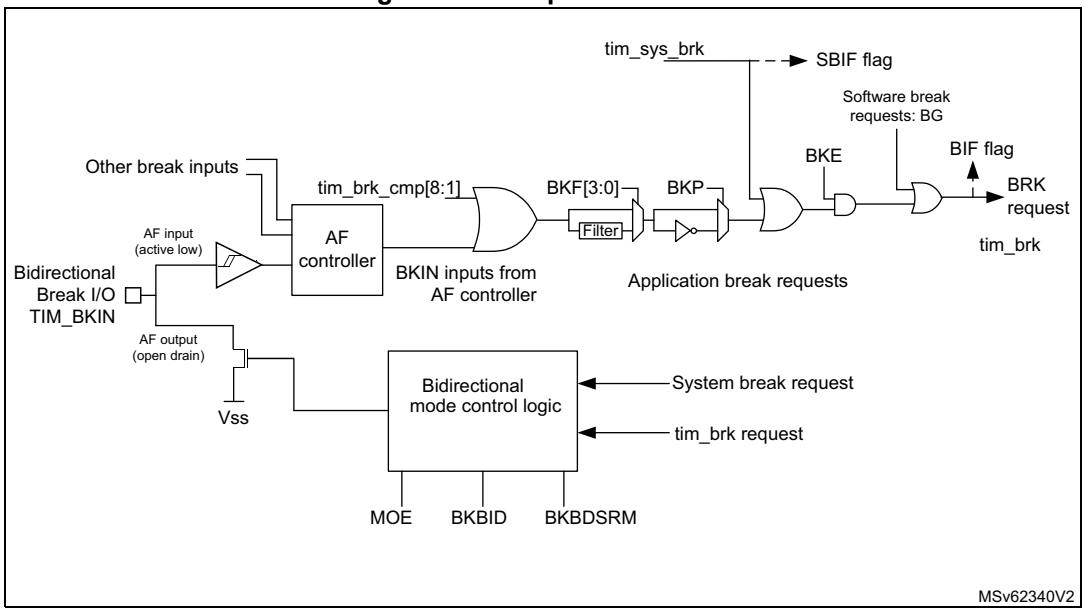
The break circuitry (in input or bidirectional mode) is armed by default (peripheral reset configuration).

The following procedure must be followed to re-arm the protection after a break event:

- The BKDSRM bit must be set to release the output control.
- The software must wait until the system break condition disappears (if any) and clear the SBIF status flag (or clear it systematically before rearming).
- The software must poll the BKDSRM bit until it is cleared by hardware (when the application break condition disappears).

From this point, the break circuitry is armed and active, and the MOE bit can be set to re-enable the PWM outputs.

Figure 732. Output redirection

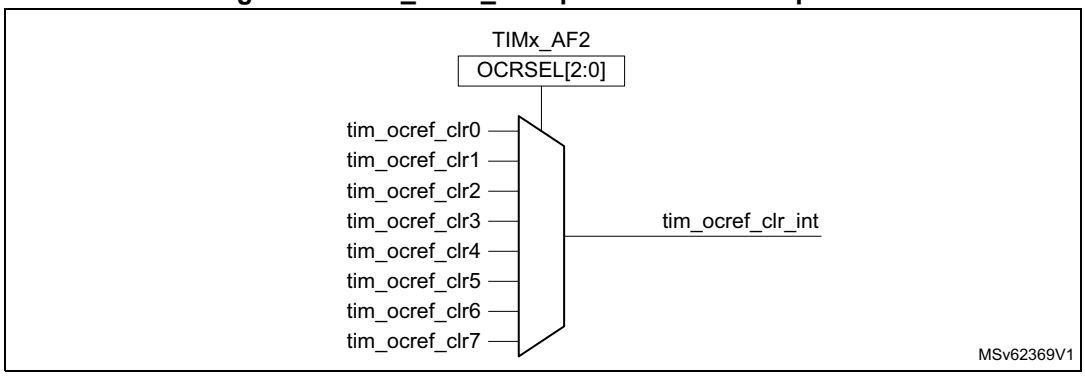


53.4.17 Clearing the tim_ocxref signal on an external event

The tim_ocxref signal of a given channel can be cleared when a high level is applied on the tim_ocref_clr_int input (OCxCE enable bit in the corresponding TIMx_CCMRx register set to 1). tim_ocxref remains low until the next transition to the active state, on the following PWM cycle. This function can only be used in Output compare and PWM modes. It does not work in Forced mode.

The tim_ocref_clr_int input can be selected among several inputs, as shown on *Figure 509* below.

Figure 733. tim_ocref_clr input selection multiplexer



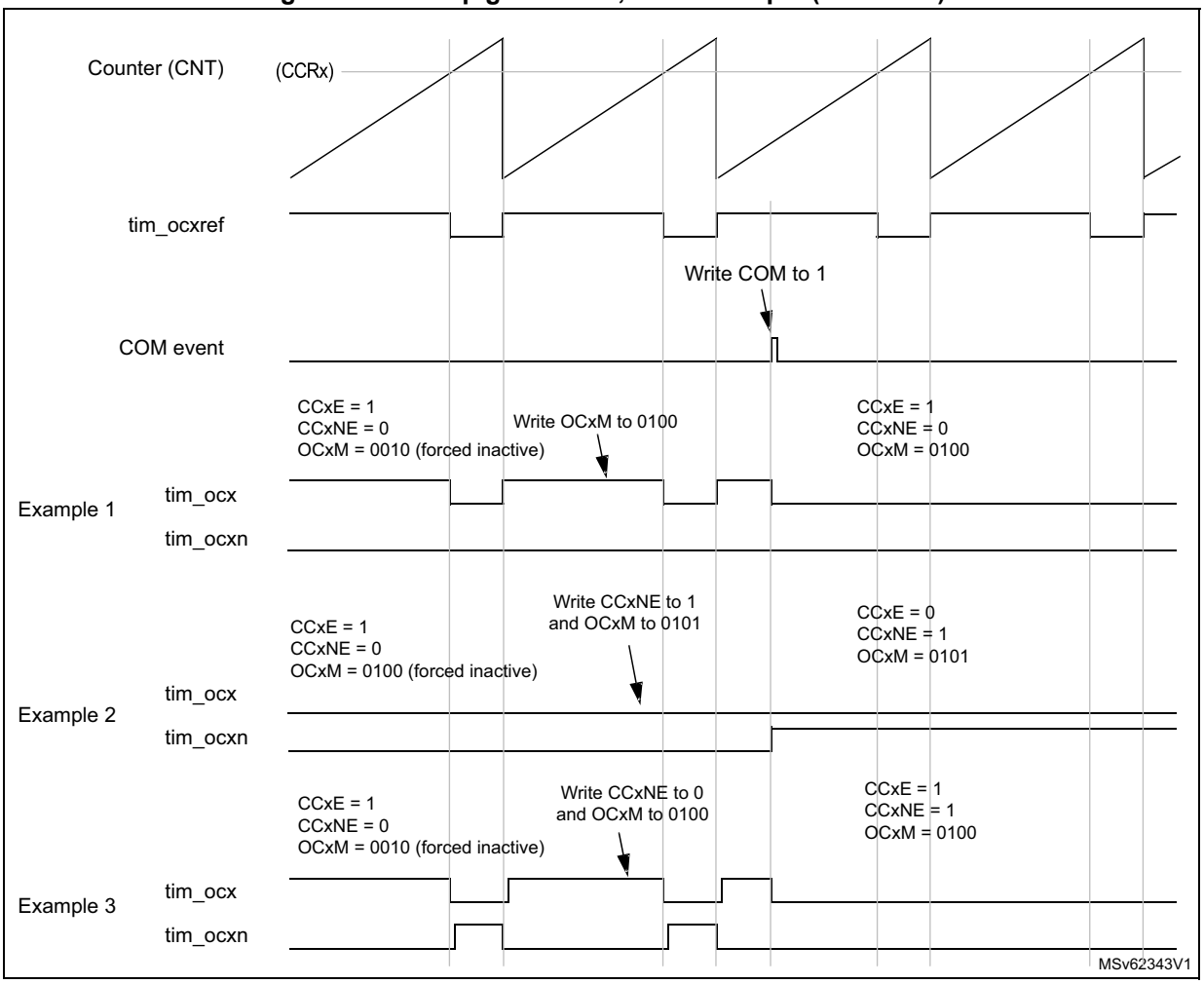
53.4.18 6-step PWM generation

When complementary outputs are used on a channel, preload bits are available on the OCxM, CCxE, and CCxNE bits. The preload bits are transferred to the shadow bits at the COM commutation event. Thus one can program in advance the configuration for the next step and change the configuration of all the channels at the same time. COM can be generated by software by setting the COM bit in the TIMx_EGR register or by hardware (on tim_trgi rising edge).

A flag is set when the COM event occurs (COMIF bit in the TIMx_SR register), which can generate an interrupt (if the COMIE bit is set in the TIMx_DIER register) or a DMA request (if the COMDE bit is set in the TIMx_DIER register).

The *Figure 734* describes the behavior of the tim_ocx and tim_ocxn outputs when a COM event occurs, in 3 different examples of programmed configurations.

Figure 734. 6-step generation, COM example (OSSR = 1)



53.4.19 One-pulse mode

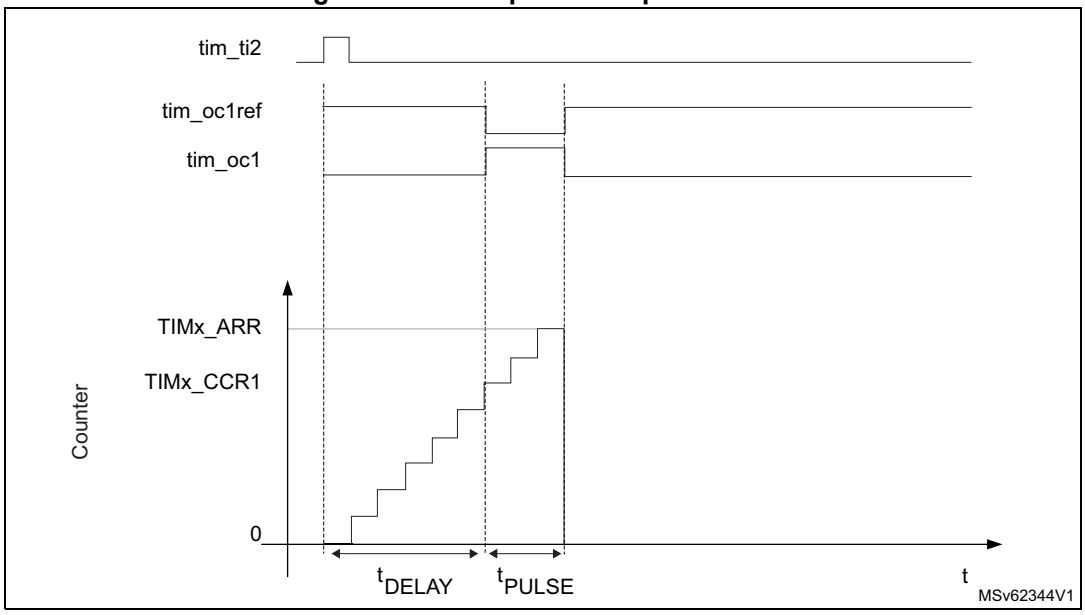
One-pulse mode (OPM) is a particular case of the previous modes. It allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length after a programmable delay.

Starting the counter can be controlled through the slave mode controller. Generating the waveform can be done in output compare mode or PWM mode. One-pulse mode is selected by setting the OPM bit in the TIMx_CR1 register. This makes the counter stop automatically at the next update event UEV.

A pulse can be correctly generated only if the compare value is different from the counter initial value. Before starting (when the timer is waiting for the trigger), the configuration must be:

- CNT < CCRx ≤ ARR (in particular, 0 < CCRx).

Figure 735. Example of one pulse mode.



For example one may want to generate a positive pulse on tim_oc1 with a length of t_{PULSE} and after a delay of t_{DELAY} as soon as a positive edge is detected on the tim_ti2 input pin.

Let's use tim_ti2fp2 as trigger 1:

1. Select the proper tim_ti2_in[15:1] source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Map tim_ti2fp2 to tim_ti2 by writing CC2S = 01 in the TIMx_CCMR1 register.
3. tim_ti2fp2 must detect a rising edge, write CC2P = 0 and CC2NP = 0 in the TIMx_CCER register.
4. Configure tim_ti2fp2 as trigger for the slave mode controller (tim_trgi) by writing TS = 00110 in the TIMx_SMCR register.
5. tim_ti2fp2 is used to start the counter by writing SMS to 110 in the TIMx_SMCR register (trigger mode).

The OPM waveform is defined by writing the compare registers (taking into account the clock frequency and the counter prescaler).

- The t_{DELAY} is defined by the value written in the TIMx_CCR1 register.
- The t_{PULSE} is defined by the difference between the autoreload value and the compare value (TIMx_ARR - TIMx_CCR1).
- Let's say one want to build a waveform with a transition from 0 to 1 when a compare match occurs and a transition from 1 to 0 when the counter reaches the autoreload value. To do this PWM mode 2 must be enabled by writing OC1M = 111 in the TIMx_CCMR1 register. Optionally the preload registers can be enabled by writing OC1PE = 1 in the TIMx_CCMR1 register and ARPE in the TIMx_CR1 register. In this case one has to write the compare value in the TIMx_CCR1 register, the autoreload value in the TIMx_ARR register, generate an update by setting the UG bit and wait for external trigger event on tim_ti2. CC1P is written to 0 in this example.

Since only one pulse is needed, a 1 must be written in the OPM bit in the TIMx_CR1 register to stop the counter at the next update event (when the counter rolls over from the autoreload value back to 0).

Particular case: tim_ocx fast enable

In One-pulse mode, the edge detection on tim_tix input set the CEN bit which enables the counter. Then the comparison between the counter and the compare value makes the output toggle. But several clock cycles are needed for these operations and it limits the minimum delay t_{DELAY} min that can be obtained.

If one wants to output a waveform with the minimum delay, the OCxFE bit can be set in the TIMx_CCMRx register. Then tim_ocxref (and tim_ocx) are forced in response to the stimulus, without taking in account the comparison. Its new level is the same as if a compare match had occurred. OCxFE acts only if the channel is configured in PWM1 or PWM2 mode.

53.4.20 Retriggerable one pulse mode (TIM15 only)

This mode allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length, but with the following differences with non-retriggerable one pulse mode described in *Section 53.4.19*:

- The pulse starts as soon as the trigger occurs (no programmable delay)
- The pulse is extended if a new trigger occurs before the previous one is completed

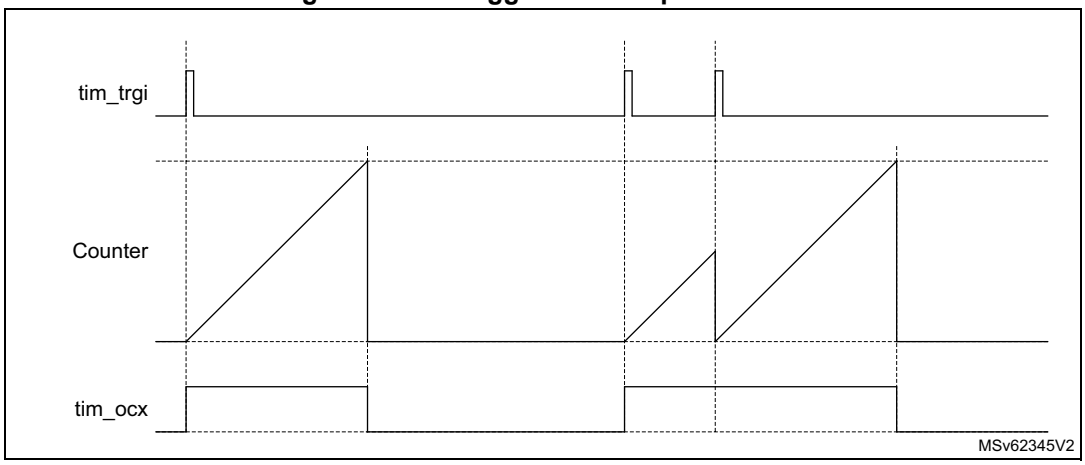
The timer must be in Slave mode, with the bits SMS[3:0] = 1000 (Combined reset + trigger mode) in the TIMx_SMCR register, and the OCxM[3:0] bits set to 1000 or 1001 for Retriggerable OPM mode 1 or 2.

If the timer is configured in Up-counting mode, the corresponding CCRx must be set to 0 (the ARR register sets the pulse length). If the timer is configured in Down-counting mode, CCRx must be above or equal to ARR.

Note: The OCxM[3:0] and SMS[3:0] bit fields are split into two parts for compatibility reasons, the most significant bit are not contiguous with the three least significant ones.

This mode must not be used with center-aligned PWM modes. It is mandatory to have CMS[1:0] = 00 in TIMx_CR1.

Figure 736. Retriggerable one pulse mode



53.4.21 UIF bit remapping

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the update interrupt flag UIF into bit 31 of the timer counter register (TIMx_CNT[31]). This is used to atomically read both the counter value and a potential roll-over condition signaled by the UIFCPY flag. In particular cases, it can ease the calculations by avoiding race conditions caused for instance by a processing shared between a background task (counter reading) and an interrupt (update interrupt).

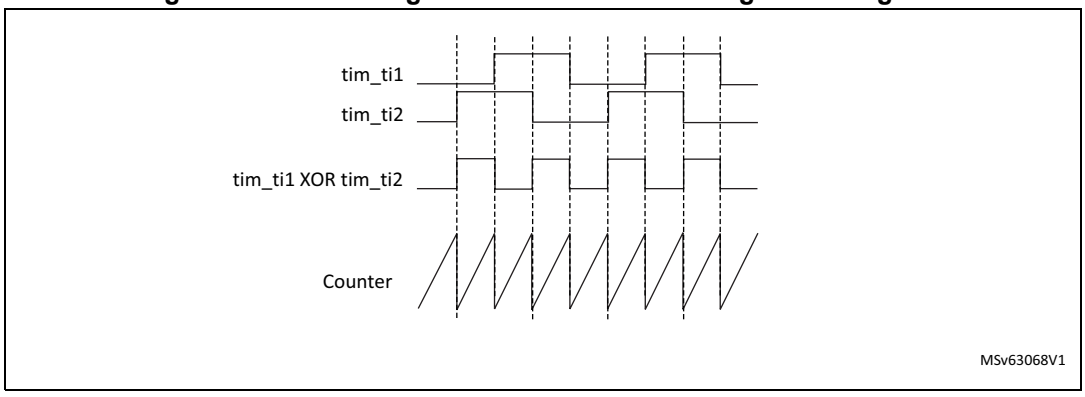
There is no latency between the assertions of the UIF and UIFCPY flags.

53.4.22 Timer input XOR function (TIM15 only)

The TI1S bit in the TIMx_CR2 register, allows the input filter of channel 1 to be connected to the output of a XOR gate, combining the two input pins tim_ti1 and tim_ti2.

The XOR output can be used with all the timer input functions such as trigger or input capture. It is useful for measuring the interval between the edges on two input signals, as shown in *Figure 737*.

Figure 737. Measuring time interval between edges on 2 signals



53.4.23 External trigger synchronization (TIM15 only)

The TIM timers are linked together internally for timer synchronization or chaining.

The TIM15 timer can be synchronized with an external trigger in several modes: Reset mode, Gated mode, Trigger mode, Reset + trigger, and gated + reset modes.

Slave mode: Reset mode

The counter and its prescaler can be reinitialized in response to an event on a trigger input. Moreover, if the URS bit from the TIMx_CR1 register is low, an update event UEV is generated. Then all the preloaded registers (TIMx_ARR, TIMx_CCRx) are updated.

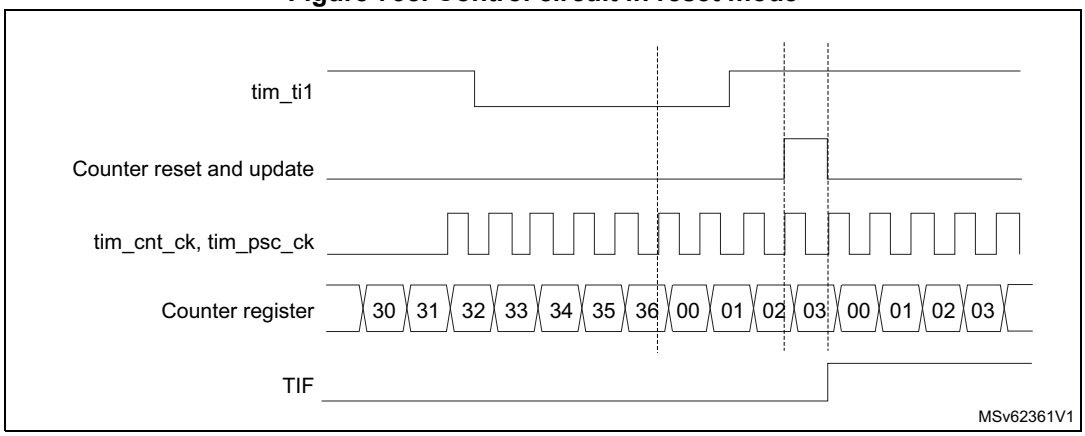
In the following example, the upcounter is cleared in response to a rising edge on tim_ti1 input:

1. Configure the channel 1 to detect rising edges on tim_ti1. Configure the input filter duration (in this example, no need for any filter, so IC1F is kept at 0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S = 01 in the TIMx_CCMR1 register. Write CC1P = 0 and CC1NP = 0 in the TIMx_CCER register to validate the polarity (and detect rising edges only).
2. Configure the timer in reset mode by writing SMS = 100 in TIMx_SMCR register. Select tim_ti1 as the input source by writing TS = 00101 in TIMx_SMCR register.
3. Start the counter by writing CEN = 1 in the TIMx_CR1 register.

The counter starts counting on the internal clock, then behaves normally until tim_ti1 rising edge. When tim_ti1 rises, the counter is cleared and restarts from 0. In the meantime, the trigger flag is set (TIF bit in the TIMx_SR register) and an interrupt request, or a DMA request can be sent if enabled (depending on the TIE and TDE bits in TIMx_DIER register).

The following figure shows this behavior when the autoreload register TIMx_ARR = 0x36. The delay between the rising edge on tim_ti1 and the actual reset of the counter is due to the resynchronization circuit on tim_ti1 input.

Figure 738. Control circuit in reset mode



Slave mode: Gated mode

The counter can be enabled depending on the level of a selected input.

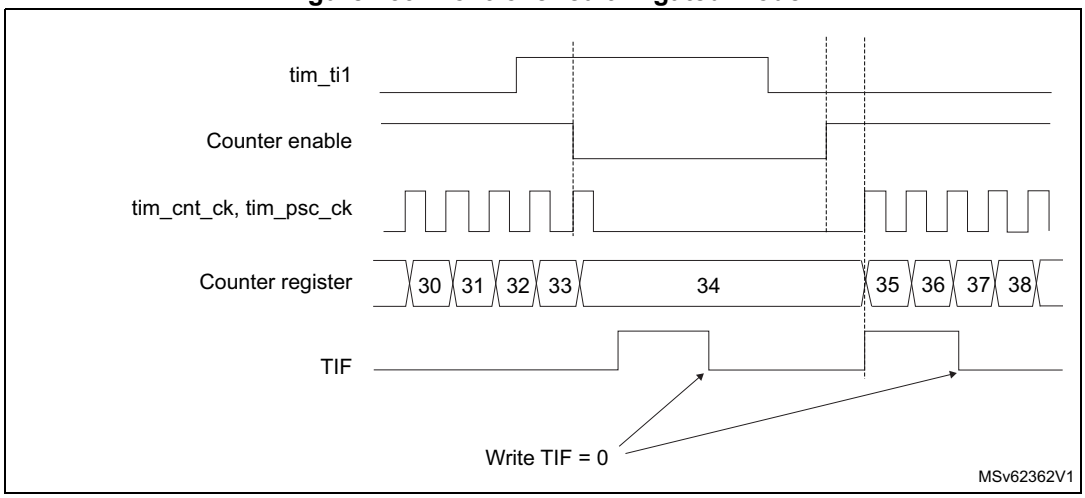
In the following example, the upcounter counts only when tim_ti1 input is low:

1. Configure the channel 1 to detect low levels on tim_ti1. Configure the input filter duration (in this example, no need for any filter, so IC1F is kept at 0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S = 01 in TIMx_CCMR1 register. Write CC1P = 1 and CC1NP = 0 in the TIMx_CCER register to validate the polarity (and detect low level only).
2. Configure the timer in gated mode by writing SMS = 101 in TIMx_SMCR register. Select tim_ti1 as the input source by writing TS = 00101 in TIMx_SMCR register.
3. Enable the counter by writing CEN = 1 in the TIMx_CR1 register (in gated mode, the counter does not start if CEN = 0, whatever is the trigger input level).

The counter starts counting on the internal clock as long as tim_ti1 is low and stops as soon as tim_ti1 becomes high. The TIF flag in the TIMx_SR register is set both when the counter starts or stops.

The delay between the rising edge on tim_ti1 and the actual stop of the counter is due to the resynchronization circuit on tim_ti1 input.

Figure 739. Control circuit in gated mode



Slave mode: Trigger mode

The counter can start in response to an event on a selected input.

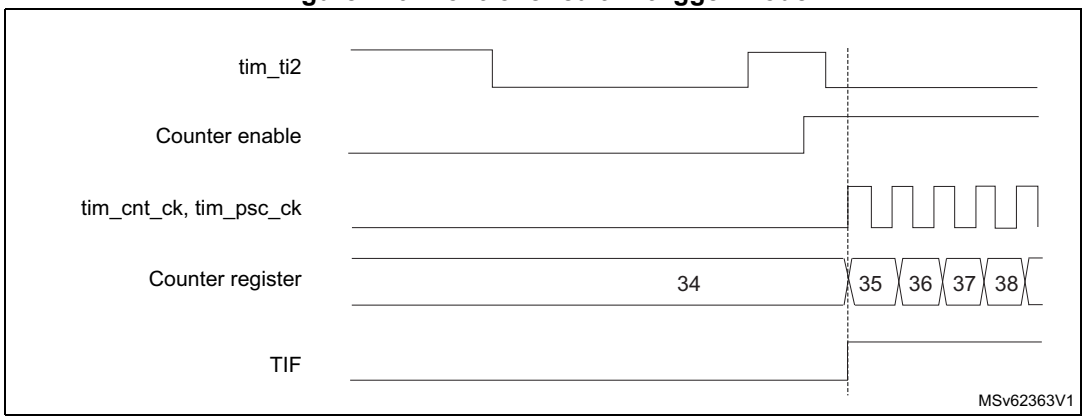
In the following example, the upcounter starts in response to a rising edge on tim_ti2 input:

1. Configure the channel 2 to detect rising edges on tim_ti2. Configure the input filter duration (in this example, no need for any filter, so IC2F is kept at 0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC2S bits are configured to select the input capture source only, CC2S = 01 in TIMx_CCMR1 register. Write CC2P = 1 and CC2NP = 0 in the TIMx_CCER register to validate the polarity (and detect low level only).
2. Configure the timer in trigger mode by writing SMS = 110 in the TIMx_SMCR register. Select tim_ti2 as the input source by writing TS = 00110 in the TIMx_SMCR register.

When a rising edge occurs on tim_ti2, the counter starts counting on the internal clock and the TIF flag is set.

The delay between the rising edge on tim_ti2 and the actual start of the counter is due to the resynchronization circuit on tim_ti2 input.

Figure 740. Control circuit in trigger mode



Slave mode selection preload for run-time update

The SMS[3:0] bit can be preloaded. This is enabled by setting the SMSPE enable bit in the TIMx_SMCR register. The trigger for the transfer from SMS[3:0] preload to active value is the update event (UEV) occurring when the counter overflows.

53.4.24 Slave mode – combined reset + trigger mode (TIM15 only)

In this case, a rising edge of the selected trigger input (tim_trgi) reinitializes the counter, generates an update of the registers, and starts the counter.

This mode is used for one-pulse mode.

53.4.25 Slave mode – combined reset + gated mode (TIM15 only)

The counter clock is enabled when the trigger input (tim_trgi) is high. The counter stops and is reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

This mode is used to detect out-of-range PWM signal (duty cycle exceeding a maximum expected value).

53.4.26 Timer synchronization (TIM15 only)

The TIMx timers are linked together internally for timer synchronization or chaining. Refer to *Section 50.4.23: Timer synchronization* for details.

Note: The clock of the slave peripherals (such as timer and ADC) receiving the tim_trgo signal must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

53.4.27 Using timer output as trigger for other timers (TIM16/TIM17 only)

The timers with one channel only do not feature a master mode. However, the OC1 output signal can be used to trigger some other timers (including timers described in other sections of this document). Check the “TIMx internal trigger connection” table of any timer on the device to identify which timers can be targeted as slave.

The OC1 signal pulse width must be programmed to be at least two clock cycles of the destination timer, to make sure the slave timer detects the trigger.

For instance, if the destination's timer CK_INT clock is four times slower than the source timer, the OC1 pulse width must be eight clock cycles.

53.4.28 ADC triggers (TIM15 only)

The timer can generate an ADC triggering event with various internal signals, such as reset, enable or compare events.

Note: The clock of the slave peripherals (such as timer, ADC) receiving the tim_trgo signal must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

53.4.29 DMA burst mode

The TIMx timers have the capability to generate multiple DMA requests on a single event. The main purpose is to be able to reprogram several timer registers multiple times without software overhead, but it can also be used to read several registers in a row, at regular intervals.

The DMA controller destination is unique and must point to the virtual register TIMx_DMAR. On a given timer event, the timer launches a sequence of DMA requests (burst). Each write into the TIMx_DMAR register is actually redirected to one of the timer registers.

The DBL[4:0] bits in the TIMx_DCR register set the DMA burst length. The timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address), i.e. the number of transfers (either in half-words or in bytes).

The DBA[4:0] bits in the TIMx_DCR registers define the DMA base address for DMA transfers (when read/write accesses are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register.

Example:

00000: TIMx_CR1

00001: TIMx_CR2

00010: TIMx_SMCR

The DBSS[3:0] bits in the TIMx_DCR register defines the interrupt source that triggers the DMA burst transfers (see *Section 53.8.20: TIMx DMA control register (TIMx_DCR)(x = 16 to 17)* for details).

For example, the timer DMA burst feature can be used to update the contents of the CCRx registers (x = 2, 3, 4) on an update event, with the DMA transferring half words into the CCRx registers.

This is done in the following steps:

1. Configure the corresponding DMA channel as follows:
   - DMA channel peripheral address is the DMAR register address
   - DMA channel memory address is the address of the buffer in the RAM containing the data to be transferred by DMA into the CCRx registers.
   - Number of data to transfer = 3 (See note below).
   - Circular mode disabled.
2. Configure the DCR register by configuring the DBA and DBL bit fields as follows: DBL = 3 transfers, DBA = 0xE and DBSS = 1.
3. Enable the TIMx update DMA request (set the UDE bit in the DIER register).
4. Enable TIMx
5. Enable the DMA channel

This example is for the case where every CCRx register is to be updated once. If every CCRx register is to be updated twice for example, the number of data to transfer must be 6. Let's take the example of a buffer in the RAM containing data1, data2, data3, data4, data5, and data6. The data is transferred to the CCRx registers as follows: on the first update DMA request, data1 is transferred to CCR2, data2 is transferred to CCR3, data3 is transferred to CCR4 and on the second update DMA request, data4 is transferred to CCR2, data5 is transferred to CCR3, and data6 is transferred to CCR4.

Note: A null value can be written to the reserved registers.

53.4.30 TIM15/TIM16/TIM17 DMA requests

The TIM15/TIM16/TIM17 can generate a DMA request, as shown in *Table 579*.

Table 579. DMA request

DMA request signal	DMA request	Enable control bit
tim_upd_dma	Update	UDE
tim_cc1_dma	Capture/compare 1	CC1DE
tim_com_dma(1)	Commutation (COM)	COMDE
tim_trgi_dma(1)	Trigger	TDE

1. Available for TIM15 only.

53.4.31 Debug mode

When the microcontroller enters debug mode (Cortex®-M33 core halted), the TIMx counter can either continue to work normally or stop.

The behavior in debug mode can be programmed with a dedicated configuration bit per timer in the Debug support (DBG) module.

For safety purposes, when the counter is stopped, the outputs are disabled (as if the MOE bit was reset). The outputs can either be forced to an inactive state (OSSI bit = 1), or have their control taken over by the GPIO controller (OSSI bit = 0) to force them to Hi-Z.

For more details, refer to the Debug section.

53.5 TIM15/TIM16/TIM17 low-power modes

Table 580. Effect of low-power modes on TIM15/TIM16/TIM17

Mode	Description
Sleep	No effect, peripheral is active. The interrupts can cause the device to exit from Sleep mode.
Stop	The timer operation is stopped and the register content is kept. No interrupt can be generated.
Standby	The timer is powered-down and must be reinitialized after exiting the Standby mode.

53.6 TIM15/TIM16/TIM17 interrupts

The TIM15/TIM16/TIM17 can generate multiple interrupts, as shown in *Table 581*.

Table 581. Interrupt requests

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop and Standby mode
TIM	Update	UIF	UIE	write 0 in UIF	Yes	No
	Capture/compare 1	CC1IF	CC1IE	write 0 in CC1IF	Yes	No
	Capture/compare 2(1)	CC2IF	CC2IE	write 0 in CC2IF	Yes	No
	Commutation (COM)	COMIF	COMIE	write 0 in COMIF	Yes	No
	Trigger(1)	TIF	TIE	write 0 in TIF	Yes	No
	Break	BIF	BIE	write 0 in BIF	Yes	No

1. Available for TIM15 only.

53.7 TIM15 registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by half-words (16-bit) or words (32-bit).

53.7.1 TIM15 control register 1 (TIM15_CR1)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DITHEN	UIFREMAP	Res.	CKD[1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
			rw	rw		rw	rw	rw				rw	rw	rw	rw

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 DITHEN: Dithering enable
0: Dithering disabled
1: Dithering enabled
Note: The DITHEN bit can only be modified when CEN bit is reset.

Bit 11 **UIFREMAP**: UIF status bit remapping
0: No remapping. UIF status bit is not copied to TIM15_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIM15_CNT register bit 31.

Bit 10 Reserved, must be kept at reset value.

Bits 9:8 **CKD[1:0]**: Clock division
This bitfield indicates the division ratio between the timer clock (tim_ker_ck) frequency and the dead-time and sampling clock (t_{DTS}) used by the dead-time generators and the digital filters (tim_tix)
00: $t_{DTS} = t_{tim_ker_ck}$
01: $t_{DTS} = 2*t_{tim_ker_ck}$
10: $t_{DTS} = 4*t_{tim_ker_ck}$
11: Reserved

Bit 7 **ARPE**: Auto-reload preload enable
0: TIM15_ARR register is not buffered
1: TIM15_ARR register is buffered

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **OPM**: One-pulse mode
0: Counter is not stopped at update event
1: Counter stops counting at the next update event (clearing the bit CEN)

Bit 2 **URS**: Update request source

This bit is set and cleared by software to select the UEV event sources.

0: Any of the following events generate an update interrupt if enabled. These events can be:

– Counter overflow/underflow

– Setting the UG bit

– Update generation through the slave mode controller

1: Only counter overflow/underflow generates an update interrupt if enabled

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable UEV event generation.

0: UEV enabled. The Update (UEV) event is generated by one of the following events:

– Counter overflow/underflow

– Setting the UG bit

– Update generation through the slave mode controller

Buffered registers are then loaded with their preload values.

1: UEV disabled. The Update event is not generated, shadow registers keep their value (ARR, PSC, CCRx). However the counter and the prescaler are reinitialized if the UG bit is set or if a hardware reset is received from the slave mode controller.

Bit 0 **CEN**: Counter enable

0: Counter disabled

1: Counter enabled

Note: External clock and gated mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

53.7.2 TIM15 control register 2 (TIM15_CR2)

Address offset: 0x04

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	OIS2	OIS1N	OIS1	TI1S	MMS[2:0]			CCDS	CCUS	Res.	CCPC
					rw	rw	rw	rw	rw	rw	rw	rw	rw		rw

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **OIS2:** Output idle state 2 (tim_oc2 output)

0: tim_oc2 = 0 when MOE = 0

1: tim_oc2 = 1 when MOE = 0

Note: This bit cannot be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in the TIM15_BKR register).

Bit 9 **OIS1N**: Output Idle state 1 (tim_oc1n output)

0: tim_oc1n = 0 after a dead-time when MOE = 0

1: tim_oc1n = 1 after a dead-time when MOE = 0

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIM15_BKR register).

Bit 8 **OIS1**: Output Idle state 1 (tim_oc1 output)

0: tim_oc1 = 0 after a dead-time when MOE = 0

1: tim_oc1 = 1 after a dead-time when MOE = 0

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIM15_BKR register).

Bit 7 **TI1S**: tim_ti1 selection

0: The tim_ti1_in[15:0] multiplexer output is connected to tim_ti1 input

1: The tim_ti1_in[15:0] and tim_ti2_in[15:0] multiplexers output are connected to the tim_ti1 input (XOR combination)

Bits 6:4 **MMS[2:0]**: Master mode selection

These bits are used to select the information to be sent in master mode to slave timers for synchronization (tim_trgo). The combination is as follows:

000: **Reset** - the UG bit from the TIM15_EGR register is used as trigger output (tim_trgo). If the reset is generated by the trigger input (slave mode controller configured in reset mode) then the signal on tim_trgo is delayed compared to the actual reset.

001: **Enable** - the Counter Enable signal CNT_EN is used as trigger output (tim_trgo). It is useful to start several timers at the same time or to control a window in which a slave timer is enable. The Counter Enable signal is generated by a logic AND between CEN control bit and the trigger input when configured in gated mode. When the Counter Enable signal is controlled by the trigger input, there is a delay on tim_trgo, except if the master/slave mode is selected (see the MSM bit description in TIM15_SMCR register).

010: **Update** - The update event is selected as trigger output (tim_trgo). For instance a master timer can then be used as a prescaler for a slave timer.

011: **Compare Pulse** - The trigger output send a positive pulse when the CC1IF flag is to be set (even if it was already high), as soon as a capture or a compare match occurred (tim_trgo).

100: **Compare** - tim_oc1refc signal is used as trigger output (tim_trgo).

101: **Compare** - tim_oc2refc signal is used as trigger output (tim_trgo).

Bit 3 **CCDS**: Capture/compare DMA selection

0: CCx DMA request sent when CCx event occurs

1: CCx DMA requests sent when update event occurs

Bit 2 **CCUS**: Capture/compare control update selection

0: When capture/compare control bits are preloaded (CCPC = 1), they are updated by setting the COMG bit only.

1: When capture/compare control bits are preloaded (CCPC = 1), they are updated by setting the COMG bit or when an rising edge occurs on tim_trgi.

Note: This bit acts only on channels that have a complementary output.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **CCPC**: Capture/compare preloaded control

0: CCxE, CCxNE and OCxM bits are not preloaded

1: CCxE, CCxNE and OCxM bits are preloaded, after having been written, they are updated only when a commutation event (COM) occurs (COMG bit set or rising edge detected on tim_trgi, depending on the CCUS bit).

Note: This bit acts only on channels that have a complementary output.

53.7.3 TIM15 slave mode control register (TIM15_SMCR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	SMSPE	Res.	Res.	TS[4:3]		Res.	Res.	Res.	SMS[3]
							rw			rw	rw				rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MSM	TS[2:0]			Res.	SMS[2:0]		
								rw	rw	rw	rw		rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **SMSPE:** SMS preload enable

This bit selects whether the SMS[3:0] bitfield is preloaded.

0: SMS[3:0] bitfield is not preloaded

1: SMS[3:0] preload is enabled

Bits 23:22 Reserved, must be kept at reset value.

Bits 19:17 Reserved, must be kept at reset value.

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **MSM:** Master/slave mode

0: No action

1: The effect of an event on the trigger input (tim_trgi) is delayed to allow a perfect synchronization between the current timer and its slaves (through tim_trgo). It is useful if the user wants to synchronize several timers on a single external event.

Bits 21, 20, 6, 5, 4 **TS[4:0]:** Trigger selection

This bitfield selects the trigger input to be used to synchronize the counter.

00000: Internal Trigger 0 (tim_itr0)
00001: Internal Trigger 1 (tim_itr1)
00010: Internal Trigger 2 (tim_itr2)
00011: Internal Trigger 3 (tim_itr3)
00100: tim_ti1 Edge Detector (tim_ti1f_ed)
00101: Filtered Timer Input 1 (tim_ti1fp1)
00110: Filtered Timer Input 2 (tim_ti2fp2)
00111: Reserved
01000: Internal Trigger 4 (tim_itr4)
01001: Internal Trigger 5 (tim_itr5)
01010: Internal Trigger 6 (tim_itr6)
01011: Internal Trigger 7 (tim_itr7)
01100: Internal Trigger 8 (tim_itr8)
01101: Internal Trigger 9 (tim_itr9)
01110: Internal Trigger 10 (tim_itr10)
10000: Internal trigger 12 (tim_itr12)
10001: Internal trigger 13 (tim_itr13)
10010: Internal trigger 14 (tim_itr14)
10011: Internal trigger 15 (tim_itr15)
Others: Reserved

See *Section 53.4.2: TIM15/TIM16/TIM17 pins and internal signals* for more details on tim_itrx meaning for each timer.

Note: These bits must be changed only when they are not used (for example when SMS = 000) to avoid wrong edge detections at the transition.

Bit 3 Reserved, must be kept at reset value.

Bits 16, 2, 1, 0 **SMS[3:0]:** Slave mode selection

When external signals are selected the active edge of the trigger signal (tim_trgi) is linked to the polarity selected on the external input (refer to ETP bit in TIMx_SMCR for tim_etr_in and CCxP/CCxNP bits in TIMx_CCER register for tim_ti1fp1 and tim_ti2fp2).

0000: Slave mode disabled - if CEN = 1 then the prescaler is clocked directly by the internal clock.

0001: Reserved

0010: Reserved

0011: Reserved

0100: Reset mode - Rising edge of the selected trigger input (tim_trgi) reinitializes the counter and generates an update of the registers.

0101: Gated mode - The counter clock is enabled when the trigger input (tim_trgi) is high. The counter stops (but is not reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

0110: Trigger mode - The counter starts at a rising edge of the trigger tim_trgi (but it is not reset). Only the start of the counter is controlled.

0111: External Clock mode 1 - Rising edges of the selected trigger (tim_trgi) clock the counter.

1000: Combined reset + trigger mode - Rising edge of the selected trigger input (tim_trgi) reinitializes the counter, generates an update of the registers and starts the counter.

1001: Combined gated + reset mode - The counter clock is enabled when the trigger input (tim_trgi) is high. The counter stops and is reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

Others: Reserved.

Note: The gated mode must not be used if tim_ti1f_ed is selected as the trigger input (TS = 00100). Indeed, tim_ti1f_ed outputs 1 pulse for each transition on tim_ti1f, whereas the gated mode checks the level of the trigger signal.

The clock of the slave peripherals (such as timer and ADC) receiving the tim_trgo signal must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

53.7.4 TIM15 DMA/interrupt enable register (TIM15_DIER)

Address offset: 0x0C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TDE	COMDE	Res.	Res.	Res.	CC1DE	UDE	BIE	TIE	COMIE	Res.	Res.	CC2IE	CC1IE	UIE
	rw	rw				rw	rw	rw	rw	rw			rw	rw	rw

Bit 15 Reserved, must be kept at reset value.

Bit 14 **TDE**: Trigger DMA request enable

0: Trigger DMA request disabled

1: Trigger DMA request enabled

Bit 13 **COMDE**: COM DMA request enable

0: COM DMA request disabled

1: COM DMA request enabled

Bits 12:10 Reserved, must be kept at reset value.

Bit 9 **CC1DE**: Capture/Compare 1 DMA request enable
0: CC1 DMA request disabled
1: CC1 DMA request enabled

Bit 8 **UDE**: Update DMA request enable
0: Update DMA request disabled
1: Update DMA request enabled

Bit 7 **BIE**: Break interrupt enable
0: Break interrupt disabled
1: Break interrupt enabled

Bit 6 **TIE**: Trigger interrupt enable
0: Trigger interrupt disabled
1: Trigger interrupt enabled

Bit 5 **COMIE:** COM interrupt enable
0: COM interrupt disabled
1: COM interrupt enabled

Bits 4:3 Reserved, must be kept at reset value.

Bit 2 **CC2IE**: Capture/Compare 2 interrupt enable
0: CC2 interrupt disabled
1: CC2 interrupt enabled

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable
0: CC1 interrupt disabled
1: CC1 interrupt enabled

Bit 0 **UIE**: Update interrupt enable
0: Update interrupt disabled
1: Update interrupt enabled

53.7.5 TIM15 status register (TIM15_SR)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	CC2OF	CC1OF	Res.	BIF	TIF	COMIF	Res.	Res.	CC2IF	CC1IF	UIF
					rc_w0	rc_w0		rc_w0	rc_w0	rc_w0			rc_w0	rc_w0	rc_w0

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **CC2OF**: Capture/Compare 2 overcapture flag
Refer to CC1OF description

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag
This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to 0.
0: No overcapture has been detected
1: The counter value has been captured in TIM15_CCR1 register while CC1IF flag was already set

Bit 8 Reserved, must be kept at reset value.

Bit 7 **BIF**: Break interrupt flag

This flag is set by hardware as soon as the break input goes active. It can be cleared by software if the break input is not active.

0: No break event occurred

1: An active level has been detected on the break input

Bit 6 **TIF**: Trigger interrupt flag

This flag is set by hardware on the TRG trigger event (active edge detected on tim_trgi input when the slave mode controller is enabled in all modes but gated mode, both edges in case gated mode is selected). It is set when the counter starts or stops when gated mode is selected. It is cleared by software.

0: No trigger event occurred

1: Trigger interrupt pending

Bit 5 **COMIF:** COM interrupt flag

This flag is set by hardware on a COM event (once the capture/compare control bits –CCxE, CCxNE, OCxM– have been updated). It is cleared by software.

0: No COM event occurred

1: COM interrupt pending

Bits 4:3 Reserved, must be kept at reset value.

Bit 2 **CC2IF**: Capture/Compare 2 interrupt flag

refer to CC1IF description

Bit 1 **CC1IF**: Capture/Compare 1 interrupt flag

This flag is set by hardware. It is cleared by software (input capture or output compare mode) or by reading the TIMx_CCR1 register (input capture mode only).

0: No compare match / No input capture occurred

1: A compare match or an input capture occurred

If channel CC1 is configured as output: this flag is set when the content of the counter TIMx_CNT matches the content of the TIMx_CCR1 register. When the content of TIMx_CCR1 is greater than the content of TIMx_ARR, the CC1IF bit goes high on the counter overflow (in up-counting and up/down-counting modes) or underflow (in downcounting mode). There are 3 possible options for flag setting in center-aligned mode, refer to the CMS bits in the TIMx_CR1 register for the full description.

If channel CC1 is configured as input: this bit is set when counter value has been captured in TIMx_CCR1 register (an edge has been detected on IC1, as per the edge sensitivity defined with the CC1P and CC1NP bits setting, in TIMx_CCER).

Bit 0 **UIF**: Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.

0: No update occurred.

1: Update interrupt pending. This bit is set by hardware when the registers are updated:

– At overflow regarding the repetition counter value (update if repetition counter = 0) and if the UDIS = 0 in the TIM15_CR1 register.

– When CNT is reinitialized by software using the UG bit in TIM15_EGR register, if URS = 0 and UDIS = 0 in the TIM15_CR1 register.

– When CNT is reinitialized by a trigger event (refer to *Section 53.7.3: TIM15 slave mode control register (TIM15_SMCR)*), if URS = 0 and UDIS = 0 in the TIM15_CR1 register.

53.7.6 TIM15 event generation register (TIM15_EGR)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BG	TG	COMG	Res.	Res.	CC2G	CC1G	UG
								w	w	rw			w	w	w

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **BG**: Break generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: A break event is generated. MOE bit is cleared and BIF flag is set. Related interrupt or DMA transfer can occur if enabled.

Bit 6 **TG**: Trigger generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: The TIF flag is set in TIM15_SR register. Related interrupt or DMA transfer can occur if enabled

Bit 5 **COMG:** Capture/Compare control update generation

This bit can be set by software, it is automatically cleared by hardware.

0: No action

1: When the CCPC bit is set, it is possible to update the CCxE, CCxNE and OCxM bits

Note: This bit acts only on channels that have a complementary output.

Bits 4:3 Reserved, must be kept at reset value.

Bit 2 **CC2G**: Capture/Compare 2 generation

Refer to CC1G description

Bit 1 **CC1G**: Capture/Compare 1 generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1 A capture/compare event is generated on channel 1:

If channel CC1 is configured as output:

CC1IF flag is set, Corresponding interrupt or DMA request is sent if enabled.

If channel CC1 is configured as input:

The current value of the counter is captured in TIM15_CCR1 register. The CC1IF flag is set, the corresponding interrupt or DMA request is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation

This bit can be set by software, it is automatically cleared by hardware.

0: No action

1: Reinitialize the counter and generates an update of the registers. Note that the prescaler counter is cleared too (anyway the prescaler ratio is not affected).

53.7.7 TIM15 capture/compare mode register 1 (TIM15_CCMR1)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (for example channel 1 in input capture mode and channel 2 in output compare mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IC2F[3:0]				IC2PSC[1:0]		CC2S[1:0]		IC1F[3:0]				IC1PSC[1:0]		CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Input capture mode

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **IC2F[3:0]**: Input capture 2 filter

Bits 11:10 **IC2PSC[1:0]**: Input capture 2 prescaler

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC2 channel is configured as output

01: CC2 channel is configured as input, tim_ic2 is mapped on tim_ti2

10: CC2 channel is configured as input, tim_ic2 is mapped on tim_ti1

11: CC2 channel is configured as input, tim_ic2 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIM15_SMCR register)

Note: CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIM15_CCER).

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bitfield defines the frequency used to sample tim_ti1 input and the length of the digital filter applied to tim_ti1. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}
0001: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 2
0010: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 4
0011: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 8
0100: $f_{SAMPLING} = f_{DTS}/2$, N = 6
0101: $f_{SAMPLING} = f_{DTS}/2$, N = 8
0110: $f_{SAMPLING} = f_{DTS}/4$, N = 6
0111: $f_{SAMPLING} = f_{DTS}/4$, N = 8
1000: $f_{SAMPLING} = f_{DTS}/8$, N = 6
1001: $f_{SAMPLING} = f_{DTS}/8$, N = 8
1010: $f_{SAMPLING} = f_{DTS}/16$, N = 5
1011: $f_{SAMPLING} = f_{DTS}/16$, N = 6
1100: $f_{SAMPLING} = f_{DTS}/16$, N = 8
1101: $f_{SAMPLING} = f_{DTS}/32$, N = 5
1110: $f_{SAMPLING} = f_{DTS}/32$, N = 6
1111: $f_{SAMPLING} = f_{DTS}/32$, N = 8

Bits 3:2 **IC1PSC[1:0]**: Input capture 1 prescaler

This bitfield defines the ratio of the prescaler acting on CC1 input (tim_ic1). The prescaler is reset as soon as CC1E = 0 (TIM15_CCER register).

00: no prescaler, capture is done each time an edge is detected on the capture input
01: capture is done once every 2 events
10: capture is done once every 4 events
11: capture is done once every 8 events

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output
01: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti1
10: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti2
11: CC1 channel is configured as input, tim_ic1 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIM15_SMCR register)

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIM15_CCER).

53.7.8 TIM15 capture/compare mode register 1 [alternate] (TIM15_CCMR1)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (for example channel 1 in input capture mode and channel 2 in output compare mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M [3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M [3]
							rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC2 CE	OC2M[2:0]			OC2 PE	OC2 FE	CC2S[1:0]		OC1 CE	OC1M[2:0]			OC1 PE	OC1 FE	CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Output compare mode:

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 **OC2CE**: Output compare 2 clear enable

Bits 24, 14:12 **OC2M[3:0]**: Output compare 2 mode

Bit 11 **OC2PE**: Output compare 2 preload enable

Bit 10 **OC2FE**: Output compare 2 fast enable

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC2 channel is configured as output.

01: CC2 channel is configured as input, tim_ic2 is mapped on tim_ti2.

10: C2 channel is configured as input, tim_ic2 is mapped on tim_ti1.

11: CC2 channel is configured as input, tim_ic2 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through the TS bit (TIM15_SMCR register)

Note: CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIM15_CCER).

Bit 7 **OC1CE**: Output compare 1 clear enable

0: tim_oc1ref is not affected by the tim_ocref_clr_int input.

1: tim_oc1ref is cleared as soon as a High level is detected on tim_ocref_clr_int input.

Bits 16, 6:4 **OC1M[3:0]**: Output compare 1 mode

These bits define the behavior of the output reference signal tim_oc1ref from which tim_oc1 and tim_oc1n are derived. tim_oc1ref is active high whereas tim_oc1 and tim_oc1n active level depends on CC1P and CC1NP bits.

0000: Frozen - The comparison between the output compare register TIM15_CCR1 and the counter TIM15_CNT has no effect on the outputs. This mode can be used when the timer serves as a software timebase. When the frozen mode is enabled during timer operation, the output keeps the state (active or inactive) it had before entering the frozen state.

0001: Set channel 1 to active level on match. tim_oc1ref signal is forced high when the counter TIM15_CNT matches the capture/compare register 1 (TIM15_CCR1).

0010: Set channel 1 to inactive level on match. tim_oc1ref signal is forced low when the counter TIM15_CNT matches the capture/compare register 1 (TIM15_CCR1).

0011: Toggle - tim_oc1ref toggles when TIM15_CNT = TIM15_CCR1.

0100: Force inactive level - tim_oc1ref is forced low.

0101: Force active level - tim_oc1ref is forced high.

0110: PWM mode 1 - Channel 1 is active as long as TIM15_CNT<TIM15_CCR1 else inactive.

0111: PWM mode 2 - Channel 1 is inactive as long as TIM15_CNT<TIM15_CCR1 else active.

1000: Retrigerrable OPM mode 1 - In up-counting mode, the channel is active until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update. In down-counting mode, the channel is inactive until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes inactive again at the next update.

1001: Retrigerrable OPM mode 2 - In up-counting mode, the channel is inactive until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 2 and the channels becomes inactive again at the next update. In down-counting mode, the channel is active until a trigger event is detected (on tim_trgi signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update.

1010: Reserved

1011: Reserved

1100: Combined PWM mode 1 - tim_oc1ref has the same behavior as in PWM mode 1. tim_oc1refc is the logical OR between tim_oc1ref and tim_oc2ref.

1101: Combined PWM mode 2 - tim_oc1ref has the same behavior as in PWM mode 2. tim_oc1refc is the logical AND between tim_oc1ref and tim_oc2ref.

1110: Reserved,

1111: Reserved,

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIM15_BDTR register) and CC1S = 00 (the channel is configured in output).

In PWM mode, the OCREF level changes when the result of the comparison changes, when the output compare mode switches from “frozen” mode to “PWM” mode and when the output compare mode switches from “force active/inactive” mode to “PWM” mode.

On channels that have a complementary output, this bitfield is preloaded. If the CCPC bit is set in the TIM15_CR2 register then the OC1M active bits take the new value from the preloaded bits only when a COM event is generated.

Bit 3 **OC1PE**: Output Compare 1 preload enable

0: Preload register on TIM15_CCR1 disabled. TIM15_CCR1 can be written at anytime, the new value is taken in account immediately.

1: Preload register on TIM15_CCR1 enabled. Read/Write operations access the preload register. TIM15_CCR1 preload value is loaded in the active register at each update event.

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIM15_BDTR register) and CC1S = 00 (the channel is configured in output).

Bit 2 **OC1FE**: Output Compare 1 fast enable

This bit decreases the latency between a trigger event and a transition on the timer output. It must be used in one-pulse mode (OPM bit set in TIMx_CR1 register), to have the output pulse starting as soon as possible after the starting trigger.

0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.

1: An active edge on the trigger input acts like a compare match on CC1 output. Then, tim_ocx is set to the compare level independently of the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OCFE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output.

01: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti1.

10: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti2.

11: CC1 channel is configured as input, tim_ic1 is mapped on tim_trc. This mode is working only if an internal trigger input is selected through TS bit (TIM15_SMCR register)

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIM15_CCER).

53.7.9 TIM15 capture/compare enable register (TIM15_CCER)

Address offset: 0x20

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2NP	Res.	CC2P	CC2E	CC1NP	CC1NE	CC1P	CC1E
								rw		rw	rw	rw	rw	rw	rw

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **CC2NP**: Capture/Compare 2 complementary output polarity
Refer to CC1NP description

Bit 6 Reserved, must be kept at reset value.

Bit 5 **CC2P**: Capture/Compare 2 output polarity
Refer to CC1P description

Bit 4 **CC2E**: Capture/Compare 2 output enable
Refer to CC1E description

Bit 3 **CC1NP**: Capture/Compare 1 complementary output polarity

CC1 channel configured as output:

0: tim_oc1n active high

1: tim_oc1n active low

CC1 channel configured as input:

This bit is used in conjunction with CC1P to define the polarity of tim_ti1fp1 and tim_ti2fp1. Refer to CC1P description.

Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIM15_BDTR register) and CC1S = 00 (the channel is configured in output).

On channels that have a complementary output, this bit is preloaded. If the CCPC bit is set in the TIM15_CR2 register then the CC1NP active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Bit 2 **CC1NE**: Capture/Compare 1 complementary output enable

0: Off - tim_oc1n is not active. tim_oc1n level is then function of MOE, OSSI, OSSR, OIS1, OIS1N and CC1E bits.

1: On - tim_oc1n signal is output on the corresponding output pin depending on MOE, OSSI, OSSR, OIS1, OIS1N and CC1E bits.

Bit 1 **CC1P**: Capture/Compare 1 output polarity

CC1 channel configured as output:

0: OC1 active high (output mode) / Edge sensitivity selection (input mode, see below)

1: OC1 active low (output mode) / Edge sensitivity selection (input mode, see below)

When CC1 channel is configured as input, both CC1NP/CC1P bits select the active polarity of TI1FP1 and TI2FP1 for trigger or capture operations.

CC1NP = 0, CC1P = 0: non-inverted/rising edge. The circuit is sensitive to TIxFP1 rising edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode).

CC1NP = 0, CC1P = 1: inverted/falling edge. The circuit is sensitive to TIxFP1 falling edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is inverted (trigger operation in gated mode).

CC1NP = 1, CC1P = 1: non-inverted/both edges/ The circuit is sensitive to both TIxFP1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), TIxFP1is not inverted (trigger operation in gated mode).

CC1NP = 1, CC1P = 0: this configuration is reserved, it must not be used.

Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIM15_BDTR register).

On channels that have a complementary output, this bit is preloaded. If the CCPC bit is set in the TIM15_CR2 register then the CC1P active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Bit 0 **CC1E**: Capture/Compare 1 output enable

0: Capture mode disabled / OC1 is not active (see below)

1: Capture mode enabled / OC1 signal is output on the corresponding output pin

When CC1 channel is configured as output, the OC1 level depends on MOE, OSSI, OSSR, OIS1, OIS1N and CC1NE bits, regardless of the CC1E bits state. Refer to *Table 582* for details.

Table 582. Output control bits for complementary tim_ocx and tim_ocxn channels with break feature (TIM15)

Control bits					Output states(1)	
MOE bit	OSSI bit	OSSR bit	CCxE bit	CCxNE bit	tim_ocx output state	tim_ocxn output state
1	X	X	0	0	Output Disabled (not driven by the timer: Hi-Z) tim_ocx = 0 tim_ocxn = 0	
		0	0	1	Output Disabled (not driven by the timer: Hi-Z) tim_ocx = 0	tim_ocxref + Polarity tim_ocxn = tim_ocxref XOR CCxNP
		0	1	0	tim_ocxref + Polarity tim_ocx = tim_ocxref XOR CCxP	Output Disabled (not driven by the timer: Hi-Z) tim_ocxn = 0
		X	1	1	tim_ocxref + Polarity + dead-time	Complementary to tim_ocxref (not OCREF) + Polarity + dead-time
		1	0	1	Off-State (output enabled with inactive state) tim_ocx = CCxP	tim_ocxref + Polarity tim_ocxn = tim_ocxref XOR CCxNP
		1	1	0	tim_ocxref + Polarity tim_ocx = tim_ocxref xor CCxP	Off-State (output enabled with inactive state) tim_ocxn = CCxNP
0	0	X	X	X	Output disabled (not driven by the timer: Hi-Z)	
	1		0	0		
			0	1	Off-State (output enabled with inactive state) Asynchronously: tim_ocx = CCxP, tim_ocxn = CCxNP Then if the clock is present: tim_ocx = OISx and tim_ocxn = OISxN after a dead-time, assuming that OISx and OISxN do not correspond to tim_ocx and tim_ocxn both in active state	
			1	0		
			1	1		

1. When both outputs of a channel are not used (control taken over by GPIO controller), the OISx, OISxN, CCxP and CCxNP bits must be kept cleared.

Note: The state of the external I/O pins connected to the complementary tim_ocx and tim_ocxn channels depends on the tim_ocx and tim_ocxn channel state and GPIO control and alternate function selection registers.

53.7.10 TIM15 counter (TIM15_CNT)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF Copy
This bit is a read-only copy of the UIF bit in the TIM15_ISR register.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value
Non-dithering mode (DITHEN = 0)
The register holds the counter value.
Dithering mode (DITHEN = 1)
The register only holds the non-dithered part in CNT[15:0]. The fractional part is not available.

53.7.11 TIM15 prescaler (TIM15_PSC)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value
The counter clock frequency ($f_{tim_cnt_ck}$) is equal to $f_{tim_psc_ck}$ / (PSC[15:0] + 1).
PSC contains the value to be loaded in the active prescaler register at each update event (including when the counter is cleared through UG bit of TIM15_EGR register or through trigger controller when configured in “reset mode”).

53.7.12 TIM15 autoreload register (TIM15_ARR)

Address offset: 0x2C

Reset value: 0x0000 FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **ARR[19:0]**: Auto-reload value

ARR is the value to be loaded in the actual auto-reload register.

Refer to the *Section 53.4.3: Time-base unit* for more details about ARR update and behavior.

The counter is blocked while the auto-reload value is null.

Non-dithering mode (DITHEN = 0)

The register holds the auto-reload value in ARR[15:0]. The ARR[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in ARR[19:4]. The ARR[3:0] bitfield contains the dithered part.

53.7.13 TIM15 repetition counter register (TIM15_RCR)

Address offset: 0x30

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **REP[7:0]**: Repetition counter reload value

This bitfield defines the update rate of the compare registers (i.e. periodic transfers from preload to active registers) when preload registers are enable. It also defines the update interrupt generation rate, if this interrupt is enable.

When the repetition down-counter reaches zero, an update event is generated and it restarts counting from REP value. As the reptition counter is reloaded with REP value only at the repetition update event UEV, any write to the TIM15_RCR register is not taken in account until the next repetition update event.

It means in PWM mode (REP+1) corresponds to the number of PWM periods in edge-aligned mode:

– The number of PWM periods in edge-aligned mode.
– The number of half PWM period in center-aligned mode.

53.7.14 TIM15 capture/compare register 1 (TIM15_CCR1)

Address offset: 0x34

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR1[19:0]**: Capture/compare 1 value

If channel CC1 is configured as output:

CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIM15_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIM15_CNT and signaled on tim_oc1 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value in CCR1[15:0]. The CCR1[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR1[19:4]. The CCR1[3:0] bitfield contains the dithered part.

If channel CC1 is configured as input:

CR1 is the counter value transferred by the last input capture 1 event (tim_ic1). The TIMx_CCR1 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The register holds the capture value in CCR1[15:0]. The CCR1[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR1[19:4]. The CCR1[3:0] bits are reset.

53.7.15 TIM15 capture/compare register 2 (TIM15_CCR2)

Address offset: 0x38

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR2[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR2[19:0]**: Capture/compare 2 value

If channel CC2 is configured as output:

CCR2 is the value to be loaded in the actual capture/compare 2 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIM15_CCMR2 register (bit OC2PE). Else the preload value is copied in the active capture/compare 2 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIM15_CNT and signalled on tim_oc2 output.

Non-dithering mode (DITHEN = 0)

The register holds the compare value in CCR2[15:0]. The CCR2[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in CCR2[19:4]. The CCR2[3:0] bitfield contains the dithered part.

If channel CC2 is configured as input:

CCR2 is the counter value transferred by the last input capture 1 event (tim_ic2). The TIMx_CCR2 register is read-only and cannot be programmed.

Non-dithering mode (DITHEN = 0)

The register holds the capture value in CCR2[15:0]. The CCR2[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the capture in CCR2[19:4]. The CCR2[3:0] bits are reset.

53.7.16 TIM15 break and dead-time register (TIM15_BDTR)

Address offset: 0x44

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	BKBID	Res.	BK DSRM	Res.	Res.	Res.	Res.	Res.	Res.	BKF[3:0]			
			rw		rw							rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK[1:0]		DTG[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Note: As the BKBID, BKDSRM, BKF[3:0], AOE, BKP, BKE, OSSI, OSSR, and DTG[7:0] bits may be write-locked depending on the LOCK configuration, it may be necessary to configure all of them during the first write access to the TIM15_BDTR register.

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **BKBID**: Break bidirectional

0: Break input tim_brk in input mode
1: Break input tim_brk in bidirectional mode
In the bidirectional mode (BKBID bit set to 1), the break input is configured both in input mode and in open drain output mode. Any active break event asserts a low logic level on the Break input to indicate an internal break event to external devices.

Note: This bit cannot be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 27 Reserved, must be kept at reset value.

Bit 26 **BKDSRM**: Break disarm

0: Break input tim_brk is armed
1: Break input tim_brk is disarmed
This bit is cleared by hardware when no break source is active.
The BKDSRM bit must be set by software to release the bidirectional output control (open-drain output in Hi-Z state) and then be polled until it is reset by hardware, indicating that the fault condition has disappeared.

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bits 25:20 Reserved, must be kept at reset value.

Bits 19:16 **BKF[3:0]**: Break filter

This bitfield defines the frequency used to sample the tim_brk input signal and the length of the digital filter applied to tim_brk. The digital filter is made of an event counter in which N events are needed to validate a transition on the output:
0000: No filter, tim_brk acts asynchronously
0001: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 2
0010: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 4
0011: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 8
0100: $f_{SAMPLING} = f_{DTS}/2$, N = 6
0101: $f_{SAMPLING} = f_{DTS}/2$, N = 8
0110: $f_{SAMPLING} = f_{DTS}/4$, N = 6
0111: $f_{SAMPLING} = f_{DTS}/4$, N = 8
1000: $f_{SAMPLING} = f_{DTS}/8$, N = 6
1001: $f_{SAMPLING} = f_{DTS}/8$, N = 8
1010: $f_{SAMPLING} = f_{DTS}/16$, N = 5
1011: $f_{SAMPLING} = f_{DTS}/16$, N = 6
1100: $f_{SAMPLING} = f_{DTS}/16$, N = 8
1101: $f_{SAMPLING} = f_{DTS}/32$, N = 5
1110: $f_{SAMPLING} = f_{DTS}/32$, N = 6
1111: $f_{SAMPLING} = f_{DTS}/32$, N = 8

Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 15 **MOE**: Main output enable

This bit is cleared asynchronously by hardware as soon as the tim_brk input is active. It is set by software or automatically depending on the AOE bit. It is acting only on the channels which are configured in output.

0: tim_ocx and tim_ocxn outputs are disabled or forced to idle state depending on the OSSI bit.

1: tim_ocx and tim_ocxn outputs are enabled if their respective enable bits are set (CCxE, CCxNE in TIM15_CCER register)

See tim_ocx/tim_ocxn enable description for more details (*Section 53.7.9: TIM15 capture/compare enable register (TIM15_CCER) on page 2355*).

Bit 14 **AOE**: Automatic output enable

0: MOE can be set only by software

1: MOE can be set by software or automatically at the next update event (if the break input is not be active)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 13 **BKP**: Break polarity

0: Break input tim_brk is active low

1: Break input tim_brk is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 12 **BKE**: Break enable

0: Break inputs (tim_brk and tim_sys_brk clock failure event) disabled

1; Break inputs (tim_brk and tim_sys_brk clock failure event) enabled

This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 11 **OSSR**: Off-state selection for Run mode

This bit is used when MOE = 1 on channels that have a complementary output which are configured as outputs. OSSR is not implemented if no complementary output is implemented in the timer.

See tim_ocx/tim_ocxn enable description for more details (*Section 53.7.9: TIM15 capture/compare enable register (TIM15_CCER) on page 2355*).

0: When inactive, tim_ocx/tim_ocxn outputs are disabled (the timer releases the output control which is taken over by the GPIO, which forces a Hi-Z state)

1: When inactive, tim_ocx/tim_ocxn outputs are enabled with their inactive level as soon as CCxE = 1 or CCxNE = 1 (the output is still controlled by the timer).

Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 10 **OSSI**: Off-state selection for Idle mode

This bit is used when MOE = 0 on channels configured as outputs.

See tim_ocx/tim_ocxn enable description for more details (*Section 53.7.9: TIM15 capture/compare enable register (TIM15_CCER) on page 2355*).

0: When inactive, tim_ocx/tim_ocxn outputs are disabled (tim_ocx/tim_ocxn enable output signal = 0)

1: When inactive, tim_ocx/tim_ocxn outputs are forced first with their idle level as soon as CCxE = 1 or CCxNE = 1. tim_ocx/tim_ocxn enable output signal = 1)

Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIM15_BDTR register).

Bits 9:8 **LOCK[1:0]**: Lock configuration

These bits offer a write protection against software errors.

00: LOCK OFF - No bit is write protected

01: LOCK Level 1 = DTG bits in TIM15_BDTR register, OISx and OISxN bits in TIM15_CR2 register and BKBID/BKE/BKP/AOE bits in TIM15_BDTR register can no longer be written

10: LOCK Level 2 = LOCK Level 1 + CC Polarity bits (CCxP/CCxNP bits in TIM15_CCER register, as long as the related channel is configured in output through the CCxS bits) as well as OSSR and OSSI bits can no longer be written.

11: OCK Level 3 = LOCK Level 2 + CC Control bits (OCxM and OCxPE bits in TIM15_CCMRx registers, as long as the related channel is configured in output through the CCxS bits) can no longer be written.

Note: The LOCK bits can be written only once after the reset. Once the TIM15_BDTR register has been written, their content is frozen until the next reset.

Bits 7:0 **DTG[7:0]**: Dead-time generator setup

This bitfield defines the duration of the dead-time inserted between the complementary outputs. DT correspond to this duration.

DTG[7:5] = 0xx → DT = DTG[7:0]x t_{dtg} with $t_{dtg} = t_{DTS}$

DTG[7:5] = 10x → DT = (64+DTG[5:0])xt_{dtg} with $T_{dtg} = 2xt_{DTS}$

DTG[7:5] = 110 → DT = (32+DTG[4:0])xt_{dtg} with $T_{dtg} = 8xt_{DTS}$

DTG[7:5] = 111 → DT = (32+DTG[4:0])xt_{dtg} with $T_{dtg} = 16xt_{DTS}$

Example if T_{DTS} = 125 ns (8MHz), dead-time possible values are:

0 to 15875 ns by 125 ns steps,

16 µs to 31750 ns by 250 ns steps,

32 µs to 63 µs by 1 µs steps,

64 µs to 126 µs by 2 µs steps

Note: This bitfield can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIM15_BDTR register).

53.7.17 TIM15 timer deadtime register 2 (TIM15_DTR2)

Address offset: 0x054

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTPE	DTAE
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTGF[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **DTPE**: Deadtime preload enable

0: Deadtime value is not preloaded

1: Deadtime value preload is enabled

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 16 **DTAE**: Deadtime asymmetric enable
0: Deadtime on rising and falling edges are identical, and defined with DTG[7:0] register
1: Deadtime on rising edge is defined with DTG[7:0] register and deadtime on falling edge is defined with DTGF[7:0] bits.
Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIM15_BDTR register).

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **DTGF[7:0]**: Dead-time falling edge generator setup
This bitfield defines the duration of the dead-time inserted between the complementary outputs, on the falling edge.
DTGF[7:5] = 0xx → DTF = DTGF[7:0]x t_{dtg} with $t_{dtg} = t_{DTS}$.
DTGF[7:5] = 10x → DTF = (64+DTGF[5:0])xt_{dtg} with $T_{dtg} = 2xt_{DTS}$.
DTGF[7:5] = 110 → DTF = (32+DTGF[4:0])xt_{dtg} with $T_{dtg} = 8xt_{DTS}$.
DTGF[7:5] = 111 → DTF = (32+DTGF[4:0])xt_{dtg} with $T_{dtg} = 16xt_{DTS}$.
Example if T_{DTS} = 125 ns (8 MHz), dead-time possible values are:
0 to 15875 ns by 125 ns steps,
16 µs to 31750 ns by 250 ns steps,
32 µs to 63 µs by 1 µs steps,
64 µs to 126 µs by 2 µs steps
Note: This bitfield can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIM15_BDTR register).

53.7.18 TIM15 input selection register (TIM15_TISEL)

Address offset: 0x5C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: selects tim_ti2_in[15:0] input
0000: TIM15_CH2 input (tim_ti2_in0)
0001: tim_ti2_in1
...
1111: tim_ti2_in15
Refer to *Section 53.4.2: TIM15/TIM16/TIM17 pins and internal signals* for interconnects list.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: selects tim_ti1_in[15:0] input
0000: TIM15_CH1 input (tim_ti1_in0)
0001: tim_ti1_in1
...
1111: tim_ti1_in15
Refer to *Section 53.4.2: TIM15/TIM16/TIM17 pins and internal signals* for interconnects list.

53.7.19 TIM15 alternate function register 1 (TIM15_AF1)

Address offset: 0x060

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	BK CMP4P	BK CMP3P	BK CMP2P	BK CMP1P	BKINP	BK CMP8E	BK CMP7E	BK CMP6E	BK CMP5E	BK CMP4E	BK CMP3E	BK CMP2E	BK CMP1E	BKINE
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Refer to *Section 53.4.2: TIM15/TIM16/TIM17 pins and internal signals* for product specific implementation.

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **BKCMP4P**: tim_brk_cmp4 input polarity

This bit selects the tim_brk_cmp4 input sensitivity. It must be programmed together with the BKP polarity bit.

0: tim_brk_cmp4 input is active high

1: tim_brk_cmp4 input is active low

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 12 **BKCMP3P**: tim_brk_cmp3 input polarity

This bit selects the tim_brk_cmp3 input sensitivity. It must be programmed together with the BKP polarity bit.

0: tim_brk_cmp3 input is active high

1: tim_brk_cmp3 input is active low

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 11 **BKCMP2P**: tim_brk_cmp2 input polarity

This bit selects the tim_brk_cmp2 input sensitivity. It must be programmed together with the BKP polarity bit.

0: tim_brk_cmp2 input is active high

1: tim_brk_cmp2 input is active low

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 10 **BKCMP1P**: tim_brk_cmp1 input polarity

This bit selects the tim_brk_cmp1 input sensitivity. It must be programmed together with the BKP polarity bit.

0: tim_brk_cmp1 input is active high

1: tim_brk_cmp1 input is active low

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 9 **BKINP**: TIMx_BKIN input polarity

This bit selects the TIMx_BKIN alternate function input sensitivity. It must be programmed together with the BKP polarity bit.

0: TIMx_BKIN input is active high

1: TIMx_BKIN input is active low

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 8 **BKCMP8E**: tim_brk_cmp8 enable

This bit enables the tim_brk_cmp8 for the timer's tim_brk input. tim_brk_cmp8 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp8 input disabled

1: tim_brk_cmp8 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 7 **BKCMP7E**: tim_brk_cmp7 enable

This bit enables the tim_brk_cmp7 for the timer's tim_brk input. tim_brk_cmp7 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp7 input disabled

1: tim_brk_cmp7 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 6 **BKCMP6E**: tim_brk_cmp6 enable

This bit enables the tim_brk_cmp6 for the timer's tim_brk input. tim_brk_cmp6 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp6 input disabled

1: tim_brk_cmp6 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 5 **BKCMP5E**: tim_brk_cmp5 enable

This bit enables the tim_brk_cmp5 for the timer's tim_brk input. tim_brk_cmp5 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp5 input disabled

1: tim_brk_cmp5 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 4 **BKCMP4E**: tim_brk_cmp4 enable

This bit enables the tim_brk_cmp4 for the timer's tim_brk input. tim_brk_cmp4 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp4 input disabled

1: tim_brk_cmp4 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 3 **BKCMP3E**: tim_brk_cmp3 enable

This bit enables the tim_brk_cmp3 for the timer's tim_brk input. tim_brk_cmp3 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp3 input disabled

1: tim_brk_cmp3 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 2 **BKCMP2E**: tim_brk_cmp2 enable

This bit enables the tim_brk_cmp2 for the timer's tim_brk input. tim_brk_cmp2 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp2 input disabled

1: tim_brk_cmp2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 1 **BKCMP1E**: tim_brk_cmp1 enable

This bit enables the tim_brk_cmp1 for the timer's tim_brk input. tim_brk_cmp1 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp1 input disabled

1: tim_brk_cmp1 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 0 **BKINE**: TIMx_BKIN input enable

This bit enables the TIMx_BKIN alternate function input for the timer's tim_brk input. TIMx_BKIN input is 'ORed' with the other tim_brk sources.

0: TIMx_BKIN input disabled

1: TIMx_BKIN input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

53.7.20 TIM15 alternate function register 2 (TIM15_AF2)

Address offset: 0x064

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCRSEL[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **OCRSEL[2:0]**: ocref_clr source selection

These bits select the ocref_clr input source.

000: tim_ocref_clr0

001: tim_ocref_clr1

010: tim_ocref_clr2

011: tim_ocref_clr3

100: tim_ocref_clr4

101: tim_ocref_clr5

110: tim_ocref_clr6

111: tim_ocref_clr7

Refer to *Section 53.4.2: TIM15/TIM16/TIM17 pins and internal signals* for product specific implementation.

Note: These bits can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIM15_BDTR register).

Bits 15:0 Reserved, must be kept at reset value.

53.7.21 TIM15 DMA control register (TIM15_DCR)

Address offset: 0x3DC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBSS[3:0]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:16 **DBSS[3:0]**: DMA burst source selection

This bitfield defines the interrupt source that triggers the DMA burst transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address).

0000: Reserved

0001: Update

0010: CC1

0110: COM

0111: Trigger

Other: reserved

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **DBL[4:0]**: DMA burst length

This 5-bitfield defines the length of DMA transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIM15_DMAR address).

00000: 1 transfer,
00001: 2 transfers,
00010: 3 transfers,
...
10001: 18 transfers.

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **DBA[4:0]**: DMA base address

This 5-bitfield defines the base-address for DMA transfers (when read/write access are done through the TIM15_DMAR address). DBA is defined as an offset starting from the address of the TIM15_CR1 register.

Example:

00000: TIM15_CR1,
00001: TIM15_CR2,
00010: TIM15_SMCR,
...

53.7.22 TIM15 DMA address for full transfer (TIM15_DMAR)

Address offset: 0x3E0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMAB[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAB[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DMAB[31:0]**: DMA register for burst accesses

A read or write operation to the DMAR register accesses the register located at the address

(TIM15_CR1 address) + (DBA + DMA index) x 4

where TIM15_CR1 address is the address of the control register 1, DBA is the DMA base address configured in TIM15_DCR register, DMA index is automatically controlled by the DMA transfer, and ranges from 0 to DBL (DBL configured in TIM15_DCR).

53.7.23 TIM15 register map

TIM15 registers are mapped as 16-bit addressable registers as described in the table below:

Table 583. TIM15 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	TIM15_CR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIFREMA	Res.	CKD [1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
	Reset value																					0		0	0	0				0	0	0	0
0x04	TIM15_CR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OIS2	OIS1N	OIS1	TI1S	MMS[2:0]			CCDS	CCUS	Res.	CCPC
	Reset value																						0	0	0	0	0	0	0	0	0		0
0x08	TIM15_SMCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SMSPE	Res.	Res.	TS [4:3]		Res.	Res.	Res.	SMS[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MSM	TS[2:0]			Res.	SMS[2:0]		
	Reset value								0			0	0				0								0	0	0	0			0	0	0
0x0C	TIM15_DIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDE	COMDE	Res.	Res.	Res.	CC1DE	UDE	BIE	TIE	COMIE	Res.	Res.	CC2IE	CC1IE	UIE
	Reset value																		0	0				0	0	0	0	0			0	0	0
0x10	TIM15_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2OF	CC1OF	Res.	BIF	TIF	COMIF	Res.	Res.	CC2IF	CC1IF	UIF
	Reset value																						0	0		0	0	0			0	0	0
0x14	TIM15_EGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BG	TG	COMG	Res.	Res.	CC2G	CC1G	UG
	Reset value																									0	0	0			0	0	0

Table 583. TIM15 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x18	TIM15_CCMR1 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC2F[3:0]				IC2 PSC [1:0]		CC2S [1:0]		IC1F[3:0]				IC1 PSC [1:0]		CC1S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TIM15_CCMR1 Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]	OC2CE	OC2M [2:0]			OC2PE	OC2FE	CC2S [1:0]		OC1CE	OC1M [2:0]			OC1PE	OC1FE	CC1S [1:0]	
	Reset value								0								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	TIM15_CCER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2NP	Res.	CC2P	CC2E	CC1NP	CC1NE	CC1P	CC1E
	Reset value																									0		0	0	0	0	0	0
0x24	TIM15_CNT	UIFCPY or Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	TIM15_PSC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	TIM15_ARR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:0]																			
	Reset value													0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x30	TIM15_RCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x34	TIM15_CCR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x38	TIM15_CCR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR2[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x38 - 0x40	Reserved	Res.																															
0x44	TIM15_BDTR	Res.	Res.	Res.	BKBID	Res.	BKDSRM	Res.	Res.	Res.	Res.	Res.	Res.	BKF[3:0]				MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK [1:0]		DT[7:0]							
	Reset value				0		0							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x48 - 0x50	Reserved	Res.																															
0x54	TIM15_DTR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTPE	DTAE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTGF[7:0]							
	Reset value															0	0									0	0	0	0	0	0	0	0
0x58	Reserved	Res.																															

Table 583. TIM15 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x5C	TIM15_TISEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value																					0	0	0	0					0	0	0	0
0x60	TIM15_AF1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BKCMP4P	BKCMP3P	BKCMP2P	BKCMP1P	BKINP	BKCMP8E	BKCMP7E	BKCMP6E	BKCMP5E	BKCMP4E	BKCMP3E	BKCMP2E	BKCMP1E	BKINE
	Reset value																			0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x64	TIM15_AF2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCR SEL[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value														0	0	0																
0x68 - 0x3D8	Reserved	Res.																															
0x3DC	TIM15_DCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBSS[3:0]				Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
	Reset value													0	0	0	0				0	0	0	0	0				0	0	0	0	0
0x3E0	TIM15_DMAR	DMAB[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

53.8 TIM16/TIM17 registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by half-words (16-bit) or words (32-bit).

53.8.1 TIMx control register 1 (TIMx_CR1)(x = 16 to 17)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DITHEN	UIFREMAP	Res.	CKD[1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
			rw	rw		rw	rw	rw				rw	rw	rw	rw

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **DITHEN**: Dithering enable
0: Dithering disabled
1: Dithering enabled
Note: The DITHEN bit can only be modified when CEN bit is reset.

Bit 11 **UIFREMAP**: UIF status bit remapping
0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bit 10 Reserved, must be kept at reset value.

Bits 9:8 **CKD[1:0]**: Clock division
This bitfield indicates the division ratio between the timer clock (tim_ker_ck) frequency and the dead-time and sampling clock (t_{DTS})used by the dead-time generators and the digital filters (tim_tix),
00: $t_{DTS} = t_{tim_ker_ck}$
01: $t_{DTS} = 2*t_{tim_ker_ck}$
10: $t_{DTS} = 4*t_{tim_ker_ck}$
11: Reserved

Bit 7 **ARPE**: Auto-reload preload enable
0: TIMx_ARR register is not buffered
1: TIMx_ARR register is buffered

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **OPM**: One pulse mode
0: Counter is not stopped at update event
1: Counter stops counting at the next update event (clearing the bit CEN)

Bit 2 **URS**: Update request source
This bit is set and cleared by software to select the UEV event sources.
0: Any of the following events generate an update interrupt or DMA request if enabled. These events can be:
– Counter overflow/underflow
– Setting the UG bit
– Update generation through the slave mode controller
1: nly counter overflow/underflow generates an update interrupt or DMA request if enabled.

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable UEV event generation.

0: UEV enabled. The Update (UEV) event is generated by one of the following events:

– Counter overflow/underflow

– Setting the UG bit

– Update generation through the slave mode controller

Buffered registers are then loaded with their preload values.

1: UEV disabled. The Update event is not generated, shadow registers keep their value (ARR, PSC, CCRx). However the counter and the prescaler are reinitialized if the UG bit is set or if a hardware reset is received from the slave mode controller.

Bit 0 **CEN**: Counter enable

0: Counter disabled

1: Counter enabled

Note: External clock and gated mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

53.8.2 TIMx control register 2 (TIMx_CR2)(x = 16 to 17)

Address offset: 0x04

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	OIS1N	OIS1	Res.	Res.	Res.	Res.	CCDS	CCUS	Res.	CCPC
						rw	rw					rw	rw		rw

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **OIS1N**: Output Idle state 1 (tim_oc1n output)

0: tim_oc1n = 0 after a dead-time when MOE = 0

1: tim_oc1n = 1 after a dead-time when MOE = 0

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BKR register).

Bit 8 **OIS1**: Output Idle state 1 (tim_oc1 output)

0: tim_oc1 = 0 after a dead-time when MOE = 0

1: tim_oc1 = 1 after a dead-time when MOE = 0

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BKR register).

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **CCDS**: Capture/compare DMA selection

0: CCx DMA request sent when CCx event occurs

1: CCx DMA requests sent when update event occurs

Bit 2 **CCUS**: Capture/compare control update selection

0: When capture/compare control bits are preloaded (CCPC = 1), they are updated by setting the COMG bit only.

1: When capture/compare control bits are preloaded (CCPC = 1), they are updated by setting the COMG bit or when a rising edge occurs on tim_trgi (if available).

Note: This bit acts only on channels that have a complementary output.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **CCPC**: Capture/compare preloaded control
0: CCxE, CCxNE and OCxM bits are not preloaded
1: CCxE, CCxNE and OCxM bits are preloaded, after having been written, they are updated only when COM bit is set.
Note: This bit acts only on channels that have a complementary output.

53.8.3 TIMx DMA/interrupt enable register (TIMx_DIER)(x = 16 to 17)

Address offset: 0x0C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CC1DE	UDE	BIE	Res.	COMIE	Res.	Res.	Res.	CC1IE	UIE
						rw	rw	rw		rw				rw	rw

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **CC1DE**: Capture/Compare 1 DMA request enable
0: CC1 DMA request disabled
1: CC1 DMA request enabled

Bit 8 **UDE**: Update DMA request enable
0: Update DMA request disabled
1: Update DMA request enabled

Bit 7 **BIE**: Break interrupt enable
0: Break interrupt disabled
1: Break interrupt enabled

Bit 6 Reserved, must be kept at reset value.

Bit 5 **COMIE:** COM interrupt enable
0: COM interrupt disabled
1: COM interrupt enabled

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable
0: CC1 interrupt disabled
1: CC1 interrupt enabled

Bit 0 **UIE**: Update interrupt enable
0: Update interrupt disabled
1: Update interrupt enabled

53.8.4 TIMx status register (TIMx_SR)(x = 16 to 17)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CC1OF	Res.	BIF	Res.	COMIF	Res.	Res.	Res.	CC1IF	UIF
						rc_w0		rc_w0		rc_w0				rc_w0	rc_w0

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag

This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to 0.

0: No overcapture has been detected

1: The counter value has been captured in TIMx_CCR1 register while CC1IF flag was already set

Bit 8 Reserved, must be kept at reset value.

Bit 7 **BIF**: Break interrupt flag

This flag is set by hardware as soon as the tim_brk input goes active. It can be cleared by software if the break input is not active.

0: No break event occurred

1: An active level has been detected on the break input

Bit 6 Reserved, must be kept at reset value.

Bit 5 **COMIF:** COM interrupt flag

This flag is set by hardware on a COM event (once the capture/compare control bits –CCxE, CCxNE, OCxM– have been updated). It is cleared by software.

0: No COM event occurred

1: COM interrupt pending

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **CC1IF**: Capture/Compare 1 interrupt flag

This flag is set by hardware. It is cleared by software (input capture or output compare mode) or by reading the TIMx_CCR1 register (input capture mode only).

0: No compare match / No input capture occurred

1: A compare match or an input capture occurred

If channel CC1 is configured as output: this flag is set when the content of the counter TIMx_CNT matches the content of the TIMx_CCR1 register. When the content of TIMx_CCR1 is greater than the content of TIMx_ARR, the CC1IF bit goes high on the counter overflow (in up-counting and up/down-counting modes) or underflow (in down-counting mode). There are 3 possible options for flag setting in center-aligned mode, refer to the CMS bits in the TIMx_CR1 register for the full description.

If channel CC1 is configured as input: this bit is set when counter value has been captured in TIMx_CCR1 register (an edge has been detected on IC1, as per the edge sensitivity defined with the CC1P and CC1NP bits setting, in TIMx_CCER).

Bit 0 **UIF**: Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.

0: No update occurred.

1: Update interrupt pending. This bit is set by hardware when the registers are updated:

– At overflow regarding the repetition counter value (update if repetition counter = 0) and if the UDIS = 0 in the TIMx_CR1 register.

– When CNT is reinitialized by software using the UG bit in TIMx_EGR register, if URS = 0 and UDIS = 0 in the TIMx_CR1 register.

53.8.5 TIMx event generation register (TIMx_EGR)(x = 16 to 17)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BG	Res.	COMG	Res.	Res.	Res.	CC1G	UG
								w		w				w	w

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **BG**: Break generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action.

1: A break event is generated. MOE bit is cleared and BIF flag is set. Related interrupt or DMA transfer can occur if enabled.

Bit 6 Reserved, must be kept at reset value.

Bit 5 **COMG:** Capture/Compare control update generation

This bit can be set by software, it is automatically cleared by hardware.

0: No action

1: When the CCPC bit is set, it is possible to update the CCxE, CCxNE and OCxM bits

Note: This bit acts only on channels that have a complementary output.

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **CC1G**: Capture/Compare 1 generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action.

1: A capture/compare event is generated on channel 1:

If channel CC1 is configured as output:

CC1IF flag is set, Corresponding interrupt or DMA request is sent if enabled.

If channel CC1 is configured as input:

The current value of the counter is captured in TIMx_CCR1 register. The CC1IF flag is set, the corresponding interrupt or DMA request is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation

This bit can be set by software, it is automatically cleared by hardware.

0: No action.

1: Reinitialize the counter and generates an update of the registers. Note that the prescaler counter is cleared too (anyway the prescaler ratio is not affected).

53.8.6 TIMx capture/compare mode register 1 (TIMx_CCMR1) (x = 16 to 17)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (for example channel 1 in input capture mode and channel 2 in output compare mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC1F[3:0]				IC1PSC[1:0]		CC1S[1:0]	
								rw	rw	rw	rw	rw	rw	rw	rw

Input capture mode

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bitfield defines the frequency used to sample tim_ti1 input and the length of the digital filter applied to tim_ti1. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}
0001: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 2
0010: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 4
0011: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 8
0100: $f_{SAMPLING} = f_{DTS}/2$, N =
0101: $f_{SAMPLING} = f_{DTS}/2$, N = 8
0110: $f_{SAMPLING} = f_{DTS}/4$, N = 6
0111: $f_{SAMPLING} = f_{DTS}/4$, N = 8
1000: $f_{SAMPLING} = f_{DTS}/8$, N = 6
1001: $f_{SAMPLING} = f_{DTS}/8$, N = 8
1010: $f_{SAMPLING} = f_{DTS}/16$, N = 5
1011: $f_{SAMPLING} = f_{DTS}/16$, N = 6
1100: $f_{SAMPLING} = f_{DTS}/16$, N = 8
1101: $f_{SAMPLING} = f_{DTS}/32$, N = 5
1110: $f_{SAMPLING} = f_{DTS}/32$, N = 6
1111: $f_{SAMPLING} = f_{DTS}/32$, N = 8

Bits 3:2 **IC1PSC[1:0]**: Input capture 1 prescaler

This bitfield defines the ratio of the prescaler acting on CC1 input (tim_ic1).
The prescaler is reset as soon as CC1E = 0 (TIMx_CCER register).
00: no prescaler, capture is done each time an edge is detected on the capture input.
01: capture is done once every 2 events
10: capture is done once every 4 events
11: capture is done once every 8 events

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output

01: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti1

Others: Reserved

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

53.8.7 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 16 to 17)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (for example channel 1 in input capture mode and channel 2 in output compare mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M [3]
															rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1CE	OC1M[2:0]			OC1PE	OC1FE	CC1S[1:0]	
								rw	rw	rw	rw	rw	rw	rw	rw

Output compare mode:

Bits 31:17 Reserved, must be kept at reset value.

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **OC1CE**: Output Compare 1 clear enable

0: tim_oc1ref is not affected by the tim_ocref_clr input.

1: tim_oc1ref is cleared as soon as a High level is detected on tim_ocref_clr input.

Bits 16, 6:4 **OC1M[3:0]**: Output Compare 1 mode

These bits define the behavior of the output reference signal tim_oc1ref from which tim_oc1 and tim_oc1n are derived. tim_oc1ref is active high whereas tim_oc1 and tim_oc1n active level depends on CC1P and CC1NP bits.

0000: Frozen - The comparison between the output compare register TIMx_CCR1 and the counter TIMx_CNT has no effect on the outputs. This mode can be used when the timer serves as a software timebase. When the frozen mode is enabled during timer operation, the output keeps the state (active or inactive) it had before entering the frozen state.

0001: Set channel 1 to active level on match. tim_oc1ref signal is forced high when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0010: Set channel 1 to inactive level on match. tim_oc1ref signal is forced low when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0011: Toggle - tim_oc1ref toggles when TIMx_CNT = TIMx_CCR1.

0100: Force inactive level - tim_oc1ref is forced low.

0101: Force active level - tim_oc1ref is forced high.

0110: PWM mode 1 - Channel 1 is active as long as TIMx_CNT<TIMx_CCR1 else inactive.

0111: PWM mode 2 - Channel 1 is inactive as long as TIMx_CNT<TIMx_CCR1 else active.

Others: Reserved

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S = 00 (the channel is configured in output).

In PWM mode, the OCREF level changes when the result of the comparison changes, when the output compare mode switches from “frozen” mode to “PWM” mode and when the output compare mode switches from “force active/inactive” mode to “PWM” mode.

Bit 3 **OC1PE**: Output Compare 1 preload enable

0: Preload register on TIMx_CCR1 disabled. TIMx_CCR1 can be written at anytime, the new value is taken in account immediately.

1: Preload register on TIMx_CCR1 enabled. Read/Write operations access the preload register. TIMx_CCR1 preload value is loaded in the active register at each update event.

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S = 00 (the channel is configured in output).

Bit 2 **OC1FE**: Output Compare 1 fast enable

This bit decreases the latency between a trigger event and a transition on the timer output. It must be used in one-pulse mode (OPM bit set in TIMx_CR1 register), to have the output pulse starting as soon as possible after the starting trigger.

0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.

1: An active edge on the trigger input acts like a compare match on CC1 output. Then, tim_ocx is set to the compare level independently of the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OC1FE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output

01: CC1 channel is configured as input, tim_ic1 is mapped on tim_ti1

Others: Reserved

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

53.8.8 TIMx capture/compare enable register (TIMx_CCER)(x = 16 to 17)

Address offset: 0x20

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1NP	CC1NE	CC1P	CC1E
												rw	rw	rw	rw

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **CC1NP**: Capture/Compare 1 complementary output polarity

CC1 channel configured as output:

0: tim_oc1n active high

1: tim_oc1n active low

CC1 channel configured as input:

This bit is used in conjunction with CC1P to define the polarity of tim_ti1fp1. Refer to the description of CC1P.

Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S = 00 (the channel is configured in output).

On channels that have a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1NP active bit takes the new value from the preloaded bit only when a commutation event is generated.

Bit 2 **CC1NE**: Capture/Compare 1 complementary output enable

0: Off - tim_oc1n is not active. tim_oc1n level is then function of MOE, OSSI, OSSR, OIS1, OIS1N and CC1E bits.

1: On - tim_oc1n signal is output on the corresponding output pin depending on MOE, OSSI, OSSR, OIS1, OIS1N and CC1E bits.

Bit 1 **CC1P**: Capture/Compare 1 output polarity

0: OC1 active high (output mode) / Edge sensitivity selection (input mode, see below)

1: OC1 active low (output mode) / Edge sensitivity selection (input mode, see below)

When CC1 channel is configured as input, both CC1NP/CC1P bits select the active polarity of TI1FP1 and TI2FP1 for trigger or capture operations.

CC1NP = 0, CC1P = 0: non-inverted/rising edge. The circuit is sensitive to TIxFP1 rising edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode).

CC1NP = 0, CC1P = 1: inverted/falling edge. The circuit is sensitive to TIxFP1 falling edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is inverted (trigger operation in gated mode).

CC1NP = 1, CC1P = 1: non-inverted/both edges/ The circuit is sensitive to both TIxFP1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), TIxFP1is not inverted (trigger operation in gated mode).

CC1NP = 1, CC1P = 0: this configuration is reserved, it must not be used.

Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

On channels that have a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1P active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Bit 0 **CC1E**: Capture/Compare 1 output enable

0: Capture mode disabled / OC1 is not active (see below)

1: Capture mode enabled / OC1 signal is output on the corresponding output pin

When CC1 channel is configured as output, the OC1 level depends on MOE, OSSI, OSSR, OIS1, OIS1N and CC1NE bits, regardless of the CC1E bits state. Refer to *Table 584* for details.

Table 584. Output control bits for complementary tim_oc1 and tim_oc1n channels with break feature (TIM16/TIM17)

<table>
<tr><th colspan="5">Control bits</th><th colspan="2">Output states(1)</th></tr>
<tr><th>MOE bit</th><th>OSSI bit</th><th>OSSR bit</th><th>CC1E bit</th><th>CC1NE bit</th><th>tim_oc1 output state</th><th>tim_oc1n output state</th></tr>
<tr><td rowspan="7">1</td><td rowspan="7">X</td><td>X</td><td>0</td><td>0</td><td colspan="2">Output Disabled (not driven by the timer: Hi-Z)
tim_oc1 = 0
tim_oc1n = 0</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>Output Disabled (not driven by the timer: Hi-Z)
tim_oc1 = 0</td><td>tim_oc1ref + Polarity
tim_oc1n = tim_oc1ref XOR CC1NP</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>tim_oc1ref + Polarity
tim_oc1 = tim_oc1ref XOR CC1P</td><td>Output Disabled (not driven by the timer: Hi-Z)
tim_oc1n = 0</td></tr>
<tr><td>X</td><td>1</td><td>1</td><td>tim_oc1ref + Polarity + dead-time</td><td>Complementary to tim_oc1ref (not tim_oc1ref) + Polarity + dead-time</td></tr>
<tr><td>1</td><td>0</td><td>1</td><td>Off-State (output enabled with inactive state)
tim_oc1 = CC1P</td><td>tim_oc1ref + Polarity
tim_oc1n = tim_oc1ref XOR CC1NP</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>tim_oc1ref + Polarity
tim_oc1 = tim_oc1ref XOR CC1P</td><td>Off-State (output enabled with inactive state)
tim_oc1n = CC1NP</td></tr>
<tr><td rowspan="5">0</td><td>0</td><td rowspan="5">X</td><td>X</td><td>X</td><td colspan="2" rowspan="2">Output disabled (not driven by the timer: Hi-Z)</td></tr>
<tr><td rowspan="4">1</td><td>0</td><td>0</td></tr>
<tr><td>0</td><td>1</td><td colspan="2" rowspan="3">Off-State (output enabled with inactive state)
Asynchronously: tim_oc1 = CC1P, tim_oc1n = CC1NP
Then if the clock is present: tim_oc1 = OIS1 and tim_oc1n = OIS1N after a dead-time, assuming that OIS1 and OIS1N do not correspond to tim_oc1 and tim_oc1n both in active state</td></tr>
<tr><td>1</td><td>0</td></tr>
<tr><td>1</td><td>1</td></tr>
</table>

1. When both outputs of a channel are not used (control taken over by the GPIO controller), the OIS1, OIS1N, CC1P and CC1NP bits must be kept cleared.

Note: The state of the external I/O pins connected to the complementary tim_oc1 and tim_oc1n channels depends on the tim_oc1 and tim_oc1n channel state and GPIO control and alternate function selection registers.

53.8.9 TIMx counter (TIMx_CNT)(x = 16 to 17)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF Copy

This bit is a read-only copy of the UIF bit of the TIMx_ISR register. If the UIFREMAP bit in TIMx_CR1 is reset, bit 31 is reserved.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value

Non-dithering mode (DITHEN = 0)

The register holds the counter value.

Dithering mode (DITHEN = 1)

The register only holds the non-dithered part in CNT[15:0]. The fractional part is not available.

53.8.10 TIMx prescaler (TIMx_PSC)(x = 16 to 17)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency (tim_cnt_ck) is equal to $f_{tim_psc_ck}$ / (PSC[15:0] + 1).

PSC contains the value to be loaded in the active prescaler register at each update event (including when the counter is cleared through UG bit of TIMx_EGR register or through trigger controller when configured in “reset mode”).

53.8.11 TIMx auto-reautoreload register (TIMx_ARR)(x = 16 to 17)

Address offset: 0x2C

Reset value: 0x0000 FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:16]			
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **ARR[19:0]**: Auto-reload value

ARR is the value to be loaded in the actual auto-reload register.

Refer to the *Section 53.4.3: Time-base unit on page 2300* for more details about ARR update and behavior.

The counter is blocked while the auto-reload value is null.

Non-dithering mode (DITHEN = 0)

The register holds the auto-reload value in ARR[15:0]. The ARR[19:16] bits are reset.

Dithering mode (DITHEN = 1)

The register holds the integer part in ARR[19:4]. The ARR[3:0] bitfield contains the dithered part.

53.8.12 TIMx repetition counter register (TIMx_RCR)(x = 16 to 17)

Address offset: 0x30

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **REP[7:0]**: Repetition counter reload value

This bitfield defines the update rate of the compare registers (i.e. periodic transfers from preload to active registers) when preload registers are enable. It also defines the update interrupt generation rate, if this interrupt is enable.

When the repetition down-counter reaches zero, an update event is generated and it restarts counting from REP value. As the repetition counter is reloaded with REP value only at the repetition update event UEV, any write to the TIMx_RCR register is not taken in account until the next repetition update event.

It means in PWM mode (REP+1) corresponds to the number of PWM periods in edge-aligned mode:

– The number of PWM periods in edge-aligned mode.
– The number of half PWM period in center-aligned mode.

53.8.13 TIMx capture/compare register 1 (TIMx_CCR1)(x = 16 to 17)

Address offset: 0x34

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **CCR1[19:0]**: Capture/Compare 1 value

If channel CC1 is configured as output:
CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).
It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.
The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on tim_oc1 output.
Non-dithering mode (DITHEN = 0)
The register holds the compare value in CCR1[15:0]. The CCR1[19:16] bits are reset.
Dithering mode (DITHEN = 1)
The register holds the integer part in CCR1[19:4]. The CCR1[3:0] bitfield contains the dithered part.
If channel CC1 is configured as input:
CCR1 is the counter value transferred by the last input capture 1 event (tim_ic1).
Non-dithering mode (DITHEN = 0)
The register holds the capture value in CCR1[15:0]. The CCR1[19:16] bits are reset.
Dithering mode (DITHEN = 1)
The register holds the capture in CCR1[19:4]. The CCR1[3:0] bits are reset.

53.8.14 TIMx break and dead-time register (TIMx_BDTR)(x = 16 to 17)

Address offset: 0x44

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	BKBID	Res.	BK DSRM	Res.	Res.	Res.	Res.	Res.	Res.	BKF[3:0]			
			rw		rw							rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK[1:0]		DTG[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Note: As the BKBID, BKDSRM, BKF[3:0], AOE, BKP, BKE, OSSI, OSSR, and DTG[7:0] bits may be write-locked depending on the LOCK configuration, it may be necessary to configure all of them during the first write access to the TIMx_BDTR register.

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **BKBID**: Break Bidirectional

0: Break input tim_brk in input mode
1: Break input tim_brk in bidirectional mode
In the bidirectional mode (BKBID bit set to 1), the break input is configured both in input mode and in open drain output mode. Any active break event asserts a low logic level on the Break input to indicate an internal break event to external devices.

Note: This bit cannot be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 27 Reserved, must be kept at reset value.

Bit 26 **BKDSRM**: Break Disarm

0: Break input tim_brk is armed
1: Break input tim_brk is disarmed
This bit is cleared by hardware when no break source is active.
The BKDSRM bit must be set by software to release the bidirectional output control (open-drain output in Hi-Z state) and then be polled it until it is reset by hardware, indicating that the fault condition has disappeared.

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bits 25:20 Reserved, must be kept at reset value.

Bits 19:16 **BKF[3:0]**: Break filter

This bitfield defines the frequency used to sample tim_brk input and the length of the digital filter applied to tim_brk. The digital filter is made of an event counter in which N events are needed to validate a transition on the output:

0000: No filter, tim_brk acts asynchronously
0001: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 2
0010: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 4
0011: $f_{SAMPLING} = f_{tim_ker_ck}$, N = 8
0100: $f_{SAMPLING} = f_{DTS}/2$, N = 6
0101: $f_{SAMPLING} = f_{DTS}/2$, N = 8
0110: $f_{SAMPLING} = f_{DTS}/4$, N = 6
0111: $f_{SAMPLING} = f_{DTS}/4$, N = 8
1000: $f_{SAMPLING} = f_{DTS}/8$, N = 6
1001: $f_{SAMPLING} = f_{DTS}/8$, N = 8
1010: $f_{SAMPLING} = f_{DTS}/16$, N = 5
1011: $f_{SAMPLING} = f_{DTS}/16$, N = 6
1100: $f_{SAMPLING} = f_{DTS}/16$, N = 8
1101: $f_{SAMPLING} = f_{DTS}/32$, N = 5
1110: $f_{SAMPLING} = f_{DTS}/32$, N = 6
1111: $f_{SAMPLING} = f_{DTS}/32$, N = 8

This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 15 **MOE**: Main output enable

This bit is cleared asynchronously by hardware as soon as the tim_brk input is active. It is set by software or automatically depending on the AOE bit. It is acting only on the channels which are configured in output.

0: tim_oc1 and tim_oc1n outputs are disabled or forced to idle state depending on the OSSI bit.

1: tim_oc1 and tim_oc1n outputs are enabled if their respective enable bits are set (CC1E, CC1NE in TIMx_CCER register)

See tim_oc1/tim_oc1n enable description for more details (*Section 53.8.8: TIMx capture/compare enable register (TIMx_CCER)(x = 16 to 17)*).

Bit 14 **AOE**: Automatic output enable

0: MOE can be set only by software

1: MOE can be set by software or automatically at the next update event (if the tim_brk input is not active)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 13 **BKP**: Break polarity

0: Break input tim_brk is active low
1: Break input tim_brk is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 12 **BKE**: Break enable

0: Break inputs (tim_brk and tim_sys_brk event) disabled
1; Break inputs (tim_brk and tim_sys_brk event) enabled

Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 11 **OSSR**: Off-state selection for Run mode

This bit is used when MOE = 1 on channels that have a complementary output which are configured as outputs. OSSR is not implemented if no complementary output is implemented in the timer.

See tim_oc1/tim_oc1n enable description for more details (*Section 53.8.8: TIMx capture/compare enable register (TIMx_CCER)(x = 16 to 17)*).

0: When inactive, tim_oc1/tim_oc1n outputs are disabled (the timer releases the output control which is taken over by the GPIO, which forces a Hi-Z state)

1: When inactive, tim_oc1/tim_oc1n outputs are enabled with their inactive level as soon as CC1E = 1 or CC1NE = 1 (the output is still controlled by the timer).

Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **OSSI**: Off-state selection for Idle mode

This bit is used when MOE = 0 on channels configured as outputs.

See tim_oc1/tim_oc1n enable description for more details (*Section 53.8.8: TIMx capture/compare enable register (TIMx_CCER)(x = 16 to 17)*).

0: When inactive, tim_oc1/tim_oc1n outputs are disabled (tim_oc1/tim_oc1n enable output signal = 0)

1: When inactive, tim_oc1/tim_oc1n outputs are forced first with their idle level as soon as CC1E = 1 or CC1NE = 1. tim_oc1/tim_oc1n enable output signal = 1)

Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 9:8 **LOCK[1:0]**: Lock configuration

These bits offer a write protection against software errors.

00: LOCK OFF - No bit is write protected

01: LOCK Level 1 = DTG bits in TIMx_BDTR register, OISx and OISxN bits in TIMx_CR2 register and BKBID/BKE/BKP/AOE bits in TIMx_BDTR register can no longer be written.

10: LOCK Level 2 = LOCK Level 1 + CC Polarity bits (CCxP/CCxNP bits in TIMx_CCER register, as long as the related channel is configured in output through the CCxS bits) as well as OSSR and OSSI bits can no longer be written.

11: LOCK Level 3 = LOCK Level 2 + CC Control bits (OCxM and OCxPE bits in TIMx_CCMRx registers, as long as the related channel is configured in output through the CCxS bits) can no longer be written.

Note: The LOCK bits can be written only once after the reset. Once the TIMx_BDTR register has been written, their content is frozen until the next reset.

Bits 7:0 **DTG[7:0]**: Dead-time generator setup

This bitfield defines the duration of the dead-time inserted between the complementary outputs. DT correspond to this duration.

DTG[7:5] = 0xx → DT = DTG[7:0]x t_{dtg} with $t_{dtg} = t_{DTS}$

DTG[7:5] = 10x → DT = (64+DTG[5:0])xt_{dtg} with $T_{dtg} = 2xt_{DTS}$

DTG[7:5] = 110 → DT = (32+DTG[4:0])xt_{dtg} with $T_{dtg} = 8xt_{DTS}$

DTG[7:5] = 111 → DT = (32+DTG[4:0])xt_{dtg} with $T_{dtg} = 16xt_{DTS}$

Example if T_{DTS}=125 ns (8 MHz), dead-time possible values are:

0 to 15875 ns by 125 ns steps,

16 µs to 31750 ns by 250 ns steps,

32 µs to 63 µs by 1 µs steps,

64 µs to 126 µs by 2 µs steps

Note: This bitfield can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

53.8.15 TIMx timer deadtime register 2 (TIMx_DTR2)(x = 16 to 17)

Address offset: 0x054

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTPE	DTAE
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTGF[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **DTPE**: Deadtime preload enable

0: Deadtime value is not preloaded

1: Deadtime value preload is enabled

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 16 **DTAE**: Deadtime asymmetric enable

0: Deadtime on rising and falling edges are identical, and defined with DTG[7:0] register

1: Deadtime on rising edge is defined with DTG[7:0] register and deadtime on falling edge is defined with DTGF[7:0] bits.

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **DTGF[7:0]**: Dead-time falling edge generator setup

This bitfield defines the duration of the dead-time inserted between the complementary outputs, on the falling edge.

DTGF[7:5] = 0xx → DTF = DTGF[7:0]x t_{dtg} with $t_{dtg} = t_{DTS}$.

DTGF[7:5] = 10x → DTF = (64+DTGF[5:0])xt_{dtg} with $T_{dtg} = 2xt_{DTS}$.

DTGF[7:5] = 110 → DTF = (32+DTGF[4:0])xt_{dtg} with $T_{dtg} = 8xt_{DTS}$.

DTGF[7:5] = 111 → DTF = (32+DTGF[4:0])xt_{dtg} with $T_{dtg} = 16xt_{DTS}$.

Example if T_{DTS} = 125 ns (8 MHz), dead-time possible values are:

0 to 15875 ns by 125 ns steps,

16 µs to 31750 ns by 250 ns steps,

32 µs to 63 µs by 1 µs steps,

64 µs to 126 µs by 2 µs steps

Note: This bitfield can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

53.8.16 TIMx input selection register (TIMx_TISEL)(x = 16 to 17)

Address offset: 0x5C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1SEL[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: selects tim_ti1_in[15:0] input
0000: TIMx_CH1 input (tim_ti1_in0)
0001: tim_ti1_in1
...
1111: tim_ti1_in15
Refer to *Section 53.4.2: TIM15/TIM16/TIM17 pins and internal signals* for interconnects list.

53.8.17 TIMx alternate function register 1 (TIMx_AF1)(x = 16 to 17)

Address offset: 0x060

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	BK CMP4P	BK CMP3P	BK CMP2P	BK CMP1P	BKINP	BK CMP8E	BK CMP7E	BK CMP6E	BK CMP5E	BK CMP4E	BK CMP3E	BK CMP2E	BK CMP1E	BKINE
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Refer to *Section 53.4.2: TIM15/TIM16/TIM17 pins and internal signals* for product specific implementation.

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **BKCMP4P**: tim_brk_cmp4 input polarity
This bit selects the tim_brk_cmp4 input sensitivity. It must be programmed together with the BKP polarity bit.
0: tim_brk_cmp4 input is active high
1: tim_brk_cmp4 input is active low

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 12 **BKCMP3P**: tim_brk_cmp3 input polarity

This bit selects the tim_brk_cmp3 input sensitivity. It must be programmed together with the BKP polarity bit.

0: tim_brk_cmp3 input is active high

1: tim_brk_cmp3 input is active low

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 11 **BKCMP2P**: tim_brk_cmp2 input polarity

This bit selects the tim_brk_cmp2 input sensitivity. It must be programmed together with the BKP polarity bit.

0: tim_brk_cmp2 input is active high

1: tim_brk_cmp2 input is active low

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **BKCMP1P**: tim_brk_cmp1 input polarity

This bit selects the tim_brk_cmp1 input sensitivity. It must be programmed together with the BKP polarity bit.

0: tim_brk_cmp1 input is active high

1: tim_brk_cmp1 input is active low

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 9 **BKINP**: TIMx_BKIN input polarity

This bit selects the TIMx_BKIN alternate function input sensitivity. It must be programmed together with the BKP polarity bit.

0: TIMx_BKIN input is active high

1: TIMx_BKIN input is active low

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **BKCMP8E**: tim_brk_cmp8 enable

This bit enables the tim_brk_cmp8 for the timer's tim_brk input. tim_brk_cmp8 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp8 input disabled

1: tim_brk_cmp8 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 7 **BKCMP7E**: tim_brk_cmp7 enable

This bit enables the tim_brk_cmp7 for the timer's tim_brk input. tim_brk_cmp7 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp7 input disabled

1: tim_brk_cmp7 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 6 **BKCMP6E**: tim_brk_cmp6 enable

This bit enables the tim_brk_cmp6 for the timer's tim_brk input. tim_brk_cmp6 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp6 input disabled

1: tim_brk_cmp6 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 5 **BKCMP5E**: tim_brk_cmp5 enable

This bit enables the tim_brk_cmp5 for the timer's tim_brk input. tim_brk_cmp5 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp5 input disabled

1: tim_brk_cmp5 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 4 **BKCMP4E**: tim_brk_cmp4 enable

This bit enables the tim_brk_cmp4 for the timer's tim_brk input. tim_brk_cmp4 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp4 input disabled

1: tim_brk_cmp4 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 3 **BKCMP3E**: tim_brk_cmp3 enable

This bit enables the tim_brk_cmp3 for the timer's tim_brk input. tim_brk_cmp3 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp3 input disabled

1: tim_brk_cmp3 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 2 **BKCMP2E**: tim_brk_cmp2 enable

This bit enables the tim_brk_cmp2 for the timer's tim_brk input. tim_brk_cmp2 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp2 input disabled

1: tim_brk_cmp2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 1 **BKCMP1E**: tim_brk_cmp1 enable

This bit enables the tim_brk_cmp1 for the timer's tim_brk input. tim_brk_cmp1 output is 'ORed' with the other tim_brk sources.

0: tim_brk_cmp1 input disabled

1: tim_brk_cmp1 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 0 **BKINE**: TIMx_BKIN input enable

This bit enables the TIMx_BKIN alternate function input for the timer's tim_brk input. TIMx_BKIN input is 'ORed' with the other tim_brk sources.

0: TIMx_BKIN input disabled

1: TIMx_BKIN input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

53.8.18 TIMx alternate function register 2 (TIMx_AF2)(x = 16 to 17)

Address offset: 0x064

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCRSEL[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **OCRSEL[2:0]**: tim_ocref_clr source selection

These bits select the tim_ocref_clr input source.

000: tim_ocref_clr0

001: tim_ocref_clr1

010: tim_ocref_clr2

011: tim_ocref_clr3

100: tim_ocref_clr4

101: tim_ocref_clr5

110: tim_ocref_clr6

111: tim_ocref_clr7

Refer to *Section 53.4.2: TIM15/TIM16/TIM17 pins and internal signals* for product specific implementation.

Note: These bits can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 15:0 Reserved, must be kept at reset value.

53.8.19 TIM17 option register 1 (TIM17_OR1)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RTCPREEN[1:0]	
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1:0 **RTCPREEN[1:0]**: RTCPRE divider enable

This bit enables the RTCPRE HSE divider for the tim_ti1_in2. See *Section 53.4.2: TIM15/TIM16/TIM17 pins and internal signals* and *Section 15: Peripherals interconnect matrix*.

10: RTCPRE HSE divider for the tim_ti1_in2 enabled

Others: RTCPRE HSE divider for the tim_ti1_in2 disabled

53.8.20 TIMx DMA control register (TIMx_DCR)(x = 16 to 17)

Address offset: 0x3DC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBSS[3:0]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:16 **DBSS[3:0]**: DMA burst source selection

This bitfield defines the interrupt source that triggers the DMA burst transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address).

0000: Reserved

0001: Update

0010: CC1

Other: reserved

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **DBL[4:0]**: DMA burst length

This 5-bitfield defines the length of DMA transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address), i.e. the number of transfers. Transfers can be in half-words or in bytes (see example below).

00000: 1 transfer,
00001: 2 transfers,
00010: 3 transfers,
...
10001: 18 transfers.

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **DBA[4:0]**: DMA base address

This 5-bitfield defines the base-address for DMA transfers (when read/write access are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register.

Example:
00000: TIMx_CR1,
00001: TIMx_CR2,
00010: TIMx_SMCR,
...

Example: Let us consider the following transfer: DBL = 7 transfers and DBA = TIMx_CR1. In this case the transfer is done to/from 7 registers starting from the TIMx_CR1 address.

53.8.21 TIM16/TIM17 DMA address for full transfer (TIMx_DMAR)(x = 16 to 17)

Address offset: 0x3E0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMAB[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAB[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DMAB[31:0]**: DMA register for burst accesses

A read or write operation to the DMAR register accesses the register located at the address

(TIMx_CR1 address) + (DBA + DMA index) x 4

where TIMx_CR1 address is the address of the control register 1, DBA is the DMA base address configured in TIMx_DCR register, DMA index is automatically controlled by the DMA transfer, and ranges from 0 to DBL (DBL configured in TIMx_DCR).

53.8.22 TIM16/TIM17 register map

TIM16/TIM17 registers are mapped as 16-bit addressable registers as described in the table below:

Table 585. TIM16/TIM17 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	TIMx_CR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIFREMA	Res.	CKD [1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
	Reset value																					0		0	0	0				0	0	0	0
0x04	TIMx_CR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OIS1N	OIS1	Res.	Res.	Res.	Res.	CCDS	CCUS	Res.	CCPC
	Reset value																							0	0					0	0		0
0x08	Reserved	Res.																															
0x0C	TIMx_DIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1DE	UDE	BIE		COMIE	Res.	Res.	Res.	CC1IE	UIE
	Reset value																							0	0	0		0				0	0
0x10	TIMx_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1OF	Res.	BIF	Res.	COMIF	Res.	Res.	Res.	CC1IF	UIF
	Reset value																							0		0		0				0	0
0x14	TIMx_EGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BG	Res.	COMG	Res.	Res.	Res.	CC1G	UG
	Reset value																									0		0				0	0
0x18	TIMx_CCMR1 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC1F[3:0]				IC1 PSC [1:0]		CC1 S [1:0]	
	Reset value																									0	0	0	0	0	0	0	0
	TIMx_CCMR1 Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1CE	OC1M [2:0]				OC1PE	OC1FE	CC1 S [1:0]	
	Reset value																0									0	0	0	0		0	0	0	0
0x1C	Reserved	Res.																															
0x20	TIMx_CCER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1NP	CC1NE	CC1P	CC1E
	Reset value																													0	0	0	0
0x24	TIMx_CNT	UIFCPY or Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	TIMx_PSC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 585. TIM16/TIM17 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x2C	TIMx_ARR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[19:0]																			
	Reset value													0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x30	TIMx_RCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x34	TIMx_CCR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x38 - 0x40	Reserved	Res.																															
0x44	TIMx_BDTR	Res.	Res.	Res.	BKBID	Res.	BKDSRM	Res.	Res.	Res.	Res.	Res.	Res.	BKF[3:0]				MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK [1:0]		DT[7:0]							
	Reset value				0		0							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x48 - 0x50	Reserved	Res.																															
0x54	TIMx_DTR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTPE	DTAE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTGF[7:0]							
	Reset value															0	0									0	0	0	0	0	0	0	0
0x58	Reserved	Res.																															
0x5C	TIMx_TISEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value																													0	0	0	0
0x60	TIMx_AF1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BKCMP4P	BKCMP3P	BKCMP2P	BKCMP1P	BKINP	BKCMP8E	BKCMP7E	BKCMP6E	BKCMP5E	BKCMP4E	BKCMP3E	BKCMP2E	BKCMP1E	BKINE	
	Reset value																		0	0	0	0	0	0	0	0	0	0	0	0	0	1	
0x64	TIMx_AF2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCR SEL[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value														0	0	0																
0x68	TIMx_OR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RTCPREEN[1:0]	
	Reset value																															0	0
0x6C - 0x3D8	Reserved	Res.																															
0x3DC	TIMx_DCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBSS[3:0]				Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
	Reset value													0	0	0	0				0	0	0	0	0				0	0	0	0	0
0x3E0	TIMx_DMAR	DMAB[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

54 Low-power timer (LPTIM)

54.1 LPTIM introduction

The LPTIM is a 16-bit timer that benefits from the ultimate developments in power consumption reduction. Thanks to its diversity of clock sources, the LPTIM is able to keep running in all power modes except for Standby mode. Given its capability to run even with no internal clock source, the LPTIM can be used as a “Pulse Counter” which can be useful in some applications. The LPTIM capability to wake up the system from low-power modes, makes it suitable to realize “Timeout functions” with extremely low power consumption.

The LPTIM introduces a flexible clock scheme that provides the needed functionalities and performance, while minimizing the power consumption.

54.2 LPTIM main features

- 16-bit upcounter
- 3-bit prescaler with 8 possible dividing factors (1,2,4,8,16,32,64,128)
- Selectable clock
  - Internal clock sources: configurable internal clock source (see RCC section)
  - External clock source over LPTIM input (working with no LP oscillator running, used by pulse counter application)
- 16-bit ARR autoreload register
- 16-bit capture/compare register
- Continuous/One-shot mode
- Selectable software/hardware input trigger
- Programmable digital glitch filter
- Configurable output: Pulse, PWM
- Configurable I/O polarity
- Encoder mode
- Repetition counter
- Up to 2 independent channels for:
  - Input capture
  - PWM generation (edge-aligned mode)
  - One-pulse mode output
- Interrupt generation on 10 events
- DMA request generation on the following events:
  - Update event
  - Input capture

54.3 LPTIM implementation

Table 586 describes LPTIM implementation on STM32H5E4/5F4 and STM32H5E5/5F5 devices. The full set of features is implemented in LPTIM1, 2, 3, 5 and 6. LPTIM4 supports a smaller set of features.

Table 586. STM32H5E4/5F4 and STM32H5E5/5F5 LPTIM features

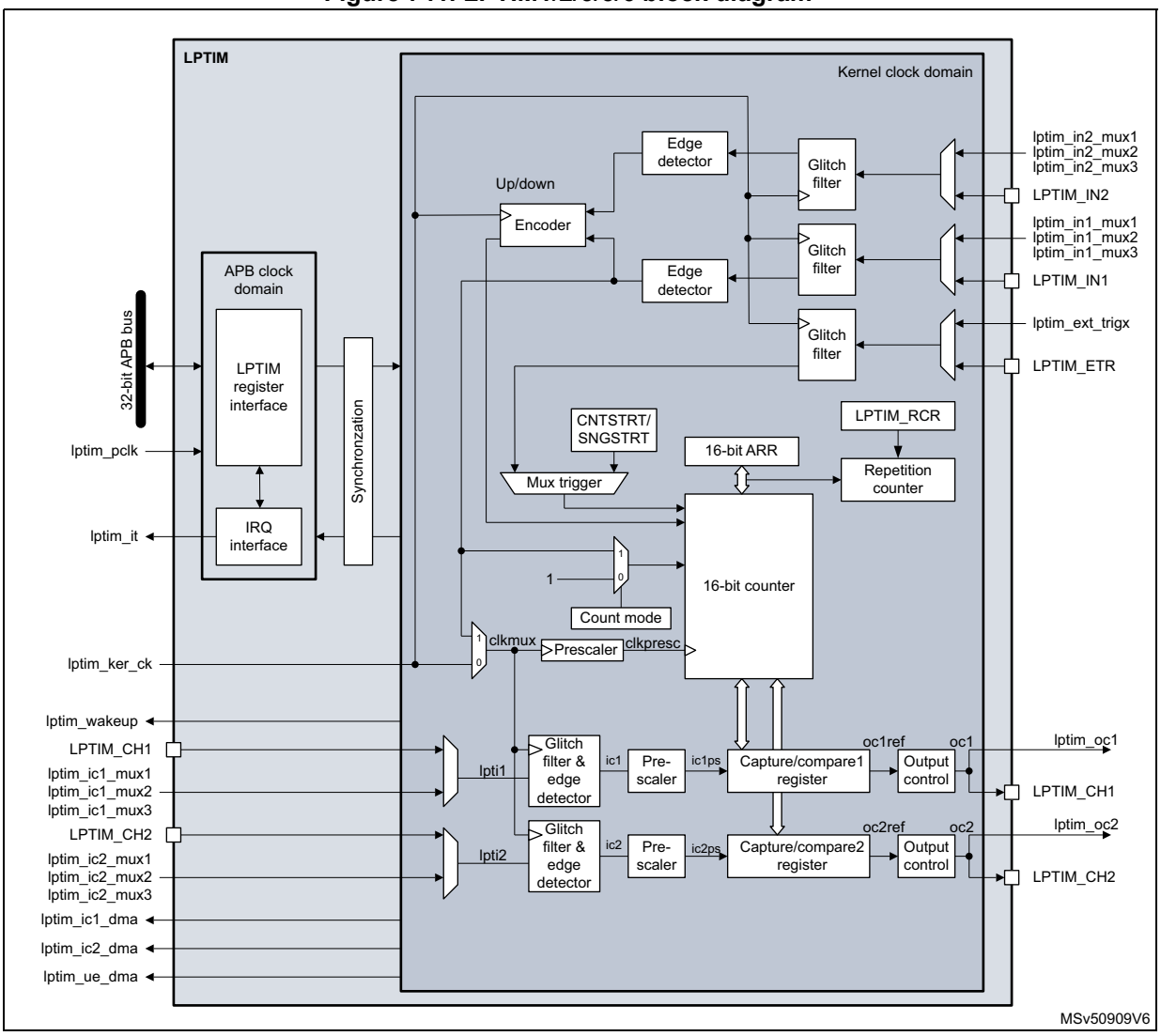
LPTIM modes/features(1)	LPTIM1	LPTIM2	LPTIM3	LPTIM4	LPTIM5	LPTIM6
Encoder mode	X	X	X	-	X	X
PWM mode	X	X	X	X	X	X
Input Capture	X	X	X	-	X	X
Number of channels	2	2	2	0	2	2
Number of DMA requests	3	3	3	0	3	3
Wake-up from Stop mode	X	X	X	X	X	X
Autonomous mode	-	-	-	-	-	-

1. X = supported.

54.4 LPTIM functional description

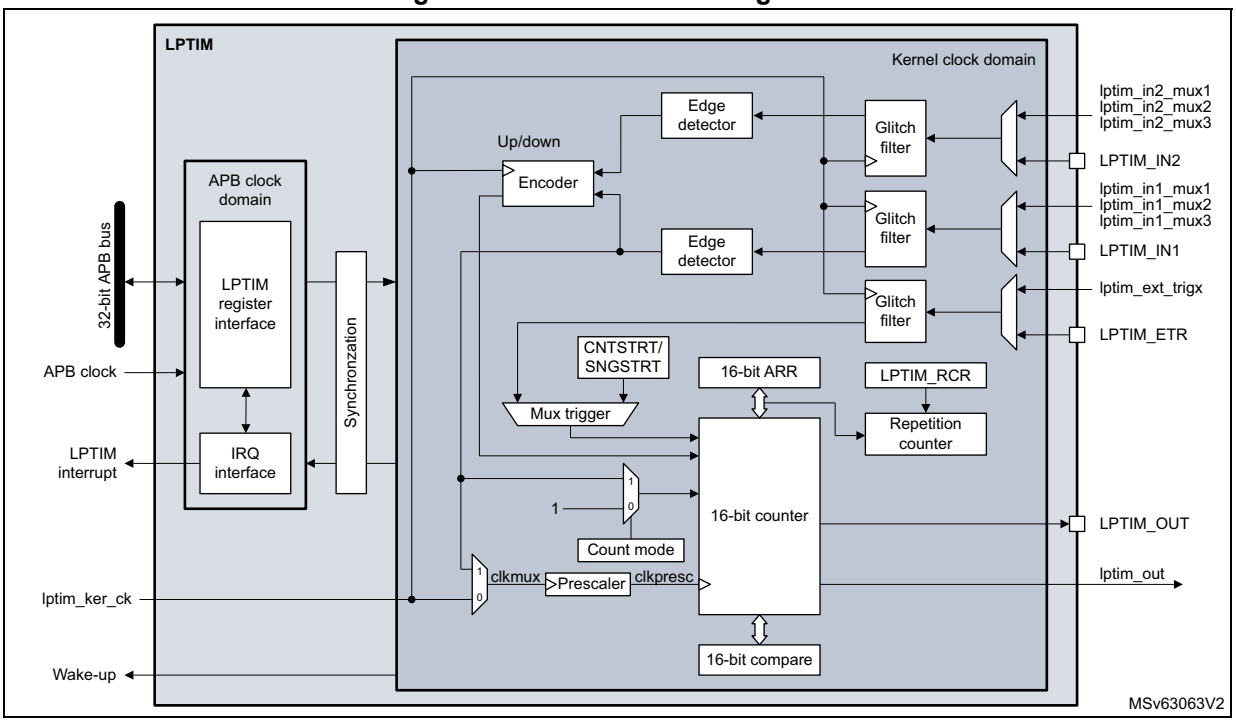
54.4.1 LPTIM block diagram

Figure 741. LPTIM1/2/3/5/6 block diagram(1)



1. Some I/Os may not be available, refer to *Section 54.4.2: LPTIM pins and internal signals*.

Figure 742. LPTIM4 block diagram(1)



1. Some I/Os may not be available, refer to *Section 54.4.2: LPTIM pins and internal signals*.

54.4.2 LPTIM pins and internal signals

The following tables provide the list of LPTIM pins and internal signals, respectively.

Table 587. LPTIM1/2/3/5/6 input/output pins

Pin name	Pin type	Description
LPTIM_IN1	Digital input	LPTIM Input 1 from GPIO pin on mux input 0
LPTIM_IN2	Digital input	LPTIM Input 2 from GPIO pin on mux input 0
LPTIM_ETR	Digital input	LPTIM external trigger GPIO pin
LPTIM_CH1	Digital input/output	LPTIM channel 1 input/output GPIO pin
LPTIM_CH2	Digital input/output	LPTIM channel 2 input/output GPIO pin

Table 588. LPTIM4 input/output pins

Pin name	Pin type	Description
LPTIM_IN1	Digital input	LPTIM Input 1 from GPIO pin on mux input 0
LPTIM_ETR	Digital input	LPTIM external trigger GPIO pin
LPTIM_OUT	Digital output	LPTIM Output GPIO pin

Table 589. LPTIM1/2/3/5/6 internal signals

Signal name	Signal type	Description
lptim_pclk	Digital input	LPTIM APB clock domain
lptim_ker_ck	Digital input	LPTIM kernel clock
lptim_in1_mux1	Digital input	Internal LPTIM input 1 connected to mux input 1
lptim_in1_mux2	Digital input	Internal LPTIM input 1 connected to mux input 2
lptim_in1_mux3	Digital input	Internal LPTIM input 1 connected to mux input 3
lptim_in2_mux1	Digital input	Internal LPTIM input 2 connected to mux input 1
lptim_in2_mux2	Digital input	Internal LPTIM input 2 connected to mux input 2
lptim_in2_mux3	Digital input	Internal LPTIM input 2 connected to mux input 3
lptim_ic1_mux1	Digital input	Internal LPTIM input capture 1 connected to mux input 1
lptim_ic1_mux2	Digital input	Internal LPTIM input capture 1 connected to mux input 2
lptim_ic1_mux3	Digital input	Internal LPTIM input capture 1 connected to mux input 3
lptim_ic2_mux1	Digital input	Internal LPTIM input capture 2 connected to mux input 1
lptim_ic2_mux2	Digital input	Internal LPTIM input capture 2 connected to mux input 2
lptim_ic2_mux3	Digital input	Internal LPTIM input capture 2 connected to mux input 3
lptim_ext_trigx	Digital input	LPTIM external trigger input x
lptim_it	Digital output	LPTIM global interrupt
lptim_wakeup	Digital output	LPTIM wake-up event
lptim_ic1_dma	Digital output	LPTIM input capture 1 DMA request
lptim_ic2_dma	Digital output	LPTIM input capture 2 DMA request
lptim_ue_dma	Digital output	LPTIM update event DMA request

Table 590. LPTIM4 internal signals

Signal name	Signal type	Description
lptim_pclk	Digital input	LPTIM APB clock domain
lptim_ker_ck	Digital input	LPTIM kernel clock
lptim_in1_mux1	Digital input	Internal LPTIM input 1 connected to mux input 1
lptim_in1_mux2	Digital input	Internal LPTIM input 1 connected to mux input 2
lptim_in1_mux3	Digital input	Internal LPTIM input 1 connected to mux input 3
lptim_ext_trigx	Digital input	LPTIM external trigger input x
lptim_out	Digital output	LPTIM counter output
lptim_it	Digital output	LPTIM global interrupt
lptim_wakeup	Digital output	LPTIM wake-up event

54.4.3 LPTIM input and trigger mapping

The LPTIM external trigger and input connections are detailed hereafter.

Table 591. LPTIM1/2/3/4/5/6 external trigger connections

TRIGSEL	External trigger					
	LPTIM1	LPTIM2	LPTIM3	LPTIM4	LPTIM5	LPTIM6
lptim_ext_trig0	GPIO	GPIO	GPIO	GPIO	GPIO	GPIO
lptim_ext_trig1	rtc_alra_trg	rtc_alra_trg	rtc_alra_trg	rtc_alra_trg	rtc_alra_trg	rtc_alra_trg
lptim_ext_trig2	rtc_alrb_trg	rtc_alrb_trg	rtc_alrb_trg	rtc_alrb_trg	rtc_alrb_trg	rtc_alrb_trg
lptim_ext_trig3	tamp_trg1	tamp_trg1	tamp_trg1	tamp_trg1	tamp_trg1	tamp_trg1
lptim_ext_trig4	tamp_trg2	gpdma1_ch0_tcf	tamp_trg2	tamp_trg2	Reserved	Reserved
lptim_ext_trig5	gpdma1_ch1_tcf	gpdma1_ch4_tcf	tamp_trg3	tamp_trg3	Reserved	Reserved
lptim_ext_trig6	comp1_out	comp1_out	comp1_out	comp1_out	comp1_out	comp1_out
lptim_ext_trig7	play1_out0	play1_out0	comp2_out	comp2_out	comp2_out	comp2_out

Table 592. LPTIM1/2/3/4/5/6 input 1 connections

lptim_in1_mux	LPTIM1/2/3/4/5/6 input 1 connected to
lptim_in1_mux0	GPIO
lptim_in1_mux1	comp1_out
lptim_in1_mux2	play1_out3(1)
lptim_in1_mux3	Reserved

1. Only for LPTIM1/2.

Table 593. LPTIM1/2/3/5/6 input 2 connections

lptim_in2_mux	LPTIM1/2/3/5/6 input 2 connected to
lptim_in2_mux0	GPIO
lptim_in2_mux1	comp2_out
lptim_in2_mux2	play1_out4(1)
lptim_in2_mux3	Reserved

1. Only for LPTIM1/2.

Table 594. LPTIM1/2/3/5/6 input capture 1 connections

lptim_ic1_mux	LPTIM1/2	LPTIM3	LPTIM5	LPTIM6
lptim_ic1_mux0	GPIO	GPIO	GPIO	GPIO
lptim_ic1_mux1	comp1_out	comp1_out	comp1_out	comp1_out
lptim_ic1_mux2	comp2_out	comp2_out	comp2_out	comp2_out
lptim_ic1_mux3	play1_out5	Reserved	i3c1_ibiack	i3c2_ibiack

Table 595. LPTIM1 input capture 2 connections

lptim_ic2_mux	LPTIM1 input capture 2 connected to
lptim_ic2_mux0	I/O
lptim_ic2_mux1	LSI
lptim_ic2_mux2	LSE
lptim_ic2_mux3	rcc_hse_1mhz

Table 596. LPTIM2 input capture 2 connections

lptim_ic2_mux	LPTIM2 input capture 2 connected to
lptim_ic2_mux0	I/O
lptim_ic2_mux1	HSI/1024
lptim_ic2_mux2	CSI/128
lptim_ic2_mux3	HSI/8

Table 597. LPTIM3/5/6 input capture 2 connections

lptim_ic2_mux	LPTIM3	LPTIM4	LPTIM5
lptim_ic2_mux0	I/O	I/O	I/O
lptim_ic2_mux1	comp1_out	comp1_out	comp1_out
lptim_ic2_mux2	comp2_out	eventout	eventout
lptim_ic2_mux3	Reserved		

54.4.4 LPTIM reset and clocks

The LPTIM can be clocked using several clock sources. It can be clocked using an internal clock signal which can be any configurable internal clock source selectable through the RCC (see RCC section for more details). Also, the LPTIM can be clocked using an external clock signal injected on its external Input1. When clocked with an external clock source, the LPTIM can run in one of the following configurations:

- The first configuration is when the LPTIM is clocked by an external signal but in the same time an internal clock signal is provided to the LPTIM from configurable internal clock source (see RCC section).
- The second configuration is when the LPTIM is solely clocked by an external clock source through its external Input1. This configuration is the one used to realize Timeout

function or pulse counter function when all the embedded oscillators are turned off after entering a low-power mode.

Programming the CKSEL and COUNTMODE bits allows controlling whether the LPTIM uses an external clock source or an internal one.

When configured to use an external clock source, the CKPOL bits are used to select the external clock signal active edge. If both edges are configured to be active ones, an internal clock signal must also be provided (first configuration). In this case, the internal clock signal frequency must be at least four times higher than the external clock signal frequency.

54.4.5 Glitch filter

The LPTIM inputs, either external (mapped to GPIOs) or internal (mapped on the chip-level to other embedded peripherals), are protected with digital filters that prevent any glitches and noise perturbations to propagate inside the LPTIM. This is in order to prevent spurious counts or triggers.

Before activating the digital filters, an internal clock source must first be provided to the LPTIM. This is necessary to guarantee the proper operation of the filters.

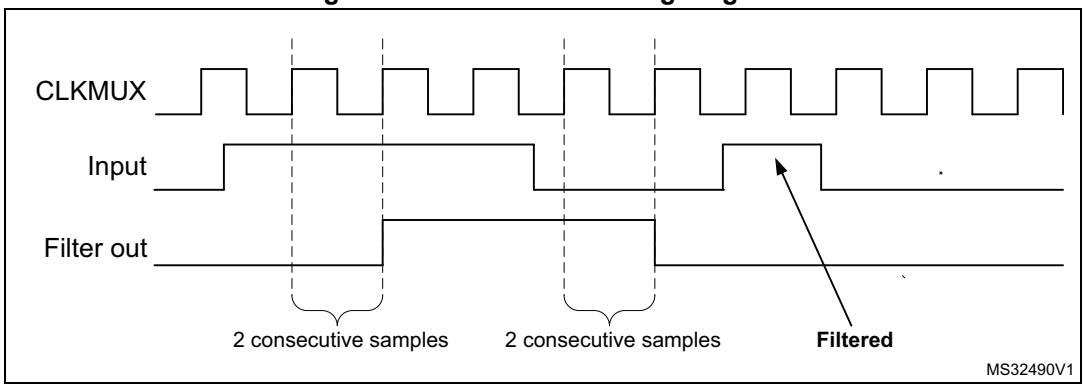
The digital filters are divided into three groups:

- The first group of digital filters protects the LPTIM internal or external inputs. The digital filters sensitivity is controlled by the CKFLT bits
- The second group of digital filters protects the LPTIM internal or external trigger inputs. The digital filters sensitivity is controlled by the TRGFLT bits.
- The third group of digital filters protects the LPTIM internal or external input captures. The digital filters sensitivity is controlled by the ICxF bits.

Note: The digital filters sensitivity is controlled by groups. It is not possible to configure each digital filter sensitivity separately inside the same group.

The filter sensitivity acts on the number of consecutive equal samples that is detected on one of the LPTIM inputs to consider a signal level change as a valid transition. *Figure 743* shows an example of glitch filter behavior in case of a two consecutive samples programmed.

Figure 743. Glitch filter timing diagram



Note: In case no internal clock signal is provided, the digital filter must be deactivated by setting the CKFLT, ICxF and TRGFLT bits to 0. In this case, an external analog filter can be used to protect the LPTIM external inputs against glitches.

54.4.6 Prescaler

The LPTIM 16-bit counter is preceded by a configurable power-of-2 prescaler. The prescaler division ratio is controlled by the PRESC[2:0] field. The table below lists all the possible division ratios:

Table 598. Prescaler division ratios

Programming	Dividing factor
000	/1
001	/2
010	/4
011	/8
100	/16
101	/32
110	/64
111	/128

54.4.7 Trigger multiplexer

The LPTIM counter can be started either by software or after the detection of an active edge on one of the eight trigger inputs.

TRIGEN[1:0] is used to determine the LPTIM trigger source:

- When TRIGEN[1:0] equals 00, the LPTIM counter is started as soon as one of the CNTSTRT or the SNGSTRT bits is set by software. The three remaining possible values for the TRIGEN[1:0] are used to configure the active edge used by the trigger inputs. The LPTIM counter starts as soon as an active edge is detected.
- When TRIGEN[1:0] is different than 00, TRIGSEL[2:0] is used to select which of the eight trigger inputs is used to start the counter.

The external triggers are considered asynchronous signals for the LPTIM. After a trigger detection, a two-counter-clock period latency is needed before the timer starts running due to the synchronization.

If a new trigger event occurs when the timer is already started it is ignored (unless timeout function is enabled).

Note: The timer must be enabled before setting the SNGSTRT/CNTSTRT bits. Any write on these bits when the timer is disabled is discarded by hardware.

Note: When starting the counter by software (TRIGEN[1:0] = 00), there is a delay of 3 kernel clock cycles between the LPTIM_CR register update (set one of SNGSTRT or CNTSTRT bits) and the effective start of the counter.

54.4.8 Operating mode

The LPTIM features two operating modes:

- Continuous mode: the timer is free running, the timer is started from a trigger event and never stops until the timer is disabled
- One-shot mode: the timer is started from a trigger event and stops when an LPTIM update event is generated.

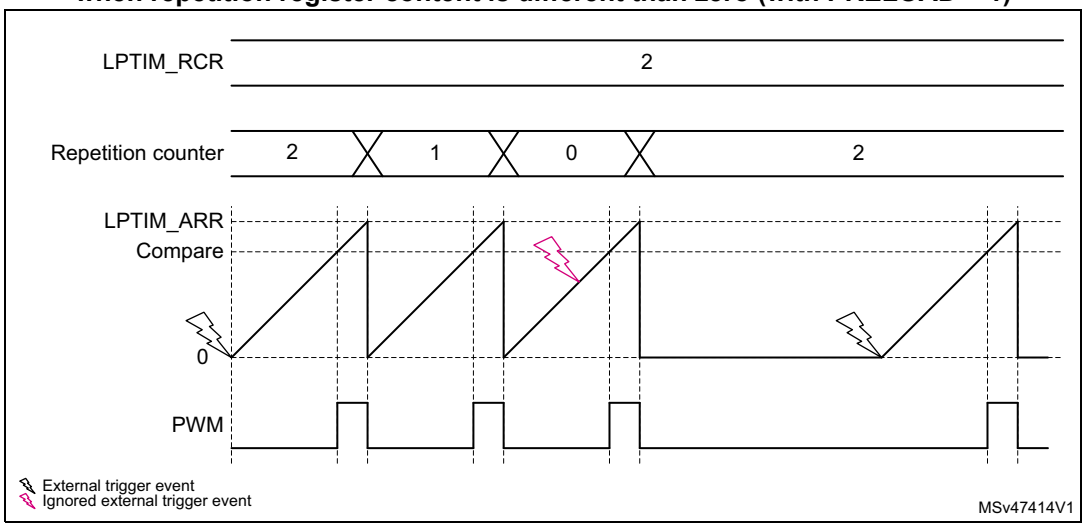
One-shot mode

To enable the one-shot counting, the SNGSTRT bit must be set.

A new trigger event re-starts the timer. Any trigger event occurring after the counter starts and before the next LPTIM update event, is discarded.

In case an external trigger is selected, each external trigger event arriving after the SNGSTRT bit is set, and after the repetition counter has stopped (after the update event), and if the repetition register content is different from zero, the repetition counter gets reloaded with the value already contained by the repetition register and a new one-shot counting cycle is started as shown in *Figure 744*.

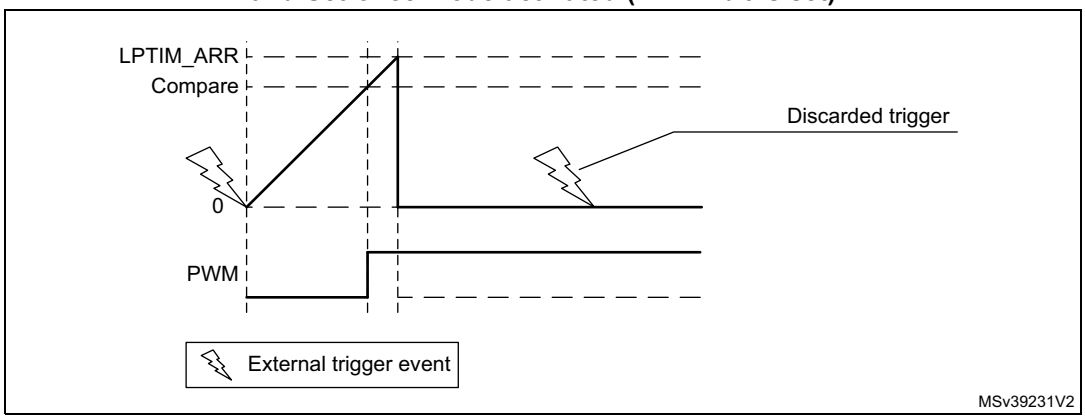
Figure 744. LPTIM output waveform, single-counting mode configuration when repetition register content is different than zero (with PRELOAD = 1)



- Set-once mode activated:

Note that when the WAVE bitfield in the LPTIM_CFGR register is set, the Set-once mode is activated. In this case, the counter is only started once following the first trigger, and any subsequent trigger event is discarded as shown in *Figure 745*.

Figure 745. LPTIM output waveform, single-counting mode configuration and Set-once mode activated (WAVE bit is set)



In case of software start (TRIGEN[1:0] = 00), the SNGSTRT setting starts the counter for one-shot counting.

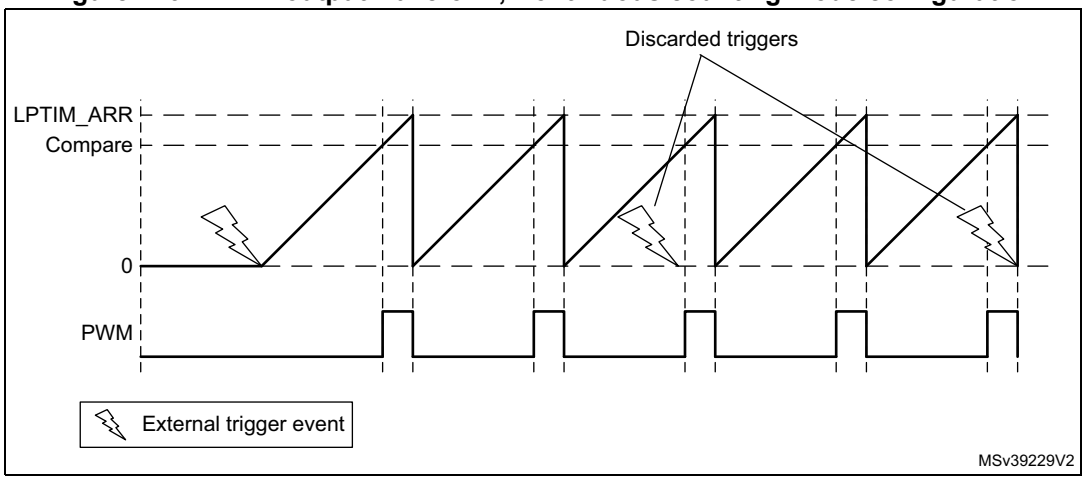
Continuous mode

To enable the continuous counting, the CNTSTRT bit must be set.

In case an external trigger is selected, an external trigger event arriving after CNTSTRT is set, starts the counter for continuous counting. Any subsequent external trigger event is discarded as shown in *Figure 746*.

In case of software start (TRIGEN[1:0] = 00), setting CNTSTRT starts the counter for continuous counting.

Figure 746. LPTIM output waveform, Continuous counting mode configuration



SNGSTRT and CNTSTRT bits can only be set when the timer is enabled (ENABLE bit set to 1). It is possible to change “on the fly” from One-shot mode to Continuous mode.

If the Continuous mode was previously selected, setting SNGSTRT switches the LPTIM to the One-shot mode. The counter (if active) stops as soon as an LPTIM update event is generated.

If the One-shot mode was previously selected, setting CNTSTRT switches the LPTIM to the Continuous mode. The counter (if active) restarts as soon as it reaches ARR.

54.4.9 Timeout function

The detection of an active edge on one selected trigger input can be used to reset the LPTIM counter. This feature is controlled through the TIMOUT bit.

The first trigger event starts the timer, any successive trigger event resets the LPTIM counter and the repetition counter and the timer restarts.

A low-power timeout function can be realized. The timeout value corresponds to the compare value; if no trigger occurs within the expected time frame, the MCU is waked-up by the compare match event.

54.4.10 Waveform generation

Two 16-bit registers, the LPTIM_ARR (autoreload register) and LPTIM_CCRx (capture/compare register), are used to generate several different waveforms on LPTIM output

The timer can generate the following waveforms:

- The PWM mode: the LPTIM output is set as soon as the counter value in LPTIM_CNT exceeds the compare value in LPTIM_CCRx. The LPTIM output is reset as soon as a match occurs between the LPTIM_ARR and the LPTIM_CNT register. For more details see *Section 54.4.19: PWM mode*.
- The One-pulse mode: the output waveform is similar to the one of the PWM mode for the first pulse, then the output is permanently reset
- The Set-once mode: the output waveform is similar to the One-pulse mode except that the output is kept to the last signal level (depends on the output configured polarity).

The above described modes require the LPTIM_ARR register value to be strictly greater than the LPTIM_CCRx register value.

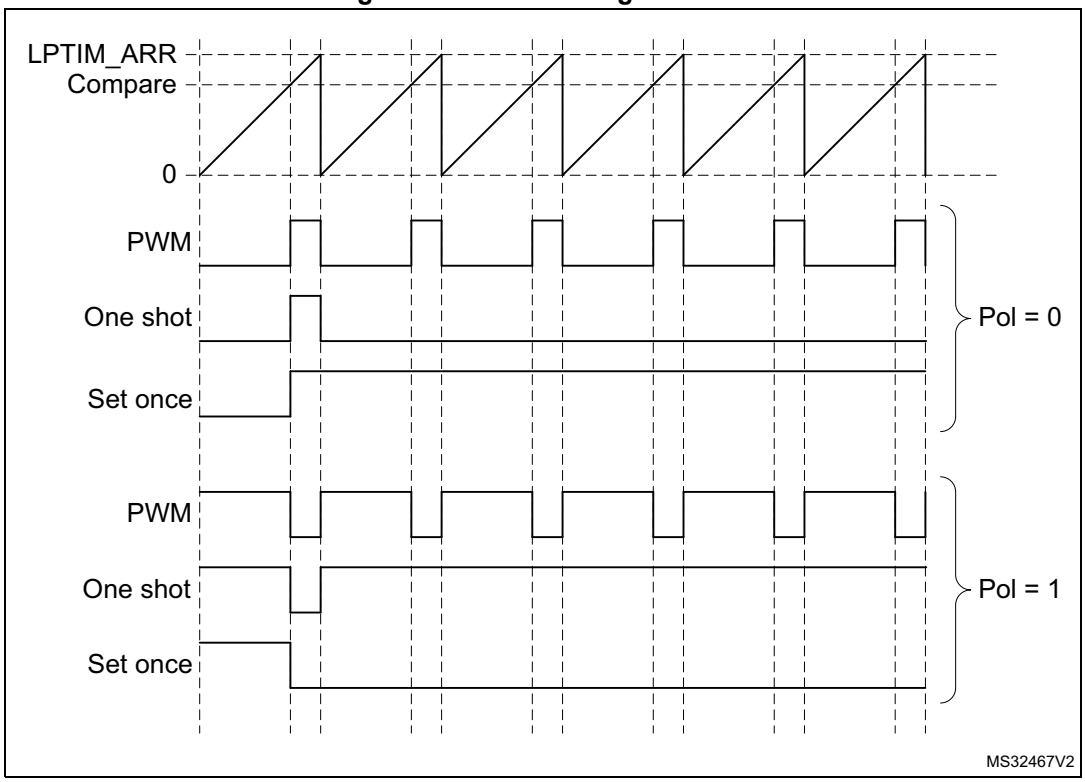
The LPTIM output waveform can be configured through the WAVE bit as follow:

- Resetting the WAVE bit to 0 forces the LPTIM to generate either a PWM waveform or a One pulse waveform depending on which bit is set: CNTSTRT or SNGSTRT.
- Setting the WAVE bit to 1 forces the LPTIM to generate a Set-once mode waveform.

The WAVPOL/CCxP bit controls the LPTIM output polarity. The change takes effect immediately, so the output default value changes immediately after the polarity is re-configured, even before the timer is enabled.

Signals with frequencies up to the LPTIM clock frequency divided by two can be generated. *Figure 747* below shows the three possible waveforms that can be generated on the LPTIM output. Also, it shows the effect of the polarity change using the WAVPOL/CCxP bit.

Figure 747. Waveform generation



54.4.11 Register update

The LPTIM_ARR register, the LPTIM_RCR register and the LPTIM_CCRx register are updated immediately after the APB bus write operation or in synchronization with the next LPTIM update event if the timer is already started.

The PRELOAD bit controls how the LPTIM_ARR, the LPTIM_RCR and the LPTIM_CCRx registers are updated:

- When the PRELOAD bit is reset to 0, the LPTIM_ARR, the LPTIM_RCR and the LPTIM_CCRx registers are immediately updated after any write access.
- When the PRELOAD bit is set to 1, the LPTIM_ARR, the LPTIM_RCR and the LPTIM_CCRx registers are updated at next LPTIM update event, if the timer has been already started.

The LPTIM APB interface and the LPTIM kernel logic use different clocks, so there is some latency between the APB write and the moment when these values are available to the counter comparator. Within this latency period, any additional write into these registers must be avoided.

The ARROK flag, the REPOK flag and the CMPxOK flag in the LPTIM_ISR register indicate when the write operation is completed to respectively the LPTIM_ARR register, the LPTIM_RCR register and the LPTIM_CCRx register.

After a write to the LPTIM_ARR, the LPTIM_RCR or the LPTIM_CCRx register, a new write operation to the same register can only be performed when the previous write operation is completed. Any successive write before respectively the ARROK flag, the REPOK flag or the CMPxOK flag be set, leads to unpredictable results.

54.4.12 Counter mode

The LPTIM counter can be used to count external events on the LPTIM input1 or it can be used to count internal clock cycles. The CKSEL and COUNTMODE bits control which source is used for updating the counter.

In case the LPTIM is configured to count external events on Input1, the counter can be updated following a rising edge, falling edge or both edges depending on the value written to the CKPOL[1:0] bits.

The count modes below can be selected, depending on CKSEL and COUNTMODE values:

- CKSEL = 0: the LPTIM is clocked by an internal clock source
  - COUNTMODE = 0

    The LPTIM is configured to be clocked by an internal clock source and the LPTIM counter is configured to be updated following each internal clock pulse.
  - COUNTMODE = 1

    The LPTIM external Input1 is sampled with the internal clock provided to the LPTIM.

    Consequently, in order not to miss any event, the frequency of the changes on the external Input1 signal must never exceed the frequency of the internal clock provided to the LPTIM. Also, the internal clock provided to the LPTIM must not be prescaled (PRESC[2:0] = 000).
- CKSEL = 1: the LPTIM is clocked by an external clock source

  COUNTMODE value is don’t care.

  In this configuration, the LPTIM has no need for an internal clock source (except if the glitch filters are enabled). The signal injected on the LPTIM external input1 is used as system clock for the LPTIM. This configuration is suitable for operation modes where no embedded oscillator is enabled.

  For this configuration, the LPTIM counter can be updated either on rising edges or falling edges of the input1 clock signal but not on both rising and falling edges.

  Since the signal injected on the LPTIM external input1 is also used to clock the LPTIM kernel logic, there is some initial latency (after the LPTIM is enabled) before the counter is incremented. More precisely, the first five active edges on the LPTIM external Input1 (after LPTIM is enable) are lost.

54.4.13 Timer enable

The ENABLE bit located in the LPTIM_CR register is used to enable/disable the LPTIM kernel logic. After setting the ENABLE bit, a delay of two counter clock cycles is needed before the LPTIM is actually enabled.

The LPTIM_CFGR register must be modified only when the LPTIM is disabled.

54.4.14 Timer counter reset

In order to reset the content of LPTIM_CNT register, two reset mechanisms are implemented:

- The synchronous reset mechanism: the synchronous reset is controlled by the COUNTRST bit in the LPTIM_CR register. After setting the COUNTRST bitfield to '1', the reset signal is propagated in the LPTIM kernel clock domain. So it is important to note that a few clock pulses of the LPTIM kernel logic elapse before the reset is taken into account. This makes the LPTIM counter count few extra pluses between the time when the reset is triggered and it become effective. Since the COUNTRST bit is located in the APB clock domain and the LPTIM counter is located in the LPTIM kernel clock domain, a delay of 3 clock cycles of the kernel clock is needed to synchronize the reset signal issued by the APB clock domain when writing '1' to the COUNTRST bit.

Note: The software ensures that COUNRST bit is '0' before generating every synchronous reset.

- The asynchronous reset mechanism: the asynchronous reset is controlled by the RSTARE bit located in the LPTIM_CR register. When this bit is set to '1', any read access to the LPTIM_CNT register resets its content to zero. Asynchronous reset must be triggered within a timeframe in which no LPTIM core clock is provided. For example when LPTIM Input1 is used as external clock source, the asynchronous reset must be applied only when there is enough insurance that no toggle occurs on the LPTIM Input1.
  To read reliably the content of the LPTIM_CNT register two successive read accesses must be performed and compared. A read access can be considered reliable when the value of the two read accesses is equal. Unfortunately when asynchronous reset is enabled there is no possibility to read twice the LPTIM_CNT register.

Warning: There is no mechanism inside the LPTIM that prevents the two reset mechanisms from being used simultaneously. The developer must make sure that these two mechanisms are used exclusively.

54.4.15 Encoder mode

This mode allows handling signals from quadrature encoders used to detect angular position of rotary elements. Encoder interface mode acts simply as an external clock with direction selection. This means that the counter just counts continuously between 0 and the auto-reload value programmed into the LPTIM_ARR register (0 up to ARR or ARR down to 0 depending on the direction). Therefore LPTIM_ARR must be configured before starting the counter. From the two external input signals, Input1 and Input2, a clock signal is generated to clock the LPTIM counter. The phase between those two signals determines the counting direction.

The Encoder mode is only available when the LPTIM is clocked by an internal clock source. The signals frequency on both Input1 and Input2 inputs must not exceed the LPTIM internal clock frequency divided by 4. This is mandatory in order to guarantee a proper operation of the LPTIM.

Direction change is signalized by the two down and up flags in the LPTIM_ISR register. An interrupt can be generated for both direction change events if enabled through the DOWNIE bit.

To activate the Encoder mode the ENC bit has to be set to 1. The LPTIM must first be configured in Continuous mode.

When Encoder mode is active, the LPTIM counter is modified automatically following the speed and the direction of the incremental encoder. Therefore, its content always represents the encoder's position. The count direction, signaled by the Up and Down flags, correspond to the rotation direction of the encoder rotor.

According to the edge sensitivity configured using the CKPOL[1:0] bits, different counting scenarios are possible. The following table summarizes the possible combinations, assuming that Input1 and Input2 do not switch at the same time.

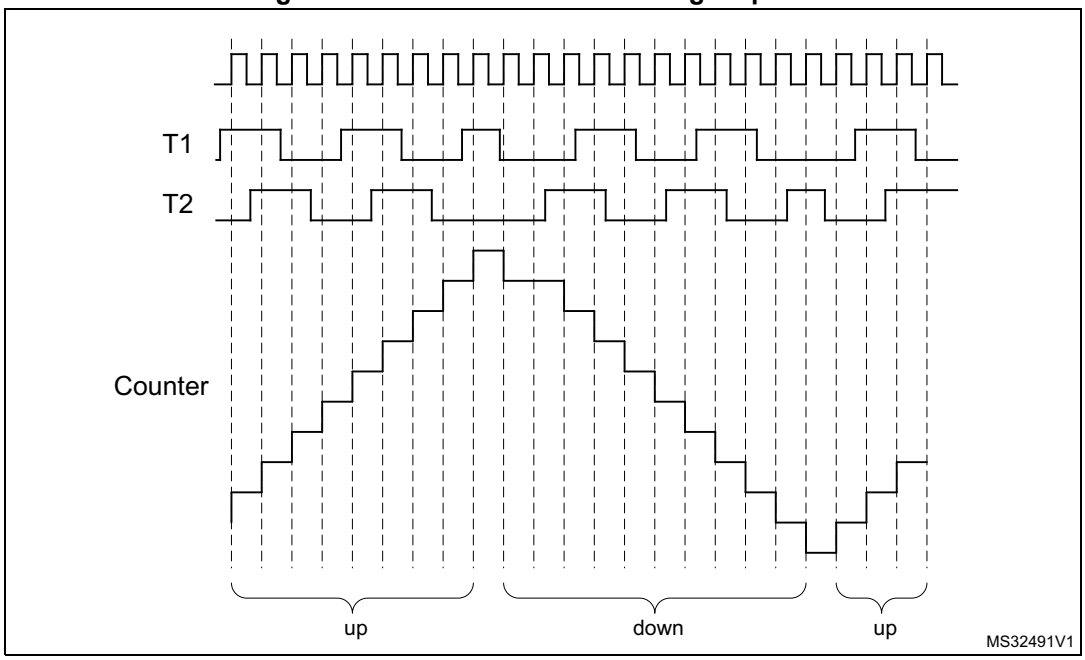
Table 599. Encoder counting scenarios

Active edge	Level on opposite signal (Input1 for Input2, Input2 for Input1)	Input1 signal		Input2 signal	
		Rising	Falling	Rising	Falling
Rising Edge (Encoder sub-mode 1)	High	Down	No count	Up	No count
	Low	Up	No count	Down	No count
Falling Edge (Encoder sub-mode 2)	High	No count	Up	No count	Down
	Low	No count	Down	No count	Up
Both Edges (Encoder sub-mode 3)	High	Down	Up	Up	Down
	Low	Up	Down	Down	Up

The following figure shows a counting sequence for Encoder mode where both-edge sensitivity is configured.

Caution: In this mode the LPTIM must be clocked by an internal clock source, so the CKSEL bit must be maintained to its reset value which is equal to 0. Also, the prescaler division ratio must be equal to its reset value which is 1 (PRESC[2:0] bits must be 000).

Figure 748. Encoder mode counting sequence



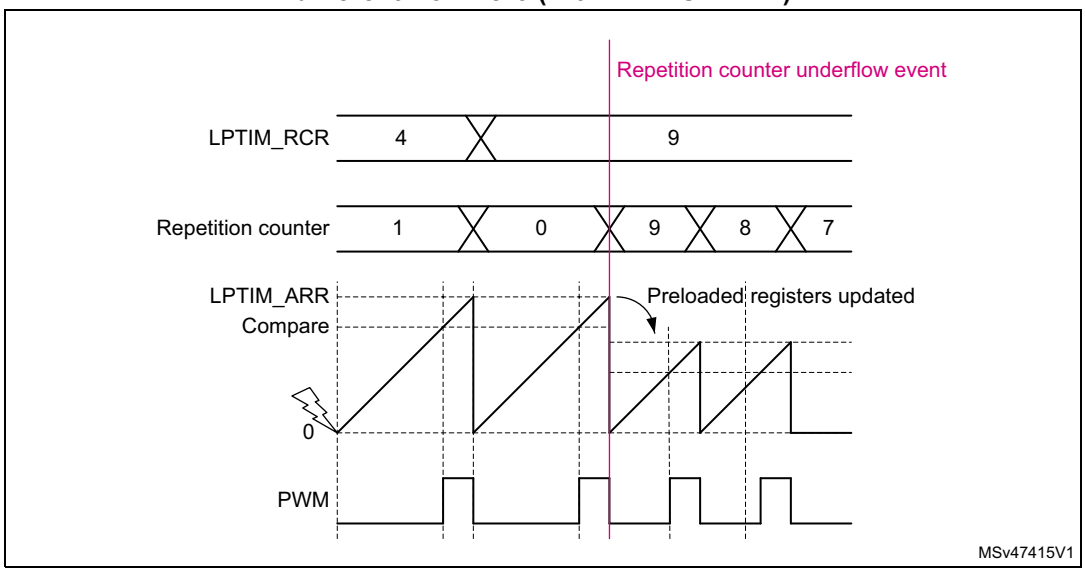
54.4.16 Repetition counter

The LPTIM features a repetition counter that decrements by 1 each time an LPTIM counter overflow event occurs. A repetition counter underflow event is generated when the repetition counter contains zero and the LPTIM counter overflows. Next to each repetition counter underflow event, the repetition counter gets loaded with the content of the REP[7:0] bitfield which belongs to the repetition register LPTIM_RCR.

A repetition underflow event is generated on each and every LPTIM counter overflow when the REP[7:0] register is set to 0.

When PRELOAD = 1, writing to the REP[7:0] bitfield has no effect on the content of the repetition counter until the next repetition underflow event occurs. The repetition counter continues to decrement each LPTIM counter overflow event and only when a repetition underflow event is generated, the new value written into REP[7:0] is loaded into the repetition counter. This behavior is depicted in *Figure 749*.

Figure 749. Continuous counting mode when repetition register LPTIM_RCR different from zero (with PRELOAD = 1)



A repetition counter underflow event is systematically associated with LPTIM preloaded registers update (refer to *Section 54.4.11: Register update* for more information).

Repetition counter underflow event is signaled to the software through the update event (UE) flag mapped into the LPTIM_ISR register. When set, the UE flag can trigger an LPTIM interrupt if its respective update event interrupt enable (UEIE) control bit, mapped to the LPTIM_DIER register, is set.

The repetition register LPTIM_RCR is located in the APB bus interface clock domain where the repetition counter itself is located in the LPTIM kernel clock domain. Each time a new value is written to the LPTIM_RCR register, this new content is propagated from the APB bus interface clock domain to the LPTIM kernel clock domain. The new written value is then loaded to the repetition counter immediately after a repetition counter underflow event. The synchronization delay for the new written content is four APB clock cycles plus three LPTIM kernel clock cycles and it is signaled by the REPOK flag located in the LPTIM_ISR register when it is elapsed. When the LPTIM kernel clock cycle is relatively slow, for instance when the LPTIM kernel is being clocked by the LSI clock source, it can be lengthy to keep polling on the REPOK flag by software to detect that the synchronization of the LPTIM_RCR register content is finished. For that reason, the REPOK flag, when set, can generate an interrupt if its associated REPOKIE control bit in the LPTIM_DIER register is set.

Note: After a write to the LPTIM_RCR register, a new write operation to the same register can only be performed when the previous write operation is completed. Any successive writes before the REPOK flag is set, lead to unpredictable results.

Caution: When using repetition counter with PRELOAD = 0, LPTIM_RCR register must be changed at least five counter cycles before the autoreload match event, otherwise an unpredictable behavior may occur.

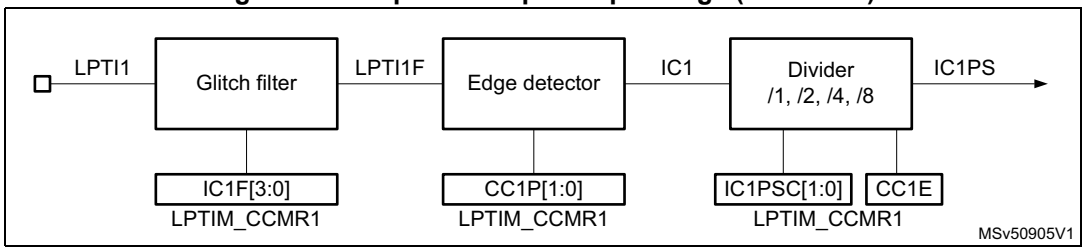
54.4.17 Capture/compare channels

Each capture/compare channel is built around a capture/compare register, an input stage for capture (with digital filter, multiplexing and prescaler) and an output stage (with comparator and output control) for PWM.

Input stage

The input stage samples the corresponding LPTIx input to generate a filtered signal LPTIxF. Then, an edge detector with polarity selection generates ICx signal used as the capture command. It is prescaled to generate the capture command signal (ICxPS).

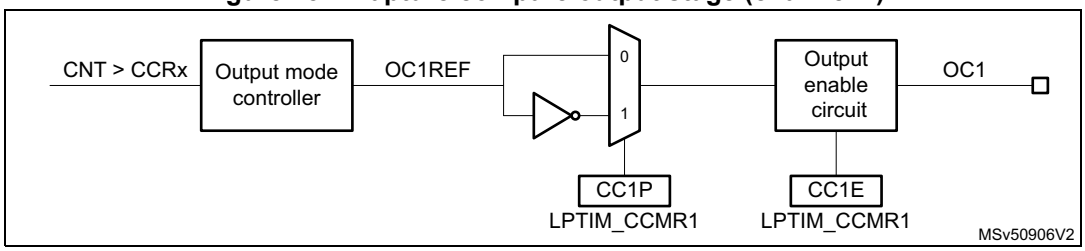
Figure 750. Capture/compare input stage (channel 1)



Output stage

The output stage generates an intermediate waveform which is then used for reference: OCxREF (active high). The polarity acts at the end of the chain.

Figure 751. Capture/compare output stage (channel 1)



54.4.18 Input capture mode

In Input capture mode, the capture/compare registers (LPTIM_CCRx) are used to latch the value of the counter after a transition detected by the corresponding ICx signal. Assuming input capture is enabled on a channel x (CCxE set) and when a capture occurs, the corresponding CCxIF flag (LPTIM_ISR register) is set and an interrupt or a DMA request can be sent if they are enabled. If a capture occurs while the CCxIF flag was already high, then the over-capture flag CCxOF (LPTIM_ISR register) is set. CCxIF can be cleared by software by writing the CCxICF to 1 or by reading the captured data stored in the LPTIM_CCRx register. CCxOF is cleared by writing CCxOCF to 1.

Note: In DMA mode, the input capture channel have to be enabled (set CCxE bit) the last, after enabling the DMA request and after starting the counter. This is in order to prevent generating an input capture DMA request when the counter is not started yet.

Input capture Glitch filter latency

When a trigger event arrives on channel x input (LPTIx) and depending on the configured glitch filter (ICxF[1:0] field in CCMRx register) and on the kernel clock prescaler value (PRESC[2:0] field in CFGR register), there is a variable latency that leads to a systematic offset (see *Table 600*) between the captured value stored in the CCRx register and the real value corresponding to the capture trigger.

This offset has no impact on pulse width measurement as it is systematic and compensated between two captures.

The real capture value corresponding to the input capture trigger can be calculated using the below formula:

Real capture value = captured(LPTIM_CCRx) - offset

The relevant offset must be used depending on the glitch filter and on the kernel clock prescaler value (PRESC field in CFGR register)

Example: determining the real capture value when PRESC[2:0] = 0x2 and ICxF = 0x3.

For this configuration (PRESC[2:0] = 0x2 and ICxF = 0x3) and according to the *Table 600*, the offset is 5.

Assuming that the captured value in CCRx is 9 (LPTIM_CNT = 9), this means that the capture trigger occurred when the LPTIM_CNT was equal to 9 - 5 = 4.

Table 600. Input capture Glitch filter latency (in counter step unit)

Prescaler PRESC[2:0]	ICxF[1:0]	Offset
0	0	2
	1	7
	2	9
	3	13
1	0	3
	1	5
	2	6
	3	8
2	0	2
	1	3
	2	4
	3	5
3	0	2
	1	2
	2	3
	3	3
4	0	2
	1	2
	2	2
	3	2
5	0	2
	1	2
	2	2
	3	2

Table 600. Input capture Glitch filter latency (in counter step unit) (continued)

Prescaler PRESC[2:0]	ICxF[1:0]	Offset
6	0	2
	1	2
	2	2
	3	2
7	0	2
	1	2
	2	2
	3	2

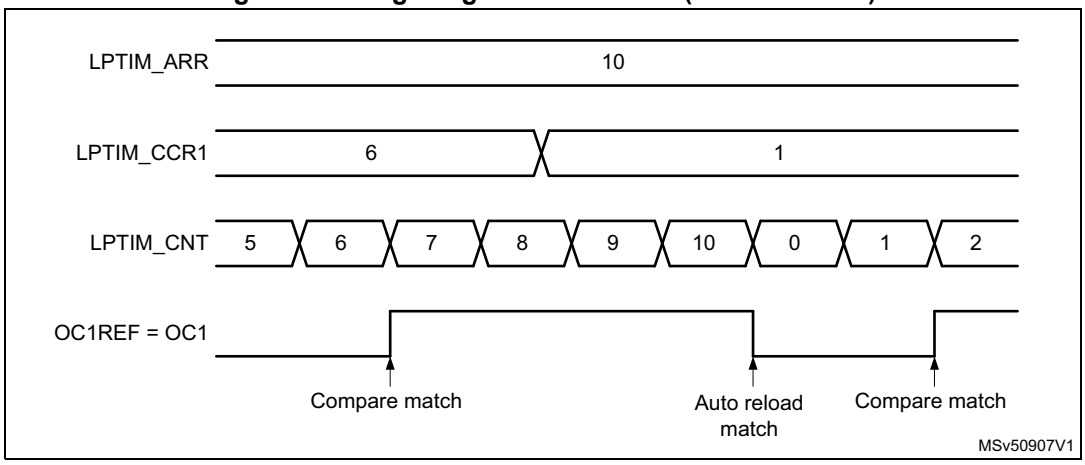
54.4.19 PWM mode

The PWM mode enables to generate a signal with a frequency determined by the value of the LPTIM_ARR register and a duty cycle determined by the value of the LPTIM_CCRx register. The LPTIM is able to generate PWM in edge-aligned mode.

OCx polarity is software programmable using the CCxP bit in the LPTIM_CCMRx register. It can be programmed as active high or active low. OCx output is enabled by the CCxE bit in the LPTIM_CCMRx register. Refer to the LPTIM_CCMRx register description for more details.

Figure 752 gives an example where the LPTIM channel 1 is configured in PWM mode with LPTIM_CCR1 = 6 then 1 and LPTIM_ARR=10.

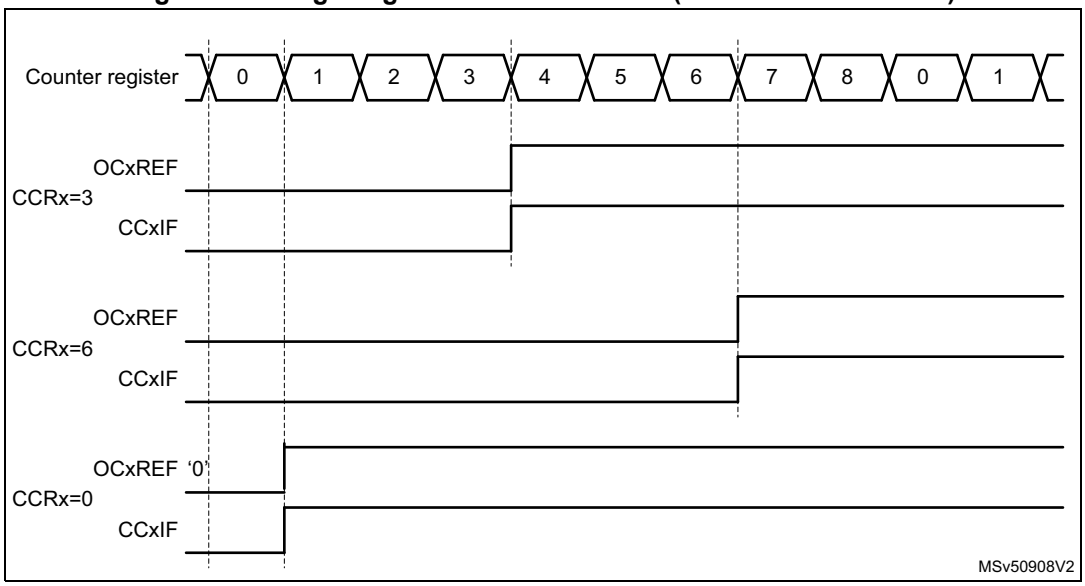
Figure 752. Edge-aligned PWM mode (PRELOAD = 1)



In the following example the reference PWM signal OCxREF is low as long as LPTIM_CNT ≤ LPTIM_CCRx else it becomes high.

Figure 753 shows some edge-aligned PWM waveforms in an example where LPTIM_ARR = 8.

Figure 753. Edge-aligned PWM waveforms (ARR=8 and CCxP = 0)



PWM mode with immediate update PRELOAD = 0

The PWM mode with PRELOAD = 0 enables the early change of the output level within the current PWM cycle. Based on the immediate update (PRELOAD = 0) of the LPTIM_CCRx register and on the continuous comparison of LPTIM_CNT and LPTIM_CCRx registers, it permits to have a new duty cycle value applied as soon as possible within the current PWM cycle, without having to wait for the completion of the current PWM period.

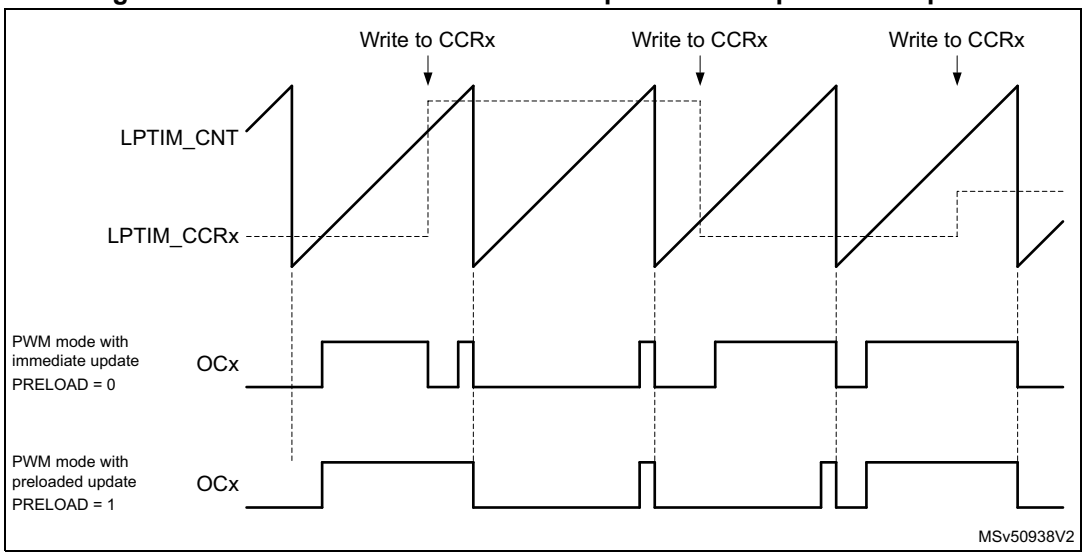
When the (PRELOAD = 0), the OCxREF signal level can be changed on-the-fly by software (or DMA) by updating the compare value in the LPTIM_CCRx register.

Depending on the written compare value and on the current counter and compare values, the OCxREF level is re-assigned as illustrated below:

- If the new compare value does not exceed the current counter value and the current compare value exceeds the counter, OCxREF level is re-assigned high as soon as the new compare value is written.
- If the new compare value exceeds the counter value and the current compare value does not exceed the counter, OCxREF level is re-assigned low as soon as the new compare value is written.

The output reference signal OCxREF level is left unchanged when none of the new compare value and the current compare value exceed the counter. *Figure 754* illustrates the behavior of the OCxREF signal level when PRELOAD = 0 and PRELOAD = 1.

Figure 754. PWM mode with immediate update versus preloaded update



Note: For both PWM modes, the compare match, auto-reload match, and the update event flags are set one LPTIM counter cycle later after the corresponding event, the OCxREF level is also changed one LPTIM counter cycle later after the corresponding event. For instance when the LPTIM_CCRx is set to 3 the CCxIF is set when the LPTIM_CNT = 4. Figure 752 illustrates this behavior.

54.4.20 DMA requests

The LPTIM can generate two categories of DMA requests:

- DMA requests used to retrieve the input-capture counter values
- DMA update requests used to re-program part of the LPTIM, multiple times, at regular intervals, without software overhead

Input capture DMA request

Each LPTIM channel has its dedicated input capture DMA request. A DMA request is generated (if CCxDE bit is set in LPTIM_DIER) and CCxIF is set each time a capture is ready in the LPTIM_CCRx register. The captured values in LPTIM_CCRx can then be transferred regularly by DMA to the desired memory destination. The CCxIF is automatically cleared by hardware when the captured value in LPTIM_CCRx register is read.

Note: The ICx DMA request signal lptim_icx_dma is reset in the following conditions:

- *if the corresponding DMA request is disabled (clear CCxDE bit in the LPTIM_DIER register)*
- *or if the channel x is disabled (clear CCxE bit)*
- *or if the LPTIM is disabled (clear the ENABLE bit in the LPTIM_CR register)*

Update event DMA request

A DMA request is generated (if UEDE is set in LPTIM_DIER) and the UE flag is set at each update event. DMA request can be used to regularly update the LPTIM_ARR, the LPTIM_RCR or the LPTIM_CCRx registers permitting to generate custom PWM waveforms.

The UE is automatically cleared by hardware upon any bus master (like CPU or DMA) write access to the LPTIM_ARR register.

Note: The UE DMA request signal lptim_ue_dma is reset in the following conditions:

- *if the corresponding DMA request is disabled (clear UEDE bit in the LPTIM_DIER register)*
- *or if the LPTIM is disabled (clear the ENABLE bit in the LPTIM_CR register)*
- *or if the channel x is disabled (clear CCxE bit) and all the other channels are already disabled*

54.4.21 Debug mode

When the microcontroller enters debug mode (core halted), the LPTIM counter either continues to work normally or stops, depending on the timer dedicated bit configuration in the debug support (DBG) peripheral.

For further details, refer to section debug support (DBG).

54.5 LPTIM low-power modes

Table 601. Effect of low-power modes on the LPTIM

Mode	Description
Sleep	No effect. LPTIM interrupts cause the device to exit Sleep mode.
Stop	If the LPTIM is clocked by an oscillator available in Stop mode, LPTIM is functional and the interrupts cause the device to exit the Stop mode.
Standby	The LPTIM peripheral is powered down and must be reinitialized after exiting Standby mode.

Note: All DMA requests must be disabled (reset UEDE and CCxDE bits) before entering Sleep, Stop and Standby modes.

54.6 LPTIM interrupts

The following events generate an interrupt/wake-up event, if they are enabled through the LPTIM_DIER register:

- Compare match
- Auto-reload match (whatever the direction if Encoder mode)
- External trigger event
- Autoreload register write completed
- Compare register write completed
- Direction change (Encoder mode), programmable (up / down / both).
- Update Event
- Repetition register update OK
- Input capture occurred
- Over-capture occurred
- Interrupt enable register update OK

Note: If any bit in the LPTIM_DIER register is set after that its corresponding flag in the LPTIM_ISR register (status register) is set, the interrupt is not asserted.

Table 602. Interrupt events

Interrupt vector	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop mode(1)
LPTIMx	Compare match	CCxIF	CCxIE	Write 1 to CCxCF	Yes	Yes
	Input capture(2)	CCxIF	CCxIE	Write 1 to CCxCF	Yes	Yes
	Over-capture(2)	CCxOF	CCxOIE	Write 1 to CCxOCF	Yes	Yes
	Auto-reload match	ARRM	ARRMIE	Write 1 to ARRMCF	Yes	Yes
	External trigger event	EXTTRIG	EXTTRIGIE	Write 1 to EXTTRIGCF	Yes	Yes
	Auto-reload register update OK	ARROK	ARROKIE	Write 1 to ARROKCF	Yes	Yes
	Capture/compare register update OK	CMPxOK	CMPxOKIE	Write 1 to CMPxOKCF	Yes	Yes
	Direction change to up(3)	UP	UPIE	Write 1 to UPCF	Yes	Yes
	Direction change to down(3)	DOWN	DOWNIE	Write 1 to DOWNCF	Yes	Yes
	Update event	UE	UEIE	Write 1 to UECF	Yes	Yes
	Repetition register update OK	REPOK	REPOKIE	Write 1 to REPOKCF	Yes	Yes

1. Each LPTIM event can wake up the device from Stop mode only if the LPTIM instance supports the wake-up from Stop mode feature. Refer to *Section 54.3: LPTIM implementation*.
2. If LPTIM does not implement any channel this event does not exist. Refer to *Section 54.3: LPTIM implementation*.
3. If LPTIM does not support Encoder mode feature, this event does not exist. Refer to *Section 54.3: LPTIM implementation*.

54.7 LPTIM registers

Refer to *Section 1.2: List of abbreviations for registers on page 128* for a list of abbreviations used in register descriptions.

The peripheral registers can only be accessed by words (32-bit).

54.7.1 LPTIM4 interrupt and status register (LPTIM4_ISR)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIEROK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
							r								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	REPOK	UE	DOWN	UP	ARROK	CMP1OK	EXTTRIG	ARRM	CC1IF
							r	r	r	r	r	r	r	r	r

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **DIEROK:** Interrupt enable register update OK

DIEROK is set by hardware to inform application that the APB bus write operation to the LPTIM_DIER register has been successfully completed. DIEROK flag can be cleared by writing 1 to the DIEROKCF bit in the LPTIM_ICR register.

Bits 23:9 Reserved, must be kept at reset value.

Bit 8 **REPOK**: Repetition register update OK

REPOK is set by hardware to inform application that the APB bus write operation to the LPTIM_RCR register has been successfully completed. REPOK flag can be cleared by writing 1 to the REPOKCF bit in the LPTIM_ICR register.

Bit 7 **UE**: LPTIM update event occurred

UE is set by hardware to inform application that an update event was generated. UE flag can be cleared by writing 1 to the UECF bit in the LPTIM_ICR register.

Bit 6 **DOWN**: Counter direction change up to down

In Encoder mode, DOWN bit is set by hardware to inform application that the counter direction has changed from up to down. DOWN flag can be cleared by writing 1 to the DOWNCF bit in the LPTIM_ICR register.

Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3: LPTIM implementation.

Bit 5 **UP**: Counter direction change down to up

In Encoder mode, UP bit is set by hardware to inform application that the counter direction has changed from down to up. UP flag can be cleared by writing 1 to the UPCF bit in the LPTIM_ICR register.

Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3: LPTIM implementation.

Bit 4 **ARROK**: Autoreload register update OK

ARROK is set by hardware to inform application that the APB bus write operation to the LPTIM_ARR register has been successfully completed. ARROK flag can be cleared by writing 1 to the ARROKCF bit in the LPTIM_ICR register.

Bit 3 **CMP1OK**: Compare register 1 update OK

CMP1OK is set by hardware to inform application that the APB bus write operation to the LPTIM_CCR1 register has been successfully completed. CMP1OK flag can be cleared by writing 1 to the CMP1OKCF bit in the LPTIM_ICR register.

Bit 2 **EXTTRIG**: External trigger edge event

EXTTRIG is set by hardware to inform application that a valid edge on the selected external trigger input has occurred. If the trigger is ignored because the timer has already started, then this flag is not set. EXTTRIG flag can be cleared by writing 1 to the EXTTRIGCF bit in the LPTIM_ICR register.

Bit 1 **ARRM**: Autoreload match

ARRM is set by hardware to inform application that LPTIM_CNT register's value reached the LPTIM_ARR register's value. ARRM flag can be cleared by writing 1 to the ARRMCF bit in the LPTIM_ICR register.

Bit 0 **CC1IF**: Compare 1 interrupt flag

The CC1IF flag is set by hardware to inform application that LPTIM_CNT register value matches the compare register's value. The CC1IF flag can be cleared by writing 1 to the CC1CF bit in the LPTIM_ICR register.

0: No match

1: The content of the counter LPTIM_CNT register value has matched the LPTIM_CCR1 register's value

54.7.2 LPTIMx interrupt and status register [alternate] (LPTIMx_ISR) (x = 1 to 3, 5, 6)

This description of the register can only be used for output compare mode. See next section for input capture mode.

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIER OK	Res.	Res.	Res.	Res.	CMP2 OK	Res.	Res.	Res.
							r					r			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CC2IF	REP OK	UE	DOWN	UP	ARR OK	CMP1 OK	EXT TRIG	ARRM	CC1IF
						r	r	r	r	r	r	r	r	r	r

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **DIEROK:** Interrupt enable register update OK

DIEROK is set by hardware to inform application that the APB bus write operation to the LPTIM_DIER register has been successfully completed. DIEROK flag can be cleared by writing 1 to the DIEROKCF bit in the LPTIM_ICR register.

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 Reserved, must be kept at reset value.

Bit 20 Reserved, must be kept at reset value.

Bit 19 **CMP2OK**: Compare register 2 update OK

CMP2OK is set by hardware to inform application that the APB bus write operation to the LPTIM_CCR2 register has been successfully completed. CMP2OK flag can be cleared by writing 1 to the CMP2OKCF bit in the LPTIM_ICR register.

Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bits 18:12 Reserved, must be kept at reset value.

Bit 11 Reserved, must be kept at reset value.

Bit 10 Reserved, must be kept at reset value.

Bit 9 **CC2IF**: Compare 2 interrupt flag

If channel CC2 is configured as output:

The CC2IF flag is set by hardware to inform application that LPTIM_CNT register value matches the compare register's value. CC2IF flag can be cleared by writing 1 to the CC2CF bit in the LPTIM_ICR register.

0: No match

1: The content of the counter LPTIM_CNT register value has matched the LPTIM_CCR2 register's value

Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bit 8 **REPOK**: Repetition register update OK

REPOK is set by hardware to inform application that the APB bus write operation to the LPTIM_RCR register has been successfully completed. REPOK flag can be cleared by writing 1 to the REPOKCF bit in the LPTIM_ICR register.

Bit 7 **UE**: LPTIM update event occurred

UE is set by hardware to inform application that an update event was generated. The corresponding interrupt or DMA request is generated if enabled. UE flag can be cleared by writing 1 to the UECF bit in the LPTIM_ICR register. The UE flag is automatically cleared by hardware once the LPTIM_ARR register is written by any bus master like CPU or DMA.

Bit 6 **DOWN**: Counter direction change up to down

In Encoder mode, DOWN bit is set by hardware to inform application that the counter direction has changed from up to down. DOWN flag can be cleared by writing 1 to the DOWNCF bit in the LPTIM_ICR register.

Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 5 **UP**: Counter direction change down to up

In Encoder mode, UP bit is set by hardware to inform application that the counter direction has changed from down to up. UP flag can be cleared by writing 1 to the UPCF bit in the LPTIM_ICR register.

Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 4 **ARROK**: Autoreload register update OK

ARROK is set by hardware to inform application that the APB bus write operation to the LPTIM_ARR register has been successfully completed. ARROK flag can be cleared by writing 1 to the ARROKCF bit in the LPTIM_ICR register.

Bit 3 **CMP1OK**: Compare register 1 update OK

CMP1OK is set by hardware to inform application that the APB bus write operation to the LPTIM_CCR1 register has been successfully completed. CMP1OK flag can be cleared by writing 1 to the CMP1OKCF bit in the LPTIM_ICR register.

Bit 2 **EXTTRIG**: External trigger edge event

EXTTRIG is set by hardware to inform application that a valid edge on the selected external trigger input has occurred. If the trigger is ignored because the timer has already started, then this flag is not set. EXTTRIG flag can be cleared by writing 1 to the EXTTRIGCF bit in the LPTIM_ICR register.

Bit 1 **ARRM**: Autoreload match

ARRM is set by hardware to inform application that LPTIM_CNT register's value reached the LPTIM_ARR register's value. ARRM flag can be cleared by writing 1 to the ARRMCF bit in the LPTIM_ICR register.

Bit 0 **CC1IF**: Compare 1 interrupt flag

If channel CC1 is configured as output:

The CC1IF flag is set by hardware to inform application that LPTIM_CNT register value matches the compare register's value. CC1IF flag can be cleared by writing 1 to the CC1CF bit in the LPTIM_ICR register.

0: No match

1: The content of the counter LPTIM_CNT register value has matched the LPTIM_CCR1 register's value

54.7.3 LPTIMx interrupt and status register [alternate] (LPTIMx_ISR) (x = 1 to 3, 5, 6)

This description of the register can only be used for input capture mode. See previous section for output compare mode.

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIER OK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
							r								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CC2 OF	CC1 OF	Res.	Res.	CC2IF	REP OK	UE	DOWN	UP	ARR OK	Res.	EXT TRIG	ARRM	CC1IF
		r	r			r	r	r	r	r	r		r	r	r

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **DIEROK:** Interrupt enable register update OK

DIEROK is set by hardware to inform application that the APB bus write operation to the LPTIM_DIER register has been successfully completed. DIEROK flag can be cleared by writing 1 to the DIEROKCF bit in the LPTIM_ICR register.

Bits 23:16 Reserved, must be kept at reset value.

Bit 15 Reserved, must be kept at reset value.

Bit 14 Reserved, must be kept at reset value.

Bit 13 **CC2OF**: Capture 2 over-capture flag

This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing 1 to the CC2OCF bit in the LPTIM_ICR register.

0: No over-capture has been detected.

1: The counter value has been captured in LPTIM_CCR2 register while CC2IF flag was already set.

Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bit 12 **CC1OF**: Capture 1 over-capture flag

This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing 1 to the CC1OCF bit in the LPTIM_ICR register.

0: No over-capture has been detected.

1: The counter value has been captured in LPTIM_CCR1 register while CC1IF flag was already set.

Note: If LPTIM does not implement at least 1 channel this bit is reserved. Refer to Section 54.3.

Bit 11 Reserved, must be kept at reset value.

Bit 10 Reserved, must be kept at reset value.

Bit 9 **CC2IF**: Capture 2 interrupt flag

If channel CC2 is configured as input:

CC2IF is set by hardware to inform application that the current value of the counter is captured in LPTIM_CCR2 register. The corresponding interrupt or DMA request is generated if enabled. The CC2OF flag is set if the CC2IF flag was already high.

0: No input capture occurred

1: The counter value has been captured in the LPTIM_CCR2 register. (An edge has been detected on IC2 which matches the selected polarity). The CC2IF flag is automatically cleared by hardware once the captured value is read (CPU or DMA). The CC2IF flag can be cleared by writing 1 to the CC2CF bit in the LPTIM_ICR register.

Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bit 8 **REPOK**: Repetition register update OK

REPOK is set by hardware to inform application that the APB bus write operation to the LPTIM_RCR register has been successfully completed. REPOK flag can be cleared by writing 1 to the REPOKCF bit in the LPTIM_ICR register.

Bit 7 **UE**: LPTIM update event occurred

UE is set by hardware to inform application that an update event was generated. The corresponding interrupt or DMA request is generated if enabled. The UE flag can be cleared by writing 1 to the UECF bit in the LPTIM_ICR register. The UE flag is automatically cleared by hardware once the LPTIM_ARR register is written by any bus master like CPU or DMA.

Bit 6 **DOWN**: Counter direction change up to down

In Encoder mode, DOWN bit is set by hardware to inform application that the counter direction has changed from up to down. DOWN flag can be cleared by writing 1 to the DOWNCF bit in the LPTIM_ICR register.

Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 5 **UP**: Counter direction change down to up

In Encoder mode, UP bit is set by hardware to inform application that the counter direction has changed from down to up. UP flag can be cleared by writing 1 to the UPCF bit in the LPTIM_ICR register.

Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 4 **ARROK**: Autoreload register update OK

ARROK is set by hardware to inform application that the APB bus write operation to the LPTIM_ARR register has been successfully completed. ARROK flag can be cleared by writing 1 to the ARROKCF bit in the LPTIM_ICR register.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **EXTTRIG**: External trigger edge event

EXTTRIG is set by hardware to inform application that a valid edge on the selected external trigger input has occurred. If the trigger is ignored because the timer has already started, then this flag is not set. EXTTRIG flag can be cleared by writing 1 to the EXTTRIGCF bit in the LPTIM_ICR register.

Bit 1 **ARRM**: Autoreload match

ARRM is set by hardware to inform application that LPTIM_CNT register's value reached the LPTIM_ARR register's value. ARRM flag can be cleared by writing 1 to the ARRMCF bit in the LPTIM_ICR register.

Bit 0 **CC1IF**: capture 1 interrupt flag

If channel CC1 is configured as input:

CC1IF is set by hardware to inform application that the current value of the counter is captured in LPTIM_CCR1 register. The corresponding interrupt or DMA request is generated if enabled. The CC1OF flag is set if the CC1IF flag was already high.

0: No input capture occurred

1: The counter value has been captured in the LPTIM_CCR1 register. (An edge has been detected on IC1 which matches the selected polarity). The CC1IF flag is automatically cleared by hardware once the captured value is read (CPU or DMA).CC1IF flag can be cleared by writing 1 to the CC1CF bit in the LPTIM_ICR register.

54.7.4 LPTIM4 interrupt clear register (LPTIM4_ICR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIEROKCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
							w								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	REPOKCF	UECF	DOWNCF	UPCF	ARROKCF	CMP1OKCF	EXTTRIGCF	ARRMCF	CC1CF
							w	w	w	w	w	w	w	w	w

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **DIEROKCF:** Interrupt enable register update OK clear flag

Writing 1 to this bit clears the DIEROK flag in the LPTIM_ISR register.

Bits 23:9 Reserved, must be kept at reset value.

Bit 8 **REPOKCF**: Repetition register update OK clear flag

Writing 1 to this bit clears the REPOK flag in the LPTIM_ISR register.

Bit 7 **UECF**: Update event clear flag

Writing 1 to this bit clear the UE flag in the LPTIM_ISR register.

Bit 6 **DOWNCF**: Direction change to down clear flag

Writing 1 to this bit clear the DOWN flag in the LPTIM_ISR register.

Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 5 **UPCF**: Direction change to UP clear flag

Writing 1 to this bit clear the UP flag in the LPTIM_ISR register.

Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 4 **ARROKCF**: Autoreload register update OK clear flag
Writing 1 to this bit clears the ARROK flag in the LPTIM_ISR register

Bit 3 **CMP1OKCF**: Compare register 1 update OK clear flag
Writing 1 to this bit clears the CMP1OK flag in the LPTIM_ISR register.

Bit 2 **EXTTRIGCF**: External trigger valid edge clear flag
Writing 1 to this bit clears the EXTTRIG flag in the LPTIM_ISR register

Bit 1 **ARRMCF**: Autoreload match clear flag
Writing 1 to this bit clears the ARRM flag in the LPTIM_ISR register

Bit 0 **CC1CF**: Capture/compare 1 clear flag
Writing 1 to this bit clears the CC1IF flag in the LPTIM_ISR register.

54.7.5 LPTIMx interrupt clear register [alternate] (LPTIMx_ICR) (x = 1 to 3, 5, 6)

This description of the register can only be used for output compare mode. See next section for input capture compare mode.

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIER OKCF	Res.	Res.	Res.	Res.	CMP2 OKCF	Res.	Res.	Res.
							w					w			

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CC2CF	REPOK CF	UECF	DOWN CF	UPCF	ARR OKCF	CMP1 OKCF	EXT TRIG CF	ARRM CF	CC1CF
						w	w	w	w	w	w	w	w	w	w

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **DIEROKCF:** Interrupt enable register update OK clear flag
Writing 1 to this bit clears the DIEROK flag in the LPTIM_ISR register.

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 Reserved, must be kept at reset value.

Bit 20 Reserved, must be kept at reset value.

Bit 19 **CMP2OKCF**: Compare register 2 update OK clear flag
Writing 1 to this bit clears the CMP2OK flag in the LPTIM_ISR register.
Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bits 18:12 Reserved, must be kept at reset value.

Bit 11 Reserved, must be kept at reset value.

Bit 10 Reserved, must be kept at reset value.

Bit 9 **CC2CF**: Capture/compare 2 clear flag
Writing 1 to this bit clears the CC2IF flag in the LPTIM_ISR register.
Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bit 8 **REPOKCF**: Repetition register update OK clear flag
Writing 1 to this bit clears the REPOK flag in the LPTIM_ISR register.

Bit 7 **UECF**: Update event clear flag
Writing 1 to this bit clear the UE flag in the LPTIM_ISR register.

Bit 6 **DOWNCF**: Direction change to down clear flag
Writing 1 to this bit clear the DOWN flag in the LPTIM_ISR register.
Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 5 **UPCF**: Direction change to UP clear flag
Writing 1 to this bit clear the UP flag in the LPTIM_ISR register.
Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 4 **ARROKCF**: Autoreload register update OK clear flag
Writing 1 to this bit clears the ARROK flag in the LPTIM_ISR register

Bit 3 **CMP1OKCF**: Compare register 1 update OK clear flag
Writing 1 to this bit clears the CMP1OK flag in the LPTIM_ISR register.

Bit 2 **EXTTRIGCF**: External trigger valid edge clear flag
Writing 1 to this bit clears the EXTTRIG flag in the LPTIM_ISR register

Bit 1 **ARRMCF**: Autoreload match clear flag
Writing 1 to this bit clears the ARRM flag in the LPTIM_ISR register

Bit 0 **CC1CF**: Capture/compare 1 clear flag
Writing 1 to this bit clears the CC1IF flag in the LPTIM_ISR register.

54.7.6 LPTIMx interrupt clear register [alternate] (LPTIMx_ICR) (x = 1 to 3, 5, 6)

This description of the register can only be used for input capture mode. See previous section for output compare mode.

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIER OKCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
							w								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CC2 OCF	CC1 OCF	Res.	Res.	CC2CF	REPOK CF	UECF	DOWN CF	UPCF	ARRO KCF	Res.	EXTTR IGCF	ARRM CF	CC1CF
		w	w			w	w	w	w	w	w		w	w	w

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **DIEROKCF:** Interrupt enable register update OK clear flag
Writing 1 to this bit clears the DIEROK flag in the LPTIM_ISR register.

Bits 23:16 Reserved, must be kept at reset value.

Bit 15 Reserved, must be kept at reset value.

Bit 14 Reserved, must be kept at reset value.

Bit 13 **CC2OCF**: Capture/compare 2 over-capture clear flag
Writing 1 to this bit clears the CC2OF flag in the LPTIM_ISR register.
Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bit 12 **CC1OCF**: Capture/compare 1 over-capture clear flag
Writing 1 to this bit clears the CC1OF flag in the LPTIM_ISR register.
Note: If LPTIM does not implement at least 1 channel this bit is reserved. Refer to Section 54.3.

Bit 11 Reserved, must be kept at reset value.

Bit 10 Reserved, must be kept at reset value.

Bit 9 **CC2CF**: Capture/compare 2 clear flag
Writing 1 to this bit clears the CC2IF flag in the LPTIM_ISR register.
Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bit 8 **REPOKCF**: Repetition register update OK clear flag
Writing 1 to this bit clears the REPOK flag in the LPTIM_ISR register.

Bit 7 **UECF**: Update event clear flag
Writing 1 to this bit clear the UE flag in the LPTIM_ISR register.

Bit 6 **DOWNCF**: Direction change to down clear flag
Writing 1 to this bit clear the DOWN flag in the LPTIM_ISR register.
Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 5 **UPCF**: Direction change to UP clear flag
Writing 1 to this bit clear the UP flag in the LPTIM_ISR register.
Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 4 **ARROKCF**: Autoreload register update OK clear flag
Writing 1 to this bit clears the ARROK flag in the LPTIM_ISR register

Bit 3 Reserved, must be kept at reset value.

Bit 2 **EXTTRIGCF**: External trigger valid edge clear flag
Writing 1 to this bit clears the EXTTRIG flag in the LPTIM_ISR register

Bit 1 **ARRMCF**: Autoreload match clear flag
Writing 1 to this bit clears the ARRM flag in the LPTIM_ISR register

Bit 0 **CC1CF**: Capture/compare 1 clear flag
Writing 1 to this bit clears the CC1IF flag in the LPTIM_ISR register.

54.7.7 LPTIM4 interrupt enable register (LPTIM4_DIER)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	REPOKIE	UEIE	DOWNIE	UPIE	ARROKIE	CMP1OKIE	EXTTRIGIE	ARRMIE	CC1IE
							rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **REPOKIE**: Repetition register update OK interrupt Enable
0: Repetition register update OK interrupt disabled
1: Repetition register update OK interrupt enabled

Bit 7 **UEIE**: Update event interrupt enable
0: Update event interrupt disabled
1: Update event interrupt enabled

Bit 6 **DOWNIE**: Direction change to down Interrupt Enable
0: DOWN interrupt disabled
1: DOWN interrupt enabled
Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 5 **UPIE**: Direction change to UP Interrupt Enable
0: UP interrupt disabled
1: UP interrupt enabled
Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 4 **ARROKIE**: Autoreload register update OK Interrupt Enable
0: ARROK interrupt disabled
1: ARROK interrupt enabled

Bit 3 **CMP1OKIE**: Compare register 1 update OK interrupt enable
0: CMPOK register 1 interrupt disabled
1: CMPOK register 1 interrupt enabled

Bit 2 **EXTTRIGIE**: External trigger valid edge Interrupt Enable
0: EXTTRIG interrupt disabled
1: EXTTRIG interrupt enabled

Bit 1 **ARRMIE**: Autoreload match Interrupt Enable
0: ARRM interrupt disabled
1: ARRM interrupt enabled

Bit 0 **CC1IE**: Capture/compare 1 interrupt enable
0: Capture/compare 1 interrupt disabled
1: Capture/compare 1 interrupt enabled

Caution: The LPTIMx_DIER register must only be modified when the LPTIM is enabled (ENABLE bit set to 1). After a write to the LPTIMx_DIER register, a new write operation to the same register can only be performed when the previous write operation is completed. Any successive write before the DIEROK flag is set, leads to unpredictable results.

54.7.8 LPTIMx interrupt enable register [alternate] (LPTIMx_DIER) (x = 1 to 3, 5, 6)

This description of the register can only be used for output compare mode. See next section for input capture compare mode.

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UEDE	Res.	Res.	Res.	CMP2OKIE	Res.	Res.	Res.
								rw				rw			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CC2IE	REPOKIE	UEIE	DOWNIE	UPIE	ARROKIE	CMP1OKIE	EXTTRIGIE	ARRMIE	CC1IE
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **UEDE**: Update event DMA request enable
0: UE DMA request disabled. Writing '0' to the UEDE bit resets the associated ue_dma_req signal.
1: UE DMA request enabled
Note: If LPTIM does not implement at least 1 channel this bit is reserved. Refer to Section 54.3.

Bit 22 Reserved, must be kept at reset value.

Bit 21 Reserved, must be kept at reset value.

Bit 20 Reserved, must be kept at reset value.

Bit 19 **CMP2OKIE**: Compare register 2 update OK interrupt enable
0: CMPOK register 2 interrupt disabled
1: CMPOK register 2 interrupt enabled
Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bits 18:12 Reserved, must be kept at reset value.

Bit 11 Reserved, must be kept at reset value.

Bit 10 Reserved, must be kept at reset value.

Bit 9 **CC2IE**: Capture/compare 2 interrupt enable
0: Capture/compare 2 interrupt disabled
1: Capture/compare 2 interrupt enabled
Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bit 8 **REPOKIE**: Repetition register update OK interrupt Enable
0: Repetition register update OK interrupt disabled
1: Repetition register update OK interrupt enabled

Bit 7 **UEIE**: Update event interrupt enable
0: Update event interrupt disabled
1: Update event interrupt enabled

Bit 6 **DOWNIE**: Direction change to down Interrupt Enable
0: DOWN interrupt disabled
1: DOWN interrupt enabled
Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 5 **UPIE**: Direction change to UP Interrupt Enable
0: UP interrupt disabled
1: UP interrupt enabled
Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 4 **ARROKIE**: Autoreload register update OK Interrupt Enable
0: ARROK interrupt disabled
1: ARROK interrupt enabled

Bit 3 **CMP1OKIE**: Compare register 1 update OK interrupt enable
0: CMPOK register 1 interrupt disabled
1: CMPOK register 1 interrupt enabled

Bit 2 **EXTTRIGIE**: External trigger valid edge Interrupt Enable
0: EXTTRIG interrupt disabled
1: EXTTRIG interrupt enabled

Bit 1 **ARRMIE**: Autoreload match Interrupt Enable
0: ARRM interrupt disabled
1: ARRM interrupt enabled

Bit 0 **CC1IE**: Capture/compare 1 interrupt enable
0: Capture/compare 1 interrupt disabled
1: Capture/compare 1 interrupt enabled

Caution: The LPTIMx_DIER register must only be modified when the LPTIM is enabled (ENABLE bit set to 1). After a write to the LPTIMx_DIER register, a new write operation to the same register can only be performed when the previous write operation is completed. Any successive write before the DIEROK flag is set, leads to unpredictable results.

54.7.9 LPTIMx interrupt enable register [alternate] (LPTIMx_DIER) (x = 1 to 3, 5, 6)

This description of the register can only be used for input capture mode. See previous section for output compare mode.

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	CC2DE	Res.	UEDE	Res.	Res.	Res.	Res.	Res.	Res.	CC1DE
						rw		rw							rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CC2OIE	CC1OIE	Res.	Res.	CC2IE	REPOKIE	UEIE	DOWNIE	UPIE	ARROKIE	Res.	EXTTRIGIE	ARRMIE	CC1IE
		rw	rw			rw	rw	rw	rw	rw	rw		rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 Reserved, must be kept at reset value.

Bit 26 Reserved, must be kept at reset value.

Bit 25 **CC2DE**: Capture/compare 2 DMA request enable
0: CC2 DMA request disabled. Writing '0' to the CC2DE bit resets the associated ic2_dma_req signal.
1: CC2 DMA request enabled
Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bit 24 Reserved, must be kept at reset value.

Bit 23 **UEDE**: Update event DMA request enable
0: UE DMA request disabled. Writing '0' to the UEDE bit resets the associated ue_dma_req signal.
1: UE DMA request enabled
Note: If LPTIM does not implement at least 1 channel this bit is reserved. Refer to Section 54.3.

Bits 22:17 Reserved, must be kept at reset value.

Bit 16 **CC1DE**: Capture/compare 1 DMA request enable
0: CC1 DMA request disabled. Writing '0' to the CC1DE bit resets the associated ic1_dma_req signal.
1: CC1 DMA request enabled
Note: If LPTIM does not implement at least 1 channel this bit is reserved. Refer to Section 54.3.

Bit 15 Reserved, must be kept at reset value.

Bit 14 Reserved, must be kept at reset value.

Bit 13 **CC2OIE**: Capture/compare 2 over-capture interrupt enable
0: CC2 over-capture interrupt disabled
1: CC2 over-capture interrupt enabled
Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bit 12 **CC1OIE**: Capture/compare 1 over-capture interrupt enable
0: CC1 over-capture interrupt disabled
1: CC1 over-capture interrupt enabled
Note: If LPTIM does not implement at least 1 channel this bit is reserved. Refer to Section 54.3.

Bit 11 Reserved, must be kept at reset value.

Bit 10 Reserved, must be kept at reset value.

Bit 9 **CC2IE**: Capture/compare 2 interrupt enable
0: Capture/compare 2 interrupt disabled
1: Capture/compare 2 interrupt enabled
Note: If LPTIM does not implement at least 2 channels this bit is reserved. Refer to Section 54.3.

Bit 8 **REPOKIE**: Repetition register update OK interrupt Enable
0: Repetition register update OK interrupt disabled
1: Repetition register update OK interrupt enabled

Bit 7 **UEIE**: Update event interrupt enable
0: Update event interrupt disabled
1: Update event interrupt enabled

Bit 6 **DOWNIE**: Direction change to down Interrupt Enable
0: DOWN interrupt disabled
1: DOWN interrupt enabled
Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 5 **UPIE**: Direction change to UP Interrupt Enable
0: UP interrupt disabled
1: UP interrupt enabled
Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 4 **ARROKIE**: Autoreload register update OK Interrupt Enable
0: ARROK interrupt disabled
1: ARROK interrupt enabled

Bit 3 Reserved, must be kept at reset value.

Bit 2 **EXTTRIGIE**: External trigger valid edge Interrupt Enable
0: EXTTRIG interrupt disabled
1: EXTTRIG interrupt enabled

Bit 1 **ARRMIE**: Autoreload match Interrupt Enable
0: ARRM interrupt disabled
1: ARRM interrupt enabled

Bit 0 **CC1IE**: Capture/compare 1 interrupt enable
0: Capture/compare 1 interrupt disabled
1: Capture/compare 1 interrupt enabled

Caution: The LPTIMx_DIER register must only be modified when the LPTIM is enabled (ENABLE bit set to 1). After a write to the LPTIMx_DIER register, a new write operation to the same register can only be performed when the previous write operation is completed. Any successive write before the DIEROK flag is set, leads to unpredictable results.

54.7.10 LPTIM configuration register (LPTIM_CFGR)

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	ENC	COUNT MODE	PRE LOAD	WAV POL	WAVE	TIMOUT	TRIGEN[1:0]		Res.
							rw	rw	rw	rw	rw	rw	rw	rw	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRIGSEL[2:0]			Res.	PRESC[2:0]			Res.	TRGFLT[1:0]		Res.	CKFLT[1:0]		CKPOL[1:0]		CKSEL
rw	rw	rw		rw	rw	rw		rw	rw		rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 Reserved, must be kept at reset value.

Bits 28:25 Reserved, must be kept at reset value.

Bit 24 **ENC**: Encoder mode enable

The ENC bit controls the Encoder mode

0: Encoder mode disabled

1: Encoder mode enabled

Note: If the LPTIM does not support Encoder mode feature, this bit is reserved. Refer to Section 54.3.

Bit 23 **COUNTMODE**: counter mode enabled

The COUNTMODE bit selects which clock source is used by the LPTIM to clock the counter:

0: The counter is incremented following each internal clock pulse

1: The counter is incremented following each valid clock pulse on the LPTIM external Input1

Bit 22 **PRELOAD**: Registers update mode

The PRELOAD bit controls the LPTIM_ARR, LPTIM_RCR and the LPTIM_CCRx registers update modality

0: Registers are updated after each APB bus write access

1: Registers are updated at the end of the current LPTIM period

Bit 21 **WAVPOL**: Waveform shape polarity

The WAVPOL bit controls the output polarity

0: The LPTIM output reflects the compare results between LPTIM_CNT and LPTIM_CCRx registers

1: The LPTIM output reflects the inverse of the compare results between LPTIM_CNT and LPTIM_CCRx registers

Note: If the LPTIM implements at least one capture/compare channel, this bit is reserved. Refer to Section 54.3.

Bit 20 **WAVE**: Waveform shape

The WAVE bit controls the output shape

0: Deactivate Set-once mode

1: Activate the Set-once mode

Bit 19 **TIMOUT**: Timeout enable

The TIMOUT bit controls the Timeout feature

0: A trigger event arriving when the timer is already started is ignored

1: A trigger event arriving when the timer is already started resets and restarts the LPTIM counter and the repetition counter

Bits 18:17 **TRIGEN[1:0]**: Trigger enable and polarity

The TRIGEN bits controls whether the LPTIM counter is started by an external trigger or not. If the external trigger option is selected, three configurations are possible for the trigger active edge:

00: Software trigger (counting start is initiated by software)

01: Rising edge is the active edge

10: Falling edge is the active edge

11: Both edges are active edges

Bit 16 Reserved, must be kept at reset value.

Bits 15:13 **TRIGSEL[2:0]**: Trigger selector

The TRIGSEL bits select the trigger source that serves as a trigger event for the LPTIM among the below 8 available sources:

000: lptim_ext_trig0
001: lptim_ext_trig1
010: lptim_ext_trig2
011: lptim_ext_trig3
100: lptim_ext_trig4
101: lptim_ext_trig5
110: lptim_ext_trig6
111: lptim_ext_trig7

See *Section 54.4.3: LPTIM input and trigger mapping* for details.

Bit 12 Reserved, must be kept at reset value.

Bits 11:9 **PRESC[2:0]:** Clock prescaler

The PRESC bits configure the prescaler division factor. It can be one among the following division factors:

000: /1
001: /2
010: /4
011: /8
100: /16
101: /32
110: /64
111: /128

Bit 8 Reserved, must be kept at reset value.

Bits 7:6 **TRGFLT[1:0]:** Configurable digital filter for trigger

The TRGFLT value sets the number of consecutive equal samples that are detected when a level change occurs on an internal trigger before it is considered as a valid level transition. An internal clock source must be present to use this feature

00: Any trigger active level change is considered as a valid trigger
01: Trigger active level change must be stable for at least 2 clock periods before it is considered as valid trigger.
10: Trigger active level change must be stable for at least 4 clock periods before it is considered as valid trigger.
11: Trigger active level change must be stable for at least 8 clock periods before it is considered as valid trigger.

Bit 5 Reserved, must be kept at reset value.

Bits 4:3 **CKFLT[1:0]:** Configurable digital filter for external clock

The CKFLT value sets the number of consecutive equal samples that are detected when a level change occurs on an external clock signal before it is considered as a valid level transition. An internal clock source must be present to use this feature

00: Any external clock signal level change is considered as a valid transition
01: External clock signal level change must be stable for at least 2 clock periods before it is considered as valid transition.
10: External clock signal level change must be stable for at least 4 clock periods before it is considered as valid transition.
11: External clock signal level change must be stable for at least 8 clock periods before it is considered as valid transition.

Bits 2:1 **CKPOL[1:0]:** Clock polarity

When the LPTIM is clocked by an external clock source, CKPOL bits is used to configure the active edge or edges used by the counter:

00: The rising edge is the active edge used for counting.
If the LPTIM is configured in Encoder mode (ENC bit is set), the Encoder sub-mode 1 is active.

01: The falling edge is the active edge used for counting.
If the LPTIM is configured in Encoder mode (ENC bit is set), the Encoder sub-mode 2 is active.

10: Both edges are active edges. When both external clock signal edges are considered active ones, the LPTIM must also be clocked by an internal clock source with a frequency equal to at least four times the external clock frequency.
If the LPTIM is configured in Encoder mode (ENC bit is set), the Encoder sub-mode 3 is active.

11: Not allowed

Refer to *Section 54.4.15: Encoder mode* for more details about Encoder sub-modes.

Bit 0 **CKSEL:** Clock selector

The CKSEL bit selects which clock source the LPTIM uses:

0: LPTIM is clocked by internal clock source (APB clock or any of the embedded oscillators)

1: LPTIM is clocked by an external clock source through the LPTIM external Input1

Caution: The LPTIM_CFGR register must only be modified when the LPTIM is disabled (ENABLE bit reset to 0).

54.7.11 LPTIM control register (LPTIM_CR)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RSTARE	COUNTRST	CNTSTRT	SNGSTRT	ENABLE
											rw	rs	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **RSTARE:** Reset after read enable

This bit is set and cleared by software. When RSTARE is set to '1', any read access to LPTIM_CNT register asynchronously resets LPTIM_CNT register content.
This bit can be set only when the LPTIM is enabled.

Bit 3 **COUNTRST:** Counter reset

This bit is set by software and cleared by hardware. When set to '1' this bit triggers a synchronous reset of the LPTIM_CNT counter register. Due to the synchronous nature of this reset, it only takes place after a synchronization delay of 3 LPTimer core clock cycles (LPTimer core clock can be different from APB clock).
This bit can be set only when the LPTIM is enabled. It is automatically reset by hardware.

Caution: COUNTRST must never be set to '1' by software before it is already cleared to '0' by hardware. Software must consequently check that COUNTRST bit is already cleared to '0' before attempting to set it to '1'.

Bit 2 **CNTSTRT:** Timer start in Continuous mode

This bit is set by software and cleared by hardware.

In case of software start (TRIGEN[1:0] = 00), setting this bit starts the LPTIM in Continuous mode.

If the software start is disabled (TRIGEN[1:0] different than 00), setting this bit starts the timer in Continuous mode as soon as an external trigger is detected.

If this bit is set when a single pulse mode counting is ongoing, then the timer does not stop at the next match between the LPTIM_ARR and LPTIM_CNT registers and the LPTIM counter keeps counting in Continuous mode.

This bit can be set only when the LPTIM is enabled. It is automatically reset by hardware.

Bit 1 **SNGSTRT:** LPTIM start in Single mode

This bit is set by software and cleared by hardware.

In case of software start (TRIGEN[1:0] = 00), setting this bit starts the LPTIM in single pulse mode.

If the software start is disabled (TRIGEN[1:0] different than 00), setting this bit starts the LPTIM in single pulse mode as soon as an external trigger is detected.

If this bit is set when the LPTIM is in continuous counting mode, then the LPTIM stops at the following match between LPTIM_ARR and LPTIM_CNT registers.

This bit can only be set when the LPTIM is enabled. It is automatically reset by hardware.

Bit 0 **ENABLE:** LPTIM enable

The ENABLE bit is set and cleared by software.

0: LPTIM is disabled. Writing '0' to the ENABLE bit resets all the DMA request signals (input capture and update event DMA requests).

1: LPTIM is enabled

54.7.12 LPTIM compare register 1 (LPTIM_CCR1)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **CCR1[15:0]**: Capture/compare 1 value

If channel CC1 is configured as output:

CCR1 is the value to be loaded in the capture/compare 1 register.

Depending on the PRELOAD option, the CCR1 register is immediately updated if the PRELOAD bit is reset and updated at next LPTIM update event if PREOAD bit is reset.

The capture/compare register 1 contains the value to be compared to the counter LPTIM_CNT and signaled on OC1 output.

If channel CC1 is configured as input:

CCR1 becomes read-only, it contains the counter value transferred by the last input capture 1 event. The LPTIM_CCR1 register is read-only and cannot be programmed.

If LPTIM does not implement any channel:

The compare register 1 contains the value to be compared to the counter LPTIM_CNT and signaled on LPTIM output.

Caution: The LPTIM_CCR1 register must only be modified when the LPTIM is enabled (ENABLE bit set to 1).

54.7.13 LPTIM autoreload register (LPTIM_ARR)

Address offset: 0x018

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **ARR[15:0]:** Auto reload value
ARR is the autoreload value for the LPTIM.
This value must be strictly greater than the CCRx[15:0] value.

Caution: The LPTIM_ARR register must only be modified when the LPTIM is enabled (ENABLE bit set to 1).

54.7.14 LPTIM counter register (LPTIM_CNT)

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]:** Counter value
When the LPTIM is running, reading the LPTIM_CNT register may return unreliable values. In this case it is necessary to perform consecutive reads until two returned values are identical.

54.7.15 LPTIM configuration register 2 (LPTIM_CFGR2)

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC2SEL[1:0]		Res.	Res.	IC1SEL[1:0]	
										rw	rw			rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IN2SEL[1:0]		Res.	Res.	IN1SEL[1:0]	
										rw	rw			rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:20 **IC2SEL[1:0]**: LPTIM input capture 2 selection

The IC2SEL bits control the LPTIM Input capture 2 multiplexer, which connects LPTIM Input capture 2 to one of the available inputs.
00: lptim_ic2_mux0
01: lptim_ic2_mux1
10: lptim_ic2_mux2
11: lptim_ic2_mux3
For connection details refer to *Section 54.4.3: LPTIM input and trigger mapping*.

Bits 19:18 Reserved, must be kept at reset value.

Bits 17:16 **IC1SEL[1:0]**: LPTIM input capture 1 selection

The IC1SEL bits control the LPTIM Input capture 1 multiplexer, which connects LPTIM Input capture 1 to one of the available inputs.
00: lptim_ic1_mux0
01: lptim_ic1_mux1
10: lptim_ic1_mux2
11: lptim_ic1_mux3
For connection details refer to *Section 54.4.3: LPTIM input and trigger mapping*.

Bits 15:6 Reserved, must be kept at reset value.

Bits 5:4 **IN2SEL[1:0]**: LPTIM input 2 selection

The IN2SEL bits control the LPTIM input 2 multiplexer, which connects LPTIM input 2 to one of the available inputs.
00: lptim_in2_mux0
01: lptim_in2_mux1
10: lptim_in2_mux2
11: lptim_in2_mux3
For connection details refer to *Section 54.4.3: LPTIM input and trigger mapping*.

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **IN1SEL[1:0]**: LPTIM input 1 selection

The IN1SEL bits control the LPTIM input 1 multiplexer, which connects LPTIM input 1 to one of the available inputs.
00: lptim_in1_mux0
01: lptim_in1_mux1
10: lptim_in1_mux2
11: lptim_in1_mux3
For connection details refer to *Section 54.4.3: LPTIM input and trigger mapping*.

54.7.16 LPTIM repetition register (LPTIM_RCR)

Address offset: 0x028

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **REP[7:0]**: Repetition register value
REP is the repetition value for the LPTIM.

Caution: The LPTIM_RCR register must only be modified when the LPTIM is enabled (ENABLE bit set to 1). When using repetition counter with PRELOAD = 0, LPTIM_RCR register must be changed at least five counter cycles before the auto reload match event, otherwise an unpredictable behavior may occur.

54.7.17 LPTIM capture/compare mode register 1 (LPTIM_CCMR1)

Address offset: 0x02C

Reset value: 0x0000 0000

The channels can be used in input (capture mode) or in output (PWM mode). The direction of a channel is defined by configuring the corresponding CCxSEL bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	IC2F[1:0]		Res.	Res.	IC2PSC[1:0]		Res.	Res.	Res.	Res.	CC2P[1:0]		CC2E	CC2 SEL
		rw	rw			rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	IC1F[1:0]		Res.	Res.	IC1PSC[1:0]		Res.	Res.	Res.	Res.	CC1P[1:0]		CC1E	CC1 SEL
		rw	rw			rw	rw					rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:28 **IC2F[1:0]**: Input capture 2 filter

This bitfield defines the number of consecutive equal samples that are detected when a level change occurs on an external input capture signal before it is considered as a valid level transition. An internal clock source must be present to use this feature.

00: Any external input capture signal level change is considered as a valid transition

01: External input capture signal level change must be stable for at least 2 clock periods before it is considered as valid transition.

10: External input capture signal level change must be stable for at least 4 clock periods before it is considered as valid transition.

11: External input capture signal level change must be stable for at least 8 clock periods before it is considered as valid transition.

Bits 27:26 Reserved, must be kept at reset value.

Bits 25:24 **IC2PSC[1:0]**: Input capture 2 prescaler

This bitfield defines the ratio of the prescaler acting on the CC2 input (IC2).

00: No prescaler, capture is done each time an edge is detected on the capture input

01: Capture is done once every 2 events

10: Capture is done once every 4 events

11: Capture is done once every 8 events

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:18 **CC2P[1:0]**: Capture/compare 2 output polarity.

Condition: CC2 as output

Only bit2 is used to set polarity when output mode is enabled, bit3 is don't care.

0: OC2 active high

1: OC2 active low

Condition: CC2 as input

This field is used to select the IC2 polarity for capture operations.

00: Rising edge, circuit is sensitive to IC2 rising edge

01: Falling edge, circuit is sensitive to IC2 falling edge

10: Reserved, do not use this configuration.

11: Both edges, circuit is sensitive to both IC2 rising and falling edges.

Bit 17 **CC2E**: Capture/compare 2 output enable.

Condition: CC2 as output

0: Off - OC2 is not active. Writing '0' to the CC2E bit resets the ue_dma_req signal only if all the other LPTIM channels are disabled.

1: On - OC2 signal is output on the corresponding output pin

Condition: CC2 as input

This bit determines if a capture of the counter value can actually be done into the input capture/compare register 2 (LPTIM_CCR2) or not.

0: Capture disabled. Writing '0' to the CC2E bit resets the associated ic2_dma_req signal.

1: Capture enabled.

Bit 16 **CC2SEL**: Capture/compare 2 selection

This bitfield defines the direction of the channel, input (capture) or output mode.

0: CC2 channel is configured in output PWM mode

1: CC2 channel is configured in input capture mode

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:12 **IC1F[1:0]**: Input capture 1 filter

This bitfield defines the number of consecutive equal samples that are detected when a level change occurs on an external input capture signal before it is considered as a valid level transition. An internal clock source must be present to use this feature.

00: Any external input capture signal level change is considered as a valid transition

01: External input capture signal level change must be stable for at least 2 clock periods before it is considered as valid transition.

10: External input capture signal level change must be stable for at least 4 clock periods before it is considered as valid transition.

11: External input capture signal level change must be stable for at least 8 clock periods before it is considered as valid transition.

Bits 11:10 Reserved, must be kept at reset value.

Bits 9:8 **IC1PSC[1:0]**: Input capture 1 prescaler

This bitfield defines the ratio of the prescaler acting on the CC1 input (IC1).

00: No prescaler, capture is done each time an edge is detected on the capture input

01: Capture is done once every 2 events

10: Capture is done once every 4 events

11: Capture is done once every 8 events

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:2 **CC1P[1:0]**: Capture/compare 1 output polarity.

Condition: CC1 as output

Only bit2 is used to set polarity when output mode is enabled, bit3 is don't care.

0: OC1 active high, the LPTIM output reflects the compare results between LPTIM_ARR and LPTIM_CCRx registers

1: OC1 active low, the LPTIM output reflects the inverse of the compare results between LPTIM_ARR and LPTIM_CCRx registers

Condition: CC1 as input

This field is used to select the IC1 polarity for capture operations.

00: Rising edge, circuit is sensitive to IC1 rising edge

01: Falling edge, circuit is sensitive to IC1 falling edge

10: Reserved, do not use this configuration.

11: Both edges, circuit is sensitive to both IC1 rising and falling edges.

Bit 1 **CC1E**: Capture/compare 1 output enable.

Condition: CC1 as output

0: Off - OC1 is not active. Writing '0' to the CC1E bit resets the ue_dma_req signal only if all the other LPTIM channels are disabled.

1: On - OC1 signal is output on the corresponding output pin

Condition: CC1 as input

This bit determines if a capture of the counter value can actually be done into the input capture/compare register 1 (LPTIM_CCR1) or not.

0: Capture disabled. Writing '0' to the CC1E bit resets the associated ic1_dma_req signal.

1: Capture enabled.

Bit 0 **CC1SEL**: Capture/compare 1 selection

This bitfield defines the direction of the channel input (capture) or output mode.

0: CC1 channel is configured in output PWM mode

1: CC1 channel is configured in input capture mode

Caution: After a write to the LPTIM_CCMRx register, a new write operation to the same register can only be performed after a delay that must be equal or greater than the value of (PRESC × 3)

kernel clock cycles, PRESC[2:0] being the clock decimal division factor (1, 2, 4,..128). Any successive write violating this delay, leads to unpredictable results.

Caution: The CCxSEL, ICxF[1:0], CCxP[1:0] and ICxPSC[1:0] fields must only be modified when the channel x is disabled (CCxE bit reset to 0).

If LPTIM does not implement any channel this register is reserved. Refer to Section 54.3.

54.7.18 LPTIM compare register 2 (LPTIM_CCR2)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **CCR2[15:0]**: Capture/compare 2 value

If channel CC2 is configured as output:

CCR2 is the value to be loaded in the capture/compare 2 register.

Depending on the PRELOAD option, the CCR2 register is immediately updated if the PRELOAD bit is reset and updated at next LPTIM update event if PREOAD bit is reset.

The capture/compare register 2 contains the value to be compared to the counter LPTIM_CNT and signaled on OC2 output.

If channel CC2 is configured as input:

CCR2 becomes read-only, it contains the counter value transferred by the last input capture 2 event. The LPTIM_CCR2 register is read-only and cannot be programmed.

Caution: The LPTIM_CCR2 register must only be modified when the LPTIM is enabled (ENABLE bit set to 1).

Note: If the LPTIM implements less than 2 channels this register is reserved. Refer to *Section 54.3: LPTIM implementation*.

54.7.19 LPTIM register map

The following table summarizes the LPTIM registers.

Table 603. LPTIM register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	LPTIM4_ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIEROK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REPOK	UE	DOWN(2)	UP(2)	ARROK	CMP1OK	EXTTRIG	ARRM	CC1IF
	Reset value								0																0	0	0	0	0	0	0	0	0

Table 603. LPTIM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	LPTIMx_ISR (x = 1 to 3, 5, 6) Output compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIEROK	Res.	Res.	Res.	Res.	CMP2OK(1)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2IF(1)	REPOK	UE	DOWN(2)	UP(2)	ARROK	CMP1OK	EXTTRIG	ARRM	CC1IF
	Reset value								0					0										0	0	0	0	0	0	0	0	0	0
	LPTIMx_ISR (x = 1 to 3, 5, 6) Input capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIEROK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2OF(1)	CC1OF	Res.	Res.	CC2IF(1)	REPOK	UE	DOWN(2)	UP(2)	ARROK	Res.	EXTTRIG	ARRM	CC1IF
	Reset value								0											0	0			0	0	0	0	0	0		0	0	0
0x004	LPTIM4_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIEROKCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REPOKCF	UECF	DOWNCF(2)	UPCF(2)	ARROKCF	CMP1OKCF	EXTTRIGCF	ARRMCF	CC1CF
	Reset value								0															0	0	0	0	0	0	0	0	0	0
0x004	LPTIMx_ICR (x = 1 to 3, 5, 6) Output compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIEROKCF	Res.	Res.	Res.	Res.	CMP2OKCF(1)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2CF(1)	REPOKCF	UECF	DOWNCF(2)	UPCF(2)	ARROKCF	CMP1OKCF	EXTTRIGCF	ARRMCF	CC1CF
	Reset value								0					0										0	0	0	0	0	0	0	0	0	0
	LPTIMx_ICR (x = 1 to 3, 5, 6) Input capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIEROKCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2OCF(1)	CC1OCF	Res.	Res.	CC2CF(1)	REPOKCF	UECF	DOWNCF(2)	UPCF(2)	ARROKCF	Res.	EXTTRIGCF	ARRMCF	CC1CF
	Reset value								0											0	0			0	0	0	0	0	0		0	0	0
0x008	LPTIM4_DIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REPOKIE	UEIE	DOWNIE(2)	UPIE(2)	ARROKIE	CMP1OKIE	EXTTRIGIE	ARRMIE	CC1IE
	Reset value																								0	0	0	0	0	0	0	0	0
0x008	LPTIMx_DIER (x = 1 to 3, 5, 6) Output compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UEDE	Res.	Res.	Res.	CMP2OKIE(1)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2IE(1)	REPOKIE	UEIE	DOWNIE(2)	UPIE(2)	ARROKIE	CMP1OKIE	EXTTRIGIE	ARRMIE	CC1IE
	Reset value									0				0										0	0	0	0	0	0	0	0	0	0
	LPTIMx_DIER (x = 1 to 3, 5, 6) Input capture mode	Res.	Res.	Res.	Res.	Res.	Res.	CC2DE(1)	Res.	UEDE	Res.	Res.	Res.	Res.	Res.	Res.	CC1DE	Res.	Res.	CC2OIE(1)	CC1OIE	Res.	Res.	CC2IE(1)	REPOKIE	UEIE	DOWNIE(2)	UPIE(2)	ARROKIE	Res.	EXTTRIGIE	ARRMIE	CC1IE
	Reset value							0		0							0			0	0			0	0	0	0	0	0		0	0	0
0x00C	LPTIM_CFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ENC(2)	COUNTMODE	PRELOAD	WAVPOL(3)	WAVE	TIMOUT	TRIGEN		Res.	TRIGSEL[2:0]		Res.	PRESC			Res.	TRGFLT		Res.	CKFLT		CKPOL		CKSEL	
	Reset value								0	0	0	0	0	0	0	0		0	0	0		0	0	0	0	0		0	0	0	0	0	0
0x010	LPTIM_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RSTARE	COUNTRST	CNTSTRT	SNGSTRT	ENABLE
	Reset value																												0	0	0	0	0
0x014	LPTIM_CCR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 603. LPTIM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x018	LPTIM_ARR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x01C	LPTIM_CNT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	LPTIM_ CFGR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC2SEL[1:0]		Res.	Res.	IC1SEL[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IN2SEL[1:0]		Res.	Res.	IN1SEL[1:0]	
	Reset value											0	0			0	0											0	0			0	0
0x028	LPTIM_RCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x02C	LPTIM_CCMR1(4)	Res.	Res.	IC2F[1:0]		Res.	Res.	IC2PSC[1:0]		Res.	Res.	Res.	Res.	CC2P[1:0]		CC2E	CC2SEL	Res.	Res.	IC1F[1:0]		Res.	Res.	IC1PSC[1:0]		Res.	Res.	Res.	Res.	CC1P[1:0]		CC1E	CC1SEL
	Reset value			0	0			0	0					0	0	0	0			0	0			0	0					0	0	0	0
0x034	LPTIM_CCR2(5)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR2[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1. If LPTIM does not implement at least 2 channels this bit is reserved. Refer to *Section 54.3: LPTIM implementation*.
2. If LPTIM does not support Encoder mode feature, this bit is reserved. Refer to *Section 54.3: LPTIM implementation*.
3. If the LPTIM implements at least one capture/compare channel, this bit is reserved. Refer to *Section 54.3: LPTIM implementation*.
4. If LPTIM does not implement any channel this register is reserved. Refer to *Section 54.3: LPTIM implementation*.
5. If the LPTIM implements less than 2 channels this register is reserved. Refer to *Section 54.3: LPTIM implementation*.

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

55 Independent watchdog (IWDG)

55.1 IWDG introduction

The independent watchdog (IWDG) peripheral offers a high safety level, thanks to its capability to detect malfunctions due to software or hardware failures.

The IWDG is clocked by an independent clock, and stays active even if the main clock fails.

In addition, the watchdog function is performed in the V_{DD} voltage domain, allowing the IWDG to remain functional even in low power modes. Refer to *Section 55.3* to check the capability of the IWDG in this product.

The IWDG is best suited for applications that require the watchdog to run as a totally independent process outside the main application, making it very reliable to detect any unexpected behavior.

55.2 IWDG main features

- 12-bit down-counter
- Dual voltage domain, thus enabling operation in low power modes
- Independent clock
- Early wake-up interrupt generation
- Reset generation
  - In case of timeout
  - In case of refresh outside the expected window

55.3 IWDG implementation

Table 604. IWDG features (1)

IWDG modes/features	IWDG
LSI used as IWDG kernel clock (iwdg_ker_ck)	X
Window function	X
Early wake-up interrupt generation	X
System reset generation(2)	X
Capability to work in system Stop	X
Capability to work in system Standby	X
Capability to generate an interrupt in system Stop	X
Capability to generate an interrupt in system Standby	-
Capability to be frozen when the microcontroller enters in Debug mode(3)	X
Option bytes to control the activity in Stop mode(4)	X
Option bytes to control the activity in Standby mode(5)	X
Option bytes to control the Hardware mode(6)	X

1. ‘X’ = supported, ‘-’ = not supported.
2. Refer to the RCC section for additional information.
3. Controlled via DBG_IWDG_STOP in DBG section.

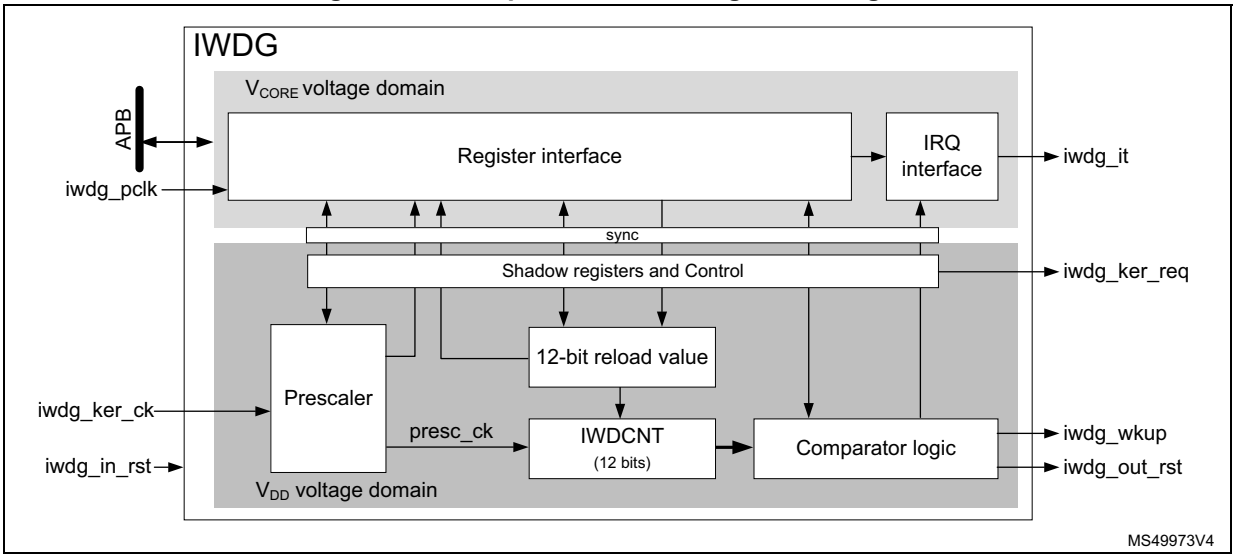
4. Controlled via the option byte IWDG_STOP in FLASH section.
5. Controlled via the option byte IWDG_STDBY in FLASH section.
6. Controlled via the option byte IWDG_SW in FLASH section.

55.4 IWDG functional description

55.4.1 IWDG block diagram

Figure 755 shows the functional blocks of the independent watchdog module.

Figure 755. Independent watchdog block diagram



The register and IRQ interfaces are located into the V_{CORE} voltage domain. The watchdog function itself is located into the V_{DD} voltage domain to remain functional in low power modes. See *Section 55.3* for IWDG capabilities.

The register and IRQ interfaces are mainly clocked by the APB clock (iwdg_pclk), while the watchdog function is clocked by a dedicated kernel clock (iwdg_ker_ck). A synchronization mechanism makes the data exchange between the two domains possible. Note that most of the registers located in the register interface are shadowed into the V_{DD} voltage domain.

The IWDG down-counter (IWDCNT) is clocked by the prescaled clock (presc_ck). The prescaled clock is generated from the kernel clock iwdg_ker_ck divided by the prescaler, according to PR[3:0] bitfield.

The table below gives the timing delays according to the actions performed on the IWDG: changing the prescaler, the timeout, the window or the early wake-up comparator values or doing a refresh.

Table 605. IWDG delays versus actions (1)

TD_{RVU}, TD_{PVU}		TD_{WVU}		TD_{EWU}		$TD_{Refresh}$		$TD_{RefAuto}$	
Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
5 T_k	6 T_k	-	6 T_k	-	6 T_k	2 T_k	2 T_k + T_p	-	T_p

1. Tk represents a period of the kernel clock input, Tp represents a period of presc_ck.

55.4.2 IWDG internal signals

The list of IWDG internal signals is detailed in *Table 606*.

Table 606. IWDG internal input/output signals

Signal name	Signal type	Description
iwdg_ker_ck	Input	IWDG kernel clock
iwdg_ker_req	Input	IWDG kernel clock request
iwdg_pclk	Input	IWDG APB clock
iwdg_out_rst	Output	IWDG reset output
iwdg_in_rst	Input	IWDG reset input
iwdg_wkup	Output	IWDG wake-up event
iwdg_it	Output	IWDG early wake-up interrupt

55.4.3 Software and hardware watchdog modes

The watchdog modes allow the application to select the way the IWDG is enabled, either by software commands (Software watchdog mode), or automatically (Hardware watchdog mode). All other functions work similarly for both Software and Hardware modes.

The software watchdog mode is the default working mode. The independent watchdog is started by writing the value 0x0000 CCCC into the *IWDG key register (IWDG_KR)*, and the IWDCNT starts counting down from the reset value (0xFFF).

In the hardware watchdog mode the independent watchdog is started automatically at power-on, or every time it is reset (via iwdg_in_rst). The IWDCNT down-counter starts counting down from the reset value 0xFFF. The hardware watchdog mode feature is enabled through the device option bits, see *Section 55.3* for details.

When the IWDG is enabled the ONF flag is set to 1.

When the IWDCNT reaches 0x000, a reset signal is generated (iwdg_out_rst asserted).

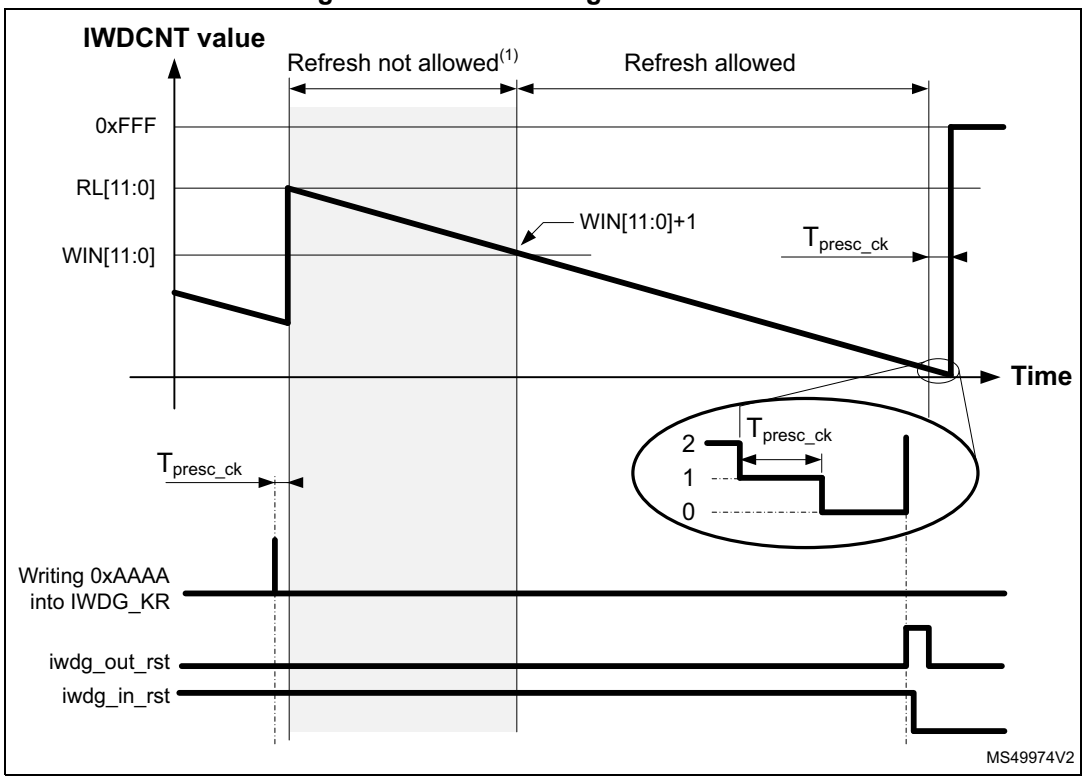
Whenever the key value 0x0000 AAAA is written in the *IWDG key register (IWDG_KR)*, the IWDG_RLR value is reloaded into the IWDCNT, and the watchdog reset is prevented.

Due to re-synchronization delays, the IWDG must be refreshed before the IWDCNT down-counter reaches 1.

Once started, the IWDG can be stopped only when it is reset (iwdg_in_rst asserted).

As shown in *Figure 756*, when the refresh command is executed, one period of presc_ck later, the IWDCNT is reloaded with the content of RL[11:0].

Figure 756. Reset timing due to timeout



1. If window option activated.

If the IWDG is not refreshed before the IWDCNT reaches 1, the IWDG generates a reset (iwdg_out_rst is asserted). In return, the RCC resets the IWDG (assertion of iwdg_in_rst) to clear the reset source.

55.4.4 Window option

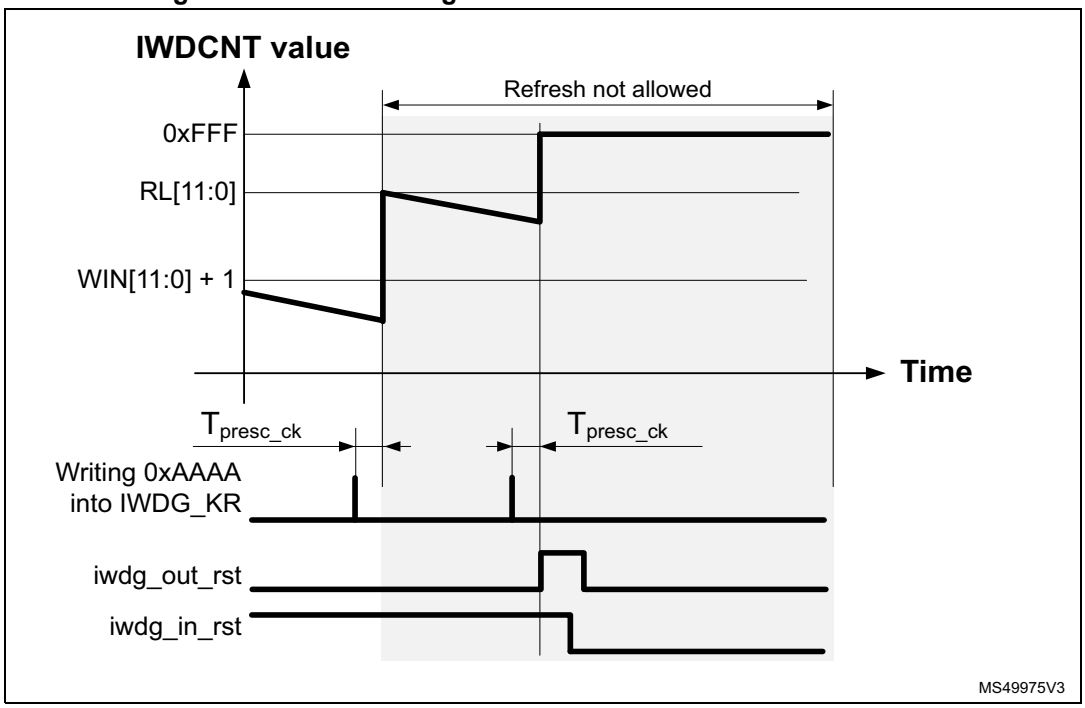
The IWDG can also work as a window watchdog, by setting the appropriate window in the *IWDG window register (IWDG_WINR)*.

If the reload operation is performed while the counter is greater than WIN[11:0] + 1, a reset is generated. WIN[11:0] is located in the *IWDG window register (IWDG_WINR)*. As shown in *Figure 757*, the reset is generated one period of presc_ck after the unexpected refresh command.

The default value of the *IWDG window register (IWDG_WINR)* is 0x0000 0FFF, so, if not updated, the window option is disabled.

As soon as the window value changes, the down-counter (IWDCNT) is reloaded with the RL[11:0] value, to ease the estimation for where the next refresh must take place.

Figure 757. Reset timing due to refresh in the not allowed area



Configuring the IWDG when the window option is enabled

1. Enable the IWDG by writing 0x0000 CCCC in the *IWDG key register (IWDG_KR)*.
2. Enable register access by writing 0x0000 5555 in the *IWDG key register (IWDG_KR)*.
3. Write the IWDG prescaler by programming *IWDG prescaler register (IWDG_PR)*.
4. Write the *IWDG reload register (IWDG_RLR)*.
5. If needed, enable the early wake-up interrupt, and program the early wake-up comparator, by writing the proper values into the *IWDG early wake-up interrupt register (IWDG_EWCR)*.
6. Write to the *IWDG window register (IWDG_WINR)*. This automatically reloads the IWDCNT down-counter with the RL[11:0] value.
7. Wait for the registers to be updated (IWDG_SR = 0x0000 0000).
8. Write 0x0000 0000 into *IWDG key register (IWDG_KR)* to write-protect registers.

Note: Step 7 can be skipped if the application does not intend to disable the APB clock after the completion of this sequence.

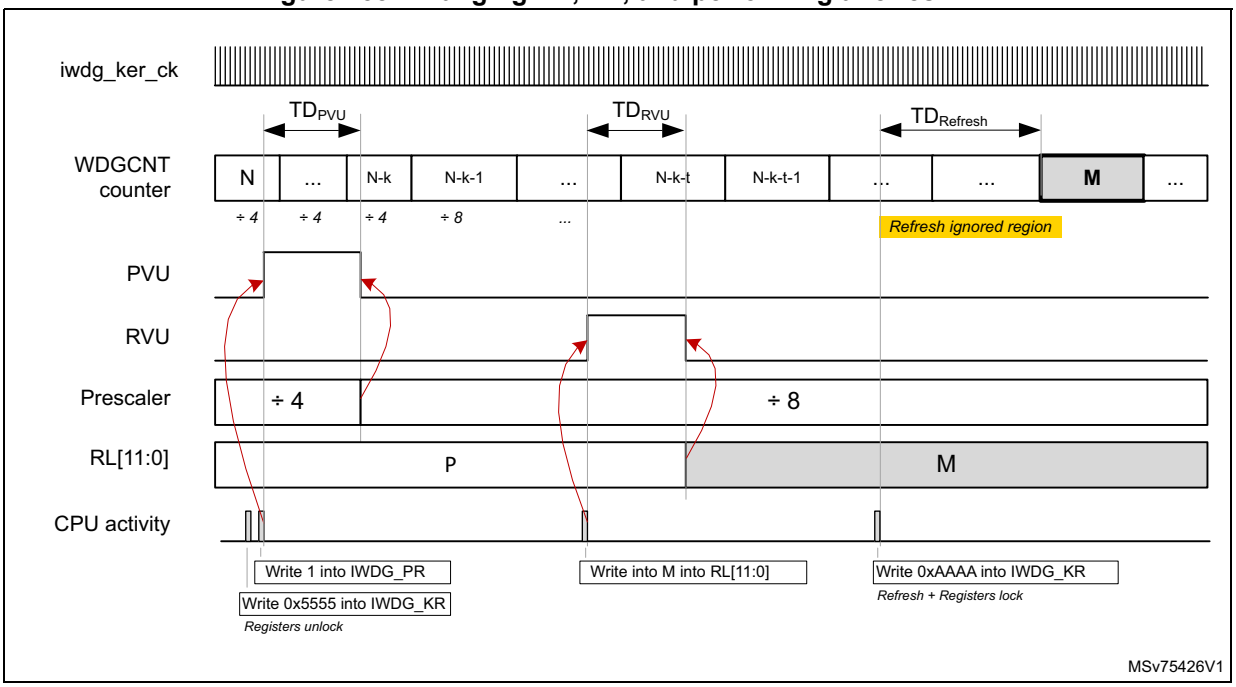
Configuring the IWDG when the window option is disabled

When the window option it is not used, the IWDG can be configured as follows:

1. Enable the IWDG by writing 0x0000 CCCC in the *IWDG key register (IWDG_KR)*.
2. Enable register access by writing 0x0000 5555 in the *IWDG key register (IWDG_KR)*.
3. Write the prescaler by programming the *IWDG prescaler register (IWDG_PR)*.
4. Write the *IWDG reload register (IWDG_RLR)*.
5. If needed, enable the early wake-up interrupt, and program the early wake-up comparator, by writing the proper values into the *IWDG early wake-up interrupt register (IWDG_EWCR)*.
6. Wait for the registers to be updated (IWDG_SR = 0x0000 0000).
7. Refresh the counter with RL[11:0] value, and write-protect registers by writing 0x0000 AAAA into *IWDG key register (IWDG_KR)*.

The figure below shows a sequence example changing the prescaler, the reload value, and then performing a refresh.

Figure 758. Changing PR, RL, and performing a refresh(1)



1. Refer to *Table 605: IWDG delays versus actions* for details on timing values.

Note: When the new prescaler value is accepted by the IWDG (falling edge of PVU), the new division ratio is effective when the current division sequence is completed (N-k in the drawing).

Note: The timeout delay between the refresh (write 0xAAAA into IWDG_KR) and the watchdog reset is increased by TDRefresh.

If a refresh command is sent while the previous refresh command is not yet completed, this last refresh command is ignored.

Updating the window comparator

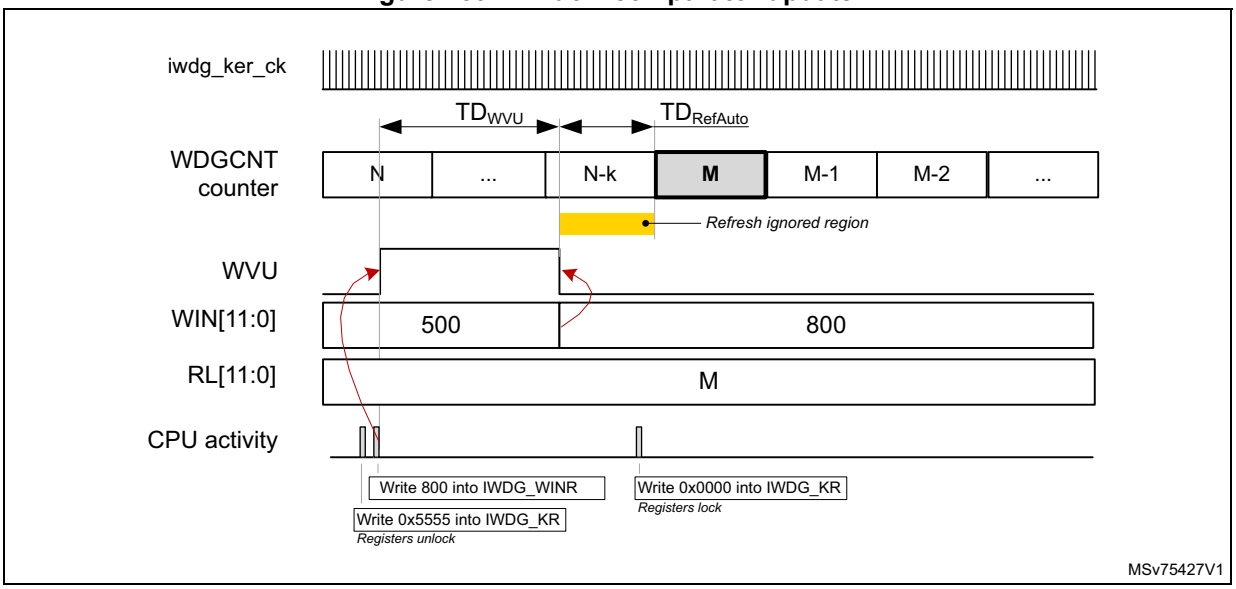
It is possible to update the window comparator when the IWDG is already running. The IWDCNT is reloaded as well. The following sequence can be performed to update the window comparator:

1. Enable register access by writing 0x0000 5555 in the IWDG key register (IWDG_KR).
2. Write to the IWDG window register (IWDG_WINR). This automatically reloads the IWDCNT down-counter with RL[11:0] value.
3. Wait for WVU = 0
4. Lock registers by writing IWDG_KR to 0x0000 0000

Step *3* can be skipped if the application does not intend to disable the APB clock after the completion of this sequence.

Figure 759 shows this sequence. As soon as the IWDG_WINR register is written, the WVU flag goes high for TDwvu. After a window comparator update, a refresh is automatically performed. The refresh is effective in the worst case, on the next prescaler clock active edge after the falling edge of WVU (TDRefAuto)

Figure 759. Window comparator update(1)



1. Refer to *Table 605: IWDG delays versus actions* for details on timing values.

55.4.5 Debug

When the processor enters into Debug mode (core halted), the IWDCNT down-counter either continues to work normally or stops, depending on debug capability of the product. Refer to *Section 55.3* for details on the capabilities of this product.

55.4.6 Register access protection

Write accesses to *IWDG prescaler register (IWDG_PR)*, *IWDG reload register (IWDG_RLR)*, *IWDG early wake-up interrupt register (IWDG_EWCR)* and *IWDG window register (IWDG_WINR)* are protected. To modify them, first write 0x0000 5555 in the *IWDG key register (IWDG_KR)*. A write access to this register with a different value breaks the

sequence and register access is protected again. This is the case of the reload operation (writing 0x0000 AAAA).

A status register is available to indicate that an update of the prescaler or the down-counter reload value or the window value is ongoing.

55.5 IWDG low power modes

Depending on option bytes configuration, the IWDG can continue counting or not during the low power modes. Refer to *Section 55.3* for details.

Table 607. Effect of low power modes on IWDG

Mode	Description
Sleep	No effect. IWDG interrupts cause the device to exit from the mode.
Stop	The IWDG remains active or not, depending on option bytes configuration. Refer to *Section 55.3* for details. IWDG interrupts cause the device exit the Stop mode.
Standby	The IWDG remains active or not, depending on option bytes configuration. Refer to *Section 55.3* for details. IWDG interrupts do not make the device to exit from Standby mode.

55.6 IWDG interrupts

The IWDG offers the possibility to generate an early interrupt depending on the value of the down-counter. The early interrupt is enabled by setting the EWIE bit of the *IWDG early wake-up interrupt register (IWDG_EWCR)* to 1.

A comparator value (EWIT[11:0]) allows the application to define the position where the early interrupt must be generated.

When the IWDCNT down-counter reaches the value of EWIT[11:0] - 1, the iwdg_wkup is activated, making it possible for the system to exit from low power modes, if needed.

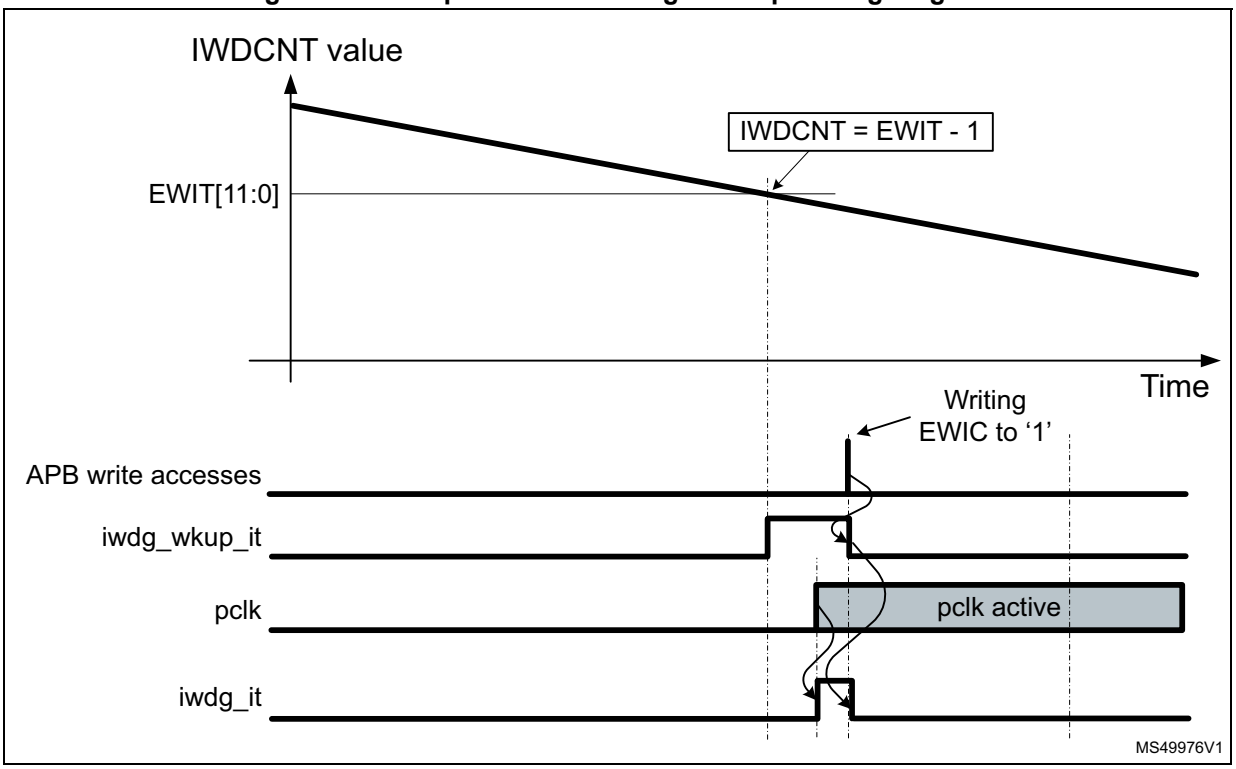
When the APB clock is available, the iwdg_it is activated as well.

In addition, the flag EWIF of the *IWDG status register (IWDG_SR)* is set to 1.

The EWI interrupt is acknowledged by writing 1 to the EWIC bit in the *IWDG early wake-up interrupt register (IWDG_EWCR)*.

Writing into the IWDG_EWCR register also triggers a refresh of the down-counter (IWDCNT) with the reload value RL[11:0].

Figure 760. Independent watchdog interrupt timing diagram



The early wake-up interrupt (EWI) can be used if specific safety operations or data logging must be performed before the watchdog reset is generated.

Changing the early wake-up comparator value

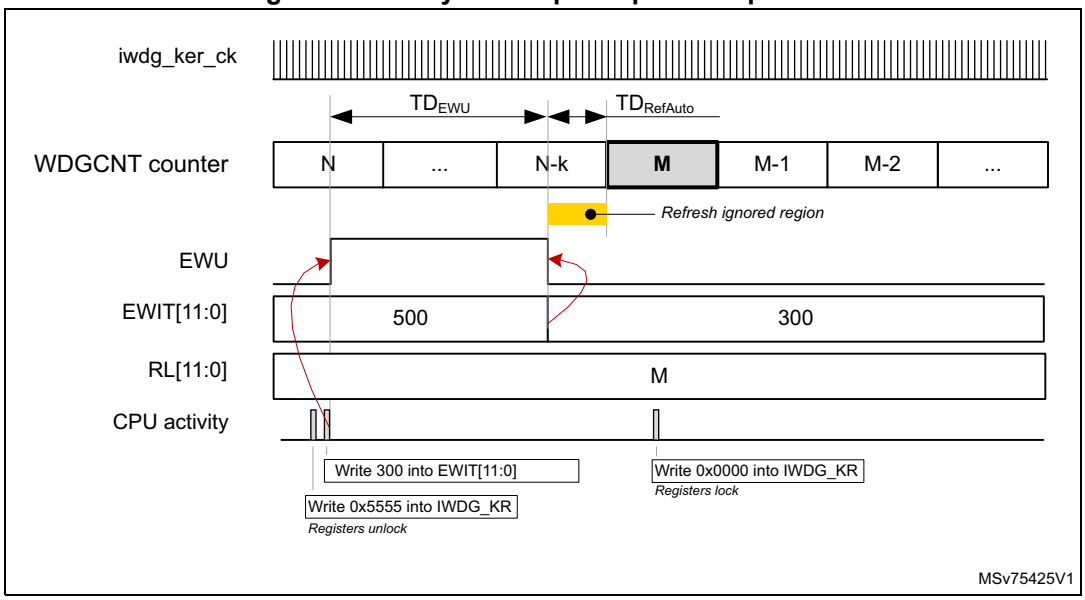
It is possible to change the early wake-up comparator value or to enable/disable the interrupt generation at any time, by performing the following sequence:

1. Enable register access by writing 0x0000 5555 in the *IWDG key register (IWDG_KR)*.
2. Enable or disable the early wake-up interrupt, and/or program the early wake-up comparator, by writing the proper values into the *IWDG early wake-up interrupt register (IWDG_EWCR)*.
3. Wait for EWU = 0, EWU is located into the *IWDG status register (IWDG_SR)*.
4. Write-protect registers by writing 0x0000 0000 to *IWDG key register (IWDG_KR)*.

Step *3* can be skipped if the application does not intend to disable the APB clock after the completion of this sequence.

Figure 761 shows this sequence. During the early wake-up comparator update operation the flag EWU remains to 1 for TDewu. A refresh is automatically performed. The refresh is effective on the worst case, on the next prescaler clock active edge after the falling edge of EWU (TDRefAuto).

Figure 761. Early wake-up comparator update(1)



1. Refer to *Table 605: IWDG delays versus actions* for details on timing values.

Table 608 summarizes the IWDG interrupt request.

Table 608. IWDG interrupt request

Interrupt event	Event flag	Interrupt clear method	Interrupt enable control bit	Activated interrupt	
				iwdg_it	iwdg_wkup_it
IWDCNT reaches EWIT value	EWIF	Writing EWIC to 1	EWIE	Y(1)	Y(2)

1. Generated when a clock is present on iwdg_pclk input.
2. Generated when a clock is present on iwdg_ker_ck input.

55.7 IWDG registers

Refer to *Section 1.2 on page 128* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by half-words (16-bit) or words (32-bit).

Most of the registers located into the register interface are shadowed into the V_{DD} voltage domain. When the iwdg_in_rst is asserted, the watchdog logic and the shadow registers located into the V_{DD} voltage domain are reset.

When the application reads back a watchdog register, the hardware transfers the value of the corresponding shadow register to the register interface.

When the application writes a watchdog register, the hardware updates the corresponding shadow register.

55.7.1 IWDG key register (IWDG_KR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **KEY[15:0]:** Key value (write only, read 0x0000)

These bits can be used for several functions, depending upon the value written by the application:

- 0xAAAA: reloads the RL[11:0] value into the IWDCNT down-counter (watchdog refresh), and write-protects registers. This value must be written by software at regular intervals, otherwise the watchdog generates a reset when the counter reaches 0.
- 0x5555: enables write-accesses to the registers.
- 0xCCCC: enables the watchdog (except if the hardware watchdog option is selected) and write-protects registers.
- values different from 0x5555: write-protects registers.

Note that only IWDG_PR, IWDG_RLR, IWDG_EWCR and IWDG_WINR registers have a write-protection mechanism.

55.7.2 IWDG prescaler register (IWDG_PR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PR[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **PR[3:0]:** Prescaler divider

These bits are write access protected, see *Section 55.4.6*. They are written by software to select the prescaler divider feeding the counter clock. PVU bit of the *IWDG status register (IWDG_SR)* must be reset to be able to change the prescaler divider.

0000: divider / 4
0001: divider / 8
0010: divider / 16
0011: divider / 32
0100: divider / 64
0101: divider / 128
0110: divider / 256
0111: divider / 512
Others: divider / 1024

Note: Reading this register returns the prescaler value from the V_{DD} voltage domain. This value may not be up to date/valid if a write operation to this register is ongoing. For this reason the value read from this register is valid only when the PVU bit in the IWDG status register (IWDG_SR) is reset.

55.7.3 IWDG reload register (IWDG_RLR)

Address offset: 0x08

Reset value: 0x0000 0FFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	RL[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **RL[11:0]:** Watchdog counter reload value

These bits are write access protected, see *Section 55.4.6*. They are written by software to define the value to be loaded in the watchdog counter each time the value 0xAAAA is written in the *IWDG key register (IWDG_KR)*. The watchdog counter counts down from this value. The timeout period is a function of this value and the prescaler.clock. It is not recommended to set RL[11:0] to a value lower than 2.

The RVU bit in the *IWDG status register (IWDG_SR)* must be reset to be able to change the reload value.

Note: Reading this register returns the reload value from the V_{DD} voltage domain. This value may not be up to date/valid if a write operation to this register is ongoing, hence the value read from this register is valid only when the RVU bit in the IWDG status register (IWDG_SR) is reset.

55.7.4 IWDG status register (IWDG_SR)

Address offset: 0x0C

Reset value: 0x0000 0000 (0xFFFF FEFF)

This register contains various status flags. Note that the mask value between parenthesis means that the reset value of ONF bit is not defined. When the IWDG is configured in

software mode, the reset value of ONF bit is 0, when the IWDG is configured in hardware mode, the reset value of ONF bit is 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	EWIF	Res.	Res.	Res.	Res.	Res.	ONF	Res.	Res.	Res.	Res.	EWU	WVU	RVU	PVU
	r						r					r	r	r	r

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **EWIF**: Watchdog early interrupt flag

This bit is set to ‘1’ by hardware in order to indicate that an early interrupt is pending. This bit must be cleared by the software by writing the bit EWIC of IWDG_EWCR register to ‘1’.

Bits 13:9 Reserved, must be kept at reset value.

Bit 8 **ONF**: Watchdog enable status bit

Set to ‘1’ by hardware as soon as the IWDG is started. In software mode, it remains to '1' until the IWDG is reset. In hardware mode, this bit is always set to '1'.

0: The IWDG is not activated

1: The IWDG is activated and needs to be refreshed regularly by the application

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **EWU**: Watchdog interrupt comparator value update

This bit is set by hardware to indicate that an update of the interrupt comparator value (EWIT[11:0]) or an update of the EWIE is ongoing. It is reset by hardware when the update operation is completed in the V_{DD} voltage domain. Refer to *Table 605: IWDG delays versus actions* for delay values.

The EWIT[11:0] and EWIE fields can be updated only when EWU bit is reset.

Bit 2 **WVU:** Watchdog counter window value update

This bit is set by hardware to indicate that an update of the window value is ongoing. It is reset by hardware when the reload value update operation is completed in the V_{DD} voltage domain. Refer to *Table 605: IWDG delays versus actions* for delay values.

The window value can be updated only when WVU bit is reset.

This bit is generated only if generic “window” = 1.

Bit 1 **RVU:** Watchdog counter reload value update

This bit is set by hardware to indicate that an update of the reload value is ongoing. It is reset by hardware when the reload value update operation is completed in the V_{DD} voltage domain. Refer to *Table 605: IWDG delays versus actions* for delay values.

The reload value can be updated only when RVU bit is reset.

Bit 0 **PVU:** Watchdog prescaler value update

This bit is set by hardware to indicate that an update of the prescaler value is ongoing. It is reset by hardware when the prescaler update operation is completed in the V_{DD} voltage domain. Refer to *Table 605: IWDG delays versus actions* for delay values.

The prescaler value can be updated only when PVU bit is reset.

Note: If several reload, prescaler, early interrupt position or window values are used by the application, it is mandatory to wait until RVU bit is reset before changing the reload value, to wait until PVU bit is reset before changing the prescaler value, to wait until WVU bit is reset before changing the window value, and to wait until EWU bit is reset before changing the

early interrupt position value. After updating the prescaler and/or the reload/window/early interrupt value, it is not necessary to wait until RVU or PVU or WVU or EWU is reset before continuing code execution, except in case of low power mode entry.

55.7.5 IWDG window register (IWDG_WINR)

Address offset: 0x10

Reset value: 0x0000 0FFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	WIN[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **WIN[11:0]:** Watchdog counter window value

These bits are write access protected, see *Section 55.4.6*.They contain the high limit of the window value to be compared with the downcounter.

To prevent a reset, the IWDCNT downcounter must be reloaded when its value is lower than WIN[11:0] + 1 and greater than 1.

The WVU bit in the *IWDG status register (IWDG_SR)* must be reset to be able to change the reload value.

Note: Reading this register returns the reload value from the V_{DD} voltage domain. This value may not be valid if a write operation to this register is ongoing. For this reason the value read from this register is valid only when the WVU bit in the IWDG status register (IWDG_SR) is reset.

55.7.6 IWDG early wake-up interrupt register (IWDG_EWCR)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EWIE	EWIC	Res.	Res.	EWIT[11:0]											
rw	w			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **EWIE**: Watchdog early interrupt enable

Set and reset by software.

0: The early interrupt interface is disabled.

1: The early interrupt interface is enabled.

The EWU bit in the *IWDG status register (IWDG_SR)* must be reset to be able to change the value of this bit.

Bit 14 **EWIC**: Watchdog early interrupt acknowledge

The software must write a 1 into this bit in order to acknowledge the early wake-up interrupt and to clear the EWIF flag. Writing 0 has not effect, reading this flag returns a 0.

Bits 13:12 Reserved, must be kept at reset value.

Bits 11:0 **EWIT[11:0]:** Watchdog counter early wake-up interrupt value

These bits are write access protected (see *Section 55.4.6*). They are written by software to define at which position of the IWDCNT down-counter the early wake-up interrupt must be generated. The early interrupt is generated when the IWDCNT is lower or equal to EWIT[11:0] - 1.

EWIT[11:0] must be bigger than 1.

An interrupt is generated only if EWIE = 1.

The EWU bit in the *IWDG status register (IWDG_SR)* must be reset to be able to change the reload value.

Note: Reading this register returns the Early wake-up comparator value and the Interrupt enable bit from the V_{DD} voltage domain. This value may not be up to date/valid if a write operation to this register is ongoing, hence the value read from this register is valid only when the EWU bit in the IWDG status register (IWDG_SR) is reset.

55.7.7 IWDG register map

Table 609. IWDG register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	IWDG_KR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEY[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	IWDG_PR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PR[3:0]			
	Reset value																													0	0	0	0
0x08	IWDG_RLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RL[11:0]											
	Reset value																					1	1	1	1	1	1	1	1	1	1	1	1
0x0C	IWDG_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EWIF	Res.	Res.	Res.	Res.	Res.	ONF	Res.	Res.	Res.	Res.	EWU	WVU	RVU	PVU
	Reset value																		0						x					0	0	0	0
0x10	IWDG_WINR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WIN[11:0]											
	Reset value																					1	1	1	1	1	1	1	1	1	1	1	1
0x14	IWDG_EWCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EWIE	EWIC	Res.	Res.	EWIT[11:0]											
	Reset value																	0	0			0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

56 System window watchdog (WWDG)

56.1 WWDG introduction

The system window watchdog (WWDG) is used to detect the occurrence of a software fault, usually generated by external interference or by unforeseen logical conditions, which causes the application program to abandon its normal sequence.

The watchdog circuit generates a reset on expiry of a programmed time period, unless the program refreshes the contents of the down-counter before the T6 bit is cleared. A reset is also generated if the 7-bit down-counter value (in the control register) is refreshed before the down-counter reaches the window register value. This implies that the counter must be refreshed in a limited window.

The WWDG clock is prescaled from the APB clock and has a configurable time window that can be programmed to detect abnormally late or early application behavior.

The WWDG is best suited for applications requiring the watchdog to react within an accurate timing window.

56.2 WWDG main features

- Programmable free-running down-counter
- Conditional reset
  - Reset (if watchdog activated) when the down-counter value becomes lower than 0x40
  - Reset (if watchdog activated) if the down-counter is reloaded outside the window (see *Figure 763*)
- Early wake-up interrupt (EWI): triggered (if enabled and the watchdog activated) when the down-counter is equal to 0x40

56.3 WWDG implementation

Table 610. WWDG features(1)

WWDG mode / feature	WWDG
Window function	X
Early wake-up interrupt generation	X
System reset generation(2)	X
Capability to work in system Stop	-
Capability to work in system Standby	-
Capability to be frozen when the microcontroller enters in Debug mode(3)	X
Option bytes to control the hardware mode(4)	X

1. “X” = supported, “-” = not supported.
2. Refer to the RCC section for additional information.
3. Controlled via WWDG_STOP in DBG block.

4. Controlled via the option byte WWDG_SW. When WWDG_SW is set in HW mode the WWDG is running as soon as the CPU is in Run or Sleep modes.

56.4 WWDG functional description

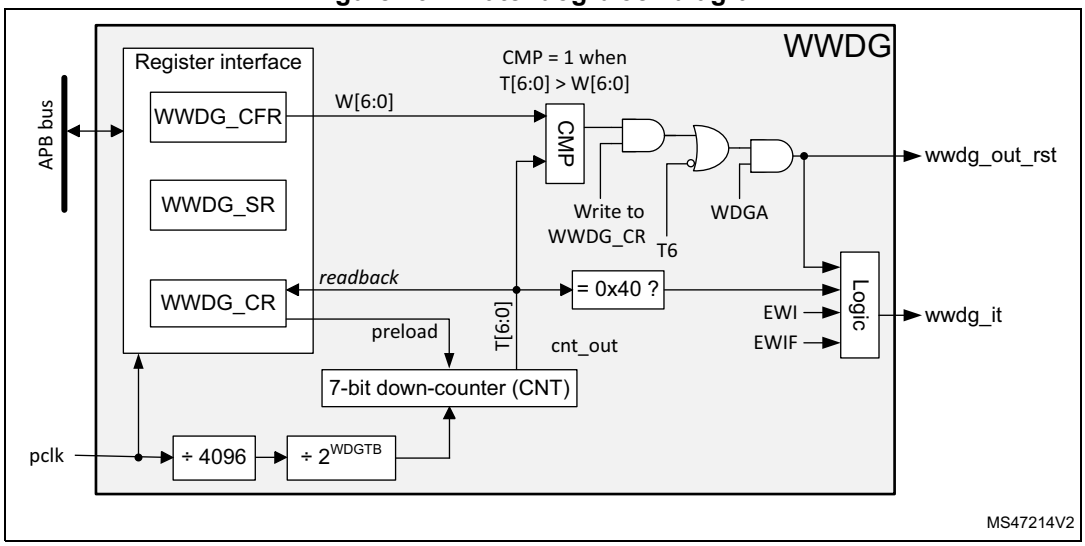
If the watchdog is activated (the WDGA bit is set in the WWDG_CR register), and when the 7-bit down-counter (T[6:0] bits) is decremented from 0x40 to 0x3F (T6 becomes cleared), it initiates a reset. If the software reloads the counter while the counter is greater than the value stored in the window register, then a reset is generated.

The application program must write in the WWDG_CR register at regular intervals during normal operation to prevent a reset. This operation can take place only when the counter value is lower than or equal to the window register value, and higher than 0x3F. The value to be stored in the WWDG_CR register must be between 0xFF and 0xC0.

Refer to *Figure 762* for the WWDG block diagram.

56.4.1 WWDG block diagram

Figure 762. Watchdog block diagram



56.4.2 WWDG internal signals

Table 611 gives the list of WWDG internal signals.

Table 611. WWDG internal input/output signals

Signal name	Signal type	Description
pclk	Digital input	APB bus clock
wwdg_out_rst	Digital output	WWDG reset signal output
wwdg_it	Digital output	WWDG early interrupt output

56.4.3 Enabling the watchdog

When the user option WWDG_SW selects “Software window watchdog”, the watchdog is always disabled after a reset. It is enabled by setting the WDGA bit in the WWDG_CR register, then it cannot be disabled again, except by a reset.

When the user option WWDG_SW selects “Hardware window watchdog”, the watchdog is always enabled after a reset, it cannot be disabled.

56.4.4 Controlling the down-counter

This down-counter is free-running, counting down even if the watchdog is disabled. When the watchdog is enabled, the T6 bit must be set to prevent generating an immediate reset.

The T[5:0] bits contain the number of increments that represent the time delay before the watchdog produces a reset. The timing varies between a minimum and a maximum value, due to the unknown status of the prescaler when writing to the WWDG_CR register (see *Figure 763*). The *WWDG configuration register (WWDG_CFR)* contains the high limit of the window: to prevent a reset, the down-counter must be reloaded when its value is lower than or equal to the window register value, and greater than 0x3F. *Figure 763* describes the window watchdog process.

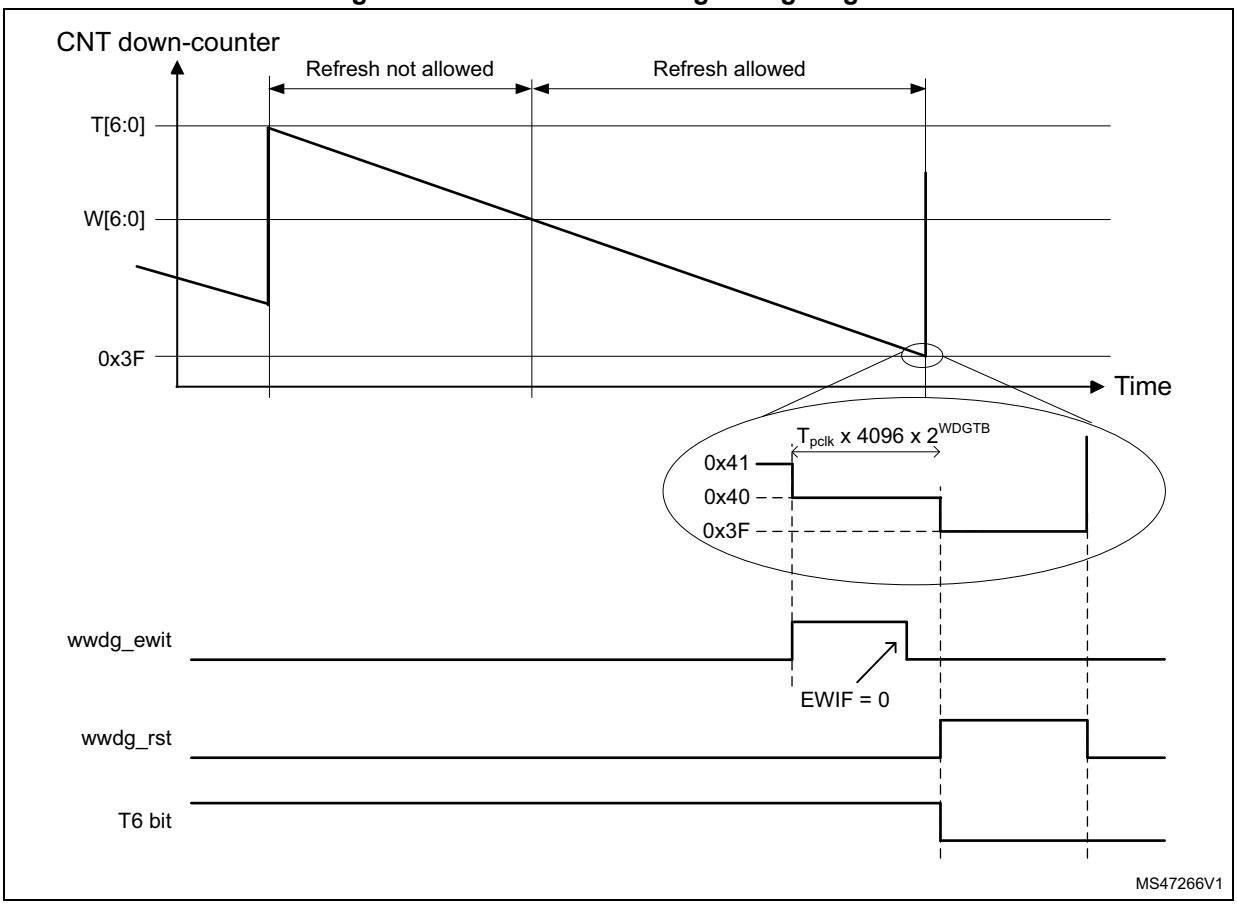
Note: The T6 bit can be used to generate a software reset (the WDGA bit is set and the T6 bit is cleared).

56.4.5 How to program the watchdog timeout

Use the formula in *Figure 763* to calculate the WWDG timeout.

Warning: When writing to the WWDG_CR register, always write 1 in the T6 bit to avoid generating an immediate reset.

Figure 763. Window watchdog timing diagram



The formula to calculate the timeout value is given by:

$$t_{WWDG} = t_{PCLK} \times 4096 \times 2^{WDGTB[2:0]} \times (T[5:0]+1) \quad (ms)$$

where:

- t_{WWDG}: WWDG timeout
- t_{PCLK}: APB clock period measured in ms
- 4096: value corresponding to internal divider

As an example, if APB frequency is 48 MHz, WDGTB[2:0] is set to 3, and T[5:0] is set to 63:

$$t_{WWDG} = (1/48000) \times 4096 \times 2^{3} \times (63+1) = 43.69ms$$

Refer to the datasheet for the minimum and maximum values of t_{WWDG}.

56.4.6 Debug mode

When the device enters debug mode (processor halted), the WWDG counter either continues to work normally or stops, depending on the configuration bit in DBG module. For more details, refer to *Section 71: Debug support (DBG)*.

56.5 WWDG interrupts

The early wake-up interrupt (EWI) can be used if specific safety operations or data logging must be performed before the reset is generated. To enable the early wake-up interrupt, the application must:

- Write EWIF bit of WWDG_SR register to 0, to clear unwanted pending interrupt
- Write EWI bit of WWDG_CFR register to 1, to enable interrupt

When the down-counter reaches the value 0x40, a watchdog interrupt is generated, and the corresponding interrupt service routine (ISR) can be used to trigger specific actions (such as communications or data logging), before resetting the device.

In some applications, the EWI interrupt can be used to manage a software system check and/or system recovery/graceful degradation, without generating a WWDG reset. In this case the corresponding ISR must reload the WWDG counter to avoid the WWDG reset, then trigger the required actions.

The watchdog interrupt is cleared by writing 0 to the EWIF bit in the WWDG_SR register.

Note: When the watchdog interrupt cannot be served (for example due to a system lock in a higher priority task), the WWDG reset is eventually generated.

Table 612. WWDG interrupt requests

Interrupt		Event flag	Enable control bit	Interrupt clearing method	Exit from mode		
Vector	Event				Sleep	Stop(1)	Standby(1)
WWDG(2)	Early wake-up interrupt	EWIF	EWI	Write EWIF flag to 0	Yes	No	No

1. The WWDG interrupt can have additional capabilities, refer to *Section 56.3* for details.
2. WWDG vector corresponds to the assertion of the wwdg_it signal.

56.6 WWDG registers

Refer to *Section 1.2: List of abbreviations for registers* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by halfwords (16-bit) or words (32-bit).

56.6.1 WWDG control register (WWDG_CR)

Address offset: 0x000

Reset value: 0x0000 007F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDGA	T[6:0]						
								rs	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **WDGA:** Activation bit

This bit is set by software and only cleared by hardware after a reset. When WDGA = 1, the watchdog can generate a reset.

0: Watchdog disabled

1: Watchdog enabled

Bits 6:0 **T[6:0]:** 7-bit counter (MSB to LSB)

These bits contain the value of the watchdog counter, decremented every (4096 x $2^{WDGTB[2:0]}$) PCLK cycles. A reset is produced when it is decremented from 0x40 to 0x3F (T6 becomes cleared).

56.6.2 WWDG configuration register (WWDG_CFR)

Address offset: 0x004

Reset value: 0x0000 007F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	WDGTB[2:0]			Res.	EWI	Res.	Res.	W[6:0]						
		rw	rw	rw		rs			rw	rw	rw	rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bits 13:11 **WDGTB[2:0]:** Timer base

The timebase of the prescaler can be modified as follows:

000: CK counter clock (PCLK div 4096) div 1

001: CK counter clock (PCLK div 4096) div 2

010: CK counter clock (PCLK div 4096) div 4

011: CK counter clock (PCLK div 4096) div 8

100: CK counter clock (PCLK div 4096) div 16

101: CK counter clock (PCLK div 4096) div 32

110: CK counter clock (PCLK div 4096) div 64

111: CK counter clock (PCLK div 4096) div 128

Bit 10 Reserved, must be kept at reset value.

Bit 9 **EWI:** Early wake-up interrupt enable

Set by software and cleared by hardware after a reset. When set, an interrupt occurs whenever the counter reaches the value 0x40.

Bits 8:7 Reserved, must be kept at reset value.

Bits 6:0 **W[6:0]:** 7-bit window value

These bits contain the window value to be compared with the down-counter.

56.6.3 WWDG status register (WWDG_SR)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EWIF
															rc_w0

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **EWIF:** Early wake-up interrupt flag

This bit is set by hardware when the counter has reached the value 0x40. It must be cleared by software by writing 0. Writing 1 has no effect. This bit is also set if the interrupt is not enabled.

56.6.4 WWDG register map

The following table gives the WWDG register map and reset values.

Table 613. WWDG register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	WWDG_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDGA	T[6:0]						
	Reset value																									0	1	1	1	1	1	1	1
0x004	WWDG_CFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDGTB [2:0]			Res.	EWI	Res.	Res.	W[6:0]						
	Reset value																			0	0	0		0			1	1	1	1	1	1	1
0x008	WWDG_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EWIF
	Reset value																																0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

57 Real-time clock (RTC)

57.1 RTC introduction

The RTC provides an automatic wake-up to manage all low-power modes.

The real-time clock (RTC) is an independent BCD timer/counter. The RTC provides a time-of-day clock/calendar with programmable alarm interrupts.

As long as the supply voltage remains in the operating range, the RTC never stops, regardless of the device status (Run mode, low-power mode or under reset).

The RTC is functional in V_{BAT} mode.

57.2 RTC main features

The RTC supports the following features (see *Figure 764: RTC block diagram*):

- Calendar with subseconds, seconds, minutes, hours (12 or 24 format), week day, date, month, year, in BCD (binary-coded decimal) format.
- Binary mode with 32-bit free-running counter.
- Automatic correction for 28, 29 (leap year), 30, and 31 days of the month.
- Two programmable alarms.
- On-the-fly correction from 1 to 32767 RTC clock pulses. This can be used to synchronize it with a master clock.
- Reference clock detection: a more precise second source clock (50 or 60 Hz) can be used to enhance the calendar precision.
- Digital calibration circuit with 0.95 ppm resolution, to compensate for quartz crystal inaccuracy.
- Timestamp feature which can be used to save the calendar content. This function can be triggered by an event on the timestamp pin, or by a tamper event, or by a switch to V_{BAT} mode.
- 17-bit auto-reload wake-up timer (WUT) for periodic events with programmable resolution and period.
- TrustZone support:
  - RTC fully securable
  - Alarm A, alarm B, wake-up Timer and timestamp individual secure or nonsecure configuration
- Alarm A, alarm B, wake-up Timer and timestamp individual privilege protection

The RTC is supplied through a switch that takes power either from the V_{DD} supply when present or from the VBAT pin.

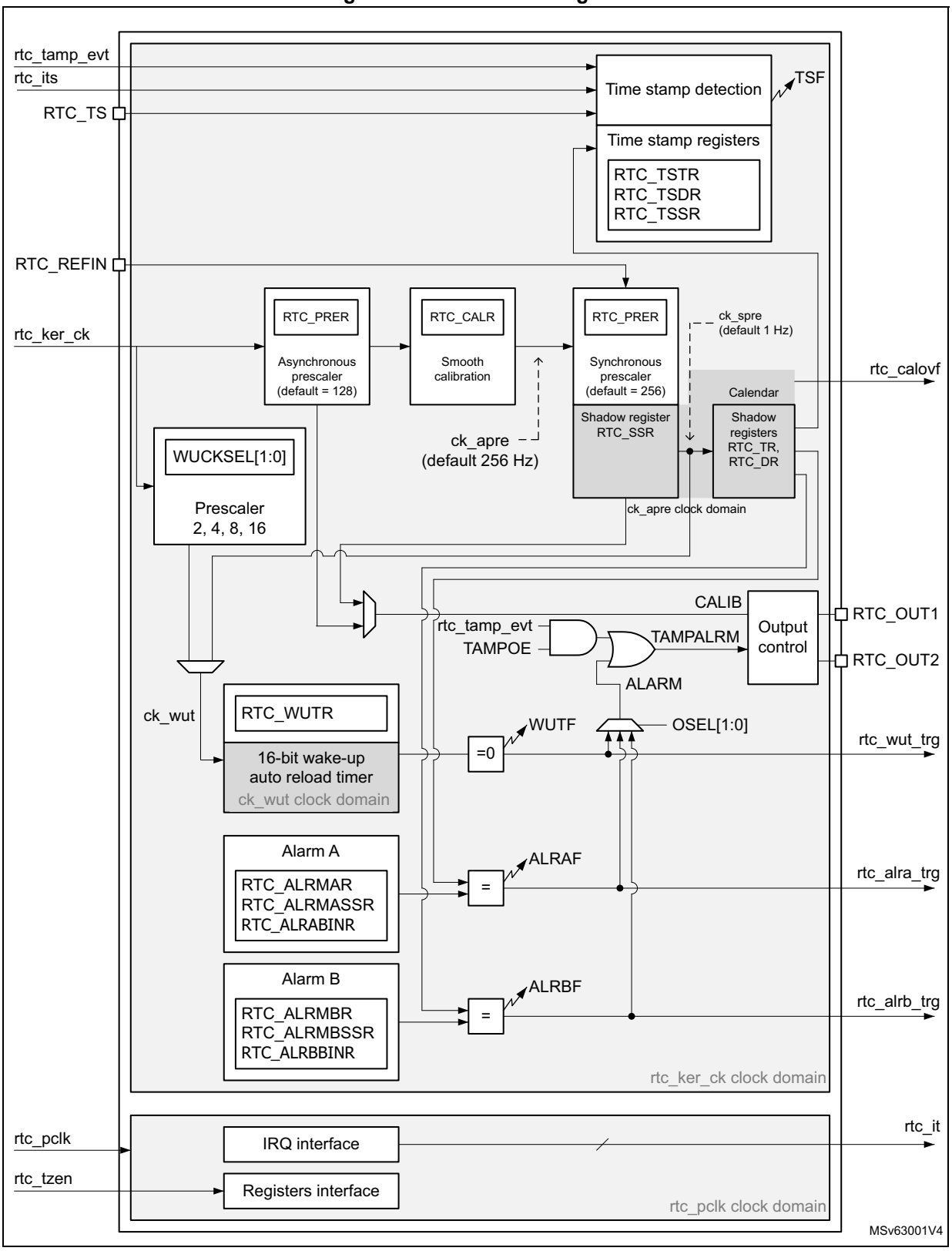
The RTC is functional in V_{BAT} mode and in all low-power modes when it is clocked by the LSE.

All RTC events (Alarm, wake-up Timer, Timestamp) can generate an interrupt and wake-up the device from the low-power modes.

57.3 RTC functional description

57.3.1 RTC block diagram

Figure 764. RTC block diagram



57.3.2 RTC pins and internal signals

Table 614. RTC input/output pins

Pin name	Signal type	Description
RTC_TS	Input	RTC timestamp input
RTC_REFIN	Input	RTC 50 or 60 Hz reference clock input
RTC_OUT1	Output	RTC output 1
RTC_OUT2	Output	RTC output 2

RTC_OUT1 and RTC_OUT2 which select one of the following two outputs:

- CALIB: 512 Hz or 1 Hz clock output (with an LSE frequency of 32.768 kHz). This output is enabled by setting the COE bit in the RTC_CR register.
- TAMPALRM: This output is the OR between rtc_tamp_evt and ALARM signals.

ALARM is enabled by configuring the OSEL[1:0] bits in the RTC_CR register which select the alarm A, alarm B or wake-up outputs. rtc_tamp_evt is enabled by setting the TAMPOE bit in the RTC_CR register which selects the tamper event outputs.

Table 615. RTC internal input/output signals

Internal signal name	Signal type	Description
rtc_ker_ck	Input	RTC kernel clock, also named RTCCLK in this document
rtc_pclk	Input	RTC APB clock
rtc_its	Input	RTC internal timestamp event
rtc_tamp_evt	Input	Tamper event (internal or external) detected in TAMP peripheral
rtc_tzen	Input	RTC TrustZone enabled
rtc_it	Output	RTC interrupts (refer to *Section 57.5: RTC interrupts* for details)
rtc_alra_trg	Output	RTC alarm A event detection trigger
rtc_alrb_trg	Output	RTC alarm B event detection trigger
rtc_wut_trg	Output	RTC wake-up timer event detection trigger
rtc_calovf	Output	RTC calendar overflow: this signal is generated when the RTC calendar reaches its maximum value, on the 31st of December 99, at 23:59:59. The calendar is then frozen and cannot overflow.

The RTC kernel clock is usually the LSE at 32.768 kHz although it is possible to select other clock sources in the RCC (refer to RCC for more details). Some functions are not available in some low-power modes or V_{BAT} when the selected clock is not LSE. Refer to *Section 57.4: RTC low-power modes* for more details.

Table 616. RTC interconnection

Signal name	Source/destination
rtc_its	From power controller (PWR): main power loss/switch to V_{BAT} detection output
rtc_tamp_evt	From TAMP peripheral: tamp_evt
rtc_tzen	From FLASH option bytes: TZEN
rtc_calovf	To TAMP peripheral: tamp_itamp5

The TZEN option bit is used to activate TrustZone in the device.

TZEN = 1: TrustZone activated.

TZEN = 0: TrustZone disabled.

When TrustZone is disabled, the APB access to the RTC registers are nonsecure.

The triggers outputs can be used as triggers for other peripherals.

57.3.3 GPIOs controlled by the RTC and TAMP

The GPIOs included in the Battery Backup Domain (V_{BAT}) are directly controlled by the peripherals providing functions on these I/Os, whatever the GPIO configuration.

RTC_OUT1, RTC_TS, TAMP_IN1, TAMP_OUT2 and TAMP_OUT3 are mapped on the same pin (PC13). The RTC and TAMP functions mapped on PC13 are available in all low-power modes and in V_{BAT} mode.

The output mechanism follows the priority order shown in *Table 617*.

Table 617. RTC pin PC13 configuration(1)

PC13 Pin function		OSEL[1:0] (ALARM output enable)	TAMPOE (TAMPER output enable)	COE (CALIB output enable)	OUT2EN	TAMPALRM_TYPE	TAMPALRM_PU	TAMP2E=TAMP2AM=1 with ATOSHARE=0, or TAMPxE=TAMPxAM=1 with ATOSHARE=1 and ATOSELx=1	TAMP3E=TAMP3AM=1 with ATOSHARE=0 and OUT3_RMP=00, or TAMPxE=TAMPxAM=1 with ATOSHARE=1, ATOSELx=2 and OUT3_RMP=00	TAMP1E (TAMP_IN1 input enable)	TSE (RTC_TS input enable)
TAMPALRM output Push-Pull		01 or 10 or 11	0	Don't care	Don't care	0	0	Don't care	Don't care	Don't care	Don't care
		00	1								
		01 or 10 or 11	1								
TAMPALRM output Open-Drain(2)	No pull	01 or 10 or 11	0	Don't care	Don't care	1	0	Don't care	Don't care	Don't care	Don't care
		00	1								
		01 or 10 or 11	1								
	Internal pull-up	01 or 10 or 11	0	Don't care	Don't care	1	1	Don't care	Don't care	Don't care	Don't care
		00	1								
		01 or 10 or 11	1								
CALIB output PP		00	0	1	0	Don't care	Don't care	Don't care	Don't care	Don't care	Don't care
TAMP_OUT2 output PP		00	0	0	0	Don't care	Don't care	1	0	Don't care	Don't care
TAMP_OUT3 output PP		00	0	0	0	Don't care	Don't care	0	1	Don't care	Don't care

Table 617. RTC pin PC13 configuration(1) (continued)

PC13 Pin function	OSEL[1:0] (ALARM output enable)	TAMPOE (TAMPER output enable)	COE (CALIB output enable)	OUT2EN	TAMPALRM_TYPE	TAMPALRM_PU	TAMP2E=TAMP2AM=1 with ATOSHARE=0, or TAMPxE=TAMPxAM=1 with ATOSHARE=1 and ATOSELx=1	TAMP3E=TAMP3AM=1 with ATOSHARE=0 and OUT3_RMP=00, or TAMPxE=TAMPxAM=1 with ATOSHARE=1, ATOSELx=2 and OUT3_RMP=00	TAMP1E (TAMP_IN1 input enable)	TSE (RTC_TS input enable)
TAMP_IN1 input floating	00	0	0	Don't care	Don't care	Don't care	0	0	1	0
	00	0	1	1						
	Don't care	Don't care	0							
RTC_TS and TAMP_IN1 input floating	00	0	0	Don't care	Don't care	Don't care	0	0	1	1
	00	0	1	1			0	0		
	Don't care	Don't care	0				0	0		
RTC_TS input floating	00	0	0	Don't care	Don't care	Don't care	0	0	0	1
	00	0	1	1			0	0		
	Don't care	Don't care	0				0	0		
Wake-up pin	00	0	0	Don't care	Don't care	Don't care	0	0	0	0
	00	0	1	1			0	0		
	Don't care	Don't care	0				0	0		
Standard GPIO	00	0	0	Don't care	Don't care	Don't care	0	0	0	0
	00	0	1	1			0	0		
	Don't care	Don't care	0				0	0		

1. OD: open drain; PP: push-pull.
2. In this configuration the GPIO must be configured in input.

RTC_OUT2, TAMP_IN2 and TAMP_OUT3 are mapped on the same pin (PI8). PI8 configuration is controlled by the RTC, whatever the PI8 GPIO configuration. The RTC or TAMP functions mapped on PI8 are available in all low-power modes and in VBAT mode.

The output mechanism follows the priority order shown in *Table 618*.

Table 618. PI8 configuration

PI1 Pin function		OSEL[1:0] (ALARM output enable)	TAMPOE (TAMPER output enable)	COE (CALIB output enable)	OUT2EN=1 and OUT2_RMP=0(1)	TAMPALRM_TYPE	TAMPALRM_PU	TAMP3E=TAMP3AM=1 with ATOSHARE=0 and OUT3_RMP=01, or TAMPxE=TAMPxAM=1 with ATOSHARE=1, ATOSELx=2 and OUT3_RMP=01	TAMP2E & IN2_RMP
TAMPALRM output Push-Pull		01 or 10 or 11	0	Don't care	1	0	0	Don't care	Don't care
		00	1						
		01 or 10 or 11	1						
TAMPALRM output Open-Drain	No pull	01 or 10 or 11	0	Don't care	1	1	0	Don't care	Don't care
		00	1						
		01 or 10 or 11	1						
	Internal pull-up	01 or 10 or 11	0	Don't care	1	1	1	Don't care	Don't care
		00	1						
		01 or 10 or 11	1						
CALIB output PP		00	0	1	1	Don't care	Don't care	Don't care	Don't care
TAMP_OUT3 output PP		00	0	0	0	Don't care	Don't care	1	0
TAMP_IN2 input floating		00	0	0	0	Don't care	Don't care	0	1
Wake-up pin		00	0	0	0	Don't care	Don't care	0	0
Standard GPIO		00	0	0	0	Don't care	Don't care	0	0

1. RTC_OUT2 is mapped on PI8 when OUT2_RMP = 0.

In addition, it is possible to output RTC_OUT2 on PB2 or PI8 pin thanks to OUT2EN and OUT2_RMP bits. The different functions are mapped on RTC_OUT1 or on RTC_OUT2 depending on OSEL, COE and OUT2EN configuration, as shown in table *Table 619*.

Table 619. RTC_OUT mapping

OSEL[1:0] bits ALARM output enable)	COE bit (CALIB output enable)	OUT2EN bit	RTC_OUT1 on PC13	RTC_OUT2 on PB2 or PI8(1)
00	0	0	-	-
00	1		CALIB	-
01 or 10 or 11	Don't care		TAMPALRM	-
00	0	1	-	-
00	1		-	CALIB
01 or 10 or 11	0		-	TAMPALRM
01 or 10 or 11	1		TAMPALRM	CALIB

1. RTC_OUT2 is mapped on PI8 when OUT2_RMP = 0, and on PB2 when OUT2_RMP = 1.

57.3.4 RTC secure protection modes

By default after a backup domain power-on reset, all RTC registers can be read or written in both secure and nonsecure modes, except for the RTC secure configuration register (RTC_SECCFGR) which can be written in secure mode only. The RTC protection configuration is not affected by a system reset.

When the SEC bit is set in the RTC_SECCFGR register:

- Writing the RTC registers is possible only in secure mode.
- Reading RTC_SECCFGR, RTC_PRIVCFGR, RTC_MISR, RTC_TR, RTC_DR, RTC_SSR, RTC_PRER and RTC_CALR is always possible in secure and nonsecure modes. All the other RTC registers can be read only in secure mode.

When the SEC bit is cleared, it is still possible to protect some of the registers by setting dedicated INITSEC, CALSEC, TSSEC, WUTSEC, ALRASEC or ALRBSEC control bits. If all

these bits are also clear, all the RTC registers can be read and written in secure and nonsecure mode.

- When INITSEC is set:
  - RTC_TR, RTC_DR, RTC_PRER registers, plus INIT, BIN and BCDU in RTC_ICSR, FMT control bits in RTC_CR and INITPRIV in the RTC_PRIVCFGR can be written only in secure mode.
  - These registers and control bits can be read in secure and nonsecure mode.
- When CALSEC is set:
  - RTC_SHIFTR and RTC_CALR registers, plus ADD1H, SUB1H and REFCKON control bits in the RTC_CR and CALPRIV in the RTC_PRIVCFGR can be written only in secure mode.
  - These registers and control bits can be read in secure and nonsecure mode.
- When ALRASEC is set:
  - RTC_ALRMAR, RTC_ALRMASSR and RTC_ALRABINR registers, plus ALRAE, ALRAFCLR, ALRAIE and SSRUIE in the RTC_CR, CALRAF and CSSRUF in the RTC_SCR, ALRAF and SSRUF in RTC_SR, and ALRAMF and SSRUMF in RTC_SMISR can be read and written only in secure mode.
  - ALRAPRIV in the RTC_PRIVCFGR can be written only in secure mode
- When ALRBSEC is set:
  - RTC_ALRMBR, RTC_ALRMBSSR and RTC_ALRBBINR registers, plus ALRBE ALRBFCLR, ALRBIE in the RTC_CR, CALRBF in the RTC_SCR, ALRBF in RTC_SR, and ALRBMF in RTC_SMISR can be read and written only in secure mode.
  - ALRBPRIV in the RTC_PRIVCFGR can be written only in secure mode.
- When WUTSEC is set:
  - RTC_WUTR register, plus WUTE, WUTIE and WUCKSEL control bits in the RTC_CR, CWUTF in the RTC_SCR, WUTF in RTC_SR, and WUTMF in RTC_SMISR can be read and written only in secure mode.
  - WUTPRIV in the RTC_PRIVCFGR can be written only in secure mode
- When TSSEC is set:
  - RTC_TSTR, RTC_TSDR and RTC_TSSSR registers, plus TAMPTS, ITSE, TSE, TSIE, TSEDGE control bits in the RTC_CR, CITSF, CTSOVF and CTSF bits in the RTC_SCR, TSF, TSOVF and ITSF in RTC_SR, and TSMF, TSOVMF and ITSMF in RTC_SMISR can be read and written only in secure mode.
  - TSPRIV in the RTC_PRIVCFGR can be written only in secure mode

A nonsecure access to a secure-protected register is denied:

- There is no bus error generated.
- In case the register has a global protection, excepting RTC_WPR: a notification is generated through a flag/interrupt in the TZIC (TrustZone illegal access controller). In case only a few bits of the register are protected (for registers with mixed features such as RTC_CR...), no notification is generated.
- When write protected, the bits are not written.
- When read protected they are read as 0.

As soon as at least one function is configured to be secured, the RTC reset and clock control is also secured in the RCC.

57.3.5 RTC privilege protection modes

By default after a backup domain power-on reset, all RTC registers can be read or written in both privileged and unprivileged modes, except for the RTC privilege mode control register (RTC_PRIVCFGR) which can be written in privilege mode only. The RTC protection configuration is not affected by a system reset.

When the PRIV bit is set in the RTC_PRIVCFGR register:

- Writing the RTC registers is possible only in privileged mode.
- Reading the RTC_SECCFGR, RTC_PRIVCFGR, RTC_TR, RTC_DR, RTC_SSR, RTC_PRER and RTC_CALR is always possible in privilege and unprivilege modes. All the other RTC registers can be read only in privilege mode.

When the PRIV bit is cleared, it is still possible to protect some of the registers by setting dedicated INITPRIV, CALPRIV, TSPRIV, WUTPRIV, ALRAPRV or ALRBPRIV control bits. If all these bits are also cleared, all the RTC registers can be read or written in privilege and unprivilege modes.

- When INITPRIV is set:
  - RTC_TR, RTC_DR, RTC_PRER registers, plus INIT, BIN and BCDU in RTC_ICSR and FMT control bits in RTC_CR, plus INITSEC in the RTC_SECCFGR can be written only in privilege mode.
  - These registers and control bits can be read in privilege and unprivilege mode.
- When CALPRIV is set:
  - RTC_SHIFTR and RTC_CALR registers, plus ADD1H, SUB1H and REFCKON control bits in the RTC_CR, plus CALDSEC in the RTC_SECCFGR can be written only in privilege mode.
  - These registers and control bits can be read in privilege and unprivilege mode.
- When ALRAPRIV is set:
  - RTC_ALRMAR, RTC_ALRMASSR and RTC_ALRABINR registers, plus ALRAE, ALRAFCLR, ALRAIE and SSRUIE in the RTC_CR, and CALRAF and CSSRUF in the RTC_SCR, ALRAF and SSRUF in RTC_SR, and ALRAMF and SSRUMF in RTC_MISR and RTC_SMISR can be read and written only in privilege mode.
  - ALRASEC in the RTC_SECCFGR can be written only in privilege mode.
- When ALRBPRIV is set:
  - RTC_ALRMBR, RTC_ALRMBSSR and RTC_ALRBBINR registers, plus ALRBE, ALRBFCLR, ALRBIE in the RTC_CR, and CALRBF in the RTC_SCR, ALRBF in RTC_SR, and ALRBMF in RTC_MISR and RTC_SMISR can be read and written only in privilege mode.
  - ALRBSEC in the RTC_SECCFGR can be written only in privilege mode.
- When WUTPRIV is set:
  - RTC_WUTR register, plus WUTE, WUTIE and WUCKSEL control bits in the RTC_CR, and CWUTF in the RTC_SCR, WUTF in RTC_SR, and WUTMF in RTC_MISR and RTC_SMISR can be read and written only in privilege mode.
  - WUTSEC in the RTC_SECCFGR can be written only in privilege mode.
- When TSPRIV is set:
  - RTC_TSTR, RTC_TSDR and RTC_TSSSR registers, plus TAMPTS, ITSE, TSE, TSIE, TSEDGE control bits in the RTC_CR, CITSF, CTSOVF and CTSF bits in the

RTC_SCR, TSF, TSOVF and ITSF in RTC_SR, and TSMF, TSOVMF and ITSMF in RTC_MISR and RTC_SMISR can be read and written only in privilege mode.

– TSSEC in the RTC_SECCFGR can be written only in privilege mode.

A unprivileged access to a privileged-protected register is denied:

- There is no bus error generated.
- When write protected, the bits are not written.
- When read protected they are read as 0.

57.3.6 Clock and prescalers

The RTC clocks must respect this ratio: frequency(PCLK) ≥ 2 × frequency(RTCCLK).

For more information on the RTC clock (RTCCLK) source configuration, refer to “Reset and clock control (RCC)”.

BCD mode (BIN=00)

A programmable prescaler stage generates a 1 Hz clock which is used to update the calendar. To minimize power consumption, the prescaler is split into 2 programmable prescalers (see *Figure 764: RTC block diagram*):

- A 7-bit asynchronous prescaler configured through the PREDIV_A bits of the RTC_PRER register.
- A 15-bit synchronous prescaler configured through the PREDIV_S bits of the RTC_PRER register.

Note: When both prescalers are used, it is recommended to configure the asynchronous prescaler to a high value to minimize consumption.

The asynchronous prescaler division factor is set to 128, and the synchronous division factor to 256, to obtain an internal clock frequency of 1 Hz (ck_spre) with an LSE frequency of 32.768 kHz.

The minimum division factor is 1 and the maximum division factor is 2^{22}.

This corresponds to a maximum input frequency of around 4 MHz.

f_{ck_apre} is given by the following formula:

$$f_{CK_APRE} = \frac{f_{RTCCLK}}{PREDIV_A + 1}$$

The ck_apre clock is used to clock the binary RTC_SSR subsecond downcounter. When it reaches 0, RTC_SSR is reloaded with the content of PREDIV_S.

f_{ck_spre} is given by the following formula:

$$f_{CK_SPRE} = \frac{f_{RTCCLK}}{(PREDIV_S + 1) \times (PREDIV_A + 1)}$$

The ck_spre clock can be used either to update the calendar or as timebase for the 16-bit wake-up auto-reload timer. To obtain short timeout periods, the 16-bit wake-up auto-reload timer can also run with the RTCCLK divided by the programmable 4-bit asynchronous prescaler (see *Section 57.3.10: Periodic auto-wake-up* for details).

Binary mode (BIN=01)

The SSR binary down-counter is extended to 32-bit length and is free running. The time and date calendar BCD registers are not functional.

This down-counter is clocked by ck_apre: the output of the 7-bit asynchronous prescaler configured through the PREDIV_A bits of the RTC_PRER register.

PREDIV_S value is don't care.

Mixed mode (BIN=10 or 11)

The SSR binary down-counter is extended to 32-bit length and is free running. The time and date calendar BCD registers are also available.

This down-counter is clocked by ck_apre: the output of the 7-bit asynchronous prescaler configured through the PREDIV_A bits of the RTC_PRER register. The bits BCDU[2:0] are used to define when the calendar is incremented by 1 second, using the SSR least significant bits.

57.3.7 Real-time clock and calendar

The RTC calendar time and date registers are accessed through shadow registers which are synchronized with PCLK (APB clock). They can also be accessed directly in order to avoid waiting for the synchronization duration.

- RTC_SSR for the subseconds
- RTC_TR for the time
- RTC_DR for the date

Every RTCCLK periods, the current calendar value is copied into the shadow registers, and the RSF bit of RTC_ICSR register is set (see *Section 57.6.12: RTC shift control register (RTC_SHIFTR)*). The copy is not performed in Stop and Standby mode. When exiting these modes, the shadow registers are updated after up to 4 RTCCLK periods.

When the application reads the calendar registers, it accesses the content of the shadow registers. It is possible to make a direct access to the calendar registers by setting the BYPSHAD control bit in the RTC_CR register. By default, this bit is cleared, and the user accesses the shadow registers.

When reading the RTC_SSR, RTC_TR or RTC_DR registers in BYPSHAD = 0 mode, the frequency of the APB clock (f_{APB}) must be at least 7 times the frequency of the RTC clock (f_{RTCCLK}).

The shadow registers are reset by system reset.

57.3.8 Calendar ultra-low power mode

It is possible to reduce drastically the RTC power consumption by setting the LPCAL bit in the RTC_CALR register. In this configuration, the whole RTC is clocked by ck_apre only instead of both RTCCLK and ck_apre. Consequently, some flags delays are longer, and the calibration window is longer (refer to *Section : RTC ultra-low-power mode*).

The LPCAL bit is ignored (assumed to be 0) when asynchronous prescaler division factor (PREDIV_A+1) is not a power of 2.

Switching from LPCAL=0 to LPCAL=1 or from LPCAL=1 to LPCAL=0 is not immediate and requires a few ck_apre periods to complete.

57.3.9 Programmable alarms

The RTC unit provides programmable alarm: alarm A and alarm B. The description below is given for alarm A, but can be translated in the same way for alarm B.

The programmable alarm function is enabled through the ALRAE bit in the RTC_CR register.

The ALRAF is set to 1 if the calendar subseconds, seconds, minutes, hours, date or day match the values programmed in the alarm registers RTC_ALRMASSR and RTC_ALRMAR. Each calendar field can be independently selected through the MSKx bits of the RTC_ALRMAR register, and through the MASKSSx bits of the RTC_ALRMASSR register.

When the binary mode is used, the subsecond field can be programmed in the alarm binary register RTC_ALRABINR.

The alarm interrupt is enabled through the ALRAIE bit in the RTC_CR register.

In case the Alarm is used to generate a trigger event for another peripheral, the ALRAF can be automatically cleared by hardware by configuring the ALRAFCLR bit at 1 in the RTC_CR register. In this configuration there is no need for software intervention if the only purpose is clearing the ALRAF flag.

Caution: If the seconds field is selected (MSK1 bit reset in RTC_ALRMAR), the synchronous prescaler division factor set in the RTC_PRER register must be at least 3 to ensure correct behavior.

Alarm A and alarm B (if enabled by bits OSEL[1:0] in RTC_CR register) can be routed to the TAMPALRM output. TAMPALRM output polarity can be configured through bit POL the RTC_CR register.

57.3.10 Periodic auto-wake-up

The periodic wake-up flag is generated by a 16-bit programmable auto-reload down-counter. The wake-up timer range can be extended to 17 bits.

The wake-up function is enabled through the WUTE bit in the RTC_CR register.

The wake-up timer clock input ck_wut can be:

- RTC clock (RTCCLK) divided by 2, 4, 8, or 16.

  When RTCCLK is LSE (32.768 kHz), this permits the wake-up interrupt period to be configured from 122 µs to 32 s, with a resolution down to 61 µs.
- ck_spre (usually 1 Hz internal clock) in BCD mode, or the clock used to update the calendar as defined by BCDU in binary or mixed (BCD-binary) modes.

  When ck_spre frequency is 1 Hz, a wake-up time from 1 s to around 36 hours can be achieved with one-second resolution. This large programmable time range is divided in 2 parts:
  - from 1 s to 18 hours when WUCKSEL [2:1] = 10
  - and from around 18 h to 36 h when WUCKSEL[2:1] = 11. In this last case 2^{16} is added to the 16-bit counter current value. When the initialization sequence is complete (see *Programming the wake-up timer on page 2490*), the timer starts counting down. When the wake-up function is enabled, the down-counting remains active in low-power modes. In addition, when it reaches 0, the WUTF flag is set in the RTC_SR register, and the wake-up counter is automatically reloaded with its reload value (RTC_WUTR register value).

Depending on WUTOCLR in the RTC_WUTR register, the WUTF flag must either be cleared by software (WUTOCLR = 0x0000), or the WUTF is automatically cleared by hardware when the auto-reload down counter reaches WUTOCLR value (0x0000 < WUTOCLR ≤ WUT).

The wake-up flag is output on an internal signal rtc_wut that can be used by other peripherals (refer to section *Section 57.3.1: RTC block diagram*).

When the periodic wake-up interrupt is enabled by setting the WUTIE bit in the RTC_CR register, it can exit the device from low-power modes.

The periodic wake-up flag can be routed to the TAMPALRM output provided it has been enabled through bits OSEL[1:0] of RTC_CR register. TAMPALRM output polarity can be configured through the POL bit in the RTC_CR register.

System reset, as well as low-power modes (Sleep, Stop, and Standby) have no influence on the wake-up timer.

57.3.11 RTC initialization and configuration

RTC Binary, BCD or Mixed mode

By default the RTC is in BCD mode (BIN = 00 in the RTC_ICSR register): the RTC_SSR register contains the subsecond field SS[15:0], clocked by ck_apre, allowing to generate a 1 Hz clock to update the calendar registers in BCD format (RTC_TR and RTC_DR).

When the RTC is configured in binary mode (BIN = 01 in the RTC_ICSR register): the RTC_SSR register contains the binary counter SS[31:0], clocked by ck_apre. The calendar registers in BCD format (RTC_TR and RTC_DR) are not used.

When the RTC is configured in mixed mode (BIN = 10 or 11 in the RTC_ICSR register): the RTC_SSR register contains the binary counter SS[31:0], clocked by ck_apre. The calendar is updated (1 second increment) each time the SSR[BCDU+7:0] reaches 0.

RTC register write protection

After a system reset, the RTC registers are protected against parasitic write access by the DBP bit in the power control peripheral (refer to the PWR power control section). DBP bit must be set to enable RTC registers write access.

After Backup domain reset, the RTC registers related to RTC initialization and RTC calibration are write-protected: Writing the unlock sequence in RTC_WPR is required to gain write access to these registers.

The following steps are required to unlock the write protection on the registers related to RTC initialization that is RTC_TR, RTC_DR, RTC_PRER, the bits INIT, BIN and BCDU in RTC_ICSR, and the bit FMT in RTC_CR:

1. Write 0xCA into the RTC_WPR register.
2. Write 0x53 into the RTC_WPR register.

Those two write accesses must be performed with the privilege and security mode defined by PRIV, INITPRIV, SEC, INITSEC configuration

Writing an incorrect key reactivates the write protection.

Any write access to RTC_WPR with incorrect privilege, security settings has no effect and is ignored without any illegal access notification.

The following steps are required to unlock the write protection of the registers related to RTC calibration, that is RTC_CALR, RTC_SHIFTR, and the bits SUB1H, ADD1H, REFCKON in RTC_CR:

1. Write 0xCA into the RTC_WPR register.
2. Write 0x53 into the RTC_WPR register.

Those two write accesses must be done with the privilege and security mode defined by PRIV, CALPRIV, SEC, CALSEC configuration.

Writing an incorrect key reactivates the write protection.

Any write access to RTC_WPR with the incorrect privilege, security settings has no effect and is ignored without any illegal access notification.

Calendar initialization and configuration

To program the initial time and date calendar values, including the time format and the prescaler configuration, the following sequence is required:

1. Set INIT bit to 1 in the RTC_ICSR register to enter initialization mode. In this mode, the calendar counter is stopped and its value can be updated.
2. Poll INITF bit of in the RTC_ICSR register. The initialization phase mode is entered when INITF is set to 1.
   – If LPCAL=0: INITF is set around 2 RTCCLK cycles after INIT bit is set.
   – If LPCAL=1: INITF is set up to 2 ck_apre cycle after INIT bit is set.
3. To generate a 1 Hz clock for the calendar counter, program both the prescaler factors in RTC_PRER register, plus BIN and BCDU in the RTC_ICSR register.
4. Load the initial time and date values in the shadow registers (RTC_TR and RTC_DR), and configure the time format (12 or 24 hours) through the FMT bit in the RTC_CR register.
5. Exit the initialization mode by clearing the INIT bit. The actual calendar counter value is then automatically loaded.
   – If LPCAL=0: the counting restarts after 4 RTCCLK clock cycles.
   – If LPCAL=1: the counting restarts after up to 2 RTCCLK + 1 ck_apre.

When the initialization sequence is complete, the calendar starts counting. The RTC_SSR content is initialized with:

- PREDIV_S in BCD mode (BIN=00)
- 0xFFFF FFFF in binary or mixed (BCD-binary) modes (BIN=01, 10 or 11).

In BCD mode, RTC_SSR contains the value of the synchronous prescaler counter. This enables one to calculate the exact time being maintained by the RTC down to a resolution of 1 / (PREDIV_S + 1) seconds. As a consequence, the resolution can be improved by increasing the synchronous prescaler value (PREDIV_S[14:0]). The maximum resolution allowed (30.52 µs with a 32768 Hz clock) is obtained with PREDIV_S set to 0x7FFF.

However, increasing PREDIV_S means that PREDIV_A must be decreased in order to maintain the synchronous prescaler output at 1 Hz. In this way, the frequency of the asynchronous prescaler output increases, which may increase the RTC dynamic consumption. The RTC dynamic consumption is optimized for PREDIV_A+1 being a power of 2.

Note: There is no hardware protection against incorrect calendar value initialization. Software must ensure that the initialization is performed correctly using allowed calendar BCD values.

Note: After a system reset, the application can read the INITS flag in the RTC_ICSR register to check if the calendar has been initialized or not. If this flag equals 0, the calendar has not been initialized since the year field is set at its Backup domain reset default value (0x00).

Note: To read the calendar after initialization, the software must first check that the RSF flag is set in the RTC_ICSR register.

Daylight saving time

The daylight saving time management is performed through bits SUB1H, ADD1H, and BKP of the RTC_CR register.

Using SUB1H or ADD1H, the software can subtract or add one hour to the calendar in one single operation without going through the initialization procedure.

In addition, the software can use the BKP bit to memorize this operation.

Programming the alarm

A similar procedure must be followed to program or update the programmable alarms. The procedure below is given for alarm A but can be translated in the same way for alarm B.

1. Clear ALRAE in RTC_CR to disable alarm A.
2. Program the alarm A registers (RTC_ALRMASSR/RTC_ALRMAR or RTC_ALRABINR).
3. Set ALRAE in the RTC_CR register to enable alarm A again.

Note: Each change of the RTC_CR register is taken into account after around 2 RTCCLK clock cycles due to clock synchronization.

Programming the wake-up timer

The following sequence is required to configure or change the wake-up timer auto-reload value (WUT[15:0] in RTC_WUTR):

1. Clear WUTE in RTC_CR to disable the wake-up timer.
2. Poll WUTWF until it is set in RTC_ICSR to make sure the access to wake-up auto-reload counter and to WUCKSEL[2:0] bits is allowed.
   - If WUCKSEL[2] = 0: WUTWF is set around 1 ck_wut + 1 RTCCLK cycles after WUTE bit is cleared.
   - If WUCKSEL[2] = 1: WUTWF is set up to 1 ck_apre + 1 RTCCLK cycles after WUTE bit is cleared.
3. Program the wake-up auto-reload value WUT[15:0], WUTOCLR[15:0] and the wake-up clock selection (WUCKSEL[2:0] bits in RTC_CR). Set WUTE in RTC_CR to enable the timer again. The wake-up timer restarts down-counting.
   - If WUCKSEL[2] = 0: WUTWF is cleared around 1 ck_wut + 1 RTCCLK cycles after WUTE bit is set.
   - If WUCKSEL[2] = 1: WUTWF is cleared up to 1 ck_apre + 1 RTCCLK cycles after WUTE bit is set.

57.3.12 Reading the calendar

When BYPSHAD control bit is cleared in the RTC_CR register

To read the RTC calendar registers (RTC_SSR, RTC_TR and RTC_DR) properly, the APB clock frequency (f_{PCLK}) must be equal to or greater than seven times the RTC clock frequency (f_{RTCCLK}). This ensures a secure behavior of the synchronization mechanism.

If the APB clock frequency is less than seven times the RTC clock frequency, the software must read the calendar time and date registers twice. If the second read of the RTC_TR gives the same result as the first read, this ensures that the data is correct. Otherwise a third read access must be done. In any case the APB clock frequency must never be lower than two times the RTC clock frequency.

The RSF bit is set in RTC_ICSR register each time the calendar registers are copied into the RTC_SSR, RTC_TR and RTC_DR shadow registers. The copy is performed every RTCCLK cycle. To ensure consistency between the 3 values, reading either RTC_SSR or RTC_TR locks the values in the higher-order calendar shadow registers until RTC_DR is read. In case the software makes read accesses to the calendar in a time interval smaller than 1 RTCCLK periods: RSF must be cleared by software after the first calendar read, and then the software must wait until RSF is set before reading again the RTC_SSR, RTC_TR and RTC_DR registers.

After waking up from low-power mode (Stop or Standby), RSF must be cleared by software. The software must then wait until it is set again before reading the RTC_SSR, RTC_TR and RTC_DR registers.

The RSF bit must be cleared after wake-up and not before entering low-power mode.

After a system reset, the software must wait until RSF is set before reading the RTC_SSR, RTC_TR and RTC_DR registers. Indeed, a system reset resets the shadow registers to their default values.

After an initialization (refer to *Calendar initialization and configuration on page 2489*): the software must wait until RSF is set before reading the RTC_SSR, RTC_TR and RTC_DR registers.

After synchronization (refer to *Section 57.3.14: RTC synchronization*): the software must wait until RSF is set before reading the RTC_SSR, RTC_TR and RTC_DR registers.

When the BYPSHAD control bit is set in the RTC_CR register (bypass shadow registers)

Reading the calendar registers gives the values from the calendar counters directly, thus eliminating the need to wait for the RSF bit to be set. This is especially useful after exiting from low-power modes (Stop or Standby), since the shadow registers are not updated during these modes.

When the BYPSHAD bit is set to 1, the results of the different registers might not be coherent with each other if an RTCCLK edge occurs between two read accesses to the registers. Additionally, the value of one of the registers may be incorrect if an RTCCLK edge occurs during the read operation. The software must read all the registers twice, and then compare the two readings. If the values differ, repeat the process until matching results are obtained. Alternatively, the software can just compare the two results of the least-significant calendar register.

Note: While BYPSHAD = 1, instructions which read the calendar registers require one extra APB cycle to complete.

57.3.13 Resetting the RTC

The calendar shadow registers (RTC_SSR, RTC_TR and RTC_DR) and some bits of the RTC status register (RTC_ICSR) are reset to their default values by all available system reset sources.

On the contrary, the following registers are reset to their default values by a Backup domain reset and are not affected by a system reset: the RTC current calendar registers, the RTC control register (RTC_CR), the prescaler register (RTC_PRER), the RTC calibration register (RTC_CALR), the RTC shift register (RTC_SHIFTR), the RTC timestamp registers (RTC_TSSSR, RTC_TSTR and RTC_TSDR), the wake-up timer register (RTC_WUTR), the alarm A and alarm B registers (RTC_ALRMASSR/RTC_ALRMAR/RTC_ALRABINR and RTC_ALRMBSSR/RTC_ALRMBR/RTC_ALRBBINR).

In addition, when clocked by LSE, the RTC keeps on running under system reset if the reset source is different from the Backup domain reset one (refer to RCC for details about RTC clock sources not affected by system reset). When a Backup domain reset occurs, the RTC is stopped and all the RTC registers are set to their reset values.

57.3.14 RTC synchronization

The RTC can be synchronized to a remote clock with a high degree of precision. After reading the subsecond field (RTC_SSR or RTC_TSSSR), a calculation can be made of the precise offset between the times being maintained by the remote clock and the RTC. The RTC can then be adjusted to eliminate this offset by “shifting” its clock by a fraction of a second using RTC_SHIFTR.

The RTC can be finely adjusted using the RTC shift control register (RTC_SHIFTR). Writing to RTC_SHIFTR can shift (either delay or advance) the clock with a resolution of 1 ck_apre period.

The shift operation consists in adding the SUBFS[14:0] value to the synchronous prescaler counter SS[15:0]: this delays the clock.

If at the same time the ADD1S bit is set in BCD or mixed mode, this results in adding one second and at the same time subtracting a fraction of second, so this advances the clock. ADD1S has no effect in binary mode.

As soon as a shift operation is initiated by a write to the RTC_SHIFTR register, the SHPF flag is set by hardware to indicate that a shift operation is pending. This bit is cleared by hardware as soon as the shift operation has completed.

Caution: In mixed mode (BIN=10 or 11), the SUBFS[14:BCDU+8] must be written with 0.

Caution: Before initiating a shift operation in BCD mode, the user must check that SS[15] = 0 in order to ensure that no overflow occurs. In mixed mode, the user must check that the bit SS[BCDU+8] = 0.

Caution: This synchronization feature is not compatible with the reference clock detection feature: firmware must not write to RTC_SHIFTR when REFCKON = 1.

57.3.15 RTC reference clock detection

This feature is available only in BCD mode (BIN=00).

The update of the RTC calendar can be synchronized to a reference clock, RTC_REFIN, which is usually the mains frequency (50 or 60 Hz). The precision of the RTC_REFIN reference clock should be higher than the 32.768 kHz LSE clock. When the RTC_REFIN detection is enabled (REFCKON bit of RTC_CR set to 1), the calendar is still clocked by the LSE, and RTC_REFIN is used to compensate for the imprecision of the calendar update frequency (1 Hz).

Each 1 Hz clock edge is compared to the nearest RTC_REFIN clock edge (if one is found within a given time window). In most cases, the two clock edges are properly aligned. When the 1 Hz clock becomes misaligned due to the imprecision of the LSE clock, the RTC shifts the 1 Hz clock a bit so that future 1 Hz clock edges are aligned. Thanks to this mechanism, the calendar becomes as precise as the reference clock.

The RTC detects if the reference clock source is present by using the 256 Hz clock (ck_apre) generated from the 32.768 kHz quartz. The detection is performed during a time window around each of the calendar updates (every 1 s). The window equals 7 ck_apre periods when detecting the first reference clock edge. A smaller window of 3 ck_apre periods is used for subsequent calendar updates.

Each time the reference clock is detected in the window, the asynchronous prescaler which outputs the ck_spre clock is forced to reload. This has no effect when the reference clock and the 1 Hz clock are aligned because the prescaler is being reloaded at the same moment. When the clocks are not aligned, the reload shifts future 1 Hz clock edges a little for them to be aligned with the reference clock.

If the reference clock halts (no reference clock edge occurred during the 3 ck_apre window), the calendar is updated continuously based solely on the LSE clock. The RTC then waits for the reference clock using a large 7 ck_apre period detection window centered on the ck_spre edge.

When the RTC_REFIN detection is enabled, PREDIV_A and PREDIV_S must be set to their default values:

- PREDIV_A = 0x007F
- PREVID_S = 0x00FF

Note: RTC_REFIN clock detection is not available in Standby mode.

57.3.16 RTC smooth digital calibration

The RTC frequency can be digitally calibrated with a resolution of about 0.954 ppm with a range from -487.1 ppm to +488.5 ppm. The correction of the frequency is performed using series of small adjustments (adding and/or subtracting individual ck_cal pulses).

If LPCAL=0: ck_cal = RTCCLK

If LPCAL=1: ck_cal = ck_apre

These adjustments are fairly well distributed so that the RTC is well calibrated even when observed over short durations of time.

RTC ultra-low-power mode

The RTC consumption can be reduced by setting the LPCAL bit in the RTC calibration register (RTC_CALR). In this case, the calibration mechanism is applied on ck_apre instead of RTCCLK. The resulting accuracy is the same, but the calibration is performed during a calibration cycle of about 2^{20} x PREDIV_A x RTCCLK pulses instead of 2^{20} RTCCLK pulses when LPCAL=0.

Smooth calibration mechanism

The smooth calibration register (RTC_CALR) specifies the number of ck_cal clock cycles to be masked during the calibration cycle:

- Setting the bit CALM[0] to 1 causes exactly one pulse to be masked during the calibration cycle.
- Setting CALM[1] to 1 causes two additional cycles to be masked
- Setting CALM[2] to 1 causes four additional cycles to be masked
- and so on up to CALM[8] set to 1 which causes 256 clocks to be masked.

Note: CALM[8:0] (RTC_CALR) specifies the number of ck_cal pulses to be masked during the calibration cycle. Setting the bit CALM[0] to 1 causes exactly one pulse to be masked during the calibration cycle at the moment when cal_cnt[19:0] is 0x80000; CALM[1] = 1 causes two other cycles to be masked (when cal_cnt is 0x40000 and 0xC0000); CALM[2] = 1 causes four other cycles to be masked (cal_cnt = 0x20000/0x60000/0xA0000/ 0xE0000); and so on up to CALM[8] = 1 which causes 256 clocks to be masked (cal_cnt = 0xXX800).

While CALM permits the RTC frequency to be reduced by up to 487.1 ppm with fine resolution, the bit CALP can be used to increase the frequency by 488.5 ppm. Setting CALP to 1 effectively inserts an extra ck_cal pulse every 2^{11} ck_cal cycles, which means that 512 clocks are added during every calibration cycle.

Using CALM together with CALP, an offset ranging from -511 to +512 ck_cal cycles can be added during the calibration cycle, which translates to a calibration range of -487.1 ppm to +488.5 ppm with a resolution of about 0.954 ppm.

The formula to calculate the effective calibrated frequency (F_{CAL}) given the input frequency (F_{RTCCLK}) is as follows:

$$F_{CAL} = F_{RTCCLK} \times [1 + (CALP \times 512 - CALM) / (2^{20} + CALM - CALP \times 512)]$$

Caution: PREDIV_A must be greater or equal to 3.

Calibration when PREDIV_A < 3

The CALP bit can not be set to 1 when the asynchronous prescaler value (PREDIV_A bits in RTC_PRER register) is less than 3. If CALP was already set to 1 and PREDIV_A bits are set to a value less than 3, CALP is ignored and the calibration operates as if CALP was equal to 0.

It is however possible to perform a calibration with PREDIV_A less than 3 in BCD mode, the synchronous prescaler value (PREDIV_S) should be reduced so that each second is accelerated by 8 ck_cal clock cycles, which is equivalent to adding 256 clock cycles every calibration cycle. As a result, between 255 and 256 clock pulses (corresponding to a calibration range from 243.3 to 244.1 ppm) can effectively be added during each calibration cycle using only the CALM bits.

With a nominal RTCCLK frequency of 32768 Hz, when PREDIV_A equals 1 (division factor of 2), PREDIV_S should be set to 16379 rather than 16383 (4 less). The only other interesting case is when PREDIV_A equals 0, PREDIV_S should be set to 32759 rather than 32767 (8 less).

If PREDIV_S is reduced in this way, the formula given the effective frequency of the calibrated input clock is as follows:

$$F_{CAL} = F_{RTCCLK} \times [1 + (256 - CALM) / (2^{20} + CALM - 256)]$$

In this case, CALM[7:0] equals 0x100 (the midpoint of the CALM range) is the correct setting if RTCCLK is exactly 32768.00 Hz.

Verifying the RTC calibration

It is recommended to verify the RTC calibration with LPCAL = 0, in order to have a 32-second calibration cycle.

RTC precision is ensured by measuring the precise frequency of RTCCLK and calculating the correct CALM value and CALP values. An optional 1 Hz output is provided to allow applications to measure and verify the RTC precision.

Measuring the precise frequency of the RTC over a limited interval can result in a measurement error of up to 2 RTCCLK clock cycles over the measurement period, depending on how the digital calibration cycle is aligned with the measurement period.

However, this measurement error can be eliminated if the measurement period is the same length as the calibration cycle period. In this case, the only error observed is the error due to the resolution of the digital calibration.

- By default, the calibration cycle period is 32 seconds.

  Using this mode and measuring the accuracy of the 1 Hz output over exactly 32 seconds guarantees that the measure is within 0.477 ppm (0.5 RTCCLK cycles over 32 seconds, due to the limitation of the calibration resolution).
- CALW16 bit of the RTC_CALR register can be set to 1 to force a 16- second calibration cycle period.

  In this case, the RTC precision can be measured during 16 seconds with a maximum error of 0.954 ppm (0.5 RTCCLK cycles over 16 seconds). However, since the calibration resolution is reduced, the long term RTC precision is also reduced to 0.954 ppm: CALM[0] bit is stuck at 0 when CALW16 is set to 1.
- CALW8 bit of the RTC_CALR register can be set to 1 to force a 8-second calibration cycle period.

  In this case, the RTC precision can be measured during 8 seconds with a maximum error of 1.907 ppm (0.5 RTCCLK cycles over 8 s). The long term RTC precision is also reduced to 1.907 ppm: CALM[1:0] bits are stuck at 00 when CALW8 is set to 1.

Re-calibration on-the-fly

The calibration register (RTC_CALR) can be updated on-the-fly while RTC_ICSR/INITF = 0, by using the follow process:

1. Poll the RTC_ICSR/RECALPF (re-calibration pending flag).
2. If it is set to 0, write a new value to RTC_CALR, if necessary. RECALPF is then automatically set to 1
3. Within three ck_apre cycles after the write operation to RTC_CALR, the new calibration settings take effect.

57.3.17 Timestamp function

Timestamp is enabled by setting the TSE or ITSE bits of RTC_CR register to 1.

When TSE is set:

The calendar is saved in the timestamp registers (RTC_TSSSR, RTC_TSTR, RTC_TSDR) when a timestamp event is detected on the RTC_TS pin.

When TAMPTS is set:

The calendar is saved in the timestamp registers (RTC_TSSSR, RTC_TSTR, RTC_TSDR) when an internal or external tamper event is detected. Refer to *RTC control register (RTC_CR)* and refer to *Section : Timestamp on tamper event*.

When ITSE is set:

The calendar is saved in the timestamp registers (RTC_TSSSR, RTC_TSTR, RTC_TSDR) when an internal timestamp event is detected. The internal timestamp event is generated by the switch to the V_{BAT} supply.

When a timestamp event occurs, due to internal or external event, the timestamp flag bit (TSF) in RTC_SR register is set. In case the event is internal, the ITSF flag is also set in RTC_SR register.

By setting the TSIE bit in the RTC_CR register, an interrupt is generated when a timestamp event occurs.

If a new timestamp event is detected while the timestamp flag (TSF) is already set, the timestamp overflow flag (TSOVF) flag is set and the timestamp registers (RTC_TSTR and RTC_TSDR) maintain the results of the previous event.

Note: TSF is set up to 2 ck_apre cycles after the timestamp event from RTC_TS pin or from rtc_its internal signal occurs, due to synchronization process. TSF is set up to 3 ck_apre cycles after tamper flags.

TSOVF is set up to only 1 ck_apre cycle after the event occurs. This means that if two timestamp events are close together, TSOVF can be seen as '1' while TSF is still '0'. As a consequence, it is recommended to poll TSOVF only after TSF has been set.

Caution: If a timestamp event occurs immediately after the TSF bit is supposed to be cleared, then both TSF and TSOVF bits are set. To avoid masking a timestamp event occurring at the same moment, the application must not write 0 into TSF bit unless it has already read it to 1.

57.3.18 Calibration clock output

When the COE bit is set to 1 in the RTC_CR register, a reference clock is provided on the CALIB device output.

If the COSEL bit in the RTC_CR register is reset and PREDIV_A = 0x7F, the CALIB frequency is $f_{RTCCLK/64}$. This corresponds to a calibration output at 512 Hz for an RTCCLK frequency at 32.768 kHz. The CALIB duty cycle is irregular: there is a light jitter on falling edges. It is therefore recommended to use rising edges.

When COSEL is set and “PREDIV_S+1” is a non-zero multiple of 256 (i.e: PREDIV_S[7:0] = 0xFF), the CALIB frequency is fRTCCLK/(256 * (PREDIV_A+1)). This corresponds to a calibration output at 1 Hz for prescaler default values (PREDIV_A = Ox7F, PREDIV_S = 0xFF), with an RTCCLK frequency at 32.768 kHz.

Note: When COSEL is cleared, the CALIB output is the output of the 6th stage of the asynchronous prescaler. If LPCAL is changed from 0 to 1, the output can be irregular (glitch...) during the LPCAL switch. If LPCAL = 1 this output is always available. If LPCAL = 0, no output is present if PREDIV_A is < 0x20.

When COSEL is set, the CALIB output is the output of the 8th stage of the synchronous prescaler.

57.3.19 Tamper and alarm output

The OSEL[1:0] control bits in the RTC_CR register are used to activate the alarm output TAMPALRM, and to select the function which is output. These functions reflect the contents of the corresponding flags in the RTC_SR register.

When the TAMPOE control bit is set in the RTC_CR, all external and internal tamper flags are ORed and routed to the TAMPALRM output. If OSEL = 00 the TAMPALRM output reflects only the tampers flags. If OSEL ≠ 00, the signal on TAMPALRM provides both tamper flags and alarm A, B, or wake-up flag.

The polarity of the TAMPALRM output is determined by the POL control bit in RTC_CR so that the opposite of the selected flags bit is output when POL is set to 1.

TAMPALRM output

The TAMPALRM pin can be configured in output open drain or output push-pull using the control bit TAMPALRM_TYPE in the RTC_CR register. It is possible to apply the internal pull-up in output mode thanks to TAMPALRM_PU in the RTC_CR.

Note: Once the TAMPALRM *output is enabled, it has priority over CALIB on RTC_OUT1.*

57.4 RTC low-power modes

Table 620. Effect of low-power modes on RTC

Mode	Description
Sleep	No effect RTC interrupts cause the device to exit the Sleep mode.
Stop	The RTC remains active when the RTC clock source is LSE or LSI. RTC interrupts cause the device to exit the Stop mode.
Standby	The RTC remains active when the RTC clock source is LSE or LSI. RTC interrupts cause the device to exit the Standby mode.

The table below summarizes the RTC pins and functions capability in all modes.

Table 621. RTC pins functionality over modes

Functions	Functional in all low-power modes except Standby mode	Functional in Standby mode	Functional in V_{BAT} mode
RTC_TS	Yes	Yes	Yes
RTC_REFIN	Yes	No	No
RTC_OUT1	Yes	Yes	Yes
RTC_OUT2	Yes	Yes	Yes

57.5 RTC interrupts

The interrupt channel is set in the masked interrupt status register or in the secure masked interrupt status register depending on its security mode configuration. The nonsecure interrupt output or the secure interrupt output is also activated.

Table 622. Nonsecure interrupt requests

Interrupt acronym	Interrupt event	Event flag(1)	Enable control bit(2)	Interrupt clear method	Exit from low-power modes
RTC	Alarm A	ALRAF	ALRAIE and (ALRASEC=0 and SEC=0)	write 1 in CALRAF	Yes(3)
	Alarm B	ALRBF	ALRBIE and (ALRBSEC=0 and SEC=0)	write 1 in CALRBF	Yes(3)
	Timestamp	TSF	TSIE and (TSSEC=0 and SEC=0)	write 1 in CTSF	Yes(3)
	Wake-up timer	WUTF	WUTIE and (WUTSEC=0 and SEC=0)	write 1 in CWUTF	Yes(3)
	SSR underflow (reload)	SSRUF	SSRUIE and (ALRASEC=0 and SEC=0)	write 1 in CSSRUF	Yes(3)

1. The event flags are in the RTC_SR register.
2. The interrupt masked flags (resulting from event flags AND enable control bits) are in the RTC_MISR register.
3. When the RTC is clocked by an oscillator functional in the low-power mode.

Table 623. Secure interrupt requests

Interrupt acronym	Interrupt event	Event flag(1)	Enable control bit(2)	Interrupt clear method	Exit from low-power modes
RTC_S	Alarm A	ALRAF	ALRAIE and (ALRASEC=1 or SEC=1)	write 1 in CALRAF	Yes(3)
	Alarm B	ALRBF	ALRBIE and (ALRBSEC=1 or SEC=1)	write 1 in CALRBF	Yes(3)
	Timestamp	TSF	TSIE and (TSSEC=1 or SEC=1)	write 1 in CTSF	Yes(3)
	Wake-up timer	WUTF	WUTIE and (WUTSEC=1 or SEC=1)	write 1 in CWUTF	Yes(3)
	SSR underflow (reload)	SSRUF	SSRUIE and (ALRASEC=1 or SEC=1)	write 1 in CSSRUF	Yes(3)

1. The event flags are in the RTC_SR register.
2. The interrupt masked flags (resulting from event flags AND enable control bits) are in the RTC_SMISR register.
3. When the RTC is clocked by an oscillator functional in the low-power mode.

57.6 RTC registers

Refer to *Section 1.2* of the reference manual for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by words (32-bit).

57.6.1 RTC time register (RTC_TR)

The RTC_TR is the calendar time shadow register. This register must be written in initialization mode only. Refer to *Calendar initialization and configuration on page 2489* and *Reading the calendar on page 2491*.

This register is write protected. The write access procedure is described in *RTC register write protection on page 2488*.

This register can be write-protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be write-protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x00

Backup domain reset value: 0x0000 0000

System reset value: 0x0000 0000 (when BYPSHAD = 0, not affected when BYPSHAD = 1)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PM	HT[1:0]		HU[3:0]			
									rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	MNT[2:0]			MNU[3:0]				Res.	ST[2:0]			SU[3:0]			
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **PM**: AM/PM notation
0: AM or 24-hour format
1: PM

Bits 21:20 **HT[1:0]**: Hour tens in BCD format

Bits 19:16 **HU[3:0]**: Hour units in BCD format

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **MNT[2:0]**: Minute tens in BCD format

Bits 11:8 **MNU[3:0]**: Minute units in BCD format

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **ST[2:0]**: Second tens in BCD format

Bits 3:0 **SU[3:0]**: Second units in BCD format

57.6.2 RTC date register (RTC_DR)

The RTC_DR is the calendar date shadow register. This register must be written in initialization mode only. Refer to *Calendar initialization and configuration on page 2489* and *Reading the calendar on page 2491*.

This register is write protected. The write access procedure is described in *RTC register write protection on page 2488*.

This register can be write-protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be write-protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x04

Backup domain reset value: 0x0000 2101

System reset value: 0x0000 2101 (when BYPSHAD = 0, not affected when BYPSHAD = 1)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	YT[3:0]				YU[3:0]			
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WDU[2:0]			MT	MU[3:0]				Res.	Res.	DT[1:0]		DU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:20 **YT[3:0]**: Year tens in BCD format

Bits 19:16 **YU[3:0]**: Year units in BCD format

Bits 15:13 **WDU[2:0]**: Week day units
000: forbidden
001: Monday
...
111: Sunday

Bit 12 **MT**: Month tens in BCD format

Bits 11:8 **MU[3:0]**: Month units in BCD format

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **DT[1:0]**: Date tens in BCD format

Bits 3:0 **DU[3:0]**: Date units in BCD format

Note: The calendar is frozen when reaching the maximum value, and can't roll over.

57.6.3 RTC subsecond register (RTC_SSR)

Address offset: 0x08

Backup domain reset value: 0x0000 0000

System reset value: 0x0000 0000 (when BYPSHAD = 0, not affected when BYPSHAD = 1)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SS[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **SS[31:0]**: Synchronous binary counter

SS[31:16]: Synchronous binary counter MSB values

When Binary or Mixed mode is selected (BIN = 01 or 10 or 11):

SS[31:16] are the 16 MSB of the SS[31:0] free-running down-counter.

When BCD mode is selected (BIN=00):

SS[31:16] are forced by hardware to 0x0000.

SS[15:0]: Subsecond value/synchronous binary counter LSB values

When Binary mode is selected (BIN = 01 or 10 or 11):

SS[15:0] are the 16 LSB of the SS[31:0] free-running down-counter.

When BCD mode is selected (BIN=00):

SS[15:0] is the value in the synchronous prescaler counter. The fraction of a second is given by the formula below:

Second fraction = (PREDIV_S - SS) / (PREDIV_S + 1)

SS can be larger than PREDIV_S only after a shift operation. In that case, the correct time/date is one second less than as indicated by RTC_TR/RTC_DR.

57.6.4 RTC initialization control and status register (RTC_ICSR)

This register is write protected. The write access procedure is described in *RTC register write protection on page 2488*.

This register can be globally protected, or each bit of this register can be individually protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be globally protected, or each bit of this register can be individually protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x0C

Backup domain reset value: 0x0000 0007

System reset: not affected except INIT, INITF, and RSF bits which are cleared to 0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RECALPF
															r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	BCDU[2:0]			BIN[1:0]		INIT	INITF	RSF	INITS	SHPF	WUTWF	Res.	Res.
			rw	rw	rw	rw	rw	rw	r	rc_w0	r	r	r		

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **RECALPF**: Recalibration pending Flag

The RECALPF status flag is automatically set to 1 when software writes to the RTC_CALR register, indicating that the RTC_CALR register is blocked. When the new calibration settings are taken into account, this bit returns to 0. Refer to *Re-calibration on-the-fly*.

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:10 **BCDU[2:0]**: BCD update (BIN = 10 or 11)

In mixed mode when both BCD calendar and binary extended counter are used (BIN = 10 or 11), the calendar second is incremented using the SSR Least Significant Bits.

0x0: 1s calendar increment is generated each time SS[7:0] = 0
0x1: 1s calendar increment is generated each time SS[8:0] = 0
0x2: 1s calendar increment is generated each time SS[9:0] = 0
0x3: 1s calendar increment is generated each time SS[10:0] = 0
0x4: 1s calendar increment is generated each time SS[11:0] = 0
0x5: 1s calendar increment is generated each time SS[12:0] = 0
0x6: 1s calendar increment is generated each time SS[13:0] = 0
0x7: 1s calendar increment is generated each time SS[14:0] = 0

Bits 9:8 **BIN[1:0]**: Binary mode

00: Free running BCD calendar mode (Binary mode disabled).
01: Free running Binary mode (BCD mode disabled)
10: Free running BCD calendar and Binary modes
11: Free running BCD calendar and Binary modes

Bit 7 **INIT**: Initialization mode

0: Free running mode

1: Initialization mode used to program time and date register (RTC_TR and RTC_DR), and prescaler register (RTC_PRER), plus BIN and BCDU fields. Counters are stopped and start counting from the new value when INIT is reset.

Bit 6 **INITF**: Initialization flag

When this bit is set to 1, the RTC is in initialization state, and the time, date and prescaler registers can be updated.

0: Calendar registers update is not allowed

1: Calendar registers update is allowed

Bit 5 **RSF**: Registers synchronization flag

This bit is set by hardware each time the calendar registers are copied into the shadow registers (RTC_SSR, RTC_TR and RTC_DR). This bit is cleared by hardware in initialization mode, while a shift operation is pending (SHPF = 1), or when in bypass shadow register mode (BYPSHAD = 1). This bit can also be cleared by software.

It is cleared either by software or by hardware in initialization mode.

0: Calendar shadow registers not yet synchronized

1: Calendar shadow registers synchronized

Note: RSF is not set when the frequency of the APB clock is less than twice the frequency of RTCCLK.

Bit 4 **INITS**: Initialization status flag

This bit is set by hardware when the calendar year field is different from 0 (Backup domain reset state).

0: Calendar has not been initialized

1: Calendar has been initialized

Bit 3 **SHPF**: Shift operation pending

This flag is set by hardware as soon as a shift operation is initiated by a write to the RTC_SHIFTR register. It is cleared by hardware when the corresponding shift operation has been executed. Writing to the SHPF bit has no effect.

0: No shift operation is pending

1: A shift operation is pending

Bit 2 **WUTWF**: Wake-up timer write flag

This bit is set by hardware when WUT value can be changed, after the WUTE bit has been set to 0 in RTC_CR.

0: Wake-up timer configuration update not allowed

1: Wake-up timer configuration update allowed

Bits 1:0 Reserved, must be kept at reset value.

57.6.5 RTC prescaler register (RTC_PRER)

This register must be written in initialization mode only. The initialization must be performed in two separate write accesses. Refer to *Calendar initialization and configuration on page 2489*.

This register is write protected. The write access procedure is described in *RTC register write protection on page 2488*.

This register can be write-protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be write-protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x10

Backup domain reset value: 0x007F 00FF

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREDIV_A[6:0]						
									rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	PREDIV_S[14:0]														
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:16 **PREDIV_A[6:0]**: Asynchronous prescaler factor

This is the asynchronous division factor:
ck_apre frequency = RTCCLK frequency/(PREDIV_A+1)

Bit 15 Reserved, must be kept at reset value.

Bits 14:0 **PREDIV_S[14:0]**: Synchronous prescaler factor

This is the synchronous division factor:
ck_spre frequency = ck_apre frequency/(PREDIV_S+1)

57.6.6 RTC wake-up timer register (RTC_WUTR)

This register can be written only when WUTWF is set to 1 in RTC_ICSR.

This register can be protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x14

Backup domain reset value: 0x0000 FFFF

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WUTOCLR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WUT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **WUTOCLR[15:0]**: Wake-up auto-reload output clear value

When WUTOCLR[15:0] is different from 0x0000, WUTF is set by hardware when the auto-reload down-counter reaches 0 and is cleared by hardware when the auto-reload downcounter reaches WUTOCLR[15:0].

When WUTOCLR[15:0] = 0x0000, WUTF is set by hardware when the WUT down-counter reaches 0 and is cleared by software.

Bits 15:0 **WUT[15:0]**: Wake-up auto-reload value bits

When the wake-up timer is enabled (WUTE set to 1), the WUTF flag is set every (WUT[15:0] + 1) ck_wut cycles. The ck_wut period is selected through WUCKSEL[2:0] bits of the RTC_CR register.

When WUCKSEL[2] = 1, the wake-up timer becomes 17-bits and WUCKSEL[1] effectively becomes WUT[16] the most-significant bit to be reloaded into the timer.

The first assertion of WUTF occurs between WUT and (WUT + 2) ck_wut cycles after WUTE is set. Setting WUT[15:0] to 0x0000 with WUCKSEL[2:0] = 011 (RTCCLK/2) is forbidden.

57.6.7 RTC control register (RTC_CR)

This register is write protected. The write access procedure is described in RTC register write protection on page 2488.

This register can be globally protected, or each bit of this register can be individually protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be globally protected, or each bit of this register can be individually protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x18

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OUT2EN	TAMPALRM_TYPE	TAMPALRM_PU	ALRBFCLR	ALRAFCLR	TAMPOE	TAMPTS	ITSE	COE	OSEL[1:0]		POL	COSEL	BKP	SUB1H	ADD1H
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSIE	WUTIE	ALRBIE	ALRAIE	TSE	WUTE	ALRBE	ALRAE	SSRUIE	FMT	BYPSHAD	REFCKON	TSEDGE	WUCKSEL[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **OUT2EN**: RTC_OUT2 output enable

With this bit set, the RTC outputs can be remapped on RTC_OUT2 as follows:
OUT2EN = 0: RTC output 2 disable
If OSEL ≠ 00 or TAMPOE = 1: TAMPALRM is output on RTC_OUT1
If OSEL = 00 and TAMPOE = 0 and COE = 1: CALIB is output on RTC_OUT1
OUT2EN = 1: RTC output 2 enable
If (OSEL ≠ 00 or TAMPOE = 1) and COE = 0: TAMPALRM is output on RTC_OUT2
If OSEL = 00 and TAMPOE = 0 and COE = 1: CALIB is output on RTC_OUT2
If (OSEL ≠ 00 or TAMPOE = 1) and COE = 1: CALIB is output on RTC_OUT2 and TAMPALRM is output on RTC_OUT1.

Bit 30 **TAMPALRM_TYPE**: TAMPALRM output type

0: TAMPALRM is push-pull output
1: TAMPALRM is open-drain output

Bit 29 **TAMPALRM_PU**: TAMPALRM pull-up enable

0: No pull-up is applied on TAMPALRM output
1: A pull-up is applied on TAMPALRM output

Bit 28 **ALRBFCLR**: Alarm B flag automatic clear

0: Alarm B event generates a trigger event and ALRBF must be cleared by software to allow next alarm event.
1: Alarm B event generates a trigger event. ALRBF is automatically cleared by hardware after 1 ck_apre cycle.

Bit 27 **ALRAFCLR**: Alarm A flag automatic clear

0: Alarm A event generates a trigger event and ALRAF must be cleared by software to allow next alarm event.
1: Alarm A event generates a trigger event. ALRAF is automatically cleared by hardware after 1 ck_apre cycle.

Bit 26 **TAMPOE**: Tamper detection output enable on TAMPALRM
0: The tamper flag is not routed on TAMPALRM
1: The tamper flag is routed on TAMPALRM, combined with the signal provided by OSEL and with the polarity provided by POL.

Bit 25 **TAMPTS**: Activate timestamp on tamper detection event
0: Tamper detection event does not cause a RTC timestamp to be saved
1: Save RTC timestamp on tamper detection event
TAMPTS is valid even if TSE = 0 in the RTC_CR register. Timestamp flag is set up to 3 ck_apre cycles after the tamper flags.
Note: TAMPTS must be cleared before entering RTC initialization mode.

Bit 24 **ITSE**: timestamp on internal event enable
0: internal event timestamp disabled
1: internal event timestamp enabled

Bit 23 **COE**: Calibration output enable
This bit enables the CALIB output
0: Calibration output disabled
1: Calibration output enabled

Bits 22:21 **OSEL[1:0]**: Output selection
These bits are used to select the flag to be routed to TAMPALRM output.
00: Output disabled
01: Alarm A output enabled
10: Alarm B output enabled
11: Wake-up output enabled

Bit 20 **POL**: Output polarity
This bit is used to configure the polarity of TAMPALRM output.
0: The pin is high when ALRAF/ALRBF/WUTF is asserted (depending on OSEL[1:0]), or when a TAMPxF/ITAMPxF is asserted (if TAMPOE = 1).
1: The pin is low when ALRAF/ALRBF/WUTF is asserted (depending on OSEL[1:0]), or when a TAMPxF/ITAMPxF is asserted (if TAMPOE = 1).

Bit 19 **COSEL**: Calibration output selection
When COE = 1, this bit selects which signal is output on CALIB.
0: Calibration output is 512 Hz
1: Calibration output is 1 Hz
These frequencies are valid for RTCCLK at 32.768 kHz and prescalers at their default values (PREDIV_A = 127 and PREDIV_S = 255). Refer to *Section 57.3.18: Calibration clock output*.

Bit 18 **BKP**: Backup
This bit can be written by the user to memorize whether the daylight saving time change has been performed or not.

Bit 17 **SUB1H**: *S*ubtract 1 hour (winter time change)
When this bit is set outside initialization mode, 1 hour is subtracted to the calendar time if the current hour is not 0. This bit is always read as 0.
Setting this bit has no effect when current hour is 0.
0: No effect
1: Subtracts 1 hour to the current time. This can be used for winter time change.

Bit 16 **ADD1H**: Add 1 hour (summer time change)
When this bit is set outside initialization mode, 1 hour is added to the calendar time. This bit is always read as 0.
0: No effect
1: Adds 1 hour to the current time. This can be used for summer time change
Note: ADD1H is ignored when SUB1H is set.

Bit 15 **TSIE**: Timestamp interrupt enable
0: Timestamp interrupt disable
1: Timestamp interrupt enable

Bit 14 **WUTIE**: Wake-up timer interrupt enable
0: Wake-up timer interrupt disabled
1: Wake-up timer interrupt enabled

Bit 13 **ALRBIE**: Alarm B interrupt enable
0: Alarm B interrupt disable
1: Alarm B interrupt enable

Bit 12 **ALRAIE**: Alarm A interrupt enable
0: Alarm A interrupt disabled
1: Alarm A interrupt enabled

Bit 11 **TSE**: timestamp enable
0: timestamp disable
1: timestamp enable

Bit 10 **WUTE**: Wake-up timer enable
0: Wake-up timer disabled
1: Wake-up timer enabled
Note: When the wake-up timer is disabled, wait for WUTWF = 1 before enabling it again.

Bit 9 **ALRBE**: Alarm B enable
0: Alarm B disabled
1: Alarm B enabled

Bit 8 **ALRAE**: Alarm A enable
0: Alarm A disabled
1: Alarm A enabled

Bit 7 **SSRUIE**: SSR underflow interrupt enable
0: SSR underflow interrupt disabled
1: SSR underflow interrupt enabled

Bit 6 **FMT**: Hour format
0: 24 hour/day format
1: AM/PM hour format

Bit 5 **BYPSHAD**: Bypass the shadow registers
0: Calendar values (when reading from RTC_SSR, RTC_TR, and RTC_DR) are taken from the shadow registers, which are updated once every two RTCCLK cycles.
1: Calendar values (when reading from RTC_SSR, RTC_TR, and RTC_DR) are taken directly from the calendar counters.
Note: If the frequency of the APB clock is less than seven times the frequency of RTCCLK, BYPSHAD must be set to 1.

Bit 4 **REFCKON**: RTC_REFIN reference clock detection enable (50 or 60 Hz)
0: RTC_REFIN detection disabled
1: RTC_REFIN detection enabled
Note: BIN must be 0x00 and PREDIV_S must be 0x00FF.

Bit 3 **TSEDGE**: Timestamp event active edge
0: RTC_TS input rising edge generates a timestamp event
1: RTC_TS input falling edge generates a timestamp event
TSE must be reset when TSEDGE is changed to avoid unwanted TSF setting.

Bits 2:0 **WUCKSEL[2:0]**: ck_wut wake-up clock selection
000: RTC/16 clock is selected
001: RTC/8 clock is selected
010: RTC/4 clock is selected
011: RTC/2 clock is selected
10x: ck_spre (usually 1 Hz) clock is selected in BCD mode. In binary or mixed mode, this is the clock selected by BCDU.
11x: ck_spre (usually 1 Hz) clock is selected in BCD mode. In binary or mixed mode, this is the clock selected by BCDU. Furthermore, 2^{16} is added to the WUT counter value.

Note: Bits 6 and 4 of this register can be written in initialization mode only (RTC_ICSR/INITF = 1).

WUT = wake-up unit counter value. WUT = (0x0000 to 0xFFFF) + 0x10000 added when WUCKSEL[2:1 = 11].

Bits 2 to 0 of this register can be written only when RTC_CR WUTE bit = 0 and RTC_ICSR WUTWF bit = 1.

It is recommended not to change the hour during the calendar hour increment as it may mask the incrementation of the calendar hour.

ADD1H and SUB1H changes are effective in the next second.

57.6.8 RTC privilege mode control register (RTC_PRIVCFGR)

This register can be written only when the APB access is privileged. This register can be write-protected, or each bit of this register can be individually write-protected against nonsecure access depending on the RTC_SECCFGR configuration (refer to *Section 57.3.5: RTC privilege protection modes*).

Address offset: 0x1C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRIV	INIT PRIV	CAL PRIV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS PRIV	WUT PRIV	ALRB PRIV	ALRA PRIV
rw	rw	rw										rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **PRIV**: RTC privilege protection

0: All RTC registers can be written when the APB access is privileged or unprivileged, except the registers protected by other privilege protection bits.

1: All RTC registers can be written only when the APB access is privileged.

Bit 14 **INITPRIV**: Initialization privilege protection

0: RTC Initialization mode, calendar and prescalers registers can be written when the APB access is privileged or unprivileged.

1: RTC Initialization mode, calendar and prescalers registers can be written only when the APB access is privileged.

Bit 13 **CALPRIV**: Shift register, daylight saving, calibration and reference clock privilege protection

0: Shift register, daylight saving, calibration and reference clock can be written when the APB access is privileged or unprivileged.

1: Shift register, daylight saving, calibration and reference clock can be written only when the APB access is privileged.

Bits 12:4 Reserved, must be kept at reset value.

Bit 3 **TSPRIV**: Timestamp privilege protection

0: RTC Timestamp configuration and interrupt clear can be written when the APB access is privileged or unprivileged.

1: RTC Timestamp configuration and interrupt clear can be written only when the APB access is privileged.

Bit 2 **WUTPRIV**: Wake-up timer privilege protection

0: RTC wake-up timer configuration and interrupt clear can be written when the APB access is privileged or unprivileged.

1: RTC wake-up timer configuration and interrupt clear can be written only when the APB access is privileged.

Bit 1 **ALRBPRIV**: Alarm B privilege protection

0: RTC Alarm B configuration and interrupt clear can be written when the APB access is privileged or unprivileged.

1: RTC Alarm B configuration and interrupt clear can be written only when the APB access is privileged.

Bit 0 **ALRAPRIV**: Alarm A and SSR underflow privilege protection

0: RTC Alarm A and SSR underflow configuration and interrupt clear can be written when the APB access is privileged or unprivileged.

1: RTC Alarm A and SSR underflow configuration and interrupt clear can be written only when the APB access is privileged.

Note: Refer to Section 57.3.5: RTC privilege protection modes for details on the read protection.

57.6.9 RTC secure configuration register (RTC_SECCFGR)

This register can be written only when the APB access is secure.

This register can be globally write-protected, or each bit of this register can be individually write-protected against unprivileged access depending on the RTC_PRIVCFGR configuration (refer to *Section 57.3.5: RTC privilege protection modes*).

Address offset: 0x20

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEC	INIT SEC	CAL SEC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS SEC	WUT SEC	ALRB SEC	ALRA SEC
rw	rw	rw										rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **SEC**: RTC global protection

0: All RTC registers can be written when the APB access is secure or nonsecure, except the registers protected by other secure protection bits.

1: All RTC registers can be written only when the APB access is secure.

Bit 14 **INITSEC**: Initialization protection

0: RTC Initialization mode, calendar and prescalers registers can be written when the APB access is secure or nonsecure.

1: RTC Initialization mode, calendar and prescalers registers can be written only when the APB access is secure.

Bit 13 **CALSEC**: Shift register, daylight saving, calibration and reference clock protection

0: Shift register, daylight saving, calibration and reference clock can be written when the APB access is secure or nonsecure.

1: Shift register, daylight saving, calibration and reference clock can be written only when the APB access is secure.

Bits 12:4 Reserved, must be kept at reset value.

Bit 3 **TSSEC**: Timestamp protection

0: RTC timestamp configuration and interrupt clear can be written when the APB access is secure or nonsecure.

1: RTC timestamp configuration and interrupt clear can be written only when the APB access is secure.

Bit 2 **WUTSEC**: Wake-up timer protection

0: RTC wake-up timer configuration and interrupt clear can be written when the APB access is secure or nonsecure.

1: RTC wake-up timer configuration and interrupt clear can be written only when the APB access is secure.

Bit 1 **ALRBSEC**: Alarm B protection

0: RTC alarm B configuration and interrupt clear can be written when the APB access is secure or nonsecure.

1: RTC alarm B configuration and interrupt clear can be written only when the APB access is secure.

Bit 0 **ALRASEC**: Alarm A and SSR underflow protection

0: RTC alarm A and SSR underflow configuration and interrupt clear can be written when the APB access is secure or nonsecure.

1: RTC alarm A and SSR underflow configuration and interrupt clear can be written only when the APB access is secure.

Note: Refer to Section 57.3.4: RTC secure protection modes for details on the read protection.

57.6.10 RTC write protection register (RTC_WPR)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEY[7:0]							
								w	w	w	w	w	w	w	w

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **KEY[7:0]**: Write protection key

This byte is written by software.

Reading this byte always returns 0x00.

Refer to *RTC register write protection* for a description of how to unlock RTC register write protection.

57.6.11 RTC calibration register (RTC_CALR)

This register is write protected. The write access procedure is described in *RTC register write protection on page 2488*.

This register can be write-protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be write-protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x28

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CALP	CALW8	CALW 16	LPCAL	Res.	Res.	Res.	CALM[8:0]								
rw	rw	rw	rw				rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **CALP**: Increase frequency of RTC by 488.5 ppm
0: No RTCCLK pulses are added.
1: One RTCCLK pulse is effectively inserted every 2^{11} pulses (frequency increased by 488.5 ppm).
This feature is intended to be used in conjunction with CALM, which lowers the frequency of the calendar with a fine resolution. if the input frequency is 32768 Hz, the number of RTCCLK pulses added during a 32-second window is calculated as follows:
(512 × CALP) - CALM.
Refer to *Section 57.3.16: RTC smooth digital calibration*.

Bit 14 **CALW8**: Use an 8-second calibration cycle period
When CALW8 is set to 1, the 8-second calibration cycle period is selected.
Note: CALM[1:0] are stuck at 00 when CALW8 = 1. Refer to Section 57.3.16: RTC smooth digital calibration.

Bit 13 **CALW16**: Use a 16-second calibration cycle period
When CALW16 is set to 1, the 16-second calibration cycle period is selected. This bit must not be set to 1 if CALW8 = 1.
Note: CALM[0] is stuck at 0 when CALW16 = 1. Refer to Section 57.3.16: RTC smooth digital calibration.

Bit 12 **LPCAL**: RTC low-power mode

0: Calibration window is 2^{20} RTCCLK, which is a high-consumption mode. This mode must be set only when less than 32s calibration window is required.

1: Calibration window is 2^{20} ck_apre, which is the required configuration for ultra-low consumption mode.

Bits 11:9 Reserved, must be kept at reset value.

Bits 8:0 **CALM[8:0]**: Calibration minus

The frequency of the calendar is reduced by masking CALM out of 2^{20} RTCCLK pulses (32 seconds if the input frequency is 32768 Hz). This decreases the frequency of the calendar with a resolution of 0.9537 ppm.

To increase the frequency of the calendar, this feature should be used in conjunction with CALP. See *Section 57.3.16: RTC smooth digital calibration on page 2493*.

57.6.12 RTC shift control register (RTC_SHIFTR)

This register is write protected. The write access procedure is described in *RTC register write protection on page 2488*.

This register can be protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x2C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADD1S	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
w															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	SUBFS[14:0]														
	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bit 31 **ADD1S**: Add one second

0: No effect

1: Add one second to the clock/calendar

This bit is write only and is always read as zero. Writing to this bit has no effect when a shift operation is pending (when SHPF = 1, in RTC_ICSR).

This function is intended to be used with SUBFS (see description below) in order to effectively add a fraction of a second to the clock in an atomic operation.

Bits 30:15 Reserved, must be kept at reset value.

Bits 14:0 **SUBFS[14:0]**: Subtract a fraction of a second

These bits are write only and is always read as zero. Writing to this bit has no effect when a shift operation is pending (when SHPF = 1, in RTC_ICSR).

The value which is written to SUBFS is added to the synchronous prescaler counter. Since this counter counts down, this operation effectively subtracts from (delays) the clock by:

Delay (seconds) = SUBFS / (PREDIV_S + 1)

A fraction of a second can effectively be added to the clock (advancing the clock) when the ADD1S function is used in conjunction with SUBFS, effectively advancing the clock by:

Advance (seconds) = (1 - (SUBFS / (PREDIV_S + 1))).

In mixed BCD-binary mode (BIN=10 or 11), the SUBFS[14:BCDU+8] must be written with 0.

Note: Writing to SUBFS causes RSF to be cleared. Software can then wait until RSF = 1 to be sure that the shadow registers have been updated with the shifted time.

57.6.13 RTC timestamp time register (RTC_TSTR)

The content of this register is valid only when TSF is set to 1 in RTC_SR. It is cleared when TSF bit is reset.

This register can be protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x30

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PM	HT[1:0]		HU[3:0]			
									r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	MNT[2:0]			MNU[3:0]				Res.	ST[2:0]			SU[3:0]			
	r	r	r	r	r	r	r		r	r	r	r	r	r	r

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **PM**: AM/PM notation

0: AM or 24-hour format

1: PM

Bits 21:20 **HT[1:0]**: Hour tens in BCD format.

Bits 19:16 **HU[3:0]**: Hour units in BCD format.

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **MNT[2:0]**: Minute tens in BCD format.

Bits 11:8 **MNU[3:0]**: Minute units in BCD format.

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **ST[2:0]**: Second tens in BCD format.

Bits 3:0 **SU[3:0]**: Second units in BCD format.

57.6.14 RTC timestamp date register (RTC_TSDR)

The content of this register is valid only when TSF is set to 1 in RTC_SR. It is cleared when TSF bit is reset.

This register can be protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x34

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WDU[2:0]			MT	MU[3:0]				Res.	Res.	DT[1:0]		DU[3:0]			
r	r	r	r	r	r	r	r			r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:13 **WDU[2:0]**: Week day units

Bit 12 **MT**: Month tens in BCD format

Bits 11:8 **MU[3:0]**: Month units in BCD format

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **DT[1:0]**: Date tens in BCD format

Bits 3:0 **DU[3:0]**: Date units in BCD format

57.6.15 RTC timestamp subsecond register (RTC_TSSSR)

The content of this register is valid only when TSF is set to 1 in RTC_SR. It is cleared when the TSF bit is reset.

This register can be protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x38

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SS[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 SS[31:0]: Subsecond value/synchronous binary counter values

SS[31:0] is the value of the synchronous prescaler counter when the timestamp event occurred.

57.6.16 RTC alarm A register (RTC_ALRMAR)

This register can be written only when ALRAE is reset in RTC_CR register.

This register can be protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x40

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MSK4	WDSEL	DT[1:0]		DU[3:0]				MSK3	PM	HT[1:0]		HU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MSK2	MNT[2:0]			MNU[3:0]				MSK1	ST[2:0]			SU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **MSK4**: Alarm A date mask
0: Alarm A set if the date/day match
1: Date/day don’t care in alarm A comparison

Bit 30 **WDSEL**: Week day selection
0: DU[3:0] represents the date units
1: DU[3:0] represents the week day. DT[1:0] is don’t care.

Bits 29:28 **DT[1:0]**: Date tens in BCD format

Bits 27:24 **DU[3:0]**: Date units or day in BCD format

Bit 23 **MSK3**: Alarm A hours mask
0: Alarm A set if the hours match
1: Hours don’t care in alarm A comparison

Bit 22 **PM**: AM/PM notation
0: AM or 24-hour format
1: PM

Bits 21:20 **HT[1:0]**: Hour tens in BCD format

Bits 19:16 **HU[3:0]**: Hour units in BCD format

Bit 15 **MSK2**: Alarm A minutes mask
0: Alarm A set if the minutes match
1: Minutes don’t care in alarm A comparison

Bits 14:12 **MNT[2:0]**: Minute tens in BCD format

Bits 11:8 **MNU[3:0]**: Minute units in BCD format

Bit 7 **MSK1**: Alarm A seconds mask
0: Alarm A set if the seconds match
1: Seconds don’t care in alarm A comparison

Bits 6:4 **ST[2:0]**: Second tens in BCD format.

Bits 3:0 **SU[3:0]**: Second units in BCD format.

57.6.17 RTC alarm A subsecond register (RTC_ALRMASSR)

This register can be written only when ALRAE is reset in RTC_CR register.

This register can be protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x44

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SSCLR	Res.	MASKSS[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw		rw	rw	rw	rw	rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	SS[14:0]														
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw

Bit 31 **SSCLR**: Clear synchronous counter on alarm (Binary mode only)

0: The synchronous binary counter (SS[31:0] in RTC_SSR) is free-running.

1: The synchronous binary counter (SS[31:0] in RTC_SSR) is running from 0xFFFF FFFF to RTC_ALRABINR.SS[31:0] value and is automatically reloaded with 0xFFFF FFFF one ck_apre cycle after reaching RTC_ALRABINR.SS[31:0].

Note: SSCLR must be kept to 0 when BCD or mixed mode is used (BIN = 00, 10 or 11).

Bit 30 Reserved, must be kept at reset value.

Bits 29:24 **MASKSS[5:0]**: Mask the most-significant bits starting at this bit

0: No comparison on subseconds for Alarm A. The alarm is set when the seconds unit is incremented (assuming that the rest of the fields match).

1: SS[31:1] are don't care in Alarm A comparison. Only SS[0] is compared.

2: SS[31:2] are don't care in Alarm A comparison. Only SS[1:0] are compared.

...

31: SS[31] is don't care in Alarm A comparison. Only SS[30:0] are compared.

From 32 to 63: All 32 SS bits are compared and must match to activate alarm.

Note: In BCD mode (BIN=00) the overflow bits of the synchronous counter (bits 31:15) are never compared. These bits can be different from 0 only after a shift operation.

Bits 23:15 Reserved, must be kept at reset value.

Bits 14:0 **SS[14:0]**: Subseconds value

This value is compared with the contents of the synchronous prescaler counter to determine if alarm A is to be activated. Only bits 0 up MASKSS-1 are compared.

This field is the mirror of SS[14:0] in the RTC_ALRABINR, and so can also be read or written through RTC_ALRABINR.

57.6.18 RTC alarm B register (RTC_ALRMBR)

This register can be written only when ALRBE is reset in RTC_CR register.

This register can be protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x48

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MSK4	WD SEL	DT[1:0]		DU[3:0]				MSK3	PM	HT[1:0]		HU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MSK2	MNT[2:0]			MNU[3:0]				MSK1	ST[2:0]			SU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **MSK4**: Alarm B date mask
0: Alarm B set if the date and day match
1: Date and day don’t care in alarm B comparison

Bit 30 **WDSEL**: Week day selection
0: DU[3:0] represents the date units
1: DU[3:0] represents the week day. DT[1:0] is don’t care.

Bits 29:28 **DT[1:0]**: Date tens in BCD format

Bits 27:24 **DU[3:0]**: Date units or day in BCD format

Bit 23 **MSK3**: Alarm B hours mask
0: Alarm B set if the hours match
1: Hours don’t care in alarm B comparison

Bit 22 **PM**: AM/PM notation
0: AM or 24-hour format
1: PM

Bits 21:20 **HT[1:0]**: Hour tens in BCD format

Bits 19:16 **HU[3:0]**: Hour units in BCD format

Bit 15 **MSK2**: Alarm B minutes mask
0: Alarm B set if the minutes match
1: Minutes don’t care in alarm B comparison

Bits 14:12 **MNT[2:0]**: Minute tens in BCD format

Bits 11:8 **MNU[3:0]**: Minute units in BCD format

Bit 7 **MSK1**: Alarm B seconds mask
0: Alarm B set if the seconds match
1: Seconds don't care in alarm B comparison

Bits 6:4 **ST[2:0]**: Second tens in BCD format

Bits 3:0 **SU[3:0]**: Second units in BCD format

57.6.19 RTC alarm B subsecond register (RTC_ALRMBSSR)

This register can be written only when ALRBE is reset in RTC_CR register.

This register can be protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x4C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SSCLR	Res.	MASKSS[5:4]		MASKSS[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw		rw	rw	rw	rw	rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	SS[14:0]														
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw

Bit 31 **SSCLR**: Clear synchronous counter on alarm (Binary mode only)
0: The synchronous binary counter (SS[31:0] in RTC_SSR) is free-running.
1: The synchronous binary counter (SS[31:0] in RTC_SSR) is running from 0xFFFF FFFF to RTC_ALRBBINR.SS[31:0] value and is automatically reloaded with 0xFFFF FFFF one ck_apre cycle after reaching RTC_ALRBBINR.SS[31:0].
Note: SSCLR must be kept to 0 when BCD or mixed mode is used (BIN = 00, 10 or 11).

Bit 30 Reserved, must be kept at reset value.

Bits 29:24 **MASKSS[5:0]**: Mask the most-significant bits starting at this bit

0: No comparison on subseconds for Alarm B. The alarm is set when the seconds unit is incremented (assuming that the rest of the fields match).

1: SS[31:1] are don't care in Alarm B comparison. Only SS[0] is compared.

2: SS[31:2] are don't care in Alarm B comparison. Only SS[1:0] are compared.

...

31: SS[31] is don't care in Alarm B comparison. Only SS[30:0] are compared.

From 32 to 63: All 32 SS bits are compared and must match to activate alarm.

Note: In BCD mode (BIN=00)The overflow bits of the synchronous counter (bits 15) is never compared. This bit can be different from 0 only after a shift operation.

Bits 23:15 Reserved, must be kept at reset value.

Bits 14:0 **SS[14:0]**: Subseconds value

This value is compared with the contents of the synchronous prescaler counter to determine if alarm B is to be activated. Only bits 0 up to MASKSS-1 are compared.

This field is the mirror of SS[14:0] in the RTC_ALRBBINR, and so can also be read or written through RTC_ALRBBINR.

57.6.20 RTC status register (RTC_SR)

This register can be globally protected, or each bit of this register can be individually protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be globally protected, or each bit of this register can be individually protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x50

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SSRUF	ITSF	TSOVF	TSF	WUTF	ALRBF	ALRAF
									r	r	r	r	r	r	r

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **SSRUF**: SSR underflow flag

This flag is set by hardware when the SSR is reloaded with 0xFFFF FFFF after reaching 0. SSRUF is not set when SSCLR = 1.

Note: SSRUF is not an error event as SSR counter is a free-running down-counter with automatic reload. SSRUF is set only in binary and mixed modes. It is not set in BCD mode.

Bit 5 **ITSF**: Internal timestamp flag

This flag is set by hardware when a timestamp on the internal event occurs.

Bit 4 **TSOVF**: Timestamp overflow flag

This flag is set by hardware when a timestamp event occurs while TSF is already set.

It is recommended to check and then clear TSOVF only after clearing the TSF bit. Otherwise, an overflow might not be noticed if a timestamp event occurs immediately before the TSF bit is cleared.

Bit 3 **TSF**: Timestamp flag

This flag is set by hardware when a timestamp event occurs.

If ITSF flag is set, TSF must be cleared together with ITSF.

Note: TSF is not set if TAMPTS = 1 and the tamper flag is read during the 3 ck_apre cycles following tamper event. Refer to Timestamp on tamper event for more details.

Bit 2 **WUTF**: Wake-up timer flag

This flag is set by hardware when the wake-up auto-reload counter reaches 0.

If WUTOCLR[15:0] is different from 0x0000, WUTF is cleared by hardware when the wake-up auto-reload counter reaches WUTOCLR value.

If WUTOCLR[15:0] is 0x0000, WUTF must be cleared by software.

This flag must be cleared by software at least 1.5 RTCCLK periods before WUTF is set to 1 again.

Bit 1 **ALRBF**: Alarm B flag

This flag is set by hardware when the time/date registers (RTC_TR and RTC_DR) match the alarm B register (RTC_ALRMBR).

Bit 0 **ALRAF**: Alarm A flag

This flag is set by hardware when the time/date registers (RTC_TR and RTC_DR) match the alarm A register (RTC_ALRMAR).

Note: The bits of this register are cleared few APB clock cycles after setting their corresponding clear bit in the RTC_SCR register. After clearing the flag, read it until it is read at 0 before leaving the interrupt routine.

57.6.21 RTC nonsecure masked interrupt status register (RTC_MISR)

This register can be globally protected, or each bit of this register can be individually protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x54

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SSRUMF	ITSMF	TSOVMF	TSMF	WUTMF	ALRBMF	ALRAMF
									r	r	r	r	r	r	r

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **SSRUMF**: SSR underflow nonsecure masked flag

This flag is set by hardware when the SSR underflow nonsecure interrupt occurs.

Bit 5 **ITSMF**: Internal timestamp nonsecure masked flag
This flag is set by hardware when a timestamp on the internal event occurs and timestamp nonsecure interrupt is raised.

Bit 4 **TSOVMF**: Timestamp overflow nonsecure masked flag
This flag is set by hardware when a timestamp interrupt occurs while TSMF is already set.
It is recommended to check and then clear TSOVF only after clearing the TSF bit. Otherwise, an overflow might not be noticed if a timestamp event occurs immediately before the TSF bit is cleared.

Bit 3 **TSMF**: Timestamp nonsecure masked flag
This flag is set by hardware when a timestamp nonsecure interrupt occurs.
If ITSF flag is set, TSF must be cleared together with ITSF.

Bit 2 **WUTMF**: Wake-up timer nonsecure masked flag
This flag is set by hardware when the wake-up timer nonsecure interrupt occurs.
This flag must be cleared by software at least 1.5 RTCCLK periods before WUTF is set to 1 again.

Bit 1 **ALRBMF**: Alarm B nonsecure masked flag
This flag is set by hardware when the alarm B nonsecure interrupt occurs.

Bit 0 **ALRAMF**: Alarm A masked flag
This flag is set by hardware when the alarm A nonsecure interrupt occurs.

Note: The bits of this register are cleared few APB clock cycles after setting their corresponding clear bit in the RTC_SCR register. After clearing the flag, read it until it is read at 0 before leaving the interrupt routine.

57.6.22 RTC secure masked interrupt status register (RTC_SMISR)

This register can be globally protected, or each bit of this register can be individually protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be globally protected, or each bit of this register can be individually protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x58

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SSRUMF	ITSMF	TSOVMF	TSMF	WUTMF	ALRBMF	ALRAMF
									r	r	r	r	r	r	r

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **SSRUMF**: SSR underflow secure masked flag
This flag is set by hardware when the SSR underflow secure interrupt occurs.

Bit 5 **ITSMF**: Internal timestamp interrupt secure masked flag
This flag is set by hardware when a timestamp on the internal event occurs and timestamp secure interrupt is raised.

Bit 4 **TSOVMF**: Timestamp overflow interrupt secure masked flag
This flag is set by hardware when a timestamp secure interrupt occurs while TSMF is already set.
It is recommended to check and then clear TSOVF only after clearing the TSF bit. Otherwise, an overflow might not be noticed if a timestamp event occurs immediately before the TSF bit is cleared.

Bit 3 **TSMF**: Timestamp interrupt secure masked flag
This flag is set by hardware when a timestamp secure interrupt occurs.
If ITSF flag is set, TSF must be cleared together with ITSF.

Bit 2 **WUTMF**: Wake-up timer interrupt secure masked flag
This flag is set by hardware when the wake-up timer secure interrupt occurs.
This flag must be cleared by software at least 1.5 RTCCLK periods before WUTF is set to 1 again.

Bit 1 **ALRBMF**: Alarm B interrupt secure masked flag
This flag is set by hardware when the alarm B secure interrupt occurs.

Bit 0 **ALRAMF**: Alarm A interrupt secure masked flag
This flag is set by hardware when the alarm A secure interrupt occurs.

Note: The bits of this register are cleared few APB clock cycles after setting their corresponding clear bit in the RTC_SCR register. After clearing the flag, read it until it is read at 0 before leaving the interrupt routine.

57.6.23 RTC status clear register (RTC_SCR)

This register can be globally protected, or each bit of this register can be individually protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be globally protected, or each bit of this register can be individually protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x5C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSSRUF	CITSF	CTSOVF	CTSF	CWUTF	CALRBF	CALRAF
									w	w	w	w	w	w	w

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **CSSRUF**: Clear SSR underflow flag
Writing '1' in this bit clears the SSRUF in the RTC_SR register.

Bit 5 **CITSF**: Clear internal timestamp flag
Writing 1 in this bit clears the ITSF bit in the RTC_SR register.

Bit 4 **CTSOVF**: Clear timestamp overflow flag
Writing 1 in this bit clears the TSOVF bit in the RTC_SR register.
It is recommended to check and then clear TSOVF only after clearing the TSF bit. Otherwise, an overflow might not be noticed if a timestamp event occurs immediately before the TSF bit is cleared.

Bit 3 **CTSF**: Clear timestamp flag
Writing 1 in this bit clears the TSF bit in the RTC_SR register.
If ITSF flag is set, TSF must be cleared together with ITSF by setting CRSF and CITSF.

Bit 2 **CWUTF**: Clear wake-up timer flag
Writing 1 in this bit clears the WUTF bit in the RTC_SR register.

Bit 1 **CALRBF**: Clear alarm B flag
Writing 1 in this bit clears the ALRBF bit in the RTC_SR register.

Bit 0 **CALRAF**: Clear alarm A flag
Writing 1 in this bit clears the ALRAF bit in the RTC_SR register.

57.6.24 RTC option register (RTC_OR)

Address offset: 0x60

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OUT2_RMP
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **OUT2_RMP**: RTC_OUT2 mapping
0: RTC_OUT2 is mapped on PI8
1: RTC_OUT2 is mapped on PB2

57.6.25 RTC alarm A binary mode register (RTC_ALRABINR)

This register can be written only when ALRAE is reset in RTC_CR register.

This register can be protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x70

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SS[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SS[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SS[31:0]**: Synchronous counter alarm value

This value is compared with the contents of the synchronous counter to determine if Alarm A is to be activated. Only bits 0 up MASKSS-1 are compared.
SS[14:0] is the mirror of SS[14:0] in the RTC_ALRMASSR, and so can also be read or written through RTC_ALRMASSR.

57.6.26 RTC alarm B binary mode register (RTC_ALRBBINR)

This register can be written only when ALRBE is reset in RTC_CR register.

This register can be protected against nonsecure access. Refer to *Section 57.3.4: RTC secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 57.3.5: RTC privilege protection modes*.

Address offset: 0x74

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SS[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SS[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SS[31:0]**: Synchronous counter alarm value

This value is compared with the contents of the synchronous counter to determine if Alarm Bis to be activated. Only bits 0 up MASKSS-1 are compared.

SS[14:0] is the mirror of SS[14:0] in the RTC_ALRMBSSR, and so can also be read or written through RTC_ALRMBSSR.

57.6.27 RTC register map

Table 624. RTC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	RTC_TR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PM	HT [1:0]		HU[3:0]				Res.	MNT[2:0]			MNU[3:0]				Res.	ST[2:0]			SU[3:0]			
	Reset value										0	0	0	0	0	0	0		0	0	0	0	0	0	0		0	0	0	0	0	0	0
0x04	RTC_DR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	YT[3:0]				YU[3:0]				WDU[2:0]			MT	MU[3:0]				Res.	Res.	DT [1:0]		DU[3:0]			
	Reset value									0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1			0	0	0	0	0	1
0x08	RTC_SSR	SS[31:16]																SS[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	RTC_ICSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RECALPF	Res.	Res.	Res.	BCDU [2:0]			BIN [1:0]		INIT	INITF	RSF	INITS	SHPF	WUT WF	Res.	Res.
	Reset value																0				0	0	0	0	0	0	0	0	0	0	1		
0x10	RTC_PRER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREDIV_A[6:0]							PREDIV_S[14:0]															
	Reset value										1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
0x14	RTC_WUTR	WUTOCLR[15:0]																WUT[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x18	RTC_CR	OUT2EN	TAMPALRM_TYPE	TAMPALRM_PU	ALRBFCLR	ALRAFCLR	TAMPOE	TAMPTS	ITSE	COE	O SEL [1:0]		POL	COSEL	BKP	SUB1H	ADD1H	TSIE	WUTIE	ALRBIE	ALRAIE	TSE	WUTE	ALRBE	ALRAE	SSRUIE	FMT	BYPSHAD	REFCKON	TSEDGE	WUCK SEL[2:0]		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	RTC_ PRIVCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIV	INITPRIV	CALPRIV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSPRIV	WUTPRIV	ALRBPRIV	ALRAPRIV
	Reset value																	0	0	0										0	0	0	0
0x20	RTC_ SECCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEC	INITSEC	CALSEC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSSEC	WUTSEC	ALRBSEC	ALRASEC
	Reset value																	0	0	0										0	0	0	0
0x24	RTC_WPR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEY[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x28	RTC_ CALR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CALP	CALW8	CALW16	LPCAL	Res.	Res.	Res.	CALM[8:0]								
	Reset value																	0	0	0	0				0	0	0	0	0	0	0	0	0
0x2C	RTC_SHIFTR	ADD1S	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBFS[14:0]														
	Reset value	0																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 624. RTC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x30	RTC_TSTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PM	HT[1:0]		HU[3:0]				Res.	MNT[2:0]			MNU[3:0]				Res.	ST[2:0]			SU[3:0]			
	Reset value										0	0	0	0	0	0	0		0	0	0	0	0	0	0		0	0	0	0	0	0	0
0x34	RTC_TSDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDU[2:0]			MT	MU[3:0]				Res.	Res.	DT [1:0]		DU[3:0]			
	Reset value																	0	0	0	0	0	0	0	0			0	0	0	0	0	0
0x38	RTC_TSSSR	SS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x40	RTC_ALRMAR	MSK4	WDSEL	DT [1:0]		DU[3:0]				MSK3	PM	HT [1:0]		HU[3:0]				MSK2	MNT[2:0]			MNU[3:0]				MSK1	ST[2:0]			SU[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x44	RTC_ ALRMASSR	SSCLR	Res.	MASKSS [5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SS[14:0]														
	Reset value	0		0	0	0	0	0	0										0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x48	RTC_ALRMBR	MSK4	WDSEL	DT [1:0]		DU[3:0]				MSK3	PM	HT [1:0]		HU[3:0]				MSK2	MNT[2:0]			MNU[3:0]				MSK1	ST[2:0]			SU[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x4C	RTC_ ALRMBSSR	SSCLR	Res.	MASKSS [5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SS[14:0]														
	Reset value	0		0	0	0	0	0	0										0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x50	RTC_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SSRUF	ITSF	TSOVF	TSF	WUTF	ALRBF	ALRAF
	Reset value																										0	0	0	0	0	0	0
0x54	RTC_MISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SSRUMF	ITSMF	TSOVMF	TSMF	WUTMF	ALRBMF	ALRAMF
	Reset value																										0	0	0	0	0	0	0
0x58	RTC_SMISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SSRUMF	ITSMF	TSOVMF	TSMF	WUTMF	ALRBMF	ALRAMF
	Reset value																										0	0	0	0	0	0	0
0x5C	RTC_SCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSSRUF	CITSF	CTSOVF	CTSF	CWUTF	CALRBF	CALRAF
	Reset value																										0	0	0	0	0	0	0
0x60	RTC_OR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OUT2_RMP
	Reset value																																0
0x70	RTC_ ALRABINR	SS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 624. RTC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x74	RTC_ ALRBBINR	SS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

58 Tamper and backup registers (TAMP)

58.1 TAMP introduction

The anti-tamper detection circuit is used to protect sensitive data from external attacks. 32 32-bit backup registers are retained in all low-power modes and also in V_{BAT} mode. The backup registers, as well as other secrets in the device, are protected by this anti-tamper detection circuit with 11 tamper pins and 13 internal tampers. The external tamper pins can be configured for edge detection, or level detection with or without filtering, or active tamper which increases the security level by auto checking that the tamper pins are not externally opened or shorted.

58.2 TAMP main features

- A tamper detection can optionally erase the backup registers, backup SRAM, SRAM2, caches, and cryptographic peripherals. The device resources protected by tamper are named “device secrets”.
- 32×32-bit backup registers:
  - The backup registers (TAMP_BKPxR) are implemented in the backup domain that remains powered-on by V_{BAT} when the V_{DD} power is switched off.
- Up to 11 tamper pins for 8 external tamper detection events:
  - Active tamper mode: continuous comparison between tamper output and input to protect from physical open-short attacks.
  - Flexible active tamper I/O management: from 5 meshes (each input associated to its own exclusive output) to 8 meshes (single output shared for up to 8 tamper inputs)
  - Passive tampers: ultra-low power edge or level detection with internal pull-up hardware management.
  - Configurable digital filter.
- 13 internal tamper events to protect against transient or environmental perturbation attacks
- Each tamper can be configured in two modes:
  - Confirmed mode: immediate erase of secrets on tamper detection, including backup registers erase
  - Potential mode: most of the secrets erase following a tamper detection are launched by software
- Any tamper detection can generate a RTC timestamp event.
- TrustZone support:
  - Tamper secure or nonsecure configuration.
  - Backup registers configuration in 3 configurable-size areas:

    1 read/write secure area.

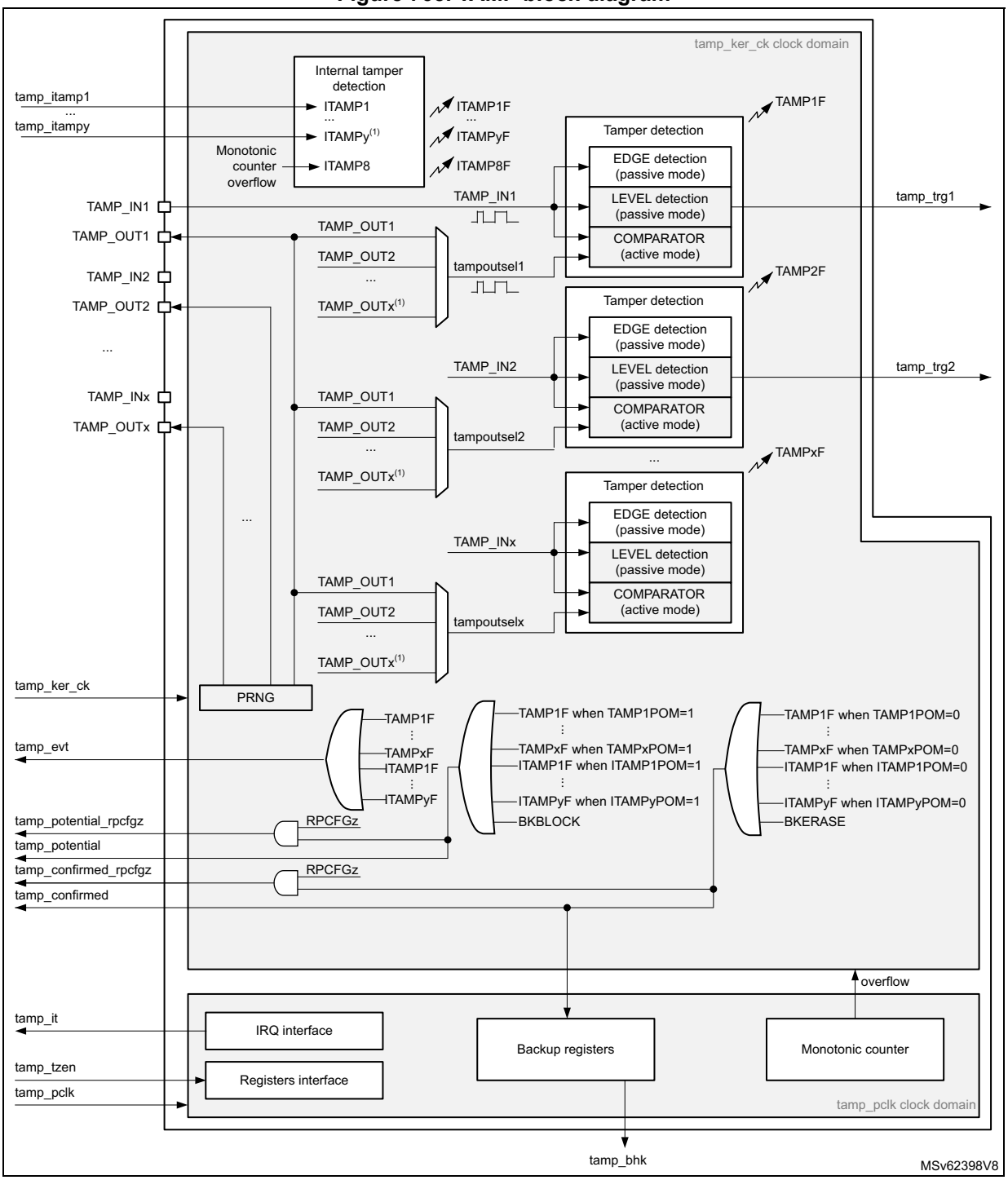
    1 write secure/read nonsecure area.

    1 read/write nonsecure area.
  - Boot hardware key for secure AES, stored in backup registers, protected against read and write access.
- Tamper configuration and backup registers privilege protection
- Monotonic counter.

58.3 TAMP functional description

58.3.1 TAMP block diagram

Figure 765. TAMP block diagram



1. The number of external and internal tampers depends on products.

58.3.2 TAMP pins and internal signals

Table 625. TAMP input/output pins

Pin name	Signal type	Description
TAMP_INx (x = pin index)	Input	Tamper input pin
TAMP_OUTx (x = pin index)	Output	Tamper output pin (active mode only)

Table 626. TAMP internal input/output signals

Internal signal name	Signal type	Description
tamp_ker_ck	Input	TAMP kernel clock, connected to rtc_ker_ck and also named RTCCLK in this document
tamp_pclk	Input	TAMP APB clock, connected to rtc_pclk
tamp_itamp[y] (y = signal index)	Inputs	Internal tamper event sources
tamp_tzen	Input	TAMP TrustZone enabled
tamp_evt	Output	Tamper event detection flag (internal or external tamper), whatever confirmed or potential mode configuration.
tamp_potential	Output	Potential tamper detection signal, used for device secrets(1) protection. This signal is active when: – a tamper event detection flag (internal or external tamper), is generated in potential mode. – or a software request is done by writing BKBLOCK to 1
tamp_confirmed	Output	Confirmed tamper detection signal, used for device secrets(1) protection. This signal is active when: – a tamper event detection flag (internal or external tamper), is generated in confirmed mode. – or a software request is done by writing BKERASE to 1
tamp_potential_rpcfgz (z = signal index)	Output	Potential tamper detection signal generated only when RPCFGz = 1. This signal is active when: – a tamper event detection flag (internal or external tamper), is generated in potential mode. – or a software request is done by writing BKBLOCK to 1

Table 626. TAMP internal input/output signals (continued)

Internal signal name	Signal type	Description
tamp_confirmed_rpcfgz (z = signal index)	Output	Confirmed tamper detection signal generated only when RPCFGz = 1. This signal is active when: – a tamper event detection flag (internal or external tamper), is generated in confirmed mode. – or a software request is done by writing BKERASE to 1
tamp_it	Output	TAMP interrupt (refer to *Section 58.5: TAMP interrupts* for details)
tamp_trg[x] (x = signal index)	Output	Tamper detection trigger
tamp_bhk	Output	Tamper boot hardware key bus

1. Refer to *Table 627: TAMP interconnection*.

The TAMP kernel clock is usually the LSE at 32.768 kHz although it is possible to select other clock sources in the RCC (refer to RCC for more details). The TAMP kernel clock is required only for external tamper inputs level with filtering, and for external active tamper detection modes. Internal tampers detection and external tampers inputs edge detection are functional without requiring any kernel clock.

Read and write access to backup registers and all other TAMP registers are also functional without any kernel clock (only APB clock is needed).

Some detections modes are not available in some low-power modes or V_{BAT} depending on the selected clock (refer to for more details.

Table 627. TAMP interconnection

Signal name	Source/Destination
tamp_tzen	From FLASH option bytes: TZEN
tamp_evt	rtc_tamp_evt used to generate a timestamp event
tamp_potential	The tamp_potential signal is used to block the read and write accesses to the device secrets listed hereafter: – backup registers – SRAM2 RHUK (root hardware unique key) in system Flash memory and BHK (boot hardware key) hardware buses to SAES are blocked. The tamp_potential signal is used to erase the device secrets listed hereafter: – ICACHE content – SAES, AES, HASH peripherals – PKA SRAM The device secrets access is blocked when erase is ongoing.

Table 627. TAMP interconnection (continued)

Signal name	Source/Destination
tamp_confirmed	The tamp_confirmed signal is used to erase the device secrets listed hereafter: – backup registers – SRAM2 – ICACHE/DCACHE content – OTFDEC keys and CRC registers – SAES, AES, HASH peripherals – PKA SRAM The device secrets access is blocked when erase is ongoing. RHUK in system Flash memory (root hardware unique key) hardware bus to SAES is blocked.
tamp_potential_rpcfg0	When the bit RPCFG0 is set in the TAMP_RPCFGR, the tamp_potential_rpcfg0 signal is used to block the read and write accesses to the device secrets listed hereafter: – Backup SRAM
tamp_confirmed_rpcfg0	When the bit RPCFG0 is set in the TAMP_RPCFGR, the tamp_confirmed_rpcfg0 signal is used to erase the device secrets listed hereafter: – Backup SRAM The device secrets access is blocked when erase is on-going.
tamp_itamp1	Backup domain voltage threshold monitoring(1)
tamp_itamp2	Temperature monitoring(1)
tamp_itamp3	LSE monitoring (LSECSS)(2)
tamp_itamp4	HSE monitoring (rcc_hsecss_fail)
tamp_itamp5	RTC calendar overflow (rtc_calovf)
tamp_itamp6	JTAG/SWD access when NVSTATE ≠ OPEN
tamp_itamp7	ADC2 watchdog monitoring 1
tamp_itamp8(3)	Monotonic counter 1 overflow
tamp_itamp9	Cryptographic peripherals fault (SAES or AES or PKA or TRNG)
tamp_itamp11	IWDG reset when tamper flag is set (potential tamper timeout)
tamp_itamp12	ADC2 analog watchdog monitoring 2
tamp_itamp13	ADC2 analog watchdog monitoring 3
tamp_itamp15	System fault
tamp_bhk	saes_bhk. This bus is used to load the boot hardware key in the secure AES co-processor.

1. This monitoring must be enabled by setting MONEN in *PWR backup domain control register (PWR_BDCR)*.
2. This monitoring must be enabled by setting LSEON in *PWR backup domain control register (PWR_BDCR)*.
3. This signal is generated in the TAMP peripheral.

The TZEN option bit is used to activate TrustZone in the device.

TZEN = 1: TrustZone activated.

TZEN = 0: TrustZone disabled.

When TrustZone is disabled, the APB access to the TAMP registers are nonsecure.

58.3.3 GPIOs controlled by the RTC and TAMP

Refer to *Section 57.3.3: GPIOs controlled by the RTC and TAMP*.

58.3.4 TAMP register write protection

After system reset, the TAMP registers (including backup registers) are protected against parasitic write access by the DBP bit in the power control peripheral (refer to the PWR power control section). DBP bit must be set in order to enable TAMP registers write access.

58.3.5 TAMP secure protection modes

By default after a backup domain power-on reset, all TAMP registers can be read or written in both secure and nonsecure modes, except for the TAMP secure configuration register (TAMP_SECCFGR) which can be written in secure mode only. The TAMP protection configuration is not affected by a system reset.

- When the TAMPSEC bit is set in the TAMP_SECCFGR register:
  - Writing the TAMP registers is possible only in secure mode, except for the backup registers and monotonic counters which have their own protection setting.
  - Reading TAMP_SECCFGR, TAMP_PRIVCFGR and TAMP_MISR is always possible in secure and nonsecure modes. All the other TAMP registers can be read only in secure mode, except for the backup registers and monotonic counters which have their own protection setting.
- When the CNT1SEC bit is set in the TAMP_SECCFGR register: the TAMP_COUNT1R can be read and written only in secure mode, and CNT1PRIV can be written only in secure mode.
- When the BKPRWSEC is set in the TAMP_SECCFGR register: the BKPRWPRIV can be written only in secure mode.
- When the BKPWSEC is set in the TAMP_SECCFGR register: the BKPRWPRIV and BKPWPRIV can be written only in secure mode.

A nonsecure access to a secure-protected register is denied:

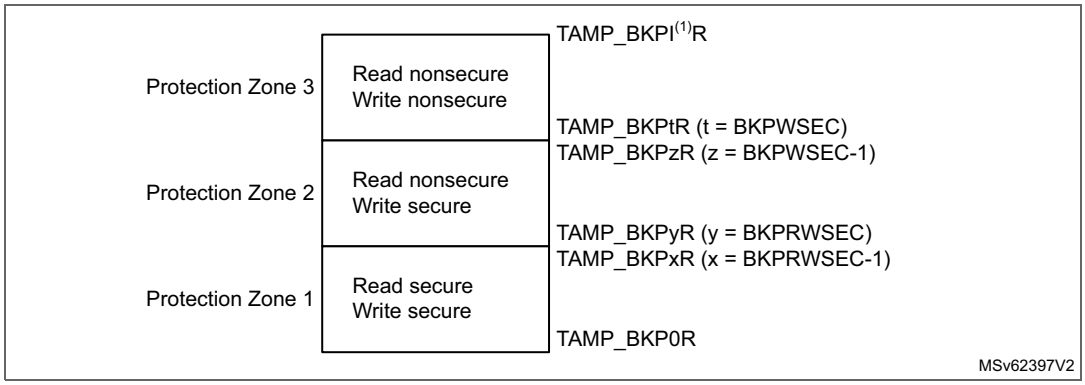
- There is no bus error generated.
- A notification is generated through a flag/interrupt in the TZIC (TrustZone illegal access controller).
- When write protected, the bits are not written.
- When read protected they are read as 0.

As soon as at least one function is configured to be secured, the TAMP reset and clock control is also secured in the RCC.

58.3.6 Backup registers protection zones

The backup registers protection is configured thanks to BKPRWSEC[7:0] and BKPWSEC[7:0] (refer to the figure below):

Figure 766. Backup registers protection zones



1. I = last backup register index

58.3.7 TAMP privilege protection modes

By default after a backup domain power-on reset, all TAMP registers can be read or written in both privileged and unprivileged modes, except for the TAMP privilege configuration register (TAMP_PRIVCFGR) which can be written in privilege mode only. The TAMP protection configuration is not affected by a system reset.

- When the TAMPPRIV bit is set in the TAMP_PRIVCFGR register:
  - Writing the TAMP registers is possible only in privilege mode, except for the backup registers and the monotonic counter which have their own protection setting.
  - Reading TAMP_SECCFGR, TAMP_PRIVCFGR is always possible in privilege and unprivilege modes. All the other TAMP registers can be read only in privileged mode, except for the backup registers and the monotonic counter which have their own protection setting.
- When the CNT1PRIV bit is set in the TAMP_PRIVCFGR register: the TAMP_COUNT1R can be read and written only in privilege mode, and CNT1SEC can be written only in privilege mode.
- When the BKPRWPRIV is set in the TAMP_PRIVCFGR register: the BKPWSEC can be written only in privilege mode.
- When the BKPWPRIV is set in the TAMP_PRIVCFGR register: the BKPRWSEC and BKPWSEC can be written only in privilege mode.

The backup registers protection is configured thanks to BKPRWSEC[7:0] and BKPRWPRIV for the protection zone 1, and thanks to BKPRWSEC[7:0], BKPWSEC[7:0] and BKPWPRIV for the protection zone 2 (refer to *Figure 766*). The BHKLOCK bit can be written only in privileged mode when the BKPRWPRIV bit is set.

A unprivileged access to a privileged-protected register is denied:

- There is no bus error generated.
- When write protected, the bits are not written.
- When read protected they are read as 0.

58.3.8 Boot hardware key (BHK)

The eight first backup registers from TAMP_BKP0R to TAMP_BKP7R can be used to store a boot hardware key for the secure AES.

For this purpose, these registers must belong to the Protection Zone 1: BKPRWSEC must be greater or equal to 8.

Once the backup registers are written with the boot hardware key, the BHKLOCK bit must be set in the TAMP_SECCFGR register. Once BHKLOCK is set, the 8 backup registers cannot be accessed anymore by software: they are read as 0 and write to these registers is ignored. BHKLOCK cannot be cleared by software, and is cleared by hardware following a tamper event or when the product state is opened. It is also cleared with BKERASE command (in all cases the backup registers are also erased).

Refer to section secure AES co-processor (SAES) for details on procedure to download the boot hardware key in the SAES.

58.3.9 Tamper detection

The tamper detection main purpose is to protect the device secrets from device external attacks. The detection is made on events on TAMP_INx (x = pin index) I/Os, or on internal monitors detecting out-of-range device conditions.

The tamper detection can be configured for the following purposes:

- erase the backup registers and other device secrets stored in SRAMs or peripherals listed in *Table 627: TAMP interconnection*. The device secrets list is configurable thanks to *TAMP resources protection configuration register (TAMP_RPCFGR)*.
- block the read/write access to the backup registers and other device secrets stored in SRAMs or peripherals listed in *Table 627: TAMP interconnection*. The device secrets list is configurable thanks to TAMP_RPCFGR.
- generate an interrupt, capable to wake-up from low-power modes
- generate a hardware trigger for the low-power timers, or a RTC timestamp event

The external I/Os tamper detection supports 2 main configurations:

- Passive mode: TAMP_INx I/Os are monitored and a tamper is detected either on edge or on level.
- Active mode: TAMP_INx (x = pin index) is continuously compared with TAMP_OUTy (y = pin index) allowing open-short detection.

A digital filter can be applied on external tamper detection to avoid false detection. In addition, it is possible to configure each tamper source in potential mode, so that the secrets erase is not launched by hardware on tamper detection. The secrets erase can then be launched by software after software checks.

58.3.10 TAMP backup registers and other device secrets erase

The backup registers (TAMP_BKPxR) are not reset by system reset or when the device wakes up from Standby mode.

The backup registers and the other device secrets are not reset when the corresponding mask is set (TAMPxMSK=1 in the TAMP_CR2 register).

Note: The backup registers are also erased when the product state is changed from Closed to Open.

Tamper detection – confirmed mode

The confirmed mode is selected for TAMPx (external tamper x) when TAMPxPOM = 0 in the TAMP_CR2 register. The confirmed mode is selected for ITAMPx (internal tamper x) when ITAMPxPOM = 0 in the TAMP_CR3 register. The effects of a tamper detection in confirmed mode are described with tamp_confirmed and tamp_confirmed_rpcfgx signals in the *Table 627: TAMP interconnection*.

This mode is selected to erase automatically the device secrets when the tamper is detected.

Tamper detection – potential mode

The potential mode is selected for TAMPx (external tamper x) when TAMPxPOM = 1 in the TAMP_CR2 register. The potential tamper mode is selected for ITAMPx (internal tamper x) when ITAMPxPOM = 1 in the TAMP_CR3 register. The effects of a tamper detection in potential mode are described with tamp_potential and tamp_potential_rpcfgx signals in the *Table 627: TAMP interconnection*.

This mode is selected to avoid irreversible erasure of some device secrets when the tamper is detected. In this mode, some device secrets are not erased when the corresponding tamper event is detected. In addition, the read and write accesses to these device secrets are blocked as soon as the tamper detection flag is set in potential mode, until this flag is cleared by setting the corresponding clear flag in the TAMP_SCR register. Therefore the software can perform some checks to discriminate false from true tampers, and decide to launch secrets erase only in case of the potential tamper is confirmed to be a true tamper. The device secrets are erased by software by setting the BKERASE bit in the TAMP_CR2 register.

Potential tamper to confirmed tamper timeout

Some internal tampers generate a tamper event if the independent watchdog reset occurs when another tamper flag is set (refer to *Table 627: TAMP interconnection*). The IWDG tamper must be configured with ITAMPxPOM = 0. This permits the erasure of device secrets to be forced by hardware after a timeout, in case the previous tamper event was in potential mode. This is equivalent to change the “potential tamper” into “confirmed tamper” if a watchdog reset occurs before any software decision following the potential tamper event.

Device resources protection configuration

Some device resources can be configured in order to be included to the list of the device secrets protected by tamper detection.

When RPCFGz = 0 in the TAMP_RPCFGR, the device resource associated to RPCFGz is not protected by the TAMP peripheral:

- It is not affected by tamper detection (whatever confirmed or potential mode)
- It is not affected by BKERASE software command
- It is not affected by BKBLOCK software command

When RPCFGz = 1 in the TAMP_RPCFGR, the device resource associated to RPCFGz is protected by the TAMP peripheral:

- It is affected by confirmed tamper detection and BKERASE software command, as described with tamp_confirmed_rpcfgz signal in *Table 627: TAMP interconnection*
- It is affected by potential tamper detection and BKBLOCK software command, as described with tamp_potential_rpcfgz signal in *Table 627: TAMP interconnection*

Table 628. Device resource x tamper protection

-	Potential tamper or BKBLOCK	Confirmed tamper or BKERASE
RPCFGx = 0	No effect on device resource x	No effect on device resource x
RPCFGx = 1	Device secret x protected as described by tamp_potential_rpcfgx(1)	Device secret x protected as described by tamp_confirmed_rpcfgx(1)

1. Refer to *Table 627: TAMP interconnection*.

Device secrets access blocked by software

By default, the device secrets can be accessed by the application, except if a tamper event flag is detected: the device secrets access is not possible as long as a tamper flag is set.

It is possible to block the access to the device secrets by software, by setting the BKBLOCK bit of the TAMP_CR2 register. The device secrets access is possible only when BKBLOCK = 0 and no tamper flag is set.

58.3.11 Tamper detection configuration and initialization

Each input can be enabled by setting the corresponding TAMPxE bits to 1 in the TAMP_CR register.

Each TAMP_INx tamper detection input is associated with a flag TAMPxF in the TAMP_SR register.

By setting the TAMPxIE bit in the TAMP_IER register, an interrupt is generated when a tamper detection event occurs (when TAMPxF is set). Setting TAMPxIE is not allowed when the corresponding TAMPxMSK is set.

Trigger output generation on tamper event

The tamper event detection can be used as trigger input by the low-power timers.

When TAMPxMSK bit is cleared in TAMP_CR register, the TAMPxF flag must be cleared by software in order to allow a new tamper detection on the same pin.

When TAMPxMSK bit is set, the TAMPxF flag is masked, and kept cleared in TAMP_SR register. This configuration permits the low-power timers to be triggered automatically in Stop mode, without requiring the system wake-up to perform the TAMPxF clearing. In this case, the backup registers are not cleared.

This feature is available only when the tamper is configured in level detection with filtering mode (TAMPFLT ≠ 00 and active mode is not selected). Refer to *Section : Level detection with filtering on tamper inputs (passive mode)*.

Timestamp on tamper event

With TAMPTS set to 1 in the RTC_CR, any internal or external tamper event causes a timestamp to occur. In case a timestamp occurs due to tamper event, either the TSF bit or the TSOVF bit is set in RTC_SR, in the same manner as if a normal timestamp event occurs.

Note: TSF is set up to 3 ck_apre cycles after TAMPxF flags. TSF is not set if RTCCLK is stopped (it is set when RTCCLK restarts).

Note: If TAMPxF is cleared before the expected rise of TSF, TSF is not set. Consequently, in case TAMPTS = 1, the software should either wait for timestamp flag before clearing the tamper flag, or should read the RTC counters values in the TAMP interrupt routine.

Edge detection on tamper inputs (passive mode)

If the TAMPFLT bits are 00, the TAMP_INx pins generate tamper detection events when either a rising edge or a falling edge is observed depending on the corresponding TAMPxTRG bit. The internal pull-up resistors on the TAMP_INx inputs are deactivated when edge detection is selected.

Caution: When TAMPFLT = 00 and TAMPxTRG = 0 (rising edge detection), a tamper event may be detected by hardware if the tamper input is already at high level before enabling the tamper detection.

After a tamper event has been detected and cleared, the TAMP_INx should be disabled and then re-enabled (TAMPxE set to 1) before re-programming the backup registers (TAMP_BKPxR). This prevents the application from writing to the backup registers while the TAMP_INx input value still indicates a tamper detection. This is equivalent to a level detection on the TAMP_INx input.

Note: Tamper detection is still active when V_{DD} power is switched off. To avoid unwanted resetting of the backup registers, the pin to which the TAMPx is mapped should be externally tied to the correct level.

Level detection with filtering on tamper inputs (passive mode)

Level detection with filtering is performed by setting TAMPFLT to a non-zero value. A tamper detection event is generated when either 2, 4, or 8 (depending on TAMPFLT) consecutive samples are observed at the level designated by the TAMPxTRG bits.

The TAMP_INx inputs are precharged through the I/O internal pull-up resistance before its state is sampled, unless disabled by setting TAMPPUDIS to 1. The duration of the precharge is determined by the TAMPPRCH bits, allowing for larger capacitances on the TAMP_INx inputs.

The trade-off between tamper detection latency and power consumption through the pull-up can be optimized by using TAMPFREQ to determine the frequency of the sampling for level detection. The TAMP_IN I/O schmitt trigger is enabled only during the precharge duration to avoid any extra consumption if the tamper switch is open (floating state).

Figure 767. Tamper sampling with precharge pulse

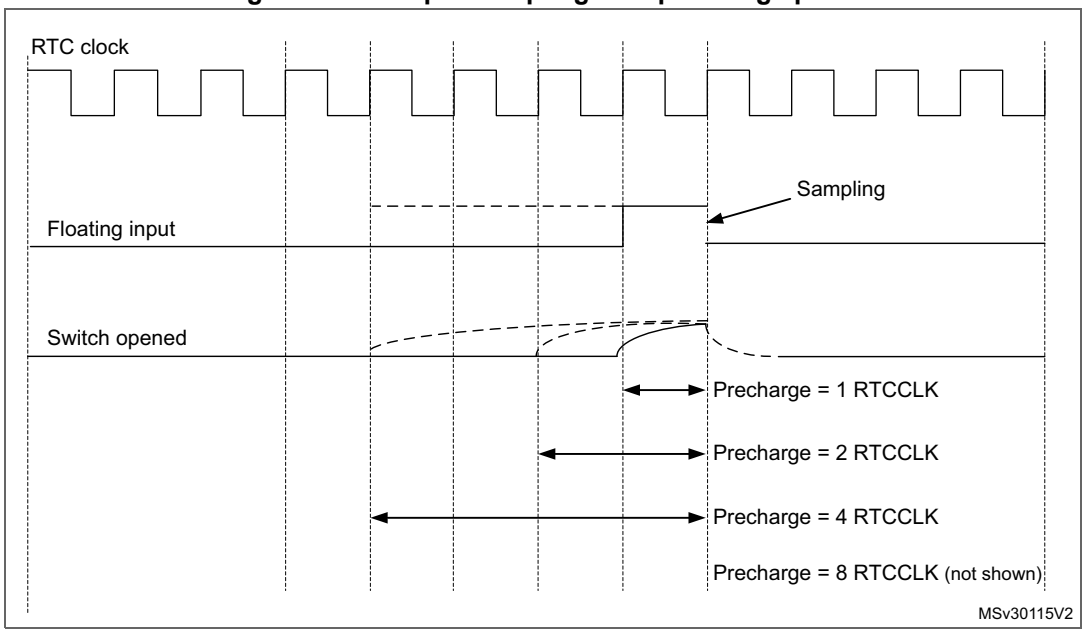
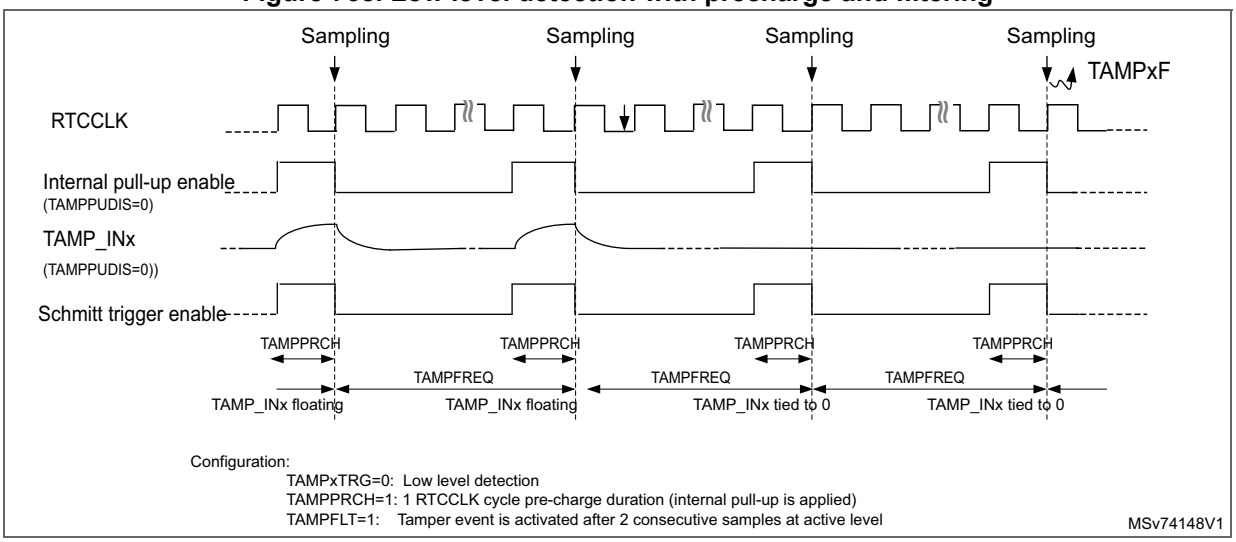


Figure 768. Low level detection with precharge and filtering



Note: Refer to the microcontroller datasheet for the electrical characteristics of the pull-up resistors.

Active tamper detection

When the TAMPxAM bit is set in the TAMP_ATCR, the tamper events are configured in active mode, which is based on a comparison between a TAMP_OUTy pin and a TAMP_INx pin. By default (ATOSHARE = 0) the comparison is made between TAMP_INx and TAMP_OUTx (y = x). When ATOSHARE bit is set, the same output can be used for several tamper inputs. The TAMP_OUTy function is enabled on the I/O as soon as it is selected for comparison with an active tamper input TAMP_INx (TAMPxEN = TAMPxAM = 1), thanks to

ATOSHARE and ATOSELx bits. Refer to ATOSHARE and ATOSEL bits descriptions in the TAMP_ATCRx (x = 1, 2) registers.

Every two CK_ATPER cycles (CK_ATPER = 2^{ATPER} × CK_ATPRE), TAMP_OUTy output pin provides a value provided by a pseudo random number generator (PRNG). After outputting this value, the TAMP_OUTy pin outputs its opposite value one CK_ATPER cycle after.

Table 629. Active tamper output change period

ATCKSEL[3:0]	CK_ATPRE frequency	ATPER[2:0]	Tamper output change (CK_ATPER) frequency	Tamper output change period(1) (ms)
0x0	f_{RTCCLK}	0x0	f_{RTCCLK}	0.030
		0x1	$f_{RTCCLK}/2$	0.061
		0x2	$f_{RTCCLK}/4$	0.122
		0x3	$f_{RTCCLK}/8$	0.244
		0x4	$f_{RTCCLK}/16$	0.488
		0x5	$f_{RTCCLK}/32$	0.977
		0x6	$f_{RTCCLK}/64$	1.953
		0x7	$f_{RTCCLK}/128$	3.906
…	…	…	…	…
0x7	$f_{RTCCLK}/128$	0x0	$f_{RTCCLK}/128$	3.906
		0x1	$f_{RTCCLK}/256$	7.8125
		0x2	$f_{RTCCLK}/512$	15.625
		0x3	$f_{RTCCLK}/1024$	31.250
		0x4	$f_{RTCCLK}/2048$	62.5
		0x5	$f_{RTCCLK}/4096$	125
		0x6	$f_{RTCCLK}/8192$	250
		0x7	$f_{RTCCLK}/16384$	500
0x8	$f_{RTCCLK}/256$	0x0	$f_{RTCCLK}/256$	7.8125
		0x1	$f_{RTCCLK}/512$	15.625
		0x2	$f_{RTCCLK}/1024$	31.250
		0x3	$f_{RTCCLK}/2048$	62.5
		0x4	$f_{RTCCLK}/4096$	125
		0x5	$f_{RTCCLK}/8192$	250
		0x6	$f_{RTCCLK}/16384$	500
		0x7	$f_{RTCCLK}/32768$	1000
…	…	…	…	…

Table 629. Active tamper output change period (continued)

ATCKSEL[3:0]	CK_ATPRE frequency	ATPER[2:0]	Tamper output change (CK_ATPER) frequency	Tamper output change period(1) (ms)
0xF	f_{RTCCLK}/32768	0x0	f_{RTCCLK}/32768	1000
		0x1	f_{RTCCLK}/65536	2000
		0x2	f_{RTCCLK}/131072	4000
		0x3	f_{RTCCLK}/262144	8000
		0x4	f_{RTCCLK}/524288	16000
		0x5	f_{RTCCLK}/1048576	32000
		0x6	f_{RTCCLK}/2097152	64000
		0x7	f_{RTCCLK}/4194304	128000

1. Assuming f_{RTCCLK} = 32768 Hz.

PRNG is consumed by the selected tamper outputs at a different frequency depending on the number of selected tamper outputs. The number of selected outputs depends on TAMPxAM, TAMPxE, ATOSEL and ATOSHARE.

- When only 1 output is selected: PRNG is consumed every 16 CK_ATPER periods.
- When 2 outputs are selected: PRNG is consumed every 8 CK_ATPER periods.
- When 3 or 4 outputs are selected: PRNG is consumed every 4 CK_ATPER periods.
- When 5 or more outputs are selected: PRNG is consumed every 2 CK_ATPER periods

The PRNG needs minimum 9 CK_ATPRE cycles to output a new value. Consequently the minimum ATPER values for correct functionality are provided in the table below:

Table 630. Minimum ATPER value

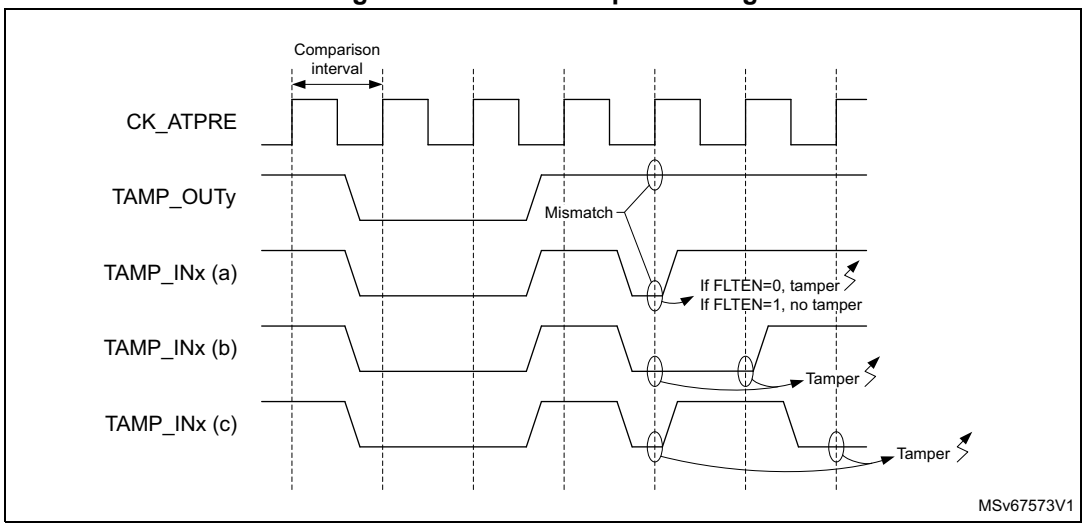
Number of selected outputs	Minimum ATPER
1	0
2	1
3 or 4	2
5 or more	3

The TAMP_INx pin is externally connected to TAMP_OUTy pin. The comparison is made between TAMP_OUTy output value and TAMP_INx received value, every CK_ATPRE cycle. In case a comparison mismatch occurs, the TAMPxF bit is set in the TAMP_SR register.

As an example, TAMP_OUT1 can be used for comparison with TAMP_IN1 and TAMP_IN2 by configuring and enabling both TAMP1 and TAMP2 in active mode, with ATOSHARE = 1, ATOSEL1 = 000 and ATOSEL2 = 000.

The active tamper can be combined with input filtering when FLTEN = 1. In this case, the tamper is detected only when 2 comparisons are false, in 4 consecutive comparison samples.

Figure 769. Active tamper filtering



As illustrated in *Figure 769*, if FLTEN = 0, any mismatch between the TAMP_OUTy output and the associated TAMP_INx input when the latter is sampled generates a tamper. This is the case in all three examples (a), (b) and (c).

If FLTEN = 1, example (a) does not generate a tamper, since only one mismatch is detected in four consecutive comparisons. In example (b), a tamper is generated since two successive mismatches are detected. Example (c) also generates a tamper, since two mismatches occur in four consecutive comparisons, even though the mismatches do not occur on successive samples.

Setting FLTEN = 1 avoids unwanted detection of tampers due to glitches, bounce or transitory states on the TAMP_INx inputs, by ignoring single pulses which are shorter than one period of CK_ATPRE, programmed in the ATCKSEL field of the TAMP_ATCR1 register. The minimum filtered pulse width is listed in *Table 631* for each possible setting of ATCKSEL, assuming f_{RTCCLK} = 32.768 kHz.

Table 631. Active tamper filtered pulse duration

ATCKSEL[3:0]	CK_ATPRE frequency	Minimum filtered pulse width (ms)
0x0	f_{RTCCLK}	0.030
0x1	$f_{RTCCLK}/2$	0.061
0x2	$f_{RTCCLK}/4$	0.122
0x3	$f_{RTCCLK}/8$	0.244
0x4	$f_{RTCCLK}/16$	0.488
0x5	$f_{RTCCLK}/32$	0.977
0x6	$f_{RTCCLK}/64$	1.953
0x7	$f_{RTCCLK}/128$	3.906
0x8	$f_{RTCCLK}/256$	7.812
0x9	$f_{RTCCLK}/512$	15.625
0xA	$f_{RTCCLK}/1024$	31.25
0xB	$f_{RTCCLK}/2048$	62.5

Table 631. Active tamper filtered pulse duration (continued)

ATCKSEL[3:0]	CK_ATPRE frequency	Minimum filtered pulse width (ms)
0xC	f_{RTCCLK}/4096	125
0xD	f_{RTCCLK}/8192	250
0xE	f_{RTCCLK}/16384	500
0xF	f_{RTCCLK}/32768	1000

Note: Multiple pulses which are shorter than one CK_ATPRE period may nevertheless cause a tamper if they result in two mismatches in four consecutive comparisons.

The pseudo-random generator must be initialized with a seed. This is done by writing consecutively four 32-bit random values in the TAMP_ATSEEDR register. Programming the seed automatically sends it to the PRNG. As long as the new seed is transferred and elaborated by the PRNG, the SEEDF bit is set in the TAMP_ATOR and it is not allowed to switch off the TAMP APB clock. The duration of the elaboration is up to 184 APB clock cycles after the forth seed is written. Consequently, after writing a new seed, the user must wait until SEEDF is cleared before entering low-power modes.

The active tamper outputs are activated only after the first seed is written and the elaboration is completed. Then new seeds can be written and elaborated during active tamper activity.

Active tamper initialization

Here is the software procedure to initialize the active tampers after system reset:

Read INITS in TAMP_ATOR register.

- If INITS = 0x0 (initialization was not done):
  a) Write TAMP_ATCR to configure Active tamper clock, filter and output sharing if any, and active mode.
  b) Write TAMP_CR1 to enable tampers (all the needed tampers must be enabled in the same write access).
  c) Write SEED by writing four times in the TAMP_ATSEEDR.
  d) Wait until SEEDF = 0 in TAMP_ATOR. Backup registers are then protected by active tamper.
- If INITS = 0x1 (initialization already done):

  No initialization. To increase randomness a new SEED should be provided regularly. When a new SEED is provided, wait until SEEDF = 0 before entering a low-power mode which switches off the TAMP APB clock.
- In case the tampers are disabled by software, and re-enabled afterwards, the SEED must be written after enabling tampers:
  a) Write TAMP_CR1 to enable tampers (all the needed tampers must be enabled in the same write access).
  b) Write SEED by writing four times in the TAMP_ATSEEDR.
  c) Wait until SEEDF = 0 in TAMP_ATOR. Backup registers are then protected by active tamper.

58.4 TAMP low-power modes

Table 632. Effect of low-power modes on TAMP

Mode	Description
Sleep	No effect. TAMP interrupts cause the device to exit the Sleep mode.
Stop	No effect on all features, except for level detection with filtering and active tamper modes which remain active only when the clock source is LSE or LSI. TAMP interrupts cause the device to exit the Stop mode.
Standby	No effect on all features, except for level detection with filtering and active tamper modes which remain active only when the clock source is LSE or LSI. TAMP interrupts cause the device to exit the Standby mode.

Table 633. TAMP pins functionality over modes

Pin name	Functional in all low-power modes	Functional in V_{BAT} mode
TAMP_IN[8:1]	Yes(1)	Yes(1)
TAMP_OUT[8:1]	Yes(2)	Yes(3)

1. Only PC13, PI8, PA0, PA1 and PA2 are functional in Standby and V_{BAT} modes.
2. Only PC13, PA1 and PI8 are functional in Standby mode.
3. Only PC13, PA1 and PI8 are functional in V_{BAT} mode.

58.5 TAMP interrupts

The interrupt channel is set in the masked interrupt status register or in the secure masked interrupt status register depending on its security mode configuration (TAMPSEC).

Table 634. Interrupt requests

Interrupt acronym	Interrupt event	Event flag(1)	Enable control bit	Interrupt clear method	Exit from low-power modes
TAMP	Tamper x(2)	TAMPxF	TAMPxIE	Write 1 in CTAMPxF	Yes(3)
	Internal tamper y(2)	ITAMPyF	ITAMPyIE	Write 1 in CITAMPyF	Yes(3)

1. The event flags are in the TAMP_SR register.
2. The number of tampers and internal tampers events depend on products.
3. Refer to *Table 632: Effect of low-power modes on TAMP* for more details about available features in the low-power modes.

58.6 TAMP registers

Refer to *Section 1.2* of the reference manual for a list of abbreviations used in register descriptions. The peripheral registers can be accessed by words (32-bit).

58.6.1 TAMP control register 1 (TAMP_CR1)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x00

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	ITAMP15E	Res.	ITAMP13E	ITAMP12E	ITAMP11E	Res.	ITAMP9E	ITAMP8E	ITAMP7E	ITAMP6E	ITAMP5E	ITAMP4E	ITAMP3E	ITAMP2E	ITAMP1E
	rw		rw	rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP8E	TAMP7E	TAMP6E	TAMP5E	TAMP4E	TAMP3E	TAMP2E	TAMP1E
								rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **ITAMP15E**: Internal tamper 15 enable
0: Internal tamper 15 disabled.
1: Internal tamper 15 enabled.

Bit 29 Reserved, must be kept at reset value.

Bit 28 **ITAMP13E**: Internal tamper 13 enable
0: Internal tamper 13 disabled.
1: Internal tamper 13 enabled.

Bit 27 **ITAMP12E**: Internal tamper 12 enable
0: Internal tamper 12 disabled.
1: Internal tamper 12 enabled.

Bit 26 **ITAMP11E**: Internal tamper 11 enable
0: Internal tamper 11 disabled.
1: Internal tamper 11 enabled.

Bit 25 Reserved, must be kept at reset value.

Bit 24 **ITAMP9E**: Internal tamper 9 enable
0: Internal tamper 9 disabled.
1: Internal tamper 9 enabled.

Bit 23 **ITAMP8E**: Internal tamper 8 enable
0: Internal tamper 8 disabled.
1: Internal tamper 8 enabled.

Bit 22 **ITAMP7E**: Internal tamper 7 enable
0: Internal tamper 7 disabled.
1: Internal tamper 7 enabled

Bit 21 **ITAMP6E**: Internal tamper 6 enable
0: Internal tamper 6 disabled.
1: Internal tamper 6 enabled.

Bit 20 **ITAMP5E**: Internal tamper 5 enable
0: Internal tamper 5 disabled.
1: Internal tamper 5 enabled.

Bit 19 **ITAMP4E**: Internal tamper 4 enable
0: Internal tamper 4 disabled.
1: Internal tamper 4 enabled.

Bit 18 **ITAMP3E**: Internal tamper 3 enable
0: Internal tamper 3 disabled.
1: Internal tamper 3 enabled.

Bit 17 **ITAMP2E**: Internal tamper 2 enable
0: Internal tamper 2 disabled.
1: Internal tamper 2 enabled.

Bit 16 **ITAMP1E**: Internal tamper 1 enable
0: Internal tamper 1 disabled.
1: Internal tamper 1 enabled.

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **TAMP8E**: Tamper detection on TAMP_IN8 enable(1)
0: Tamper detection on TAMP_IN8 is disabled.
1: Tamper detection on TAMP_IN8 is enabled.

Bit 6 **TAMP7E**: Tamper detection on TAMP_IN7 enable(1)
0: Tamper detection on TAMP_IN7 is disabled.
1: Tamper detection on TAMP_IN7 is enabled.

Bit 5 **TAMP6E**: Tamper detection on TAMP_IN6 enable(1)
0: Tamper detection on TAMP_IN6 is disabled.
1: Tamper detection on TAMP_IN6 is enabled.

Bit 4 **TAMP5E**: Tamper detection on TAMP_IN5 enable(1)
0: Tamper detection on TAMP_IN5 is disabled.
1: Tamper detection on TAMP_IN5 is enabled.

Bit 3 **TAMP4E**: Tamper detection on TAMP_IN4 enable(1)
0: Tamper detection on TAMP_IN4 is disabled.
1: Tamper detection on TAMP_IN4 is enabled.

Bit 2 **TAMP3E**: Tamper detection on TAMP_IN3 enable(1)
0: Tamper detection on TAMP_IN3 is disabled.
1: Tamper detection on TAMP_IN3 is enabled.

Bit 1 **TAMP2E**: Tamper detection on TAMP_IN2 enable(1)
0: Tamper detection on TAMP_IN2 is disabled.
1: Tamper detection on TAMP_IN2 is enabled.

Bit 0 **TAMP1E**: Tamper detection on TAMP_IN1 enable(1)
0: Tamper detection on TAMP_IN1 is disabled.
1: Tamper detection on TAMP_IN1 is enabled.

1. Tamper detection mode (selected with TAMP_FLTCR, TAMP_ATCR1, TAMP_ATCR2 registers and TAMPxTRG bits in TAMP_CR2), must be configured before enabling the tamper detection.

58.6.2 TAMP control register 2 (TAMP_CR2)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x04

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TAMP8 TRG	TAMP7 TRG	TAMP6 TRG	TAMP5 TRG	TAMP4 TRG	TAMP3 TRG	TAMP2 TRG	TAMP1 TRG	BK ERASE	BK BLOCK	Res.	Res.	Res.	TAMP3 MSK	TAMP2 MSK	TAMP1 MSK
rw	rw	rw	rw	rw	rw	rw	rw	w	rw				rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP8 POM	TAMP7 POM	TAMP6 POM	TAMP5 POM	TAMP4 POM	TAMP3 POM	TAMP2 POM	TAMP1 POM
								rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **TAMP8TRG**: Active level for tamper 8 input (active mode disabled)
- 0: If TAMPFLT ≠ 00 tamper 8 input staying low triggers a tamper detection event.
  If TAMPFLT = 00 tamper 8 input rising edge triggers a tamper detection event.
- 1: If TAMPFLT ≠ 00 tamper 8 input staying high triggers a tamper detection event.
  If TAMPFLT = 00 tamper 8 input falling edge triggers a tamper detection event.

Bit 30 **TAMP7TRG**: Active level for tamper 7 input (active mode disabled)
- 0: If TAMPFLT ≠ 00 tamper 7 input staying low triggers a tamper detection event.
  If TAMPFLT = 00 tamper 7 input rising edge triggers a tamper detection event.
- 1: If TAMPFLT ≠ 00 tamper 7 input staying high triggers a tamper detection event.
  If TAMPFLT = 00 tamper 7 input falling edge triggers a tamper detection event.

Bit 29 **TAMP6TRG**: Active level for tamper 6 input (active mode disabled)
- 0: If TAMPFLT ≠ 00 tamper 6 input staying low triggers a tamper detection event.
  If TAMPFLT = 00 tamper 6 input rising edge triggers a tamper detection event.
- 1: If TAMPFLT ≠ 00 tamper 6 input staying high triggers a tamper detection event.
  If TAMPFLT = 00 tamper 6 input falling edge triggers a tamper detection event.

Bit 28 **TAMP5TRG**: Active level for tamper 5 input (active mode disabled)
- 0: If TAMPFLT ≠ 00 tamper 5 input staying low triggers a tamper detection event.
  If TAMPFLT = 00 tamper 5 input rising edge triggers a tamper detection event.
- 1: If TAMPFLT ≠ 00 tamper 5 input staying high triggers a tamper detection event.
  If TAMPFLT = 00 tamper 5 input falling edge triggers a tamper detection event.

Bit 27 **TAMP4TRG**: Active level for tamper 4 input (active mode disabled)
- 0: If TAMPFLT ≠ 00 tamper 4 input staying low triggers a tamper detection event.
  If TAMPFLT = 00 tamper 4 input rising edge triggers a tamper detection event.
- 1: If TAMPFLT ≠ 00 tamper 4 input staying high triggers a tamper detection event.
  If TAMPFLT = 00 tamper 4 input falling edge triggers a tamper detection event.

Bit 26 **TAMP3TRG**: Active level for tamper 3 input
0: If TAMPFLT ≠ 00 tamper 3 input staying low triggers a tamper detection event.
If TAMPFLT = 00 tamper 3 input rising edge triggers a tamper detection event.
1: If TAMPFLT ≠ 00 tamper 3 input staying high triggers a tamper detection event.
If TAMPFLT = 00 tamper 3 input falling edge triggers a tamper detection event.

Bit 25 **TAMP2TRG**: Active level for tamper 2 input
0: If TAMPFLT ≠ 00 tamper 2 input staying low triggers a tamper detection event.
If TAMPFLT = 00 tamper 2 input rising edge triggers a tamper detection event.
1: If TAMPFLT ≠ 00 tamper 2 input staying high triggers a tamper detection event.
If TAMPFLT = 00 tamper 2 input falling edge triggers a tamper detection event.

Bit 24 **TAMP1TRG**: Active level for tamper 1 input
0: If TAMPFLT ≠ 00 tamper 1 input staying low triggers a tamper detection event.
If TAMPFLT = 00 tamper 1 input rising edge triggers a tamper detection event.
1: If TAMPFLT ≠ 00 tamper 1 input staying high triggers a tamper detection event.
If TAMPFLT = 00 tamper 1 input falling edge triggers a tamper detection event.

Bit 23 **BKERASE**: Backup registers and device secrets(1) erase
Writing '1' to this bit reset the backup registers and device secrets(1). Writing 0 has no effect. This bit is always read as 0.

Bit 22 **BKBLOCK**: Backup registers and device secrets(1) access blocked
0: backup registers and device secrets(1) can be accessed if no tamper flag is set
1: backup registers and device secrets(1) cannot be accessed

Bits 21:19 Reserved, must be kept at reset value.

Bit 18 **TAMP3MSK**: Tamper 3 mask
0: Tamper 3 event generates a trigger event and TAMP3F must be cleared by software to allow next tamper event detection.
1: Tamper 3 event generates a trigger event. TAMP3F is masked and internally cleared by hardware. The backup registers and device secrets(1) are not erased.
The tamper 3 interrupt must not be enabled when TAMP3MSK is set.

Bit 17 **TAMP2MSK**: Tamper 2 mask
0: Tamper 2 event generates a trigger event and TAMP2F must be cleared by software to allow next tamper event detection.
1: Tamper 2 event generates a trigger event. TAMP2F is masked and internally cleared by hardware. The backup registers and device secrets(1) are not erased.
The tamper 2 interrupt must not be enabled when TAMP2MSK is set.

Bit 16 **TAMP1MSK**: Tamper 1 mask
0: Tamper 1 event generates a trigger event and TAMP1F must be cleared by software to allow next tamper event detection.
1: Tamper 1 event generates a trigger event. TAMP1F is masked and internally cleared by hardware. The backup registers and device secrets(1) are not erased.
The tamper 1 interrupt must not be enabled when TAMP1MSK is set.

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **TAMP8POM**: Tamper 8 potential mode
0: Tamper 8 event detection is in confirmed mode(1).
1: Tamper 8 event detection is in potential mode(2).

Bit 6 **TAMP7POM**: Tamper 7 potential mode
0: Tamper 7 event detection is in confirmed mode(1).
1: Tamper 7 event detection is in potential mode(2).

Bit 5 **TAMP6POM**: Tamper 6 potential mode
0: Tamper 6 event detection is in confirmed mode(1).
1: Tamper 6 event detection is in potential mode(2).

Bit 4 **TAMP5POM**: Tamper 5 potential mode
0: Tamper 5 event detection is in confirmed mode(1).
1: Tamper 5 event detection is in potential mode(2).

Bit 3 **TAMP4POM**: Tamper 4 potential mode
0: Tamper 4 event detection is in confirmed mode(1).
1: Tamper 4 event detection is in potential mode(2).

Bit 2 **TAMP3POM**: Tamper 3 potential mode
0: Tamper 3 event detection is in confirmed mode(1).
1: Tamper 3 event detection is in potential mode(2).

Bit 1 **TAMP2POM**: Tamper 2 potential mode
0: Tamper 2 event detection is in confirmed mode(1).
1: Tamper 2 event detection is in potential mode(2).

Bit 0 **TAMP1POM**: Tamper 1 potential mode
0: Tamper 1 event detection is in confirmed mode(1).
1: Tamper 1 event detection is in potential mode(2).

1. The effects of tamper detection in confirmed mode is described with tamp_confirmed and tamp_confirmed_rpcfgx signals in *Table 627: TAMP interconnection*.
2. The effects of tamper detection in potential mode is described with tamp_potential and tamp_potential_rpcfgx signals in *Table 627: TAMP interconnection*.

58.6.3 TAMP control register 3 (TAMP_CR3)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x08

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	ITAMP 15POM	Res.	ITAMP 13POM	ITAMP 12POM	ITAMP 11POM	Res.	ITAMP9 POM	ITAMP8 POM	ITAMP7 POM	ITAMP6 POM	ITAMP5 POM	ITAMP4 POM	ITAMP3 POM	ITAMP2 POM	ITAMP1 POM
	rw		rw	rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **ITAMP15POM**: Internal tamper 15 potential mode
0: Internal tamper 15 event detection is in confirmed mode(1).
1: Internal tamper 15 event detection is in potential mode(2).

Bit 13 Reserved, must be kept at reset value.

Bit 12 **ITAMP13POM**: Internal tamper 13 potential mode
0: Internal tamper 13 event detection is in confirmed mode(1).
1: Internal tamper 13 event detection is in potential mode(2).

Bit 11 **ITAMP12POM**: Internal tamper 12 potential mode
0: Internal tamper 12 event detection is in confirmed mode(1).
1: Internal tamper 12 event detection is in potential mode(2).

Bit 10 **ITAMP11POM**: Internal tamper 11 potential mode
0: Internal tamper 11 event detection is in confirmed mode(1).
1: Internal tamper 11 event detection is in potential mode(2).

Bit 9 Reserved, must be kept at reset value.

Bit 8 **ITAMP9POM**: Internal tamper 9 potential mode
0: Internal tamper 9 event detection is in confirmed mode(1).
1: Internal tamper 9 event detection is in potential mode(2).

Bit 7 **ITAMP8POM**: Internal tamper 8 potential mode
0: Internal tamper 8 event detection is in confirmed mode(1).
1: Internal tamper 8 event detection is in potential mode(2).

Bit 6 **ITAMP7POM**: Internal tamper 7 potential mode
0: Internal tamper 7 event detection is in confirmed mode(1).
1: Internal tamper 7 event detection is in potential mode(2).

Bit 5 **ITAMP6POM**: Internal tamper 6 potential mode
0: Internal tamper 6 event detection is in confirmed mode(1).
1: Internal tamper 6 event detection is in potential mode(2).

Bit 4 **ITAMP5POM**: Internal tamper 5 potential mode
0: Internal tamper 5 event detection is in confirmed mode(1).
1: Internal tamper 5 event detection is in potential mode(2).

Bit 3 **ITAMP4POM**: Internal tamper 4 potential mode
0: Internal tamper 4 event detection is in confirmed mode(1).
1: Internal tamper 4 event detection is in potential mode(2).

Bit 2 **ITAMP3POM**: Internal tamper 3 potential mode
0: Internal tamper 3 event detection is in confirmed mode(1).
1: Internal tamper 3 event detection is in potential mode(2).

Bit 1 **ITAMP2POM**: Internal tamper 2 potential mode
0: Internal tamper 2 event detection is in confirmed mode(1).
1: Internal tamper 2 event detection is in potential mode(2).

Bit 0 **ITAMP1POM**: Internal tamper 1 potential mode
0: Internal tamper 1 event detection is in confirmed mode(1).
1: Internal tamper 1 event detection is in potential mode(2).

1. The effects of internal tamper detection in confirmed mode is described with tamp_confirmed and tamp_confirmed_rpcfgx signals in *Table 627: TAMP interconnection*
2. The effects of internal tamper detection in potential mode is described with tamp_potential and tamp_potential_rpcfgx signals in *Table 627: TAMP interconnection*.

58.6.4 TAMP filter control register (TAMP_FLTCR)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP*

secure protection modes.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x0C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP PUDIS	TAMPPRCH [1:0]		TAMPFLT [1:0]		TAMPFREQ [2:0]		
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **TAMPPUDIS**: TAMP_INx pull-up disable
This bit determines if each of the TAMPx pins are precharged before each sample.
0: Precharge TAMP_INx pins before sampling (enable internal pull-up)
1: Disable precharge of TAMP_INx pins.

Bits 6:5 **TAMPPRCH[1:0]**: TAMP_INx precharge duration
These bit determines the duration of time during which the pull-up/is activated before each sample. TAMPPRCH is valid for each of the TAMP_INx inputs.
0x0: 1 RTCCLK cycle
0x1: 2 RTCCLK cycles
0x2: 4 RTCCLK cycles
0x3: 8 RTCCLK cycles

Bits 4:3 **TAMPFLT[1:0]**: TAMP_INx filter count
These bits determines the number of consecutive samples at the specified level (TAMP*TRG) needed to activate a tamper event. TAMPFLT is valid for each of the TAMP_INx inputs.
0x0: Tamper event is activated on edge of TAMP_INx input transitions to the active level (no internal pull-up on TAMP_INx input).
0x1: Tamper event is activated after 2 consecutive samples at the active level.
0x2: Tamper event is activated after 4 consecutive samples at the active level.
0x3: Tamper event is activated after 8 consecutive samples at the active level.

Bits 2:0 **TAMPFREQ[2:0]**: Tamper sampling frequency
Determines the frequency at which each of the TAMP_INx inputs are sampled.
0x0: RTCCLK / 32768 (1 Hz when RTCCLK = 32768 Hz)
0x1: RTCCLK / 16384 (2 Hz when RTCCLK = 32768 Hz)
0x2: RTCCLK / 8192 (4 Hz when RTCCLK = 32768 Hz)
0x3: RTCCLK / 4096 (8 Hz when RTCCLK = 32768 Hz)
0x4: RTCCLK / 2048 (16 Hz when RTCCLK = 32768 Hz)
0x5: RTCCLK / 1024 (32 Hz when RTCCLK = 32768 Hz)
0x6: RTCCLK / 512 (64 Hz when RTCCLK = 32768 Hz)
0x7: RTCCLK / 256 (128 Hz when RTCCLK = 32768 Hz)

Note: This register concerns only the tamper inputs in passive mode.

58.6.5 TAMP active tamper control register 1 (TAMP_ATCR1)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x10

Backup domain reset value: 0x0007 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FLTEN	ATO SHARE	Res.	Res.	Res.	ATPER[2:0]			Res.	Res.	Res.	Res.	ATCKSEL[3:0]			
rw	rw				rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ATOSEL4[1:0]		ATOSEL3[1:0]		ATOSEL2[1:0]		ATOSEL1[1:0]		TAMP8 AM	TAMP7 AM	TAMP6 AM	TAMP5 AM	TAMP4 AM	TAMP3 AM	TAMP2 AM	TAMP1 AM
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **FLTEN**: Active tamper filter enable

0: Active tamper filtering disable

1: Active tamper filtering enable: a tamper event is detected when 2 comparison mismatches occur out of 4 consecutive samples.

Bit 30 **ATOSHARE**: Active tamper output sharing

0: Each active tamper input TAMP_INi is compared with its dedicated output TAMP_OUTi

1: Each active tamper input TAMP_INi is compared with TAMPOUTSELi defined by ATOSELi bits.

Bits 29:27 Reserved, must be kept at reset value.

Bits 26:24 **ATPER[2:0]**: Active tamper output change period

The tamper output is changed every CK_ATPER = (2^{ATPER} x CK_ATPRE) cycles. Refer to *Table 630: Minimum ATPER value*.

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **ATCKSEL[3:0]**: Active tamper RTC asynchronous prescaler clock selection

These bits selects the RTC asynchronous prescaler stage output. The selected clock is CK_ATPRE = RTCCLK/$2^{ATCKSEL}$.

Note: These bits can be written only when all active tampers are disabled. The write protection remains for up to 1.5 CK_ATPRE cycles after all the active tampers are disable.

Bits 15:14 **ATOSEL4[1:0]**: Active tamper shared output 4 selection

00: TAMPOUTSEL4 = TAMP_OUT1

01: TAMPOUTSEL4 = TAMP_OUT2

10: TAMPOUTSEL4 = TAMP_OUT3

11: TAMPOUTSEL4 = TAMP_OUT4

If the TAMP_OUTx output is not available in the package pinout, the ouput selection value is reserved and must not be used.

Bits 13:12 **ATOSEL3[1:0]**: Active tamper shared output 3 selection
00: TAMPOUTSEL3 = TAMP_OUT1
01: TAMPOUTSEL3 = TAMP_OUT2
10: TAMPOUTSEL3 = TAMP_OUT3
11: TAMPOUTSEL3 = TAMP_OUT4
If the TAMP_OUTx output is not available in the package pinout, the ouput selection value is reserved and must not be used.

Bits 11:10 **ATOSEL2[1:0]**: Active tamper shared output 2 selection
00: TAMPOUTSEL2 = TAMP_OUT1
01: TAMPOUTSEL2 = TAMP_OUT2
10: TAMPOUTSEL2 = TAMP_OUT3
11: TAMPOUTSEL2 = TAMP_OUT4
If the TAMP_OUTx output is not available in the package pinout, the ouput selection value is reserved and must not be used.

Bits 9:8 **ATOSEL1[1:0]**: Active tamper shared output 1 selection
00: TAMPOUTSEL1 = TAMP_OUT1
01: TAMPOUTSEL1 = TAMP_OUT2
10: TAMPOUTSEL1 = TAMP_OUT3
11: TAMPOUTSEL1 = TAMP_OUT4
If the TAMP_OUTx output is not available in the package pinout, the ouput selection value is reserved and must not be used.

Bit 7 **TAMP8AM**: Tamper 8 active mode
0: Tamper 8 detection mode is passive.
1: Tamper 8 detection mode is active.

Bit 6 **TAMP7AM**: Tamper 7 active mode
0: Tamper 7 detection mode is passive.
1: Tamper 7 detection mode is active.

Bit 5 **TAMP6AM**: Tamper 6 active mode
0: Tamper 6 detection mode is passive.
1: Tamper 6 detection mode is active.

Bit 4 **TAMP5AM**: Tamper 5 active mode
0: Tamper 5 detection mode is passive.
1: Tamper 5 detection mode is active.

Bit 3 **TAMP4AM**: Tamper 4 active mode
0: Tamper 4 detection mode is passive.
1: Tamper 4 detection mode is active.

Bit 2 **TAMP3AM**: Tamper 3 active mode
0: Tamper 3 detection mode is passive.
1: Tamper 3 detection mode is active.

Bit 1 **TAMP2AM**: Tamper 2 active mode
0: Tamper 2 detection mode is passive.
1: Tamper 2 detection mode is active.

Bit 0 **TAMP1AM**: Tamper 1 active mode
0: Tamper 1 detection mode is passive.
1: Tamper 1 detection mode is active.

Note: Changing the active tampers configuration in this register is not allowed when a TAMPxAM bit is set, unless the corresponding TAMPxE bits are all cleared in the TAMP_CR1 register.

All tampers configured in active mode must be enabled at the same time (by setting all related TAMPxE in the same TAMP_CR1 write).

All tampers configured in active mode must be disabled at the same time (by clearing all related TAMPxE in the same TAMP_CR1 write).

A minimum duration of 1 CK_ATPRE period must be waited for after disabling the active tampers and before re-enabling them.

58.6.6 TAMP active tamper seed register (TAMP_ATSEEDR)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x14

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SEED[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SEED[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **SEED[31:0]**: Pseudo-random generator seed value

This register must be written four times with 32-bit values to provide the 128-bit seed to the PRNG. Writing to this register automatically sends the seed value to the PRNG.

58.6.7 TAMP active tamper output register (TAMP_ATOR)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x18

Backup domain reset value: 0x0000 0000

System reset: not affected, except for SEEDF which is reset to 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INITS	SEEDF	Res.	Res.	Res.	Res.	Res.	Res.	PRNG[7:0]							
r	r							r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **INITS**: Active tamper initialization status

This flag is set by hardware when the PRNG has absorbed the first 128-bit seed, meaning that the enabled active tampers are functional. This flag is cleared when the active tampers are disabled.

Bit 14 **SEEDF**: Seed running flag

This flag is set by hardware when a new seed is written in the TAMP_ATSEEDR. It is cleared by hardware when the PRNG has absorbed this new seed, and by system reset. The TAMP APB clock must not be switched off as long as SEEDF is set.

Bits 13:8 Reserved, must be kept at reset value.

Bits 7:0 **PRNG[7:0]**: Pseudo-random generator value

This field provides the values of the PRNG output. Because of potential inconsistencies due to synchronization delays, PRNG must be read at least twice. The read value is correct if it is equal to previous read value.

This field can only be read when the APB is in secure mode.

58.6.8 TAMP active tamper control register 2 (TAMP_ATCR2)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x1C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ATOSEL8[2:0]			ATOSEL7[2:0]			ATOSEL6[2:0]			ATOSEL5[2:0]			ATOSEL4[2:0]			ATOSEL3[2]
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ATOSEL3[1:0]		ATOSEL2[2:0]			ATOSEL1[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw								

Bits 31:29 **ATOSEL8[2:0]**: Active tamper shared output 8 selection
000: TAMPOUTSEL8 = TAMP_OUT1
001: TAMPOUTSEL8 = TAMP_OUT2
010: TAMPOUTSEL8 = TAMP_OUT3
011: TAMPOUTSEL8 = TAMP_OUT4
100: TAMPOUTSEL8 = TAMP_OUT5
101: TAMPOUTSEL8 = TAMP_OUT6
110: TAMPOUTSEL8 = TAMP_OUT7
111: TAMPOUTSEL8 = TAMP_OUT8
If the TAMP_OUTx output is not available in the package pinout, the ouput selection value is reserved and must not be used.

Bits 28:26 **ATOSEL7[2:0]**: Active tamper shared output 7 selection
000: TAMPOUTSEL7 = TAMP_OUT1
001: TAMPOUTSEL7 = TAMP_OUT2
010: TAMPOUTSEL7 = TAMP_OUT3
011: TAMPOUTSEL7 = TAMP_OUT4
100: TAMPOUTSEL7 = TAMP_OUT5
101: TAMPOUTSEL7 = TAMP_OUT6
110: TAMPOUTSEL7 = TAMP_OUT7
111: TAMPOUTSEL7 = TAMP_OUT8
If the TAMP_OUTx output is not available in the package pinout, the ouput selection value is reserved and must not be used.

Bits 25:23 **ATOSEL6[2:0]**: Active tamper shared output 6 selection
000: TAMPOUTSEL6 = TAMP_OUT1
001: TAMPOUTSEL6 = TAMP_OUT2
010: TAMPOUTSEL6 = TAMP_OUT3
011: TAMPOUTSEL6 = TAMP_OUT4
100: TAMPOUTSEL6 = TAMP_OUT5
101: TAMPOUTSEL6 = TAMP_OUT6
110: TAMPOUTSEL6 = TAMP_OUT7
111: TAMPOUTSEL6 = TAMP_OUT8
If the TAMP_OUTx output is not available in the package pinout, the ouput selection value is reserved and must not be used.

Bits 22:20 **ATOSEL5[2:0]**: Active tamper shared output 5 selection
000: TAMPOUTSEL5 = TAMP_OUT1
001: TAMPOUTSEL5 = TAMP_OUT2
010: TAMPOUTSEL5 = TAMP_OUT3
011: TAMPOUTSEL5 = TAMP_OUT4
100: TAMPOUTSEL5 = TAMP_OUT5
101: TAMPOUTSEL5 = TAMP_OUT6
110: TAMPOUTSEL5 = TAMP_OUT7
111: TAMPOUTSEL5 = TAMP_OUT8
If the TAMP_OUTx output is not available in the package pinout, the ouput selection value is reserved and must not be used.

Bits 19:17 **ATOSEL4[2:0]**: Active tamper shared output 4 selection

000: TAMPOUTSEL4 = TAMP_OUT1
001: TAMPOUTSEL4 = TAMP_OUT2
010: TAMPOUTSEL4 = TAMP_OUT3
011: TAMPOUTSEL4 = TAMP_OUT4
100: TAMPOUTSEL4 = TAMP_OUT5
101: TAMPOUTSEL4 = TAMP_OUT6
110: TAMPOUTSEL4 = TAMP_OUT7
111: TAMPOUTSEL4 = TAMP_OUT8

If the TAMP_OUTx output is not available in the package pinout, the ouput selection value is reserved and must not be used.

Bits 18:17 are the mirror of ATOSEL4[1:0] in the TAMP_ATCR1, and so can also be read or written through TAMP_ATCR1.

Bits 16:14 **ATOSEL3[2:0]**: Active tamper shared output 3 selection

000: TAMPOUTSEL3 = TAMP_OUT1
001: TAMPOUTSEL3 = TAMP_OUT2
010: TAMPOUTSEL3 = TAMP_OUT3
011: TAMPOUTSEL3 = TAMP_OUT4
100: TAMPOUTSEL3 = TAMP_OUT5
101: TAMPOUTSEL3 = TAMP_OUT6
110: TAMPOUTSEL3 = TAMP_OUT7
111: TAMPOUTSEL3 = TAMP_OUT8

If the TAMP_OUTx output is not available in the package pinout, the ouput selection value is reserved and must not be used.

Bits 15:14 are the mirror of ATOSEL3[1:0] in the TAMP_ATCR1, and so can also be read or written through TAMP_ATCR1.

Bits 13:11 **ATOSEL2[2:0]**: Active tamper shared output 2 selection
000: TAMPOUTSEL2 = TAMP_OUT1
001: TAMPOUTSEL2 = TAMP_OUT2
010: TAMPOUTSEL2 = TAMP_OUT3
011: TAMPOUTSEL2 = TAMP_OUT4
100: TAMPOUTSEL2 = TAMP_OUT5
101: TAMPOUTSEL2 = TAMP_OUT6
110: TAMPOUTSEL2 = TAMP_OUT7
111: TAMPOUTSEL2 = TAMP_OUT8
If the TAMP_OUTx output is not available in the package pinout, the ouput selection value is reserved and must not be used.
Bits 12:11 are the mirror of ATOSEL2[1:0] in the TAMP_ATCR1, and so can also be read or written through TAMP_ATCR1.

Bits 10:8 **ATOSEL1[2:0]**: Active tamper shared output 1 selection
000: TAMPOUTSEL1 = TAMP_OUT1
001: TAMPOUTSEL1 = TAMP_OUT2
010: TAMPOUTSEL1 = TAMP_OUT3
011: TAMPOUTSEL1 = TAMP_OUT4
100: TAMPOUTSEL1 = TAMP_OUT5
101: TAMPOUTSEL1 = TAMP_OUT6
110: TAMPOUTSEL1 = TAMP_OUT7
111: TAMPOUTSEL1 = TAMP_OUT8
If the TAMP_OUTx output is not available in the package pinout, the ouput selection value is reserved and must not be used.
Bits 9:8 are the mirror of ATOSEL1[1:0] in the TAMP_ATCR1, and so can also be read or written through TAMP_ATCR1.

Bits 7:0 Reserved, must be kept at reset value.

Note: Changing the active tampers configuration in this register is not allowed when a TAMPxAM bit is set, unless the corresponding TAMPxE bits are all cleared in the TAMP_CR1 register.

All tampers configured in active mode must be enabled at the same time (by setting all related TAMPxE in the same TAMP_CR1 write).

All tampers configured in active mode must be disabled at the same time (by clearing all related TAMPxE in the same TAMP_CR1 write).

A minimum duration of 1 CK_ATPRE period must be waited for after disabling the active tampers and before re-enabling them.

58.6.9 TAMP secure configuration register (TAMP_SECCFGR)

If TZEN = 1, this register can be written only when the APB access is secure. If TZEN = 0, BKPRWSEC[7:0], BKPWSEC[7:0] and BHKLOCK can be written with nonsecure APB access, and TAMPSEC, CNT1SEC cannot be written.

This register can be globally write-protected, or each bit of this register can be individually write-protected against unprivileged access depending on the TAMP_PRIVCFGR configuration (refer to *Section 58.3.7: TAMP privilege protection modes*).

Address offset: 0x20

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TAMPSEC	BHKLOCK	Res.	Res.	Res.	Res.	Res.	Res.	BKPWSEC[7:0]							
rw	rs							rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT1SEC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BKPRWSEC[7:0]							
rw								rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **TAMPSEC**: Tamper protection (excluding monotonic counters and backup registers)

0: Tamper configuration and interrupt can be written when the APB access is secure or nonsecure.

1: Tamper configuration and interrupt can be written only when the APB access is secure.

Note: Refer to Section 58.3.5: TAMP secure protection modes for details on the read protection.

Bit 30 **BHKLOCK**: Boot hardware key lock

This bit can be read and can only be written to 1 by software. It is cleared by hardware together with the backup registers following a tamper detection event or when the product state is opened.

0: The Backup registers from TAMP_BKP0R to TAMP_BKP7R can be accessed according to the Protection zone they belong to.

1: The backup registers from TAMP_BKP0R to TAMP_BKP7R cannot be accessed neither in read nor in write (they are read as 0 and write ignore).

Bits 29:24 Reserved, must be kept at reset value.

Bits 23:16 **BKPWSEC[7:0]**: Backup registers write protection offset

BKPWSEC value must be from 0 to 32.

Protection zone 2 is defined for backup registers from TAMP_BKPyR (y = BKPRWSEC) to TAMP_BKPzR (z = BKPWSEC-1, with BKPWSEC > BKPRWSEC):

- if TZEN=1, these backup registers can be written only with secure access.
- They can be read with secure or nonsecure access.

If BKPWSEC = 0 or if BKPWSEC ≤ BKPRWSEC: there is no protection zone 2.

Protection zone 3 is defined for backup registers from TAMP_BKPtR (t = BKPWSEC if BKPWSEC ≥ BKPRWSEC, else t = BKPRWSEC).

- They can be read or written with secure or nonsecure access.

If BKPWSEC = 32: there is no protection zone 3.

Refer to *Figure 766: Backup registers protection zones*.

Note: If TZEN=0: the protection zone 2 can be read and written with nonsecure access.

Note: If BKPWPRIV is set, BKPWSEC[7:0] can be written only in privileged mode.

Bit 15 **CNT1SEC**: Monotonic counter 1 secure protection
0: Monotonic counter 1 (TAMP_COUNT1R) can be read and written when the APB access is secure or nonsecure.
1: Monotonic counter 1 (TAMP_COUNT1R) can be read and written only when the APB access is secure.

Bits 14:8 Reserved, must be kept at reset value.

Bits 7:0 **BKPRWSEC[7:0]**: Backup registers read/write protection offset
BKPRWSEC value must be from 0 to 32.

Protection zone 1 is defined for backup registers from TAMP_BKP0R to TAMP_BKPxR (x = BKPRWSEC-1, with BKPRWSEC ≥ 1).
– if TZEN=1, these backup registers can be read and written only with secure access.
If BKPRWSEC = 0: there is no protection zone 1.

Refer to *Figure 766: Backup registers protection zones*.

Note: If TZEN=0: the protection zone 1 can be read and written with nonsecure access.
Note: If BKPRWPRIV or BKPWPRIV is set, BKPRWSEC[7:0] can be written only in privileged mode.

58.6.10 TAMP privilege configuration register (TAMP_PRIVCFGR)

This register can be written only when the APB access is privileged.

When TZEN = 1, this register can be write-protected, or each bit of this register can be individually write-protected against nonsecure access depending on the TAMP_SECCFGR configuration (refer to *Section 58.3.5: TAMP secure protection modes*).

Address offset: 0x24

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TAMP PRIV	BKP WPRIV	BKPR WPRIV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw													
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT1 PRIV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw															

Bit 31 **TAMPPRIV**: Tamper privilege protection (excluding monotonic counters and backup registers)
0: Tamper configuration and interrupt can be written with privileged or unprivileged access.
1: Tamper configuration and interrupt can be written only with privileged access.
Note: Refer to Section 58.3.7: TAMP privilege protection modes for details on the read protection.

Bit 30 **BKPWPRIV**: Backup registers zone 2 privilege protection
0: Backup registers zone 2 can be written with privileged or unprivileged access.
1: Backup registers zone 2 can be written only with privileged access.

Bit 29 **BKPRWPRIV**: Backup registers zone 1 privilege protection
0: Backup registers zone 1 can be read and written with privileged or unprivileged access.
1: Backup registers zone 1 can be read and written only with privileged access

Bits 28:16 Reserved, must be kept at reset value.

Bit 15 **CNT1PRIV**: Monotonic counter 1 privilege protection
0: Monotonic counter 1 (TAMP_COUNT1R) can be read and written when the APB access is privileged or unprivileged.
1: Monotonic counter 1 (TAMP_COUNT1R) can be read and written only when the APB access is privileged.

Bits 14:0 Reserved, must be kept at reset value.

58.6.11 TAMP interrupt enable register (TAMP_IER)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x2C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	ITAMP15IE	Res.	ITAMP13IE	ITAMP12IE	ITAMP11IE	Res.	ITAMP9IE	ITAMP8IE	ITAMP7IE	ITAMP6IE	ITAMP5IE	ITAMP4IE	ITAMP3IE	ITAMP2IE	ITAMP1IE
	rw		rw	rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP8IE	TAMP7IE	TAMP6IE	TAMP5IE	TAMP4IE	TAMP3IE	TAMP2IE	TAMP1IE
								rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **ITAMP15IE**: Internal tamper 15 interrupt enable
0: Internal tamper 15 interrupt disabled.
1: Internal tamper 15 interrupt enabled.

Bit 29 Reserved, must be kept at reset value.

Bit 28 **ITAMP13IE**: Internal tamper 13 interrupt enable
0: Internal tamper 13 interrupt disabled.
1: Internal tamper 13 interrupt enabled.

Bit 27 **ITAMP12IE**: Internal tamper 12 interrupt enable
0: Internal tamper 12 interrupt disabled.
1: Internal tamper 12 interrupt enabled.

Bit 26 **ITAMP11IE**: Internal tamper 11 interrupt enable
0: Internal tamper 11 interrupt disabled.
1: Internal tamper 11 interrupt enabled.

Bit 25 Reserved, must be kept at reset value.

Bit 24 **ITAMP9IE**: Internal tamper 9 interrupt enable
0: Internal tamper 9 interrupt disabled.
1: Internal tamper 9 interrupt enabled.

Bit 23 **ITAMP8IE**: Internal tamper 8 interrupt enable
0: Internal tamper 8 interrupt disabled.
1: Internal tamper 8 interrupt enabled.

Bit 22 **ITAMP7IE**: Internal tamper 7 interrupt enable
0: Internal tamper 7 interrupt disabled.
1: Internal tamper 7 interrupt enabled.

Bit 21 **ITAMP6IE**: Internal tamper 6 interrupt enable
0: Internal tamper 6 interrupt disabled.
1: Internal tamper 6 interrupt enabled.

Bit 20 **ITAMP5IE**: Internal tamper 5 interrupt enable
0: Internal tamper 5 interrupt disabled.
1: Internal tamper 5 interrupt enabled.

Bit 19 **ITAMP4IE**: Internal tamper 4 interrupt enable
0: Internal tamper 4 interrupt disabled.
1: Internal tamper 4 interrupt enabled.

Bit 18 **ITAMP3IE**: Internal tamper 3 interrupt enable
0: Internal tamper 3 interrupt disabled.
1: Internal tamper 3 interrupt enabled.

Bit 17 **ITAMP2IE**: Internal tamper 2 interrupt enable
0: Internal tamper 2 interrupt disabled.
1: Internal tamper 2 interrupt enabled.

Bit 16 **ITAMP1IE**: Internal tamper 1 interrupt enable
0: Internal tamper 1 interrupt disabled.
1: Internal tamper 1 interrupt enabled

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **TAMP8IE**: Tamper 8 interrupt enable
0: Tamper 8 interrupt disabled.
1: Tamper 8 interrupt enabled.

Bit 6 **TAMP7IE**: Tamper 7interrupt enable
0: Tamper 7 interrupt disabled.
1: Tamper 7interrupt enabled.

Bit 5 **TAMP6IE**: Tamper 6 interrupt enable
0: Tamper 6 interrupt disabled.
1: Tamper 6 interrupt enabled.

Bit 4 **TAMP5IE**: Tamper 5 interrupt enable
0: Tamper 5 interrupt disabled.
1: Tamper 5 interrupt enabled.

Bit 3 **TAMP4IE**: Tamper 4 interrupt enable
0: Tamper 4 interrupt disabled.
1: Tamper 4 interrupt enabled.

Bit 2 **TAMP3IE**: Tamper 3 interrupt enable
0: Tamper 3 interrupt disabled.
1: Tamper 3 interrupt enabled..

Bit 1 **TAMP2IE**: Tamper 2 interrupt enable
0: Tamper 2 interrupt disabled.
1: Tamper 2 interrupt enabled.

Bit 0 **TAMP1IE**: Tamper 1 interrupt enable
0: Tamper 1 interrupt disabled.
1: Tamper 1 interrupt enabled.

58.6.12 TAMP status register (TAMP_SR)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x30

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	ITAMP15F	Res.	ITAMP13F	ITAMP12F	ITAMP11F	Res.	ITAMP9F	ITAMP8F	ITAMP7F	ITAMP6F	ITAMP5F	ITAMP4F	ITAMP3F	ITAMP2F	ITAMP1F
	r		r	r	r		r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP8F	TAMP7F	TAMP6F	TAMP5F	TAMP4F	TAMP3F	TAMP2F	TAMP1F
								r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bit 30 **ITAMP15F**: Internal tamper 15 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 15.

Bit 29 Reserved, must be kept at reset value.

Bit 28 **ITAMP13F**: Internal tamper 13 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 13.

Bit 27 **ITAMP12F**: Internal tamper 12 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 12.

Bit 26 **ITAMP11F**: Internal tamper 11 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 11.

Bit 25 Reserved, must be kept at reset value.

Bit 24 **ITAMP9F**: Internal tamper 9 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 9.

Bit 23 **ITAMP8F**: Internal tamper 8 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 8.

Bit 22 **ITAMP7F**: Internal tamper 7 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 7.

Bit 21 **ITAMP6F**: Internal tamper 6 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 6.

Bit 20 **ITAMP5F**: Internal tamper 5 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 5.

Bit 19 **ITAMP4F**: Internal tamper 4 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 4.

Bit 18 **ITAMP3F**: Internal tamper 3 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 3.

Bit 17 **ITAMP2F**: Internal tamper 2 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 2.

Bit 16 **ITAMP1F**: Internal tamper 1 flag
This flag is set by hardware when a tamper detection event is detected on the internal tamper 1.

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **TAMP8F**: TAMP8 detection flag
This flag is set by hardware when a tamper detection event is detected on the TAMP8 input

Bit 6 **TAMP7F**: TAMP7 detection flag
This flag is set by hardware when a tamper detection event is detected on the TAMP7 input.

Bit 5 **TAMP6F**: TAMP6 detection flag
This flag is set by hardware when a tamper detection event is detected on the TAMP6 input.

Bit 4 **TAMP5F**: TAMP5 detection flag
This flag is set by hardware when a tamper detection event is detected on the TAMP5 input.

Bit 3 **TAMP4F**: TAMP4 detection flag
This flag is set by hardware when a tamper detection event is detected on the TAMP4 input.

Bit 2 **TAMP3F**: TAMP3 detection flag
This flag is set by hardware when a tamper detection event is detected on the TAMP3 input.

Bit 1 **TAMP2F**: TAMP2 detection flag
This flag is set by hardware when a tamper detection event is detected on the TAMP2 input.

Bit 0 **TAMP1F**: TAMP1 detection flag
This flag is set by hardware when a tamper detection event is detected on the TAMP1 input.

58.6.13 TAMP nonsecure masked interrupt status register (TAMP_MISR)

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x34

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	ITAMP15MF	Res.	ITAMP13MF	ITAMP12MF	ITAMP11MF	Res.	ITAMP9MF	ITAMP8MF	ITAMP7MF	ITAMP6MF	ITAMP5MF	ITAMP4MF	ITAMP3MF	ITAMP2MF	ITAMP1MF
	r		r	r	r		r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP8MF	TAMP7MF	TAMP6MF	TAMP5MF	TAMP4MF	TAMP3MF	TAMP2MF	TAMP1MF
								r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bit 30 **ITAMP15MF**: internal tamper 15 nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 15 nonsecure interrupt is raised.

Bit 29 Reserved, must be kept at reset value.

Bit 28 **ITAMP13MF**: internal tamper 13 nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 13 nonsecure interrupt is raised.

Bit 27 **ITAMP12MF**: internal tamper 12 nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 12 nonsecure interrupt is raised.

Bit 26 **ITAMP11MF**: internal tamper 11 nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 11 nonsecure interrupt is raised.

Bit 25 Reserved, must be kept at reset value.

Bit 24 **ITAMP9MF**: internal tamper 9 nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 9 nonsecure interrupt is raised.

Bit 23 **ITAMP8MF**: Internal tamper 8 nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 8 nonsecure interrupt is raised.

Bit 22 **ITAMP7MF**: Internal tamper 7 tamper nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 7 nonsecure interrupt is raised.

Bit 21 **ITAMP6MF**: Internal tamper 6 nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 6 nonsecure interrupt is raised.

Bit 20 **ITAMP5MF**: Internal tamper 5 nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 5 nonsecure interrupt is raised.

Bit 19 **ITAMP4MF**: Internal tamper 4 nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 4 nonsecure interrupt is raised.

Bit 18 **ITAMP3MF**: Internal tamper 3 nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 3 nonsecure interrupt is raised.

Bit 17 **ITAMP2MF**: Internal tamper 2 nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 2 nonsecure interrupt is raised.

Bit 16 **ITAMP1MF**:Internal tamper 1 nonsecure interrupt masked flag
This flag is set by hardware when the internal tamper 1 nonsecure interrupt is raised.

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **TAMP8MF**: TAMP8 nonsecure interrupt masked flag
This flag is set by hardware when the tamper 8 nonsecure interrupt is raised.

Bit 6 **TAMP7MF**: TAMP7 nonsecure interrupt masked flag
This flag is set by hardware when the tamper 7 nonsecure interrupt is raised.

Bit 5 **TAMP6MF**: TAMP6 nonsecure interrupt masked flag
This flag is set by hardware when the tamper 6 nonsecure interrupt is raised.

Bit 4 **TAMP5MF**: TAMP5 nonsecure interrupt masked flag
This flag is set by hardware when the tamper 5 nonsecure interrupt is raised.

Bit 3 **TAMP4MF**: TAMP4 nonsecure interrupt masked flag
This flag is set by hardware when the tamper 4 nonsecure interrupt is raised.

Bit 2 **TAMP3MF**: TAMP3 nonsecure interrupt masked flag
This flag is set by hardware when the tamper 3 nonsecure interrupt is raised.

Bit 1 **TAMP2MF**: TAMP2 nonsecure interrupt masked flag
This flag is set by hardware when the tamper 2 nonsecure interrupt is raised.

Bit 0 **TAMP1MF**: TAMP1 nonsecure interrupt masked flag
This flag is set by hardware when the tamper 1 nonsecure interrupt is raised.

58.6.14 TAMP secure masked interrupt status register (TAMP_SMISR)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x38

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	ITAMP15MF	Res.	ITAMP13MF	ITAMP12MF	ITAMP11MF	Res.	ITAMP9MF	ITAMP8MF	ITAMP7MF	ITAMP6MF	ITAMP5MF	ITAMP4MF	ITAMP3MF	ITAMP2MF	ITAMP1MF
	r		r	r	r		r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP8MF	TAMP7MF	TAMP6MF	TAMP5MF	TAMP4MF	TAMP3MF	TAMP2MF	TAMP1MF
								r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bit 30 **ITAMP15MF**: internal tamper 15 secure interrupt masked flag
This flag is set by hardware when the internal tamper 15 secure interrupt is raised.

Bit 29 Reserved, must be kept at reset value.

Bit 28 **ITAMP13MF**: internal tamper 13 secure interrupt masked flag
This flag is set by hardware when the internal tamper 13 secure interrupt is raised.

Bit 27 **ITAMP12MF**: internal tamper 12 secure interrupt masked flag
This flag is set by hardware when the internal tamper 12 secure interrupt is raised.

Bit 26 **ITAMP11MF**: internal tamper 11 secure interrupt masked flag
This flag is set by hardware when the internal tamper 11 secure interrupt is raised.

Bit 25 Reserved, must be kept at reset value.

Bit 24 **ITAMP9MF**: internal tamper 9 secure interrupt masked flag
This flag is set by hardware when the internal tamper 9 secure interrupt is raised.

Bit 23 **ITAMP8MF**: Internal tamper 8 secure interrupt masked flag
This flag is set by hardware when the internal tamper 8 secure interrupt is raised.

Bit 22 **ITAMP7MF**: Internal tamper 7 secure interrupt masked flag
This flag is set by hardware when the internal tamper 7 secure interrupt is raised.

Bit 21 **ITAMP6MF**: Internal tamper 6 secure interrupt masked flag
This flag is set by hardware when the internal tamper 6 secure interrupt is raised.

Bit 20 **ITAMP5MF**: Internal tamper 5 secure interrupt masked flag
This flag is set by hardware when the internal tamper 5 secure interrupt is raised.

Bit 19 **ITAMP4MF**: Internal tamper 4 secure interrupt masked flag
This flag is set by hardware when the internal tamper 4 secure interrupt is raised.

Bit 18 **ITAMP3MF**: Internal tamper 3 secure interrupt masked flag
This flag is set by hardware when the internal tamper 3 secure interrupt is raised.

Bit 17 **ITAMP2MF**: Internal tamper 2 secure interrupt masked flag
This flag is set by hardware when the internal tamper 2 secure interrupt is raised.

Bit 16 **ITAMP1MF**: Internal tamper 1 secure interrupt masked flag
This flag is set by hardware when the internal tamper 1 secure interrupt is raised.

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **TAMP8MF**: TAMP8 secure interrupt masked flag
This flag is set by hardware when the tamper 8 secure interrupt is raised.

Bit 6 **TAMP7MF**: TAMP7 secure interrupt masked flag
This flag is set by hardware when the tamper 7 secure interrupt is raised.

Bit 5 **TAMP6MF**: TAMP6 secure interrupt masked flag
This flag is set by hardware when the tamper 6 secure interrupt is raised.

Bit 4 **TAMP5MF**: TAMP5 secure interrupt masked flag
This flag is set by hardware when the tamper 5 secure interrupt is raised.

Bit 3 **TAMP4MF**: TAMP4 secure interrupt masked flag
This flag is set by hardware when the tamper 4 secure interrupt is raised.

Bit 2 **TAMP3MF**: TAMP3 secure interrupt masked flag
This flag is set by hardware when the tamper 3 secure interrupt is raised.

Bit 1 **TAMP2MF**: TAMP2 secure interrupt masked flag
This flag is set by hardware when the tamper 2 secure interrupt is raised.

Bit 0 **TAMP1MF**: TAMP1 secure interrupt masked flag
This flag is set by hardware when the tamper 1 secure interrupt is raised.

58.6.15 TAMP status clear register (TAMP_SCR)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x3C

System reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	CITAMP15F	Res.	CITAMP13F	CITAMP12F	CITAMP11F	Res.	CITAMP9F	CITAMP8F	CITAMP7F	CITAMP6F	CITAMP5F	CITAMP4F	CITAMP3F	CITAMP2F	CITAMP1F
	w		w	w	w		w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CTAMP8F	CTAMP7F	CTAMP6F	CTAMP5F	CTAMP4F	CTAMP3F	CTAMP2F	CTAMP1F
								w	w	w	w	w	w	w	w

Bit 31 Reserved, must be kept at reset value.

Bit 30 **CITAMP15F**: Clear ITAMP15 detection flag
Writing 1 in this bit clears the ITAMP15F bit in the TAMP_SR register.

Bit 29 Reserved, must be kept at reset value.

Bit 28 **CITAMP13F**: Clear ITAMP13 detection flag
Writing 1 in this bit clears the ITAMP13F bit in the TAMP_SR register.

Bit 27 **CITAMP12F**: Clear ITAMP12 detection flag
Writing 1 in this bit clears the ITAMP12F bit in the TAMP_SR register.

Bit 26 **CITAMP11F**: Clear ITAMP11 detection flag
Writing 1 in this bit clears the ITAMP11F bit in the TAMP_SR register.

Bit 25 Reserved, must be kept at reset value.

Bit 24 **CITAMP9F**: Clear ITAMP9 detection flag
Writing 1 in this bit clears the ITAMP9F bit in the TAMP_SR register.

Bit 23 **CITAMP8F**: Clear ITAMP8 detection flag
Writing 1 in this bit clears the ITAMP8F bit in the TAMP_SR register.

Bit 22 **CITAMP7F**: Clear ITAMP7 detection flag
Writing 1 in this bit clears the ITAMP7F bit in the TAMP_SR register.

Bit 21 **CITAMP6F**: Clear ITAMP6 detection flag
Writing 1 in this bit clears the ITAMP6F bit in the TAMP_SR register.

Bit 20 **CITAMP5F**: Clear ITAMP5 detection flag
Writing 1 in this bit clears the ITAMP5F bit in the TAMP_SR register.

Bit 19 **CITAMP4F**: Clear ITAMP4 detection flag
Writing 1 in this bit clears the ITAMP4F bit in the TAMP_SR register.

Bit 18 **CITAMP3F**: Clear ITAMP3 detection flag
Writing 1 in this bit clears the ITAMP3F bit in the TAMP_SR register.

Bit 17 **CITAMP2F**: Clear ITAMP2 detection flag
Writing 1 in this bit clears the ITAMP2F bit in the TAMP_SR register.

Bit 16 **CITAMP1F**: Clear ITAMP1 detection flag
Writing 1 in this bit clears the ITAMP1F bit in the TAMP_SR register.

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **CTAMP8F**: Clear TAMP8 detection flag
Writing 1 in this bit clears the TAMP8F bit in the TAMP_SR register.

Bit 6 **CTAMP7F**: Clear TAMP7 detection flag
Writing 1 in this bit clears the TAMP7F bit in the TAMP_SR register.

Bit 5 **CTAMP6F**: Clear TAMP6 detection flag
Writing 1 in this bit clears the TAMP6F bit in the TAMP_SR register.

Bit 4 **CTAMP5F**: Clear TAMP5 detection flag
Writing 1 in this bit clears the TAMP5F bit in the TAMP_SR register.

Bit 3 **CTAMP4F**: Clear TAMP4 detection flag
Writing 1 in this bit clears the TAMP4F bit in the TAMP_SR register.

Bit 2 **CTAMP3F**: Clear TAMP3 detection flag
Writing 1 in this bit clears the TAMP3F bit in the TAMP_SR register.

Bit 1 **CTAMP2F**: Clear TAMP2 detection flag
Writing 1 in this bit clears the TAMP2F bit in the TAMP_SR register.

Bit 0 **CTAMP1F**: Clear TAMP1 detection flag
Writing 1 in this bit clears the TAMP1F bit in the TAMP_SR register.

58.6.16 TAMP monotonic counter 1 register (TAMP_COUNT1R)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x040

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
COUNT[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
COUNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **COUNT[31:0]:** Monotonic counter

The monotonic counter increments by one when a write access to this register occurs, regardless of the written value. Reading this register returns the monotonic counter value. This register does not roll-over and freezes upon reaching its maximum value.

58.6.17 TAMP option register (TAMP_OR)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x50

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	IN4_RMP	IN3_RMP	IN2_RMP	Res.	Res.	Res.	Res.	OUT5_RMP	OUT3_RMP[1:0]		Res.
					rw	rw	rw					rw	rw	rw	

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **IN4_RMP**: TAMP_IN4 mapping
0: TAMP_IN4 is on PA2
1: TAMP_IN4 is on PI11

Bit 9 **IN3_RMP**: TAMP_IN3 mapping
0: TAMP_IN3 is on PC1
1: TAMP_IN3 is on PE6

Bit 8 **IN2_RMP**: TAMP_IN2 mapping
0: TAMP_IN2 is on PA0
1: TAMP_IN2 is on PI8

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **OUT5_RMP**: TAMP_OUT5 mapping
0: TAMP_OUT5 is on PI11
1: TAMP_OUT5 is on PC1

Bits 2:1 **OUT3_RMP[1:0]**: TAMP_OUT3 mapping
00: TAMP_OUT3 is on PC13
01: TAMP_OUT3 is on PI8
10: TAMP_OUT3 is on PE3
11: TAMP_OUT3 is on PA2

Bit 0 Reserved, must be kept at reset value.

58.6.18 TAMP resources protection configuration register (TAMP_RPCFGR)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x54

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RP CFG0
															rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:8 Reserved, must be kept at reset value.

Bit 7 Reserved, must be kept at reset value.

Bit 6 Reserved, must be kept at reset value.

Bit 5 Reserved, must be kept at reset value.

Bit 4 Reserved, must be kept at reset value.

Bit 3 Reserved, must be kept at reset value.

Bit 2 Reserved, must be kept at reset value.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **RPCFG0**: Configurable resource 0 protection(1)

0: Resource 0 is not included in the device secrets protected by TAMP peripheral

1: Resource 0 is included in the device secrets protected by TAMP peripheral

1. Refer to tamp_confirmed_rpcfg0 and tamp_potential_rpcfg0 signals in *Table 625: TAMP input/output pins* and *Table 627: TAMP interconnection*.

58.6.19 TAMP backup x register (TAMP_BKPxR)

This register can be protected against nonsecure access. Refer to *Section 58.3.5: TAMP secure protection modes*.

This register can be protected against unprivileged access. Refer to *Section 58.3.7: TAMP privilege protection modes*.

Address offset: 0x100 + 0x04 * x, (x = 0 to 31)

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BKP[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BKP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw

Bits 31:0 **BKP[31:0]:**

The application can write or read data to and from these registers.
In the default (ERASE) configuration this register is reset on a tamper detection event. It is forced to reset value as long as there is at least one internal or external tamper flag being set. This register is also reset when the product state is opened.

58.6.20 TAMP register map

Table 635. TAMP register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	TAMP_CR1	Res.	ITAMP15E	Res.	ITAMP13E	ITAMP12E	ITAMP11E	Res.	ITAMP9E	ITAMP8E	ITAMP7E	ITAMP6E	ITAMP5E	ITAMP4E	ITAMP3E	ITAMP2E	ITAMP1E	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP8E	TAMP7E	TAMP6E	TAMP5E	TAMP4E	TAMP3E	TAMP2E	TAMP1E
	Reset value		0		0	0	0		0	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0
0x04	TAMP_CR2	TAMP8TRG	TAMP7TRG	TAMP6TRG	TAMP5TRG	TAMP4TRG	TAMP3TRG	TAMP2TRG	TAMP1TRG	BKERASE	BKBLOCK	Res.	Res.	Res.	TAMP3MSK	TAMP2MSK	TAMP1MSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP8POM	TAMP7POM	TAMP6POM	TAMP5POM	TAMP4POM	TAMP3POM	TAMP2POM	TAMP1POM
	Reset value	0	0	0	0	0	0	0	0	0	0				0	0	0									0	0	0	0	0	0	0	0
0x08	TAMP_CR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ITAMP15POM	Res.	ITAMP13POM	ITAMP12POM	ITAMP11POM	Res.	ITAMP9POM	ITAMP8POM	ITAMP7POM	ITAMP6POM	ITAMP5POM	ITAMP4POM	ITAMP3POM	ITAMP2POM	ITAMP1POM
	Reset value																		0		0	0	0		0	0	0	0	0	0	0	0	0
0x0C	TAMP_FLTCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMPPUDIS	TAMPPRCH[1:0]		TAMPFLT[1:0]		TAMPFREQ[2:0]		
	Reset value																									0	0	0	0	0	0	0	0
0x10	TAMP_ATCR1	FLTEN	ATOSHARE	Res.	Res.	Res.	AT PER[2:0]			Res.	Res.	Res.	Res.	ATCK SEL[3:0]				ATO SEL4 [1:0]		ATO SEL3 [1:0]		ATO SEL2 [1:0]		ATO SEL1 [1:0]		TAMP8AM	TAMP7AM	TAMP6AM	TAMP5AM	TAMP4AM	TAMP3AM	TAMP2AM	TAMP1AM
	Reset value	0	0				0	0	0					0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	TAMP_ ATSEEDR	SEED[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	TAMP_ATOR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INITS	SEEDF	Res.	Res.	Res.	Res.	Res.	Res.	PRNG[7:0]							
	Reset value																	0	0							0	0	0	0	0	0	0	0
0x1C	TAMP_ATCR2	ATO SEL8 [2:0]			ATO SEL7 [2:0]			ATO SEL6 [2:0]			ATO SEL5 [2:0]			ATO SEL4 [2:0]				ATO SEL3 [2:0]			ATO SEL2 [2:0]			ATO SEL1 [2:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								
0x20	TAMP_SEC CFGR	TAMPSEC	BHKLOCK	Res.	Res.	Res.	Res.	Res.	Res.	BKPWSEC[7:0]								CNT1SEC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BKPRWSEC[7:0]							
	Reset value	0	0							0	0	0	0	0	0	0	0	0								0	0	0	0	0	0	0	0
0x24	TAMP_ PRIVCFGR	TAMPPRIV	BKPWPRIV	BKPRWPRIV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT1PRIV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0														0															

Table 635. TAMP register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x2C	TAMP_IER	Res.	ITAMP15IE	Res.	ITAMP13IE	ITAMP12IE	ITAMP11IE	Res.	ITAMP9IE	ITAMP8IE	ITAMP7IF	ITAMP6IE	ITAMP5IE	ITAMP4IE	ITAMP3IE	ITAMP2IE	ITAMP1IE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP8IE	TAMP7IE	TAMP6IE	TAMP5IE	TAMP4IE	TAMP3IE	TAMP2IE	TAMP1IE
	Reset value		0		0	0	0		0	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0
0x30	TAMP_SR	Res.	ITAMP15F	Res.	ITAMP13F	ITAMP12F	ITAMP11F	Res.	ITAMP9F	ITAMP8F	ITAMP7F	ITAMP6F	ITAMP5F	ITAMP4F	ITAMP3F	ITAMP2F	ITAMP1F	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP8F	TAMP7F	TAMP6F	TAMP5F	TAMP4F	TAMP3F	TAMP2F	TAMP1F
	Reset value		0		0	0	0		0	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0
0x34	TAMP_MISR	Res.	ITAMP15MF	Res.	ITAMP13MF	ITAMP12MF	ITAMP11MF	Res.	ITAMP9MF	ITAMP8MF	ITAMP7MF	ITAMP6MF	ITAMP5MF	ITAMP4MF	ITAMP3MF	ITAMP2MF	ITAMP1MF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP8MF	TAMP7MF	TAMP6MF	TAMP5MF	TAMP4MF	TAMP3MF	TAMP2MF	TAMP1MF
	Reset value		0		0	0	0		0	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0
0x38	TAMP_SMISR	Res.	ITAMP15MF	Res.	ITAMP13MF	ITAMP12MF	ITAMP11MF	Res.	ITAMP9MF	ITAMP8MF	ITAMP7MF	ITAMP6MF	ITAMP5MF	ITAMP4MF	ITAMP3MF	ITAMP2MF	ITAMP1MF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TAMP8MF	TAMP7MF	TAMP6MF	TAMP5MF	TAMP4MF	TAMP3MF	TAMP2MF	TAMP1MF
	Reset value		0		0	0	0		0	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0
0x3C	TAMP_SCR	Res.	CITAMP15F	Res.	CITAMP13F	CITAMP12F	CITAMP11F	Res.	CITAMP9F	CITAMP8F	CITAMP7F	CITAMP6F	CITAMP5F	CITAMP4F	CITAMP3F	CITAMP2F	CITAMP1F	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CTAMP8F	CTAMP7F	CTAMP6F	CTAMP5F	CTAMP4F	CTAMP3F	CTAMP2F	CTAMP1F
	Reset value		0		0	0	0		0	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0
0x40	TAMP_ COUNT1R	COUNT[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x50	TAMP_OR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IN4_RMP	IN3_RMP	IN2_RMP	Res.	Res.	Res.	Res.	OUT5_RMP	OUT3_RMP		Res.
	Reset value																						0	0	0					0	0	0	
0x54	TAMP_ RPCFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RPCFG0
	Reset value																																0
0x100 + 0x04*x, (x= 0 to 31)	TAMP_BKPxR	BKP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

59 Inter-integrated circuit interface (I2C)

59.1 I2C introduction

The I2C peripheral handles the interface between the device and the serial I²C (inter-integrated circuit) bus. It provides multicontroller capability, and controls all I²C-bus-specific sequencing, protocol, arbitration and timing. It supports Standard-mode (Sm), Fast-mode (Fm) and Fast-mode Plus (Fm+).

The I2C peripheral is also SMBus (system management bus) and PMBus® (power management bus) compatible.

It can use DMA to reduce the CPU load.

59.2 I2C main features

- I²C-bus specification rev03 compatibility:
  - Target and controller modes
  - Multicontroller capability
  - Standard-mode (up to 100 kHz)
  - Fast-mode (up to 400 kHz)
  - Fast-mode Plus (up to 1 MHz)
  - 7-bit and 10-bit addressing mode
  - Multiple 7-bit target addresses (2 addresses, 1 with configurable mask)
  - All 7-bit-addresses acknowledge mode
  - General call
  - Programmable setup and hold times
  - Easy-to-use event management
  - Clock stretching (optional)
- 1-byte buffer with DMA capability
- Programmable analog and digital noise filters
- SMBus specification rev 3.0 compatibility[(a)]:
  - Hardware PEC (packet error checking) generation and verification with ACK control
  - Command and data acknowledge control
  - Address resolution protocol (ARP) support
  - Host and device support
  - SMBus alert
  - Timeouts and idle condition detection
- PMBus rev 1.3 standard compatibility
- Independent clock

a. To check the compliance of the GPIOs selected for SMBus with the specified logical levels, refer to the product datasheet.

- Wake-up from Stop mode on address match

For information on I2C instantiation, refer to *Section 59.3: I2C implementation*.

59.3 I2C implementation

This section provides an implementation overview with respect to the I2C instantiation.

Table 636. I2C implementation

I2C features[1]	I2C1	I2C2	I2C3	I2C4
7-bit addressing mode	X	X	X	X
10-bit addressing mode	X	X	X	X
Standard-mode (up to 100 kbit/s)	X	X	X	X
Fast-mode (up to 400 kbit/s)	X	X	X	X
Fast-mode Plus with 20 mA output drive I/Os (up to 1 Mbit/s)	X	X	X	X
Independent clock	X	X	X	X
Wake-up from Stop mode only (no autonomous mode)	X	X	X	X
SMBus/PMBus	X	X	X	X

1. X = supported.

59.4 I2C functional description

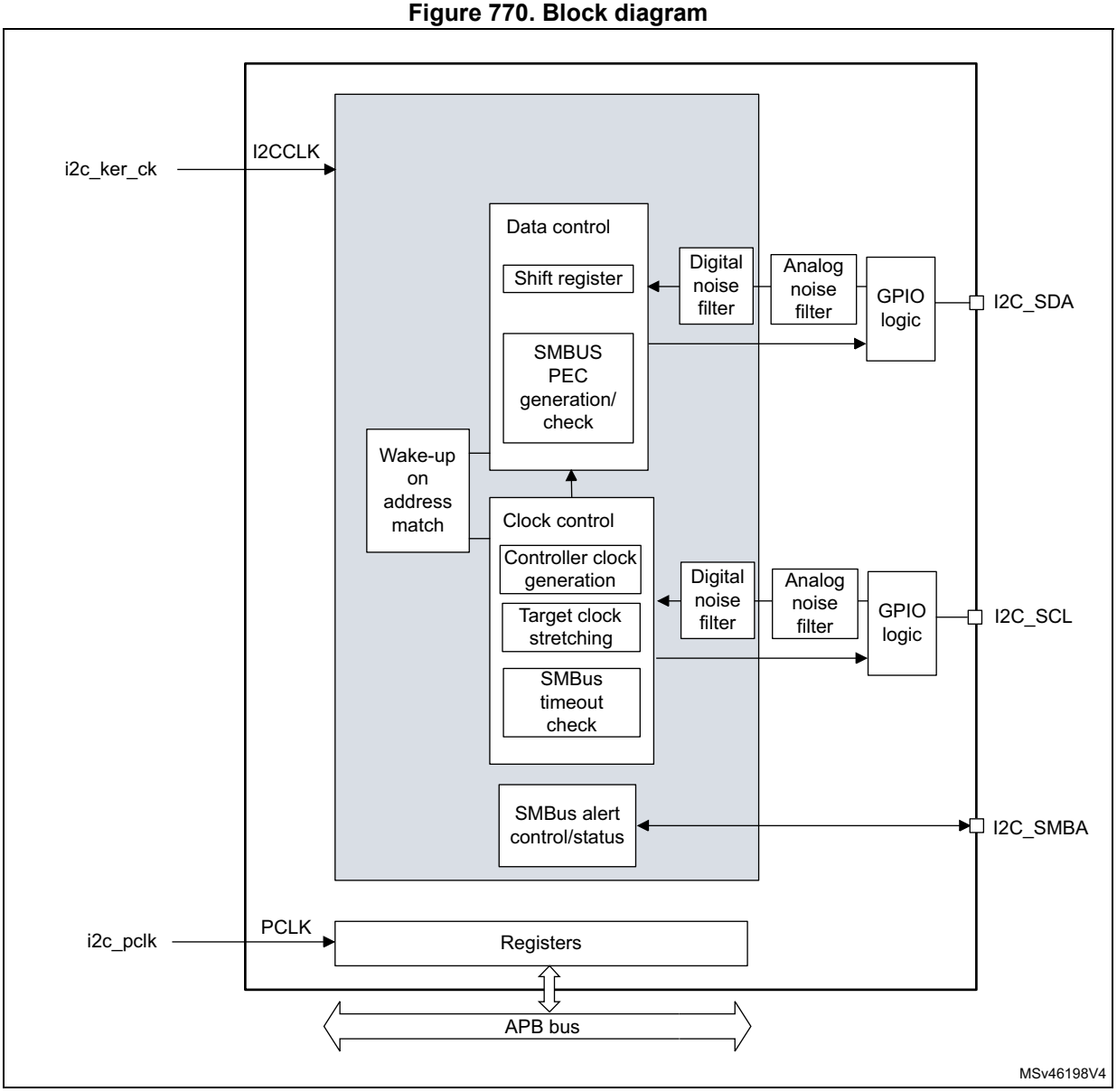
In addition to receiving and transmitting data, the peripheral converts them from serial to parallel format and vice versa. The interrupts are enabled or disabled by software. The peripheral is connected to the I²C-bus through a data pin (SDA) and a clock pin (SCL). It supports Standard-mode (up to 100 kHz), Fast-mode (up to 400 kHz), and Fast-mode Plus (up to 1 MHz) I²C-bus.

The peripheral can also be connected to an SMBus, through the data pin (SDA), the clock pin (SCL), and an optional SMBus alert pin (SMBA).

The independent clock function allows the I2C communication speed to be independent of the i2c_pclk frequency.

59.4.1 I2C block diagram

Figure 770. Block diagram



59.4.2 I2C pins and internal signals

Table 637. I2C input/output pins

Pin name	Signal type	Description
I2C_SDA	Bidirectional	I²C-bus data
I2C_SCL	Bidirectional	I²C-bus clock
I2C_SMBA	Bidirectional	SMBus alert

Table 638. I2C internal input/output signals

Internal signal name	Signal type	Description
i2c_ker_ck	Input	I2C kernel clock, also named I2CCLK in this document
i2c_pclk	Input	I2C APB clock
i2c_it	Output	I2C interrupts, refer to *Table 651* for the list of interrupt sources
i2c_rx_dma	Output	I2C receive data DMA request (I2C_RX)
i2c_tx_dma	Output	I2C transmit data DMA request (I2C_TX)

59.4.3 I2C clock requirements

The I2C kernel is clocked by i2c_ker_ck.

The i2c_ker_ck period t_{I2CCLK} must respect the following conditions:

$t_{I2CCLK} < (t_{LOW} - t_{filters}) / 4$

$t_{I2CCLK} < t_{HIGH}$

where t_{LOW} is the SCL low time, t_{HIGH} is the SCL high time, and $t_{filters}$ is the sum of the analog and digital filter delays (when enabled).

The digital filter delay is DNF[3:0] x t_{I2CCLK}.

The i2c_pclk clock period t_{PCLK} must respect the condition $t_{PCLK} < 4/3\ t_{SCL}$, where t_{SCL} is the SCL period.

Caution: When the I2C kernel is clocked by i2c_pclk, this clock must respect the conditions for t_{I2CCLK}.

59.4.4 I2C mode selection

The peripheral can operate as:

- Target transmitter
- Target receiver
- Controller transmitter
- Controller receiver

By default, the peripheral operates in target mode. It automatically switches from target to controller mode upon generating START condition, and from controller to target mode upon arbitration loss or upon generating STOP condition. This allows the use of the I2C peripheral in a multicontroller I²C-bus environment.

Communication flow

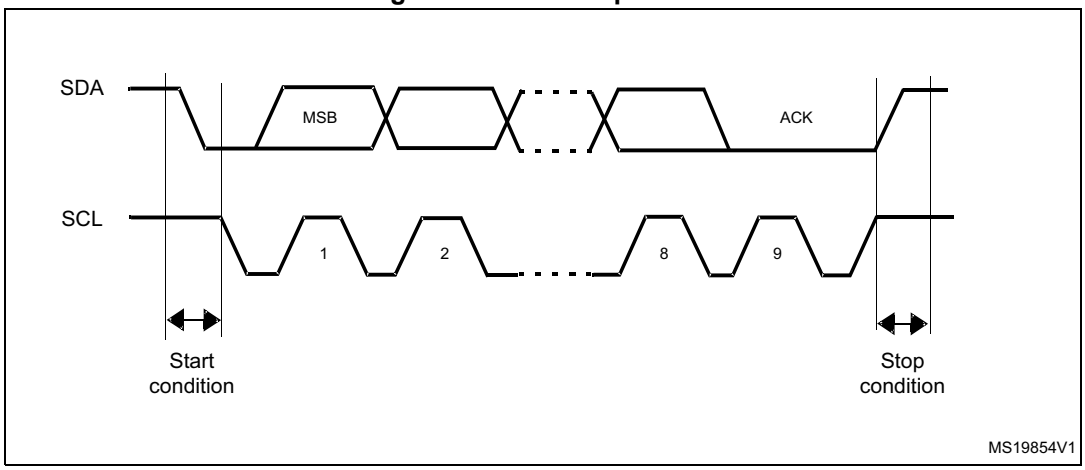
In controller mode, the I2C peripheral initiates a data transfer and generates the clock signal. Serial data transfers always begin with a START condition and end with a STOP condition. Both START and STOP conditions are generated in controller mode by software.

In target mode, the peripheral recognizes its own 7-bit or 10-bit address, and the general call address. The general call address detection can be enabled or disabled by software. The reserved SMBus addresses can also be enabled by software.

Data and addresses are transferred as 8-bit bytes, MSB first. The address is contained in the first byte (7-bit addressing) or in the first two bytes (10-bit addressing) following the START condition. The address is always transmitted in controller mode.

The following figure shows the transmission of a single byte. The controller generates nine SCL pulses. The transmitter sends the eight data bits to the receiver with the SCL pulses 1 to 8. Then the receiver sends the acknowledge bit to the transmitter with the ninth SCL pulse.

Figure 771. I²C-bus protocol



The acknowledge can be enabled or disabled by software. The own addresses of the I2C peripheral can be selected by software.

59.4.5 I2C initialization

Enabling and disabling the peripheral

Before enabling the I2C peripheral, configure and enable its clock through the RCC, and initialize its control registers.

The I2C peripheral can then be enabled by setting the PE bit of the I2C_CR1 register.

Disabling the I2C peripheral by clearing the PE bit resets the I2C peripheral. Refer to *Section 59.4.6* for more details.

Noise filters

Before enabling the I2C peripheral by setting the PE bit of the I2C_CR1 register, the user must configure the analog and/or digital noise filters, as required.

The analog noise filter on the SDA and SCL inputs complies with the I²C-bus specification which requires, in Fast-mode and Fast-mode Plus, the suppression of spikes shorter than 50 ns. Enabled by default, it can be disabled by setting the ANFOFF bit.

The digital filter is controlled through the DNF[3:0] bitfield of the I2C_CR1 register. When it is enabled, the internal SCL and SDA signals only take the level of their corresponding I²C-bus line when remaining stable for more than DNF[3:0] periods of i2c_ker_ck. This allows suppressing spikes shorter than the filtering capacity period programmable from one to fifteen i2c_ker_ck periods.

The following table compares the two filters.

Table 639. Comparison of analog and digital filters

Item	Analog filter	Digital filter
Filtering capacity(1)	≥ 50 ns	One to fifteen i2c_ker_ck periods
Benefits	Available in Stop mode	– Programmable filtering capacity – Extra filtering capability versus I²C-bus specification requirements – Stable filtering capacity
Drawbacks	Filtering capacity variation with temperature, voltage, and silicon process	Wake-up from Stop mode on address match not supported when the digital filter is enabled

1. Maximum duration of spikes that the filter can suppress

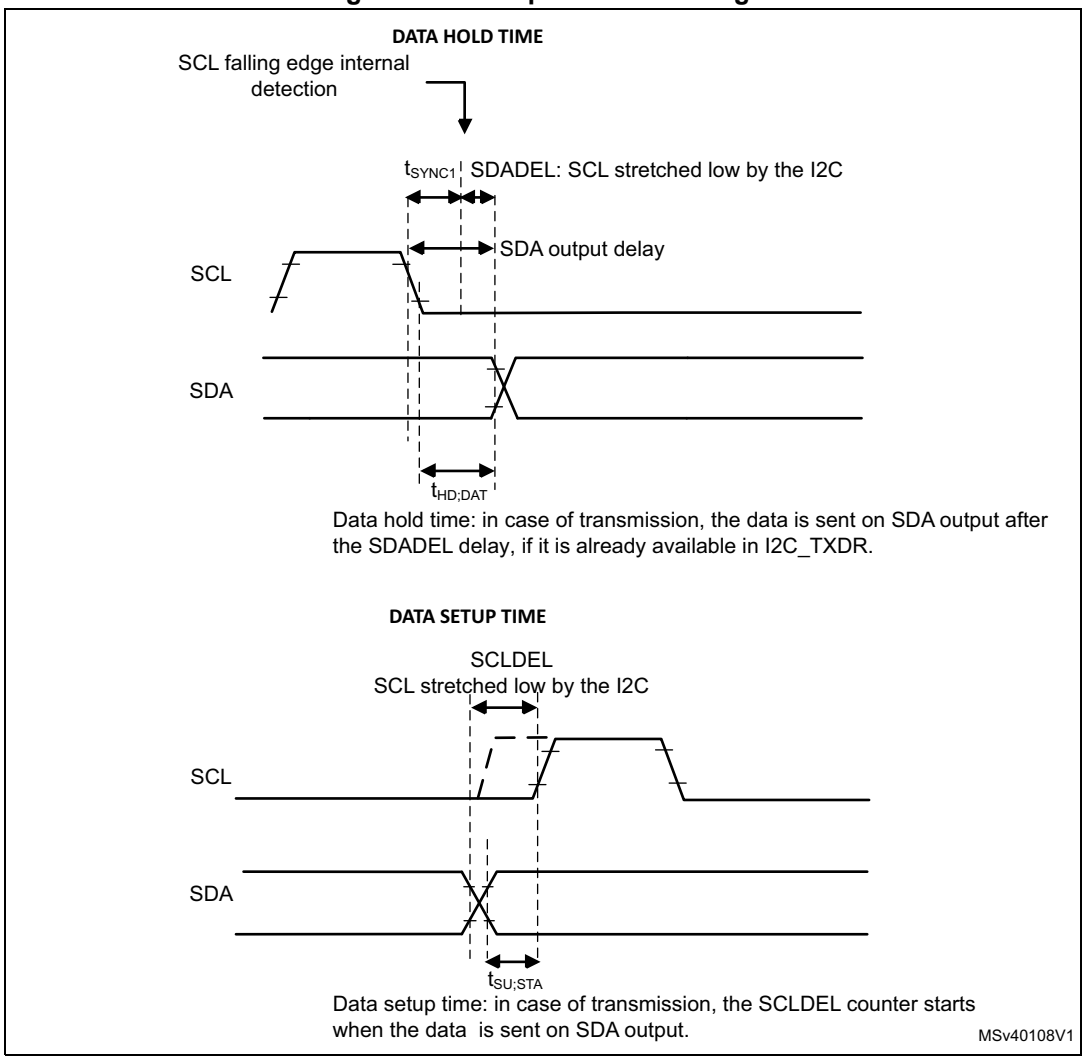
Caution: The filter configuration cannot be changed when the I2C peripheral is enabled.

I2C timings

To ensure correct data hold and setup times, the corresponding timings must be configured through the PRESC[3:0], SCLDEL[3:0], and SDADEL[3:0] bitfields of the I2C_TIMINGR register.

The STM32CubeMX tool calculates and provides the I2C_TIMINGR content in the *I2C configuration* window.

Figure 772. Setup and hold timings



When the SCL falling edge is internally detected, the delay t_{SDADEL} (impacting the hold time $t_{HD;DAT}$) is inserted before sending SDA output:

t_{SDADEL} = SDADEL x t_{PRESC} + t_{I2CCLK}, where t_{PRESC} = (PRESC + 1) x t_{I2CCLK}.

The total SDA output delay is:

t_{SYNC1} + {[SDADEL x (PRESC + 1) + 1] x t_{I2CCLK}}

The t_{SYNC1} duration depends upon:

- SCL falling slope
- input delay $t_{AF(min)} < t_{AF} < t_{AF(max)}$ introduced by the analog filter (if enabled)
- input delay t_{DNF} = DNF x t_{I2CCLK} introduced by the digital filter (if enabled)
- delay due to SCL synchronization to i2c_ker_ck clock (two to three i2c_ker_ck periods)

To bridge the undefined region of the SCL falling edge, the user must set SDADEL[3:0] so as to fulfill the following condition:

{$t_{f(max)}$ + $t_{HD;DAT(min)}$ - $t_{AF(min)}$ - [(DNF + 3) x t_{I2CCLK}]} / {(PRESC + 1) x t_{I2CCLK}} ≤ SDADEL

SDADEL ≤ {$t_{HD;DAT\ (max)}$ - $t_{AF(max)}$ - [(DNF + 4) x t_{I2CCLK}]} / {(PRESC + 1) x t_{I2CCLK}}

Note: $t_{AF(min)}$ and $t_{AF(max)}$ are only part of the condition when the analog filter is enabled. Refer to the device datasheet for t_{AF} values.

The $t_{HD;DAT}$ time can at maximum be 3.45 µs for Standard-mode, 0.9 µs for Fast-mode, and 0.45 µs for Fast-mode Plus. It must be lower than the maximum of $t_{VD;DAT}$ by a transition time. This maximum must only be met if the device does not stretch the LOW period (t_{LOW}) of the SCL signal. When it stretches SCL, the data must be valid by the set-up time before it releases the clock.

The SDA rising edge is usually the worst case. The previous condition then becomes:

$SDADEL \leq \{t_{VD;DAT\ (max)} - t_{r\ (max)} - t_{AF\ (max)} - [(DNF + 4) \times t_{I2CCLK}]\} / \{(PRESC + 1) \times t_{I2CCLK}\}$

Note: This condition can be violated when NOSTRETCH = 0, because the device stretches SCL low to guarantee the set-up time, according to the SCLDEL[3:0] value.

After t_{SDADEL}, or after sending SDA output when the target had to stretch the clock because the data was not yet written in I2C_TXDR register, the SCL line is kept at low level during the setup time. This setup time is $t_{SCLDEL} = (SCLDEL + 1) \times t_{PRESC}$, where $t_{PRESC} = (PRESC + 1) \times t_{I2CCLK}$. t_{SCLDEL} impacts the setup time $t_{SU;DAT}$.

To bridge the undefined region of the SDA transition (rising edge usually worst case), the user must program SCLDEL[3:0] so as to fulfill the following condition:

$\{[t_{r\ (max)} + t_{SU;DAT\ (min)}] / [(PRESC + 1) \times t_{I2CCLK}]\} - 1 \leq SCLDEL$

Refer to the following table for t_f, t_r, $t_{HD;DAT}$, $t_{VD;DAT}$, and $t_{SU;DAT}$ standard values.

Use the SDA and SCL real transition time values measured in the application to widen the scope of allowed SDADEL[3:0] and SCLDEL[3:0] values. Use the maximum SDA and SCL transition time values defined in the standard to make the device work reliably regardless of the application.

Note: At every clock pulse, after SCL falling edge detection, I2C operating as controller or target stretches SCL low during at least [(SDADEL + SCLDEL + 1) x (PRESC + 1) + 1] x t_{I2CCLK}, in both transmission and reception modes. In transmission mode, if the data is not yet written in I2C_TXDR when SDA delay elapses, the I2C peripheral keeps stretching SCL low until the next data is written. Then new data MSB is sent on SDA output, and SCLDEL counter starts, continuing stretching SCL low to guarantee the data setup time.

When the NOSTRETCH bit is set in target mode, the SCL is not stretched. The SDADEL[3:0] must then be programmed so that it ensures a sufficient setup time.

Table 640. I²C-bus and SMBus specification data setup and hold times

Symbol	Parameter	Standard-mode (Sm)		Fast-mode (Fm)		Fast-mode Plus (Fm+)		SMBus		Unit
		Min	Max	Min	Max	Min	Max	Min	Max	
$t_{HD;DAT}$	Data hold time	0	-	0	-	0	-	0.3	-	µs
$t_{VD;DAT}$	Data valid time	-	3.45	-	0.9	-	0.45	-	-	
$t_{SU;DAT}$	Data setup time	250	-	100	-	50	-	250	-	ns
t_r	Rise time of both SDA and SCL signals	-	1000	-	300	-	120	-	1000	
t_f	Fall time of both SDA and SCL signals	-	300	-	300	-	120	-	300	

Additionally, in controller mode, the SCL clock high and low levels must be configured by programming the PRESC[3:0], SCLH[7:0], and SCLL[7:0] bitfields of the I2C_TIMINGR register.

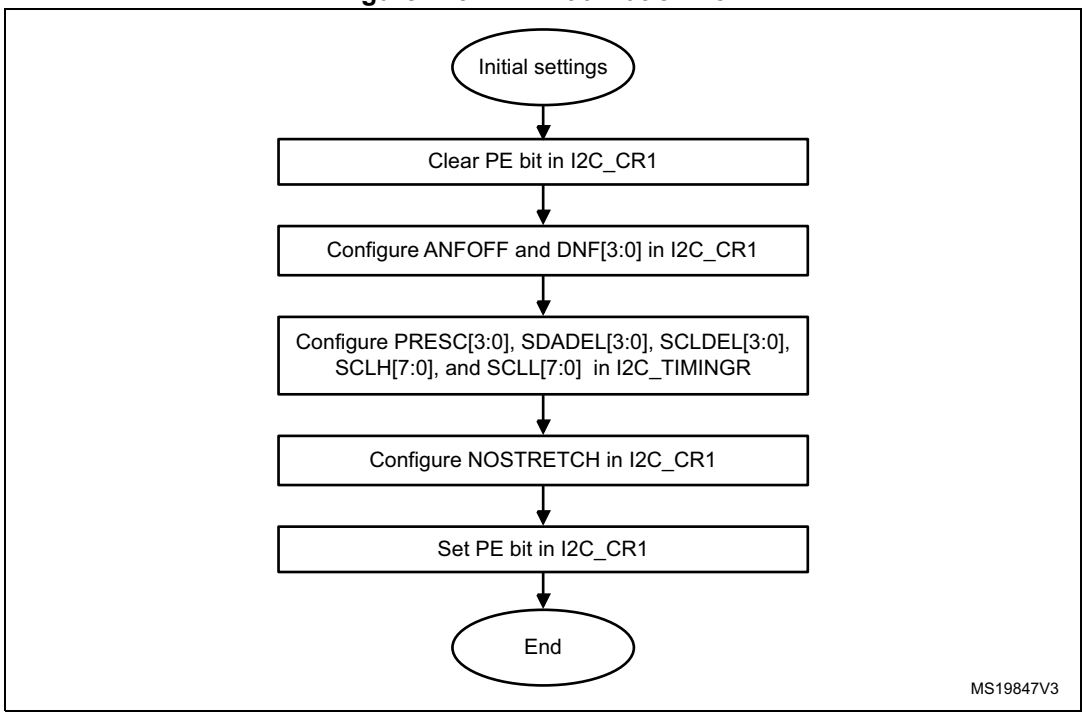
When the SCL falling edge is internally detected, the I2C peripheral releasing the SCL output after the delay t_{SCLL} = (SCLL + 1) x t_{PRESC}, where t_{PRESC} = (PRESC + 1) x t_{I2CCLK}. The t_{SCLL} delay impacts the SCL low time t_{LOW}.

When the SCL rising edge is internally detected, the I2C peripheral forces the SCL output to low level after the delay t_{SCLH} = (SCLH + 1) x t_{PRESC}, where t_{PRESC} = (PRESC + 1) x t_{I2CCLK}. The t_{SCLH} impacts the SCL high time t_{HIGH}.

Refer to *I2C controller initialization* for more details.

Caution: Changing the timing configuration and the NOSTRETCH configuration is not allowed when the I2C peripheral is enabled. Like the timing settings, the target NOSTRETCH settings must also be done before enabling the peripheral. Refer to *I2C target initialization* for more details.

Figure 773. I2C initialization flow



59.4.6 I2C reset

The reset of the I2C peripheral is performed by clearing the PE bit of the I2C_CR1 register. It has the effect of releasing the SCL and SDA lines. Internal state machines are reset and the communication control bits and the status bits revert to their reset values. This reset does not impact the configuration registers.

The impacted register bits are:

1. I2C_CR2 register: START, STOP, PECBYTE, and NACK
2. I2C_ISR register: BUSY, TXE, TXIS, RXNE, ADDR, NACKF, TCR, TC, STOPF, BERR, ARLO, PECERR, TIMEOUT, ALERT, and OVR

PE must be kept low during at least three APB clock cycles to perform the I2C reset. To ensure this, perform the following software sequence:

1. Write PE = 0
2. Check PE = 0
3. Write PE = 1

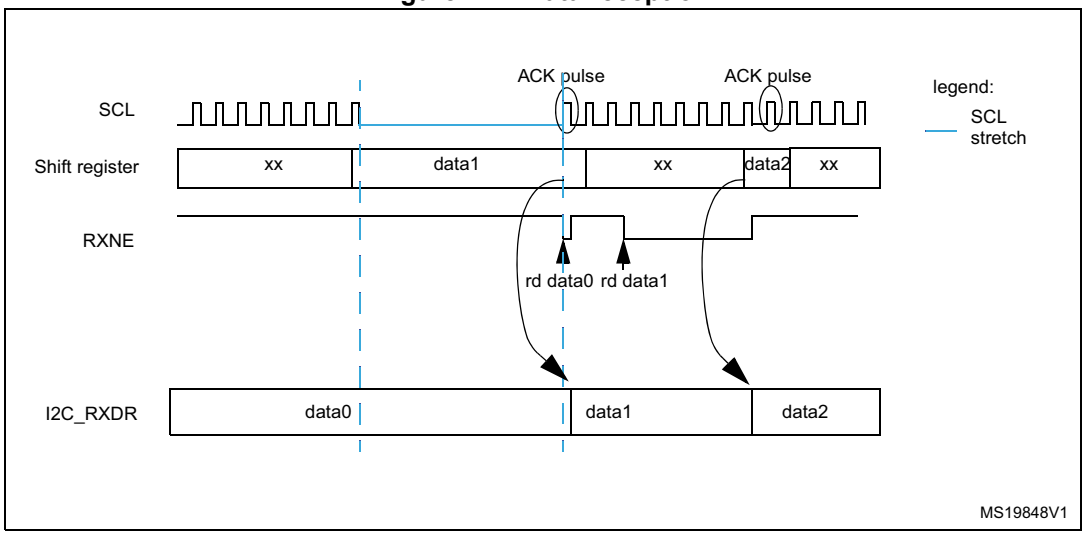
59.4.7 I2C data transfer

The data transfer is managed through transmit and receive data registers and a shift register.

Reception

The SDA input fills the shift register. After the eighth SCL pulse (when the complete data byte is received), the shift register is copied into the I2C_RXDR register if it is empty (RXNE = 0). If RXNE = 1, which means that the previous received data byte has not yet been read, the SCL line is stretched low until I2C_RXDR is read. The stretch occurs between the eighth and the ninth SCL pulse (before the acknowledge pulse).

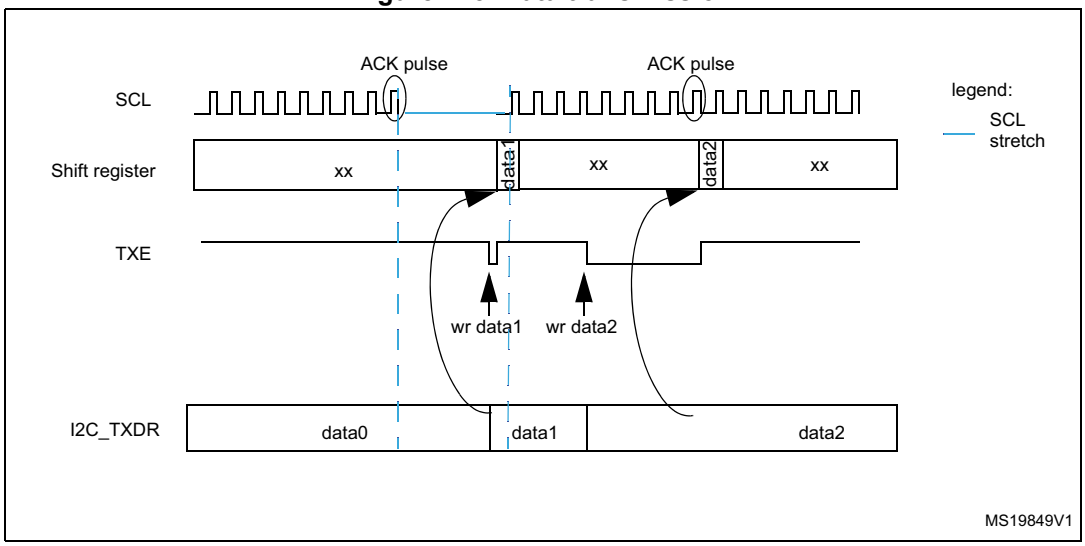
Figure 774. Data reception



Transmission

If the I2C_TXDR register is not empty (TXE = 0), its content is copied into the shift register after the ninth SCL pulse (the acknowledge pulse). Then the shift register content is shifted out on the SDA line. If TXE = 1, which means that no data is written yet in I2C_TXDR, the SCL line is stretched low until I2C_TXDR is written. The stretch starts after the ninth SCL pulse.

Figure 775. Data transmission



Hardware transfer management

The I2C features an embedded byte counter to manage byte transfer and to close the communication in various modes, such as:

- NACK, STOP and ReSTART generation in controller mode
- ACK control in target receiver mode
- PEC generation/checking

In controller mode, the byte counter is always used. By default, it is disabled in target mode. It can be enabled by software, by setting the SBC (target byte control) bit of the I2C_CR1 register.

The number of bytes to transfer is programmed in the NBYTES[7:0] bitfield of the I2C_CR2 register. If this number is greater than 255, or if a receiver wants to control the acknowledge value of a received data byte, the reload mode must be selected, by setting the RELOAD bit of the I2C_CR2 register. In this mode, the TCR flag is set when the number of bytes programmed in NBYTES[7:0] is transferred (when the associated counter reaches zero), and an interrupt is generated if TCIE is set. SCL is stretched as long as the TCR flag is set. TCR is cleared by software when NBYTES[7:0] is written to a non-zero value.

When NBYTES[7:0] is reloaded with the last number of bytes to transfer, the RELOAD bit must be cleared.

When RELOAD = 0 in controller mode, the counter can be used in two modes:

- **Automatic end** (AUTOEND = 1 in the I2C_CR2 register). In this mode, the controller automatically sends a STOP condition once the number of bytes programmed in the NBYTES[7:0] bitfield is transferred.
- **Software end** (AUTOEND = 0 in the I2C_CR2 register). In this mode, a software action is expected once the number of bytes programmed in the NBYTES[7:0] bitfield is transferred; the TC flag is set and an interrupt is generated if the TCIE bit is set. The SCL signal is stretched as long as the TC flag is set. The TC flag is cleared by software when the START or STOP bit of the I2C_CR2 register is set. This mode must be used when the controller wants to send a RESTART condition.

Caution: The AUTOEND bit has no effect when the RELOAD bit is set.

Table 641. I2C configuration

Function	SBC bit	RELOAD bit	AUTOEND bit
Controller Tx/Rx NBYTES + STOP	X	0	1
Controller Tx/Rx + NBYTES + RESTART	X	0	0
Target Tx/Rx, all received bytes ACKed	0	X	X
Target Rx with ACK control	1	1	X

59.4.8 I2C target mode

I2C target initialization

To work in target mode, the user must enable at least one target address. The I2C_OAR1 and I2C_OAR2 registers are available to program the target own addresses OA1 and OA2, respectively.

OA1 can be configured either in 7-bit (default) or in 10-bit addressing mode, by setting the OA1MODE bit of the I2C_OAR1 register.

OA1 is enabled by setting the OA1EN bit of the I2C_OAR1 register.

If an additional target addresses are required, the second target address OA2 can be configured. Up to seven OA2 LSBs can be masked, by configuring the OA2MSK[2:0] bitfield of the I2C_OAR2 register. Therefore, for OA2MSK[2:0] configured from 1 to 6, only OA2[7:2], OA2[7:3], OA2[7:4], OA2[7:5], OA2[7:6], or OA2[7] are compared with the received address. When OA2MSK[2:0] is other than 0, the address comparator for OA2 excludes the I2C reserved addresses (0000 XXX and 1111 XXX) and they are not acknowledged. If OA2MSK[2:0] = 7, all received 7-bit addresses are acknowledged (except reserved addresses). OA2 is always a 7-bit address.

When enabled through the specific bit, the reserved addresses can be acknowledged if they are programmed in the I2C_OAR1 or I2C_OAR2 register with OA2MSK[2:0] = 0.

OA2 is enabled by setting the OA2EN bit of the I2C_OAR2 register.

The general call address is enabled by setting the GCEN bit of the I2C_CR1 register.

When the I2C peripheral is selected by one of its enabled addresses, the ADDR interrupt status flag is set, and an interrupt is generated if the ADDRIE bit is set.

By default, the target uses its clock stretching capability, which means that it stretches the SCL signal at low level when required, to perform software actions. If the controller does not

support clock stretching, I2C must be configured with NOSTRETCH = 1 in the I2C_CR1 register.

After receiving an ADDR interrupt, if several addresses are enabled, the user must read the ADDCODE[6:0] bitfield of the I2C_ISR register to check which address matched. The DIR flag must also be checked to know the transfer direction.

Target with clock stretching

As long as the NOSTRETCH bit of the I2C_CR1 register is zero (default), the I2C peripheral operating as an I²C-bus target stretches the SCL signal in the following situations:

- The ADDR flag is set and the received address matches with one of the enabled target addresses.
  The stretch is released when the software clears the ADDR flag by setting the ADDRCF bit.
- In transmission, the previous data transmission is completed and no new data is written in I2C_TXDR register, or the first data byte is not written when the ADDR flag is cleared (TXE = 1).
  The stretch is released when the data is written to the I2C_TXDR register.
- In reception, the I2C_RXDR register is not read yet and a new data reception is completed.
  The stretch is released when I2C_RXDR is read.
- In target byte control mode (SBC bit set) with reload (RELOAD bit set), the last data byte transfer is finished (TCR bit set).
  The stretch is released when then TCR is cleared by writing a non-zero value in the NBYTES[7:0] bitfield.
- After SCL falling edge detection.
  The stretch is released after [(SDADEL + SCLDEL + 1) x (PRESC+ 1) + 1] x t_{I2CCLK} period.

Target without clock stretching

As long as the NOSTRETCH bit of the I2C_CR1 register is set, the I2C peripheral operating as an I²C-bus target does not stretch the SCL signal.

The SCL clock is not stretched while the ADDR flag is set.

In transmission, the data must be written in the I2C_TXDR register before the first SCL pulse corresponding to its transfer occurs. If not, an underrun occurs, the OVR flag is set in the I2C_ISR register and an interrupt is generated if the ERRIE bit of the I2C_CR1 register is set. The OVR flag is also set when the first data transmission starts and the STOPF bit is still set (has not been cleared). Therefore, if the user clears the STOPF flag of the previous transfer only after writing the first data to be transmitted in the next transfer, it ensures that the OVR status is provided, even for the first data to be transmitted.

In reception, the data must be read from the I2C_RXDR register before the ninth SCL pulse (ACK pulse) of the next data byte occurs. If not, an overrun occurs, the OVR flag is set in the I2C_ISR register, and an interrupt is generated if the ERRIE bit of the I2C_CR1 register is set.

Target byte control mode

To allow byte ACK control in target reception mode, the target byte control mode must be enabled, by setting the SBC bit of the I2C_CR1 register. This is required to comply with SMBus standards.

The reload mode must be selected to allow byte ACK control in target reception mode (RELOAD = 1). To get control of each byte, NBYTES[7:0] must be initialized to 0x1 in the ADDR interrupt subroutine, and reloaded to 0x1 after each received byte. When the byte is received, the TCR bit is set, stretching the SCL signal low between the eighth and the ninth SCL pulse. The user can read the data from the I2C_RXDR register, and then decide to acknowledge it or not by configuring the ACK bit of the I2C_CR2 register. The SCL stretch is released by programming NBYTES to a non-zero value: the acknowledge or not-acknowledge is sent and the next byte can be received.

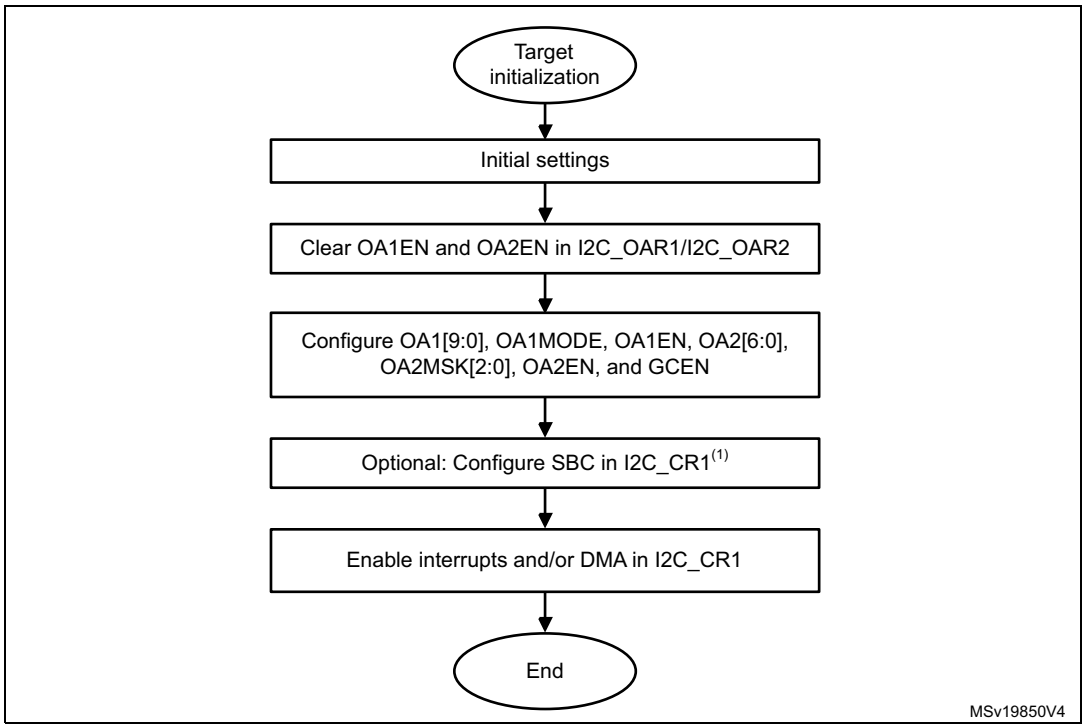
NBYTES[7:0] can be loaded with a value greater than 0x1. Receiving then continues until the corresponding number of bytes are received.

Note: The SBC bit must be configured when the I2C peripheral is disabled, when the target is not addressed, or when ADDR = 1.

The RELOAD bit value can be changed when ADDR = 1, or when TCR = 1.

Caution: The target byte control mode is not compatible with NOSTRETCH mode. Setting SBC when NOSTRETCH = 1 is not allowed.

Figure 776. Target initialization flow



1. SBC must be set to support SMBus features.

Target transmitter

A transmit interrupt status (TXIS) flag is generated when the I2C_TXDR register becomes empty. An interrupt is generated if the TXIE bit of the I2C_CR1 register is set.

The TXIS flag is cleared when the I2C_TXDR register is written with the next data byte to transmit.

When NACK is received, the NACKF flag is set in the I2C_ISR register and an interrupt is generated if the NACKIE bit of the I2C_CR1 register is set. The target automatically releases the SCL and SDA lines to let the controller perform a STOP or a RESTART condition. The TXIS bit is not set when a NACK is received.

When STOP is received and the STOPIE bit of the I2C_CR1 register is set, the STOPF flag of the I2C_ISR register is set and an interrupt is generated. In most applications, the SBC bit is usually programmed to 0. In this case, if TXE = 0 when the target address is received (ADDR = 1), the user can choose either to send the content of the I2C_TXDR register as the first data byte, or to flush the I2C_TXDR register, by setting the TXE bit in order to program a new data byte.

In target byte control mode (SBC = 1), the number of bytes to transmit must be programmed in NBYTES[7:0] in the address match interrupt subroutine (ADDR = 1). In this case, the number of TXIS events during the transfer corresponds to the value programmed in NBYTES[7:0].

Caution: When NOSTRETCH = 1, the SCL clock is not stretched while the ADDR flag is set, so the user cannot flush the I2C_TXDR register content in the ADDR subroutine to program the first data byte. The first data byte to send must be previously programmed in the I2C_TXDR register:

- This data can be the one written in the last TXIS event of the previous transmission message.
- If this data byte is not the one to send, the I2C_TXDR register can be flushed, by setting the TXE bit, to program a new data byte. The STOPF bit must be cleared only after these actions. This guarantees that they are executed before the first data transmission starts, following the address acknowledge.

  If STOPF is still set when the first data transmission starts, an underrun error is generated (the OVR flag is set).

  If a TXIS event (transmit interrupt or transmit DMA request) is required, the user must set the TXIS bit in addition to the TXE bit, to generate the event.

Figure 777. Transfer sequence flow for I2C target transmitter, NOSTRETCH = 0

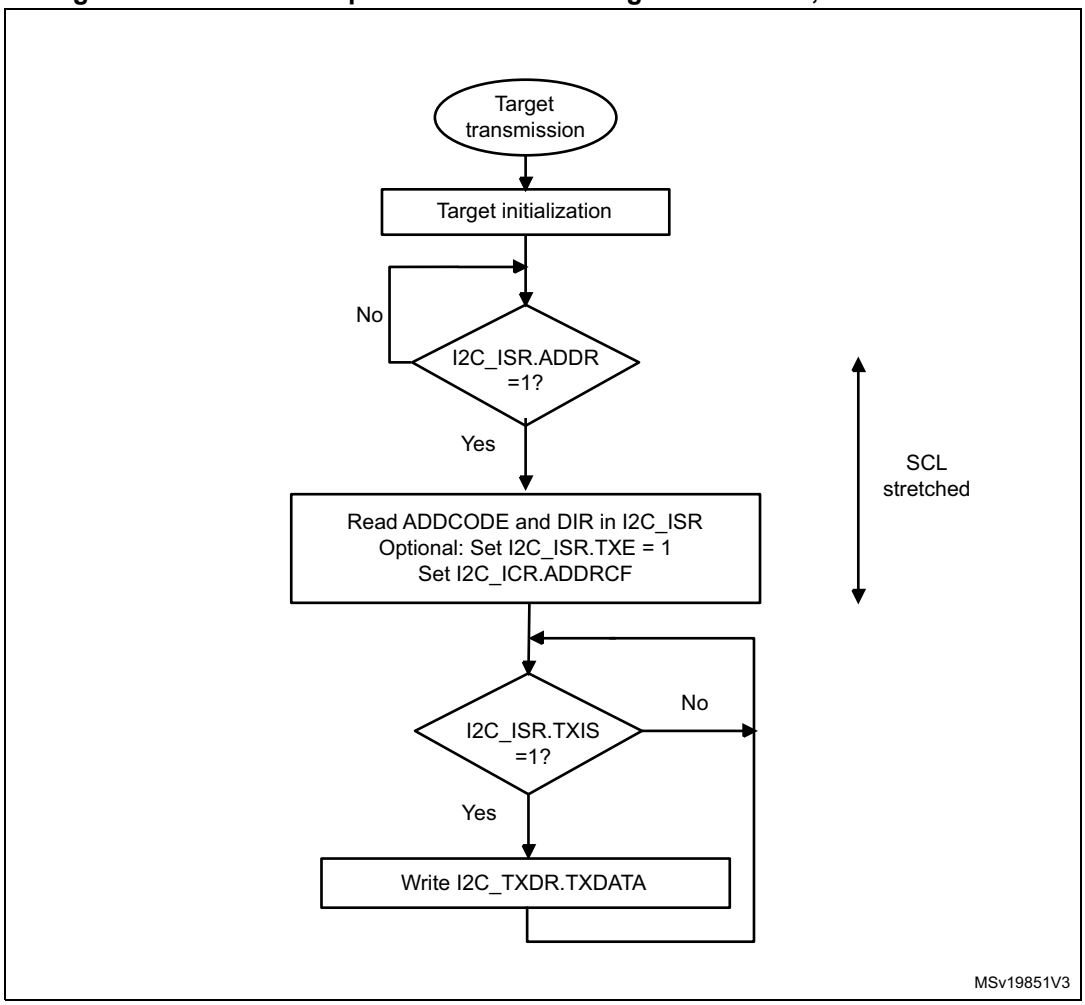


Figure 778. Transfer sequence flow for I2C target transmitter, NOSTRETCH = 1

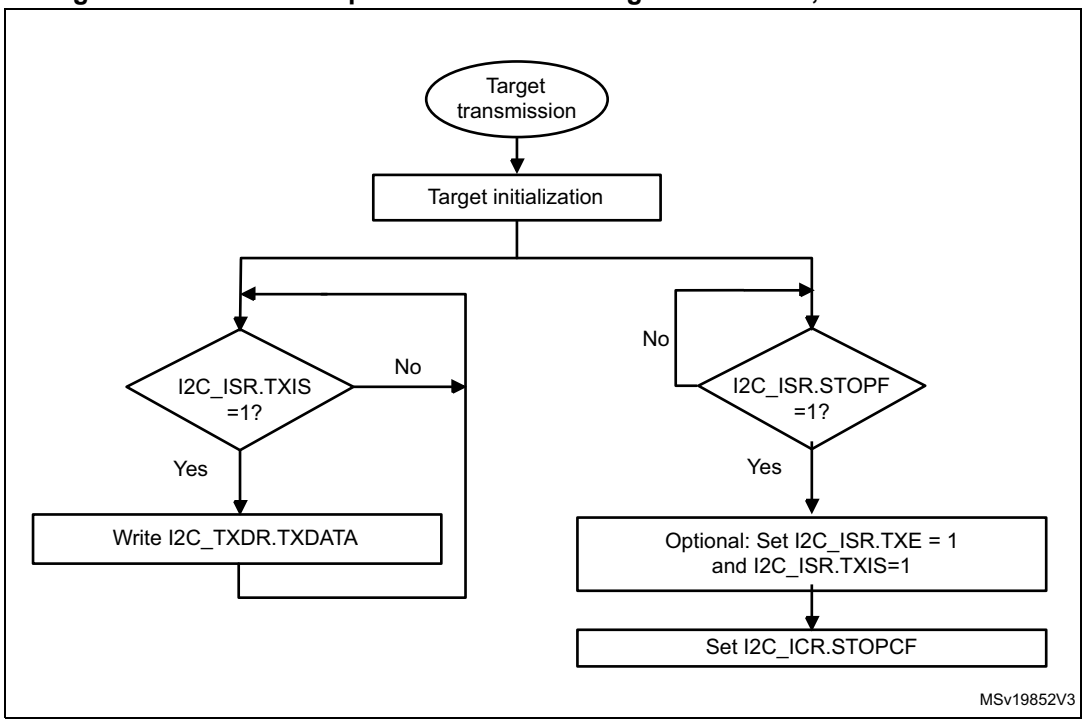
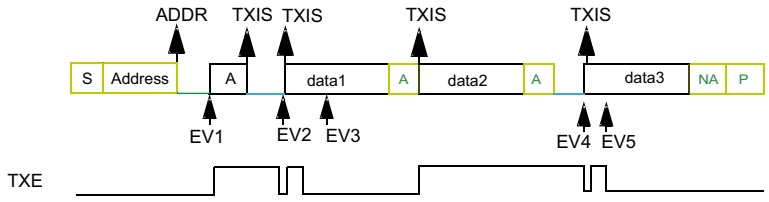


Figure 779. Transfer bus diagrams for I2C target transmitter (mandatory events only)

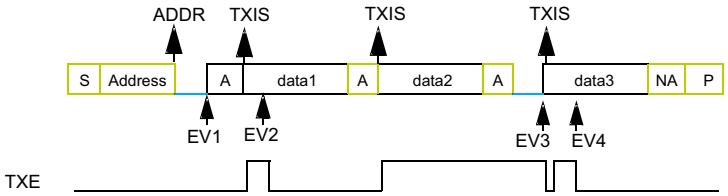
Example I2C target transmitter 3 bytes with 1st data flushed, NOSTRETCH=0:



legend:
transmission
reception
SCL stretch

EV1: ADDR ISR: check ADDCODE and DIR, set TXE, set ADDRCF
EV2: TXIS ISR: wr data1
EV3: TXIS ISR: wr data2
EV4: TXIS ISR: wr data3
EV5: TXIS ISR: wr data4 (not sent)

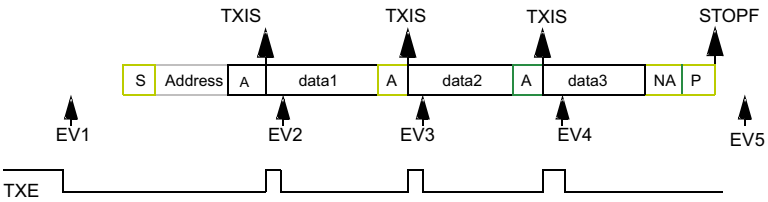
Example I2C target transmitter 3 bytes without 1st data flush, NOSTRETCH=0:



legend :
transmission
reception
SCL stretch

EV1: ADDR ISR: check ADDCODE and DIR, set ADDRCF
EV2: TXIS ISR: wr data2
EV3: TXIS ISR: wr data3
EV4: TXIS ISR: wr data4 (not sent)

Example I2C target transmitter 3 bytes, NOSTRETCH=1:



legend:
transmission
reception
SCL stretch

EV1: wr data1
EV2: TXIS ISR: wr data2
EV3: TXIS ISR: wr data3
EV4: TXIS ISR: wr data4 (not sent)
EV5: STOPF ISR: (optional: set TXE and TXIS), set STOPCF

MSv19853V3

Target receiver

The RXNE bit of the I2C_ISR register is set when the I2C_RXDR is full, which generates an interrupt if the RXIE bit of the I2C_CR1 register is set. RXNE is cleared when I2C_RXDR is read.

When STOP condition is received and the STOPIE bit of the I2C_CR1 register is set, the STOPF flag in the I2C_ISR register is set and an interrupt is generated.

Figure 780. Transfer sequence flow for I2C target receiver, NOSTRETCH = 0

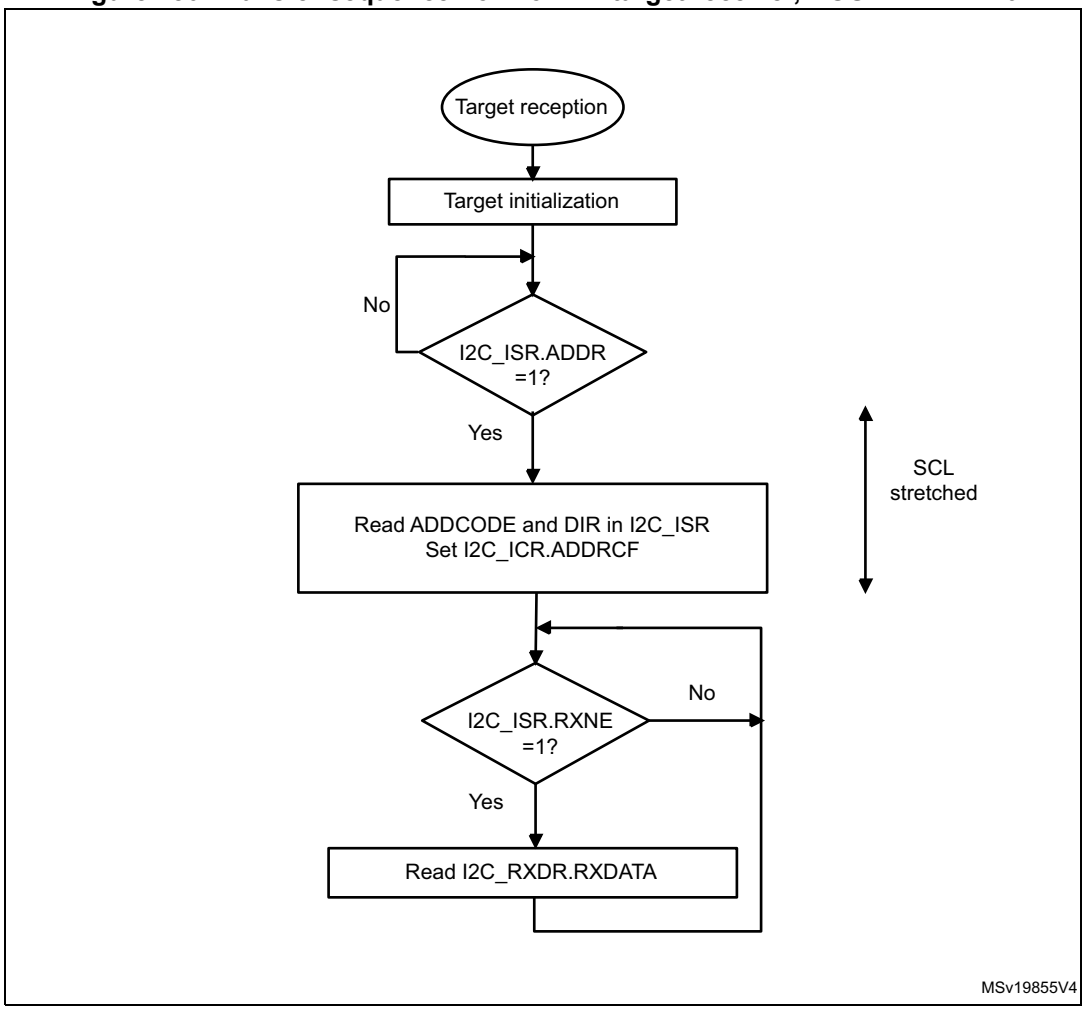


Figure 781. Transfer sequence flow for I2C target receiver, NOSTRETCH = 1

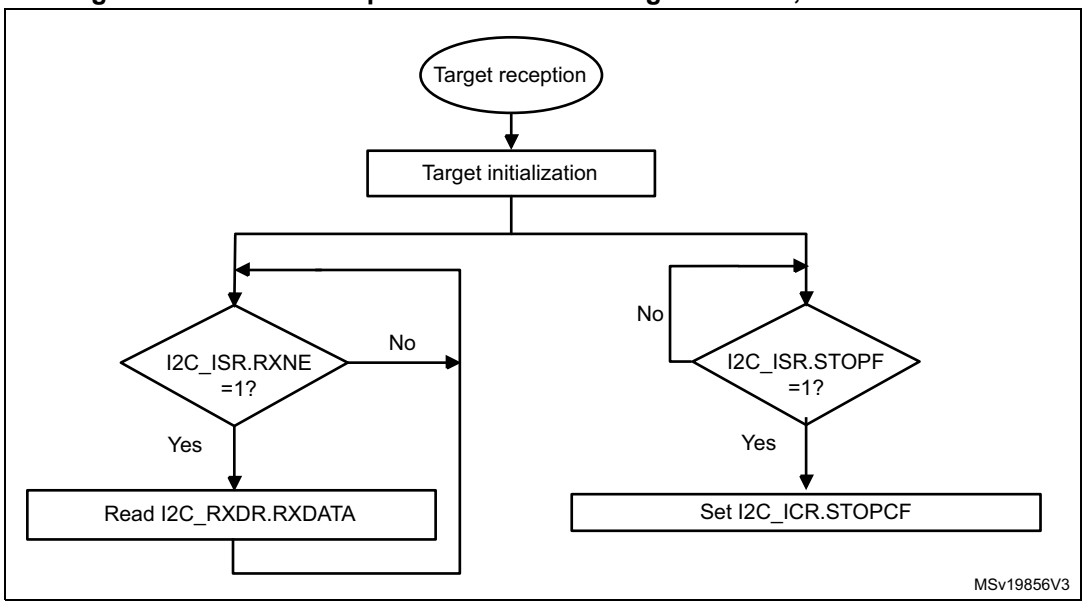
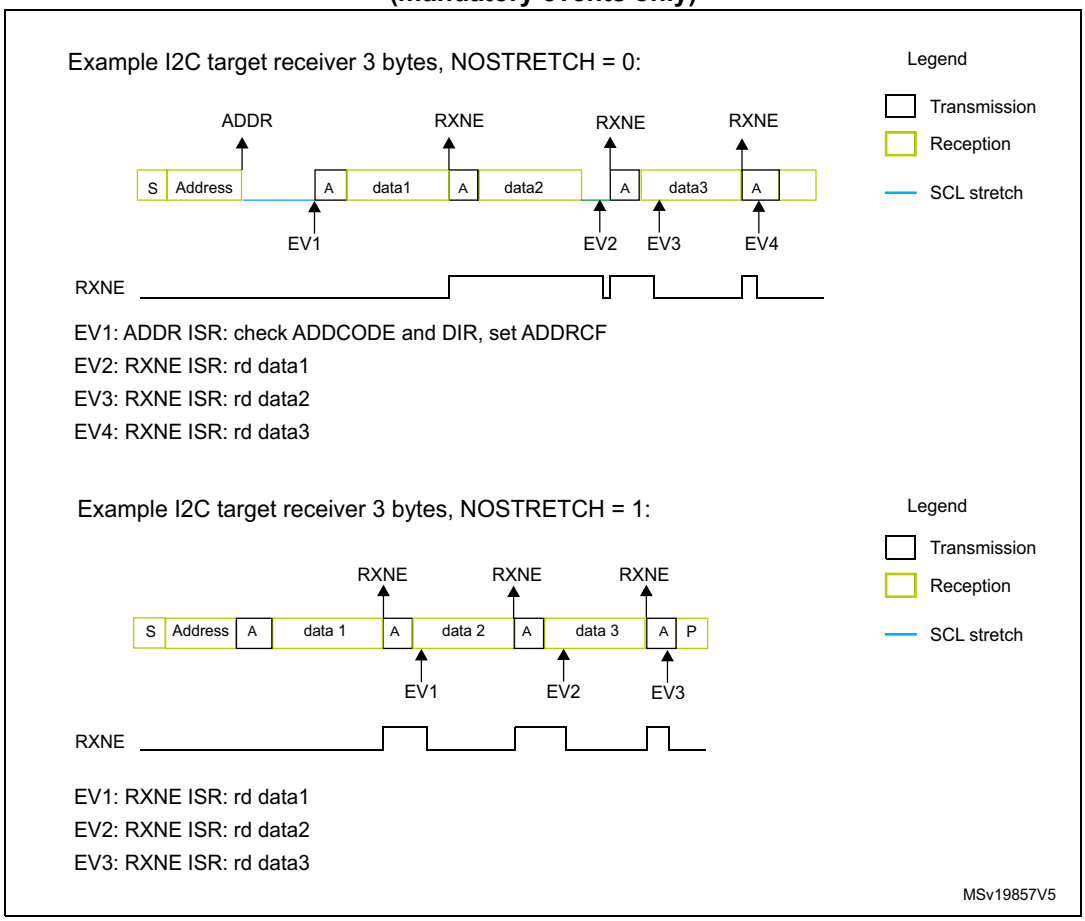


Figure 782. Transfer bus diagrams for I2C target receiver (mandatory events only)



59.4.9 I2C controller mode

I2C controller initialization

Before enabling the peripheral, the I2C controller clock must be configured, by setting the SCLH and SCLL bits in the I2C_TIMINGR register.

The STM32CubeMX tool calculates and provides the I2C_TIMINGR content in the *I2C Configuration* window.

A clock synchronization mechanism is implemented in order to support multicontroller environment and target clock stretching.

In order to allow clock synchronization:

- The low level of the clock is counted using the SCLL counter, starting from the SCL low level internal detection.
- The high level of the clock is counted using the SCLH counter, starting from the SCL high level internal detection.

I2C detects its own SCL low level after a t_{SYNC1} delay depending on the SCL falling edge, SCL input noise filters (analog and digital), and SCL synchronization to the I2CxCLK clock. I2C releases SCL to high level once the SCLL counter reaches the value programmed in the SCLL[7:0] bitfield of the I2C_TIMINGR register.

I2C detects its own SCL high level after a t_{SYNC2} delay depending on the SCL rising edge, SCL input noise filters (analog and digital), and SCL synchronization to the I2CxCLK clock. I2C ties SCL to low level once the SCLH counter reaches the value programmed in the SCLH[7:0] bitfield of the I2C_TIMINGR register.

Consequently the controller clock period is:

$t_{SCL} = t_{SYNC1} + t_{SYNC2} + \{[(SCLH+ 1) + (SCLL+ 1)] \times (PRESC+ 1) \times t_{I2CCLK}\}$

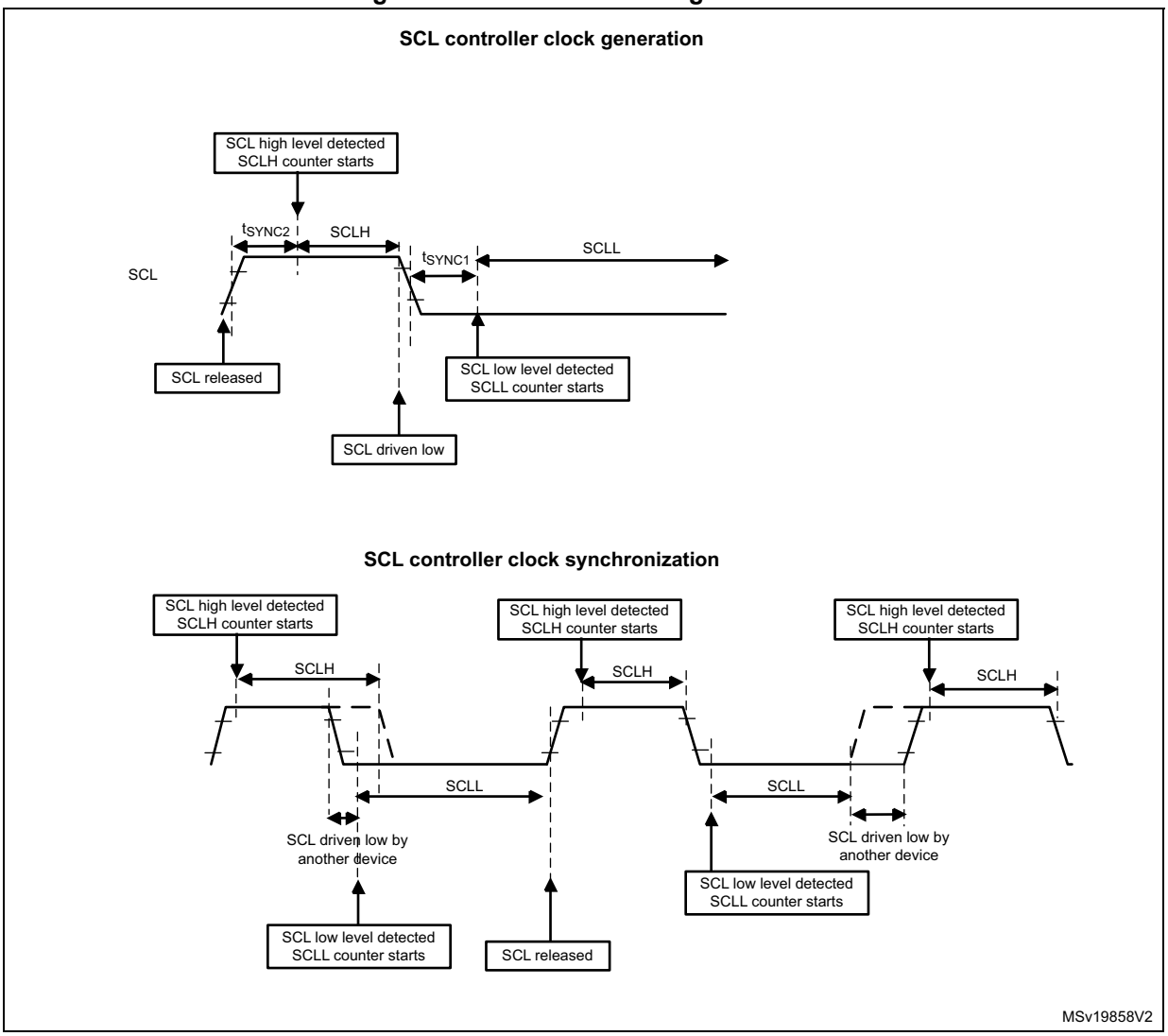
The duration of t_{SYNC1} depends upon:

- SCL falling slope
- input delay induced by the analog filter (when enabled)
- input delay induced by the digital filter (when enabled): DNF[3:0] x t_{I2CCLK}
- delay due to SCL synchronization with the i2c_ker_ck clock (two to three i2c_ker_ck periods)

The duration of t_{SYNC2} depends upon:

- SCL rising slope
- input delay induced by the analog filter (when enabled)
- input delay induced by the digital filter (when enabled): DNF[3:0] x t_{I2CCLK}
- delay due to SCL synchronization with the i2c_ker_ck clock (two to three i2c_ker_ck periods)

Figure 783. Controller clock generation



Caution: For compliance with the I²C-bus or SMBus specification, the controller clock must respect the timings in the following table.

Table 642. I²C-bus and SMBus specification clock timings

Symbol	Parameter	Standard-mode (Sm)		Fast-mode (Fm)		Fast-mode Plus (Fm+)		SMBus		Unit
		Min	Max	Min	Max	Min	Max	Min	Max	
f_{SCL}	SCL clock frequency	-	100	-	400	-	1000	-	100	kHz
$t_{HD:STA}$	Hold time (repeated) START condition	4.0	-	0.6	-	0.26	-	4.0	-	µs
$t_{SU:STA}$	Set-up time for a repeated START condition	4.7	-	0.6	-	0.26	-	4.7	-	
$t_{SU:STO}$	Set-up time for STOP condition	4.0	-	0.6	-	0.26	-	4.0	-	
t_{BUF}	Bus free time between a STOP and START condition	4.7	-	1.3	-	0.5	-	4.7	-	
t_{LOW}	Low period of the SCL clock	4.7	-	1.3	-	0.5	-	4.7	-	
t_{HIGH}	High period of the SCL clock	4.0	-	0.6	-	0.26	-	4.0	50	
t_r	Rise time of both SDA and SCL signals	-	1000	-	300	-	120	-	1000	ns
t_f	Fall time of both SDA and SCL signals	-	300	-	300	-	120	-	300	

Note: The SCLL[7:0] bitfield also determines the t_{BUF} and $t_{SU:STA}$ timings and SCLH[7:0] the $t_{HD:STA}$ and $t_{SU:STO}$ timings.

Refer to *Section 59.4.10* for examples of I2C_TIMINGR settings versus the i2c_ker_ck frequency.

Controller communication initialization (address phase)

To initiate the communication with a target to address, set the following bitfields of the I2C_CR2 register:

- ADD10: addressing mode (7-bit or 10-bit)
- SADD[9:0]: target address to send
- RD_WRN: transfer direction
- HEAD10R: in case of 10-bit address read, this bit determines whether the header only (for direction change) or the complete address sequence is sent.
- NBYTES[7:0]: the number of bytes to transfer; if equal to or greater than 255 bytes, the bitfield must initially be set to 0xFF.

Note: Changing these bitfields is not allowed as long as the START bit is set.

Before launching the communication, make sure that the I²C-bus is idle. This can be checked using the bus idle detection function or by verifying that the IDR bits of the GPIOs selected as SDA and SCL are set. Any low-level incident on the I²C-bus lines that coincides with the START condition asserted by the I2C peripheral may cause its deadlock if not filtered out by the input filters. If such incidents cannot be prevented, design the software so that it restores the normal operation of the I2C peripheral in case of a deadlock, by toggling the PE bit of the I2C_CR1 register.

To launch the communication, set the START bit of the I2C_CR2 register. The controller then automatically sends a START condition followed by the target address, either immediately if the BUSY flag is low, or t_{BUF} time after the BUSY flag transits from high to low state. The BUSY flag is set upon sending the START condition.

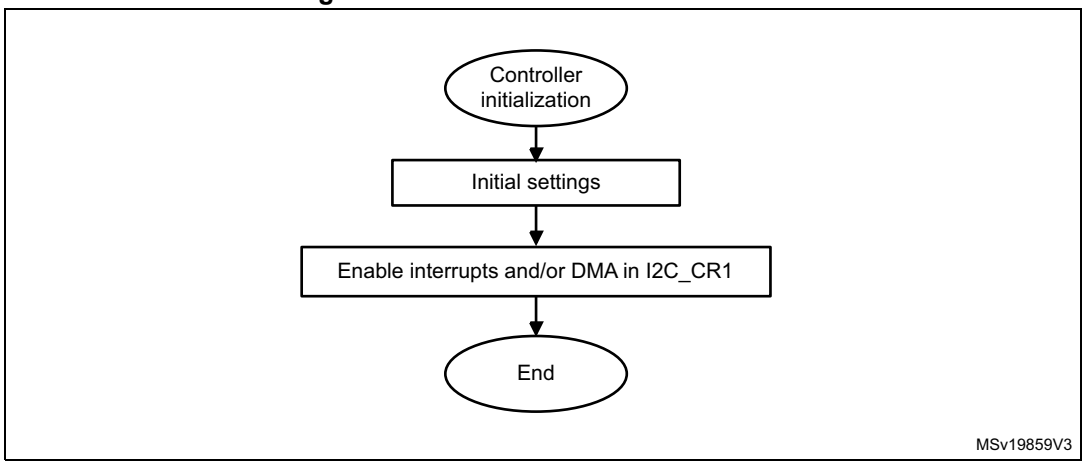
In case of an arbitration loss, the controller automatically switches back to target mode and can acknowledge its own address if it is addressed as a target.

Note: The START bit is reset by hardware when the target address is sent on the bus, whatever the received acknowledge value. The START bit is also reset by hardware upon arbitration loss.

In 10-bit addressing mode, the controller automatically keeps resending the target address in a loop until the first address byte (first seven address bits) is acknowledged by the target. Setting the ADDRCF bit makes I2C quit that loop.
If the I2C peripheral is addressed as a target (ADDR = 1) while the START bit is set, the I2C peripheral switches to target mode and the START bit is cleared.

Note: The same procedure is applied for a repeated START condition. In this case, BUSY = 1.

Figure 784. Controller initialization flow

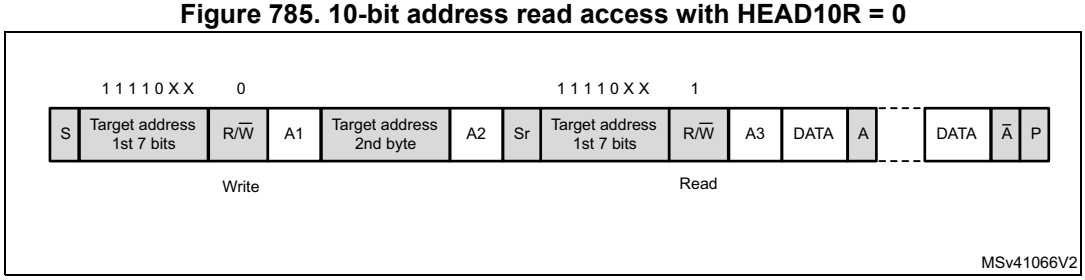


Initialization of a controller receiver addressing a 10-bit address target

If the target address is in 10-bit format, the user can choose to send the complete read sequence, by clearing the HEAD10R bit of the I2C_CR2 register. In this case, the controller automatically sends the following complete sequence after the START bit is set:

(RE)START + Target address 10-bit header Write + Target address second byte + (RE)START + Target address 10-bit header Read.

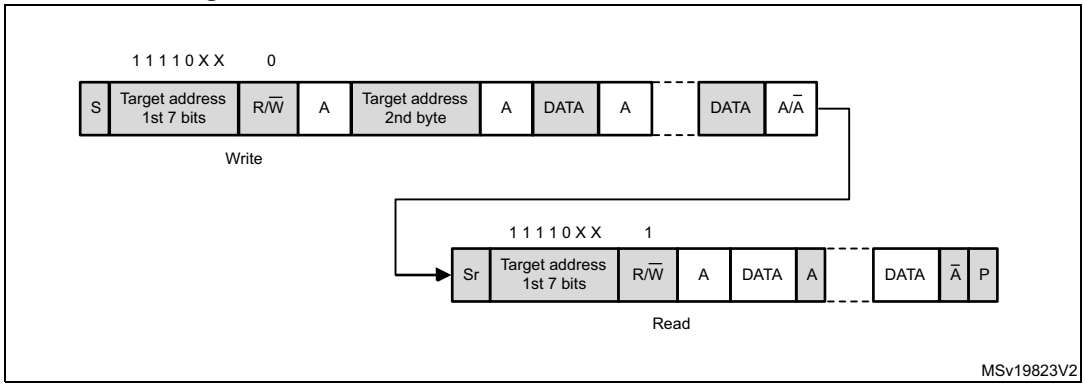
Figure 785. 10-bit address read access with HEAD10R = 0



If the controller addresses a 10-bit address target, transmits data to this target and then reads data from the same target, a controller transmission flow must be done first. Then a repeated START is set with the 10-bit target address configured with HEAD10R = 1. In this case, the controller sends this sequence:

RESTART + Target address 10-bit header Read.

Figure 786. 10-bit address read access with HEAD10R = 1



Controller transmitter

In the case of a write transfer, the TXIS flag is set after each byte transmission, after the ninth SCL pulse when an ACK is received.

A TXIS event generates an interrupt if the TXIE bit of the I2C_CR1 register is set. The flag is cleared when the I2C_TXDR register is written with the next data byte to transmit.

The number of TXIS events during the transfer corresponds to the value programmed in NBYTES[7:0]. If the total number of data bytes to transmit is greater than 255, the reload mode must be selected by setting the RELOAD bit in the I2C_CR2 register. In this case, when the NBYTES[7:0] number of data bytes is transferred, the TCR flag is set and the SCL line is stretched low until NBYTES[7:0] is written with a non-zero value.

When RELOAD = 0 and the number of data bytes defined in NBYTES[7:0] is transferred:

- In automatic end mode (AUTOEND = 1), a STOP condition is automatically sent.
- In software end mode (AUTOEND = 0), the TC flag is set and the SCL line is stretched low, to perform software actions:
  - A RESTART condition can be requested by setting the START bit of the I2C_CR2 register with the proper target address configuration and the number of bytes to transfer. Setting the START bit clears the TC flag and sends the START condition on the bus.
  - A STOP condition can be requested by setting the STOP bit of the I2C_CR2 register. This clears the TC flag and sends a STOP condition on the bus.

When a NACK is received, the TXIS flag is not set and a STOP condition is automatically sent. The NACKF flag of the I2C_ISR register is set. An interrupt is generated if the NACKIE bit is set.

Figure 787. Transfer sequence flow for I2C controller transmitter, N ≤ 255 bytes

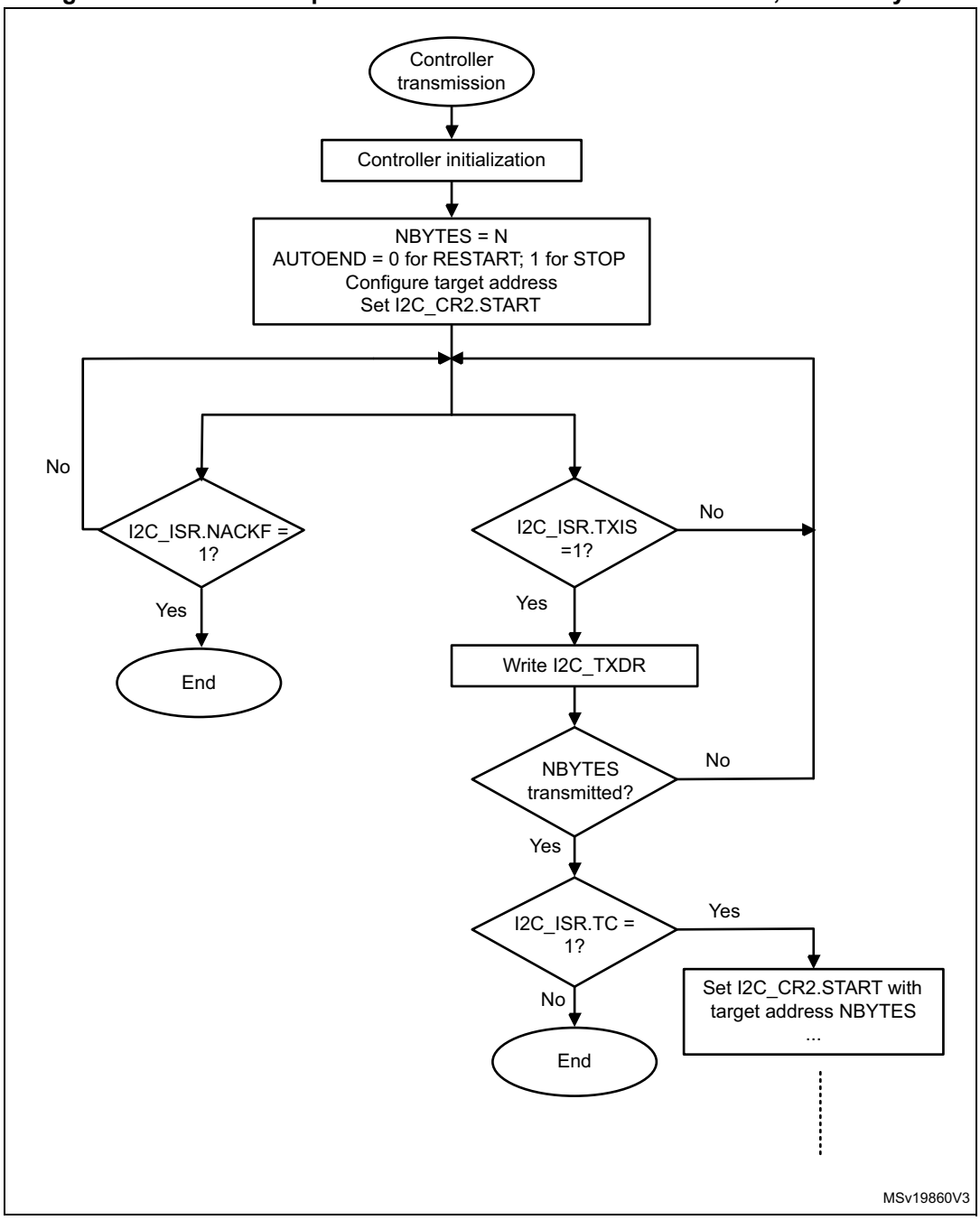


Figure 788. Transfer sequence flow for I2C controller transmitter, N > 255 bytes

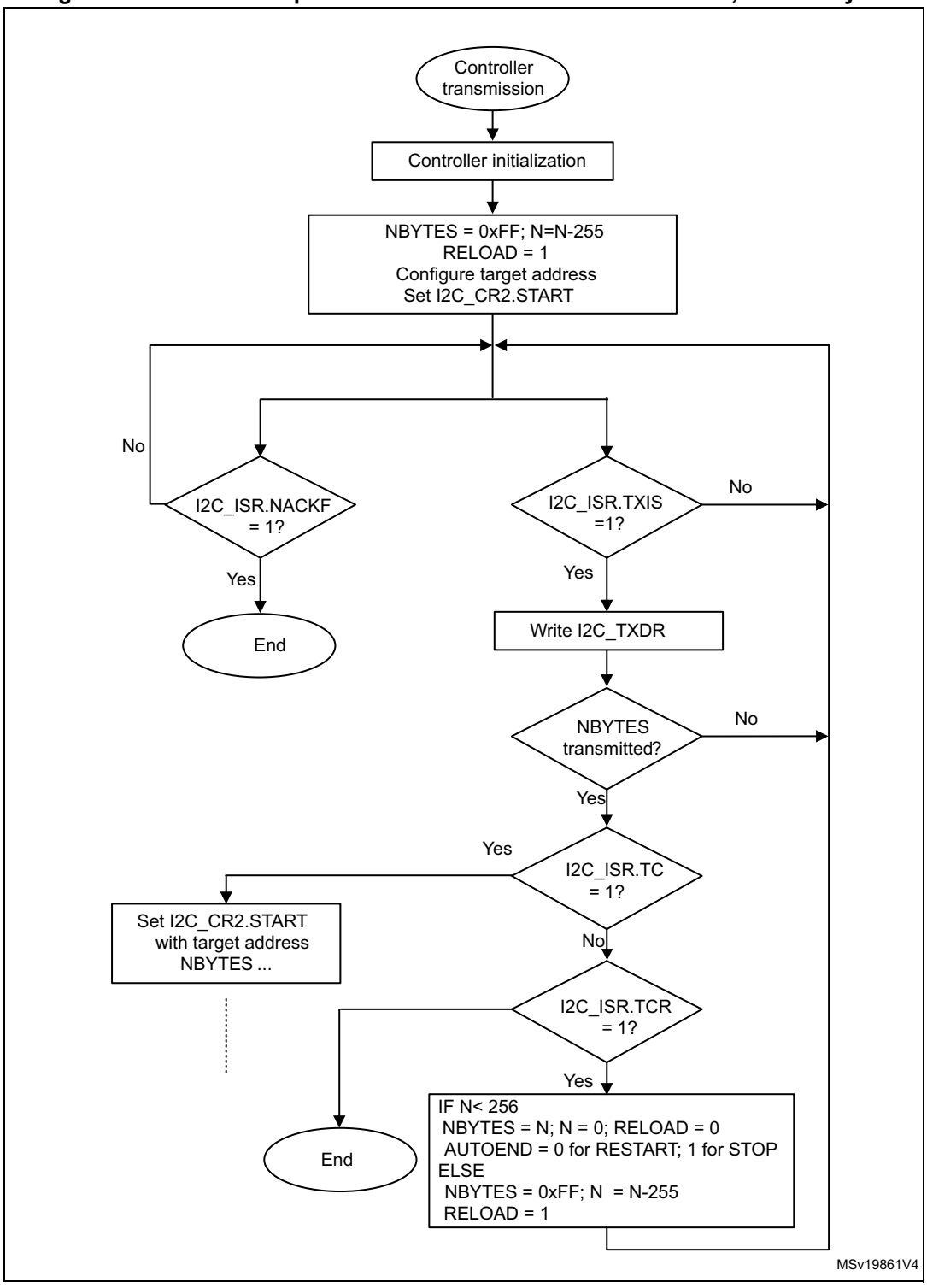
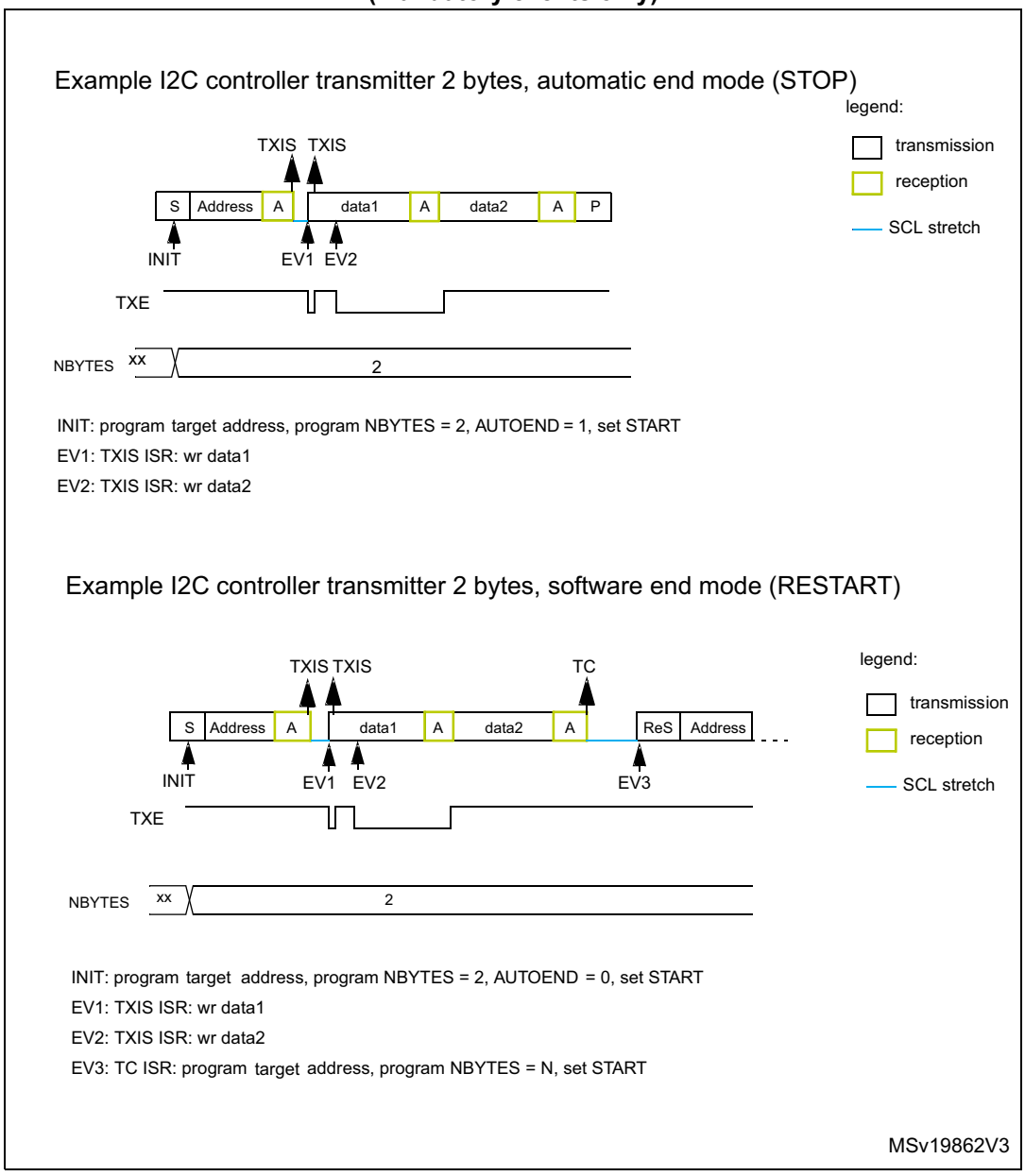


Figure 789. Transfer bus diagrams for I2C controller transmitter (mandatory events only)



Controller receiver

In the case of a read transfer, the RXNE flag is set after each byte reception, after the eighth SCL pulse. An RXNE event generates an interrupt if the RXIE bit of the I2C_CR1 register is set. The flag is cleared when I2C_RXDR is read.

If the total number of data bytes to receive is greater than 255, select the reload mode, by setting the RELOAD bit of the I2C_CR2 register. In this case, when the NBYTES[7:0] number of data bytes is transferred, the TCR flag is set and the SCL line is stretched low until NBYTES[7:0] is written with a non-zero value.

When RELOAD = 0 and he number of data bytes defined in NBYTES[7:0] is transferred:

- In automatic end mode (AUTOEND = 1), a NACK and a STOP are automatically sent after the last received byte.
- In software end mode (AUTOEND = 0), a NACK is automatically sent after the last received byte. The TC flag is set and the SCL line is stretched low in order to allow software actions:
  - A RESTART condition can be requested by setting the START bit of the I2C_CR2 register, with the proper target address configuration and the number of bytes to transfer. Setting the START bit clears the TC flag and sends the START condition and the target address on the bus.
  - A STOP condition can be requested by setting the STOP bit of the I2C_CR2 register. This clears the TC flag and sends a STOP condition on the bus.

Figure 790. Transfer sequence flow for I2C controller receiver, N ≤ 255 bytes

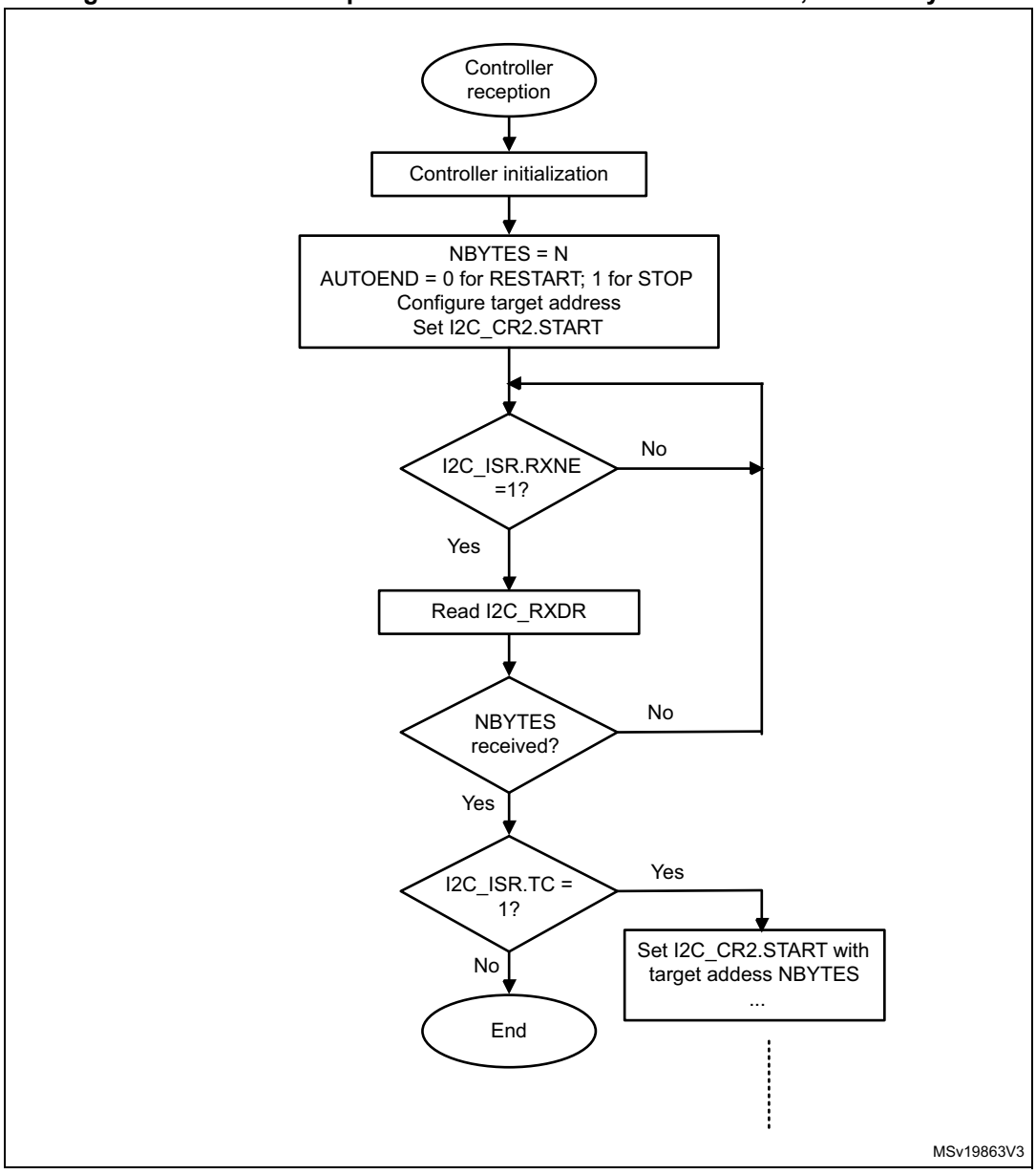


Figure 791. Transfer sequence flow for I2C controller receiver, N > 255 bytes

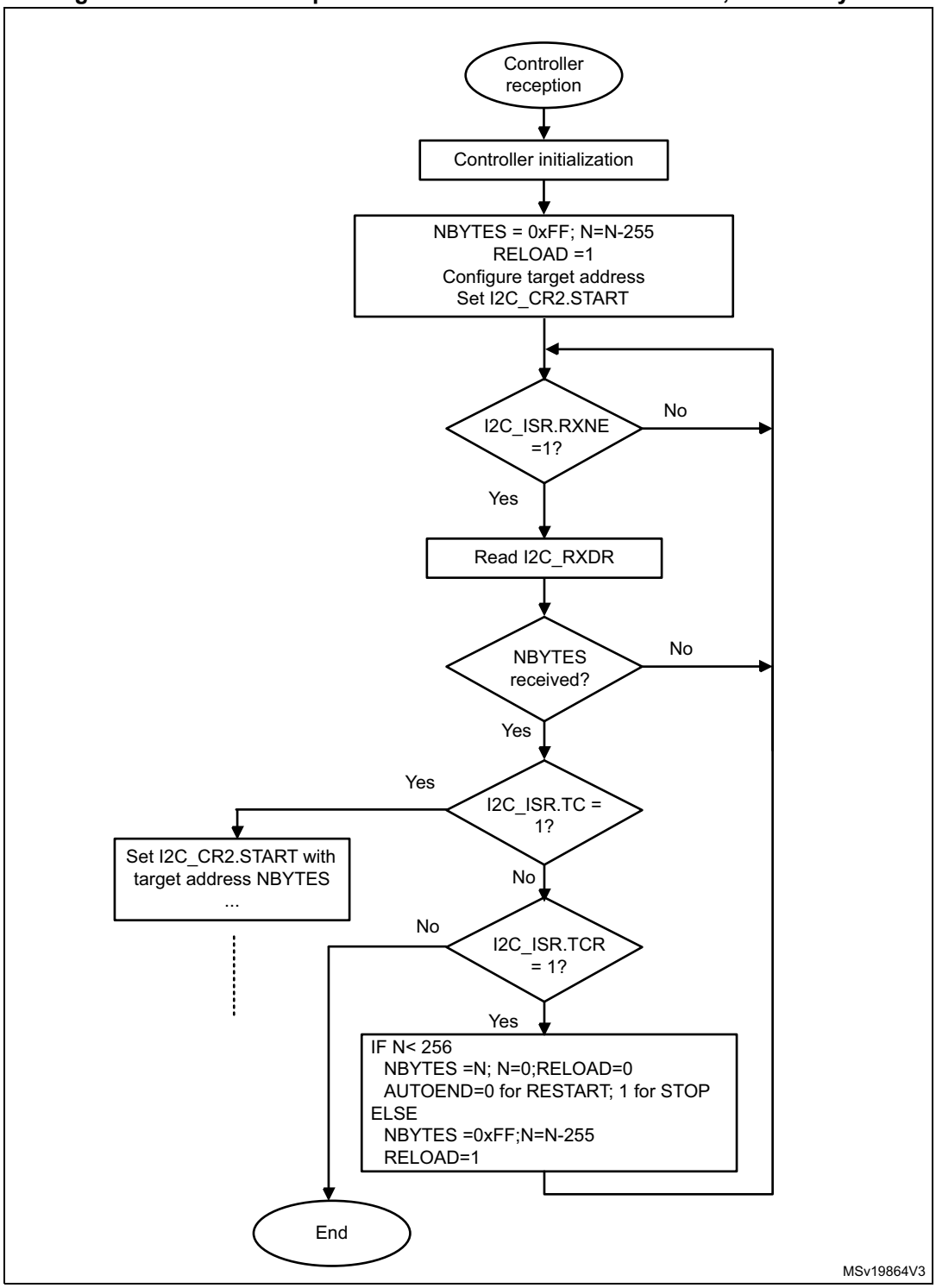
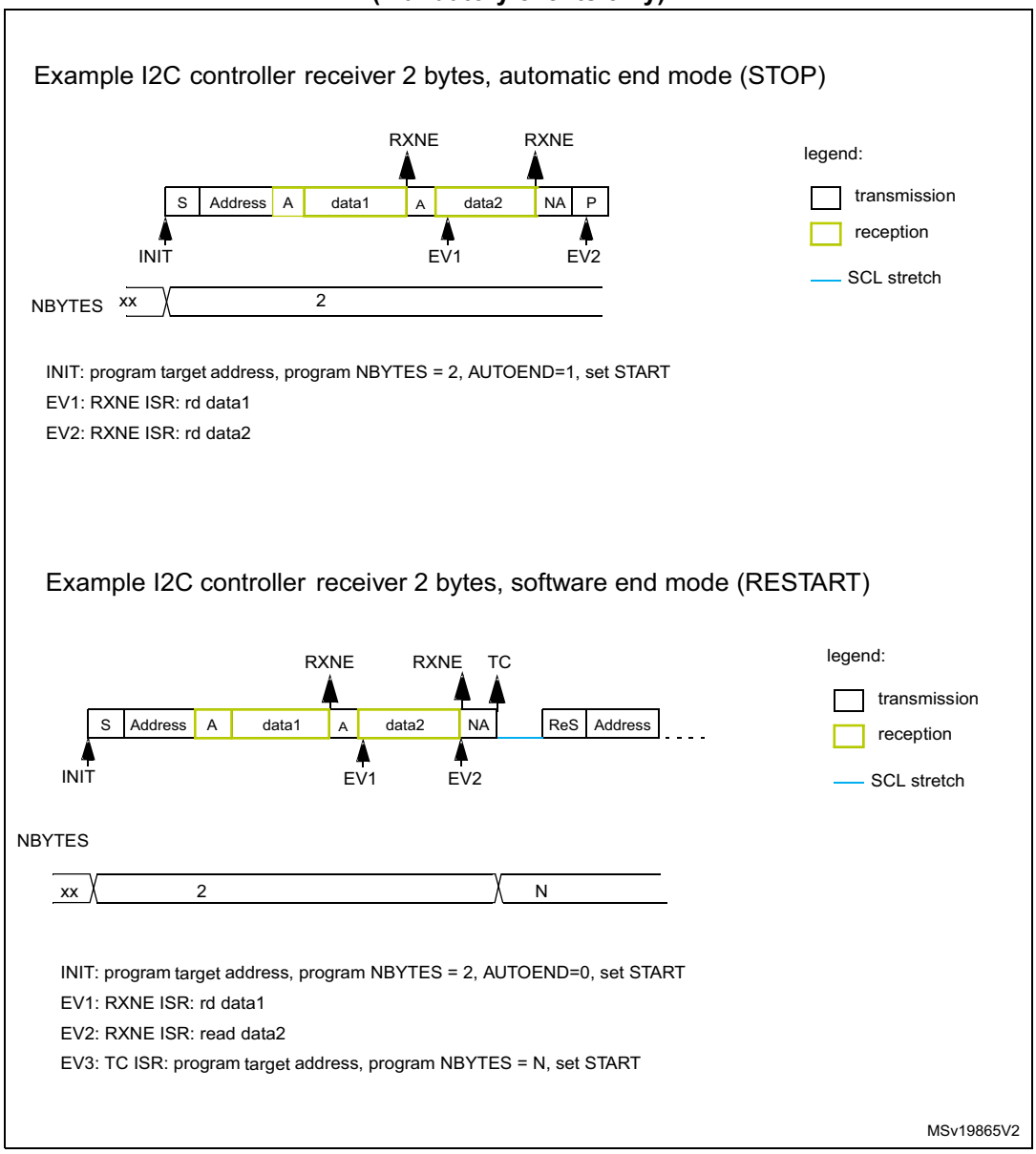


Figure 792. Transfer bus diagrams for I2C controller receiver (mandatory events only)



59.4.10 I2C_TIMINGR register configuration examples

The following tables provide examples of how to program the I2C_TIMINGR register to obtain timings compliant with the I²C-bus specification. To get more accurate configuration values, use the STM32CubeMX tool (*I2C Configuration* window).

Table 643. Timing settings for f_{I2CCLK} of 8 MHz

Parameter	Standard-mode (Sm)		Fast-mode (Fm)	Fast-mode Plus (Fm+)
	10 kHz	100 kHz	400 kHz	500 kHz
PRESC[3:0]	0x1	0x1	0x0	0x0
SCLL[7:0]	0xC7	0x13	0x9	0x6
t_{SCLL}	200 x 250 ns = 50 µs	20 x 250 ns = 5.0 µs	10 x 125 ns = 1250 ns	7 x 125 ns = 875 ns
SCLH[7:0]	0xC3	0xF	0x3	0x3
t_{SCLH}	196 x 250 ns = 49 µs	16 x 250 ns = 4.0 µs	4 x 125 ns = 500 ns	4 x 125 ns = 500 ns
t_{SCL}(1)	~100 µs(2)	~10 µs(2)	~2.5 µs(3)	~2.0 µs(4)
SDADEL[3:0]	0x2	0x2	0x1	0x0
t_{SDADEL}	2 x 250 ns = 500 ns	2 x 250 ns = 500 ns	1 x 125 ns = 125 ns	0 ns
SCLDEL[3:0]	0x4	0x4	0x3	0x1
t_{SCLDEL}	5 x 250 ns = 1250 ns	5 x 250 ns = 1250 ns	4 x 125 ns = 500 ns	2 x 125 ns = 250 ns

1. t_{SCL} is greater than t_{SCLL} + t_{SCLH} due to SCL internal detection delay. Values provided for t_{SCL} are examples only.
2. t_{SYNC1} + t_{SYNC2} minimum value is 4 x t_{I2CCLK} = 500 ns. Example with t_{SYNC1} + t_{SYNC2} = 1000 ns.
3. t_{SYNC1} + t_{SYNC2} minimum value is 4 x t_{I2CCLK} = 500 ns. Example with t_{SYNC1} + t_{SYNC2} = 750 ns.
4. t_{SYNC1} + t_{SYNC2} minimum value is 4 x t_{I2CCLK} = 500 ns. Example with t_{SYNC1} + t_{SYNC2} = 655 ns.

Table 644. Timing settings for f_{I2CCLK} of 16 MHz

Parameter	Standard-mode (Sm)		Fast-mode (Fm)	Fast-mode Plus (Fm+)
	10 kHz	100 kHz	400 kHz	1000 kHz
PRESC[3:0]	0x3	0x3	0x1	0x0
SCLL[7:0]	0xC7	0x13	0x9	0x4
t_{SCLL}	200 x 250 ns = 50 µs	20 x 250 ns = 5.0 µs	10 x 125 ns = 1250 ns	5 x 62.5 ns = 312.5 ns
SCLH[7:0]	0xC3	0xF	0x3	0x2
t_{SCLH}	196 x 250 ns = 49 µs	16 x 250 ns = 4.0 µs	4 x 125 ns = 500 ns	3 x 62.5 ns = 187.5 ns
t_{SCL}(1)	~100 µs(2)	~10 µs(2)	~2.5 µs(3)	~1.0 µs(4)
SDADEL[3:0]	0x2	0x2	0x2	0x0
t_{SDADEL}	2 x 250 ns = 500 ns	2 x 250 ns = 500 ns	2 x 125 ns = 250 ns	0 ns
SCLDEL[3:0]	0x4	0x4	0x3	0x2
t_{SCLDEL}	5 x 250 ns = 1250 ns	5 x 250 ns = 1250 ns	4 x 125 ns = 500 ns	3 x 62.5 ns = 187.5 ns

1. t_{SCL} is greater than t_{SCLL} + t_{SCLH} due to SCL internal detection delay. Values provided for t_{SCL} are examples only.
2. t_{SYNC1} + t_{SYNC2} minimum value is 4 x t_{I2CCLK} = 250 ns. Example with t_{SYNC1} + t_{SYNC2} = 1000 ns.
3. t_{SYNC1} + t_{SYNC2} minimum value is 4 x t_{I2CCLK} = 250 ns. Example with t_{SYNC1} + t_{SYNC2} = 750 ns.
4. t_{SYNC1} + t_{SYNC2} minimum value is 4 x t_{I2CCLK} = 250 ns. Example with t_{SYNC1} + t_{SYNC2} = 500 ns.

59.4.11 SMBus specific features

Introduction

The system management bus (SMBus) is a two-wire interface through which various devices can communicate with each other and with the rest of the system. It is based on operation principles of the I²C-bus. The SMBus provides a control bus for system and power management related tasks.

The I2C peripheral is compatible with the SMBus specification (http://smbus.org).

The system management bus specification refers to three types of devices:

- **Target** is a device that receives or responds to a command.
- **Controller** is a device that issues commands, generates clocks, and terminates the transfer.
- **Host** is a specialized controller that provides the main interface to the system CPU. A host must be a controller-target and must support the SMBus *host notify* protocol. Only one host is allowed in a system.

The I2C peripheral can be configured as a controller or a target device, and also as a host.

Bus protocols

There are eleven possible command protocols for any given device. The device can use any or all of them to communicate. These are: *Quick Command*, *Send Byte*, *Receive Byte*, *Write Byte*, *Write Word*, *Read Byte*, *Read Word*, *Process Call*, *Block Read*, *Block Write*, and *Block Write-Block Read Process Call*. The protocols must be implemented by the user software.

For more details on these protocols, refer to the SMBus specification (http://smbus.org).

STM32CubeMX implements an SMBus stack thanks to X-CUBE-SMBUS, a downloadable software pack that allows basic SMBus configuration per I2C instance.

Address resolution protocol (ARP)

SMBus target address conflicts can be resolved by dynamically assigning a new unique address to each target device. To provide a mechanism to isolate each device for the purpose of address assignment, each device must implement a unique 128-bit device identifier (UDID). In the I2C peripheral, it is implemented by software.

The I2C peripheral supports the Address resolution protocol (ARP). The SMBus device default address (0b1100 001) is enabled by setting the SMBDEN bit of the I2C_CR1 register. The ARP commands must be implemented by the user software.

Arbitration is also performed in target mode for ARP support.

For more details on the SMBus address resolution protocol, refer to the SMBus specification (http://smbus.org).

Received command and data acknowledge control

An SMBus receiver must be able to NACK each received command or data. In order to allow the ACK control in target mode, the target byte control mode must be enabled, by setting the SBC bit of the I2C_CR1 register. Refer to *Target byte control mode* for more details.

Host notify protocol

To enable the host notify protocol, set the SMBHEN bit of the I2C_CR1 register. The I2C peripheral then acknowledges the SMBus host address (0b0001 000).

When this protocol is used, the device acts as a controller and the host as a target.

SMBus alert

The I2C peripheral supports the SMBALERT# optional signal through the SMBA pin. With the SMBALERT# signal, an SMBus target device can signal to the SMBus host that it wants to talk. The host processes the interrupt and simultaneously accesses all SMBALERT# devices through the alert response address (0b0001 100). Only the device/devices which pulled SMBALERT# low acknowledges/acknowledge the alert response address.

When the I2C peripheral is configured as an SMBus target device (SMBHEN = 0), the SMBA pin is pulled low by setting the ALERTEN bit of the I2C_CR1 register. The alert response address is enabled at the same time.

When the I2C peripheral is configured as an SMBus host (SMBHEN = 1), the ALERT flag of the I2C_ISR register is set when a falling edge is detected on the SMBA pin and ALERTEN = 1. An interrupt is generated if the ERRIE bit of the I2C_CR1 register is set. When ALERTEN = 0, the alert line is considered high even if the external SMBA pin is low.

Note: If the SMBus alert pin is not required, keep the ALERTEN bit cleared. The SMBA pin can then be used as a standard GPIO.

Packet error checking

A packet error checking mechanism introduced in the SMBus specification improves reliability and communication robustness. The packet error checking is implemented by appending a packet error code (PEC) at the end of each message transfer. The PEC is calculated by using the $C(x) = x^8 + x^2 + x + 1$ CRC-8 polynomial on all the message bytes (including addresses and read/write bits).

The I2C peripheral embeds a hardware PEC calculator and allows a not acknowledge to be sent automatically when the received byte does not match the hardware calculated PEC.

Timeouts

To comply with the SMBus timeout specifications, the I2C peripheral embeds hardware timers.

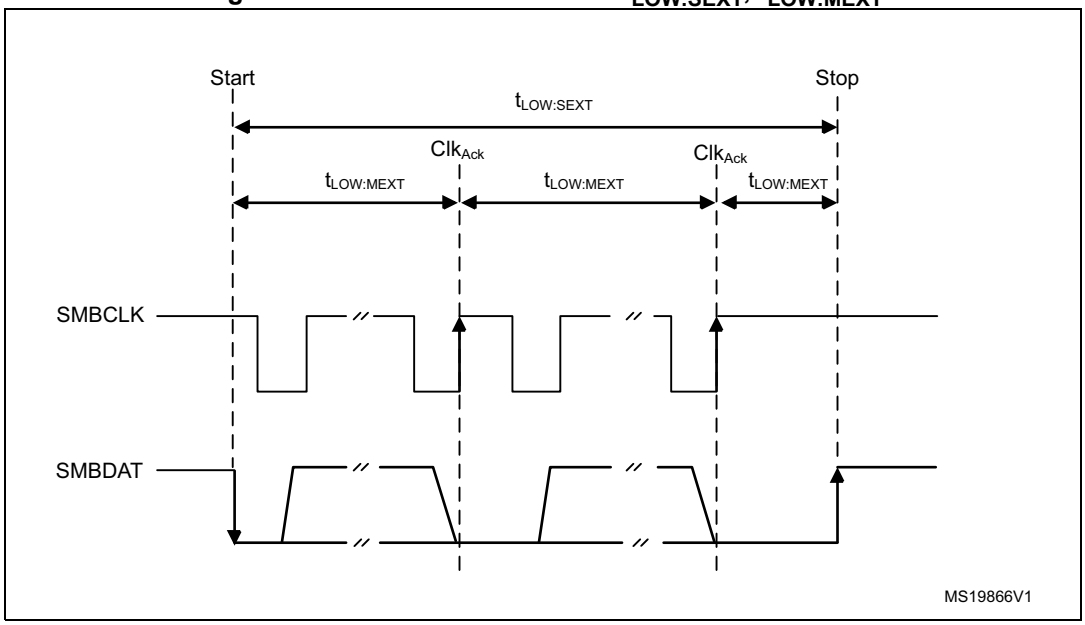
Table 645. SMBus timeout specifications

Symbol	Parameter	Limits		Unit
		Min	Max	
$t_{TIMEOUT}$	Detect clock low timeout	25	35	ms
$t_{LOW:SEXT}$(1)	Cumulative clock low extend time (target device)	-	25	
$t_{LOW:MEXT}$(2)	Cumulative clock low extend time (controller device)	-	10	

1. $t_{LOW:SEXT}$ is the cumulative time a given target device is allowed to extend the clock cycles in one message from the initial START to the STOP. It is possible that another target device or the controller also extends the clock causing the combined clock low extend time to be greater than $t_{LOW:SEXT}$. The value provided applies to a single target device connected to a full-target controller.

2. $t_{LOW:MEXT}$ is the cumulative time a controller device is allowed to extend its clock cycles within each byte of a message as defined from START-to-ACK, ACK-to-ACK, or ACK-to-STOP. It is possible that a target device or another controller also extends the clock, causing the combined clock low time to be greater than $t_{LOW:MEXT}$ on a given byte. The value provided applies to a single target device connected to a full-target controller.

Figure 793. Timeout intervals for $t_{LOW:SEXT}$, $t_{LOW:MEXT}$



Bus idle detection

A controller can assume that the bus is free if it detects that the clock and data signals have been high for $t_{IDLE} > t_{HIGH}$(max) (refer to the table in *Section 59.4.9*).

This timing parameter covers the condition where a controller is dynamically added to the bus, and may not have detected a state transition on the SMBCLK or SMBDAT lines. In this case, the controller must wait long enough to ensure that a transfer is not currently in progress. The I2C peripheral supports a hardware bus idle detection.

59.4.12 SMBus initialization

In addition to the I2C initialization for the I²C-bus, the use of the peripheral for the SMBus communication requires some extra initialization steps.

Received command and data acknowledge control (target mode)

An SMBus receiver must be able to NACK each received command or data. To allow ACK control in target mode, the target byte control mode must be enabled, by setting the SBC bit of the I2C_CR1 register. Refer to *Target byte control mode* for more details.

Specific addresses (target mode)

The specific SMBus addresses must be enabled if required. Refer to *Bus idle detection* for more details.

The SMBus device default address (0b1100 001) is enabled by setting the SMBDEN bit of the I2C_CR1 register.

The SMBus host address (0b0001 000) is enabled by setting the SMBHEN bit of the I2C_CR1 register.

The alert response address (0b0001100) is enabled by setting the ALERTEN bit of the I2C_CR1 register.

Packet error checking

PEC calculation is enabled by setting the PECEN bit of the I2C_CR1 register. Then the PEC transfer is managed with the help of the hardware byte counter associated with the NBYTES[7:0] bitfield of the I2C_CR2 register. The PECEN bit must be configured before enabling the I2C.

The PEC transfer is managed with the hardware byte counter, so the SBC bit must be set when interfacing the SMBus in target mode. The PEC is transferred after transferring NBYTES[7:0] - 1 data bytes, if the PECBYTE bit is set and the RELOAD bit is cleared. If RELOAD is set, PECBYTE has no effect.

Caution: Changing the PECEN configuration is not allowed when the I2C peripheral is enabled.

Table 646. SMBus with PEC configuration

Mode	SBC bit	RELOAD bit	AUTOEND bit	PECBYTE bit
Controller Tx/Rx NBYTES + PEC+ STOP	X	0	1	1
Controller Tx/Rx NBYTES + PEC + ReSTART	X	0	0	1
Target Tx/Rx with PEC	1	0	X	1

Timeout detection

The timeout detection is enabled by setting the TIMOUTEN and TEXTEN bits of the I2C_TIMEOUTR register. The timers must be programmed in such a way that they detect a timeout before the maximum time given in the SMBus specification.

$t_{TIMEOUT}$ check

To check the $t_{TIMEOUT}$ parameter, load the 12-bit TIMEOUTA[11:0] bitfield with the timer reload value. Keep the TIDLE bit at 0 to detect the SCL low level timeout.

Then set the TIMOUTEN bit of the I2C_TIMEOUTR register, to enable the timer.

If SCL is tied low for longer than the (TIMEOUTA + 1) x 2048 x t_{I2CCLK} period, the TIMEOUT flag of the I2C_ISR register is set.

Refer to *Table 647*.

Caution: Changing the TIMEOUTA[11:0] bitfield and the TIDLE bit values is not allowed when the TIMEOUTEN bit is set.

$t_{LOW:SEXT}$ and $t_{LOW:MEXT}$ check

A 12-bit timer associated with the TIMEOUTB[11:0] bitfield allows checking $t_{LOW:SEXT}$ for the I2C peripheral operating as a target, or $t_{LOW:MEXT}$ when it operates as a controller. As the standard only specifies a maximum, the user can choose the same value for both. The timer is then enabled by setting the TEXTEN bit in the I2C_TIMEOUTR register.

If the SMBus peripheral performs a cumulative SCL stretch for longer than the (TIMEOUTB + 1) x 2048 x t_{I2CCLK} period, and within the timeout interval described in *Bus idle detection* section, the TIMEOUT flag of the I2C_ISR register is set.

Refer to *Table 648*.

Caution: Changing the TIMEOUTB[11:0] bitfield value is not allowed when the TEXTEN bit is set.

Bus idle detection

To check the t_{IDLE} period, the TIMEOUTA[11:0] bitfield associated with 12-bit timer must be loaded with the timer reload value. Keep the TIDLE bit at 1 to detect both SCL and SDA high level timeout. Then set the TIMOUTEN bit of the I2C_TIMEOUTR register to enable the timer.

If both the SCL and SDA lines remain high for longer than the (TIMEOUTA + 1) x 4 x t_{I2CCLK} period, the TIMEOUT flag of the I2C_ISR register is set.

Refer to *Table 649*.

Caution: Changing the TIMEOUTA[11:0] bitfield and the TIDLE bit values is not allowed when the TIMEOUTEN bit is set.

59.4.13 SMBus I2C_TIMEOUTR register configuration examples

The following tables provide examples of settings to reach desired $t_{TIMEOUT}$, $t_{LOW:SEXT}$, $t_{LOW:MEXT}$, and t_{IDLE} timings at different f_{I2CCLK} frequencies.

Table 647. TIMEOUTA[11:0] for maximum $t_{TIMEOUT}$ of 25 ms

f_{I2CCLK}	TIMEOUTA[11:0]	TIDLE	TIMEOUTEN	$t_{TIMEOUT}$
8 MHz	0x61	0	1	98 x 2048 x 125 ns = 25 ms
16 MHz	0xC3	0	1	196 x 2048 x 62.5 ns = 25 ms

Table 648. TIMEOUTB[11:0] for maximum $t_{LOW:SEXT}$ and $t_{LOW:MEXT}$ of 8 ms

f_{I2CCLK}	TIMEOUTB[11:0]	TEXTEN	$t_{LOW:SEXT}$ $t_{LOW:MEXT}$
8 MHz	0x1F	1	32 x 2048 x 125 ns = 8 ms
16 MHz	0x3F	1	64 x 2048 x 62.5 ns = 8 ms

Table 649. TIMEOUTA[11:0] for maximum t_{IDLE} of 50 µs

f_{I2CCLK}	TIMEOUTA[11:0]	TIDLE	TIMEOUTEN	t_{IDLE}
8 MHz	0x63	1	1	100 x 4 x 125 ns = 50 µs
16 MHz	0xC7	1	1	200 x 4 x 62.5 ns = 50 µs

59.4.14 SMBus target mode

In addition to I2C target transfer management (refer to *Section 59.4.8: I2C target mode*), this section provides extra software flowcharts to support SMBus.

SMBus target transmitter

When using the I2C peripheral in SMBus mode, set the SBC bit to enable the PEC transmission at the end of the programmed number of data bytes. When the PECBYTE bit is set, the number of bytes programmed in NBYTES[7:0] includes the PEC transmission. In that case, the total number of TXIS interrupts is NBYTES[7:0] - 1, and the content of the I2C_PECR register is automatically transmitted if the controller requests an extra byte after the transfer of the NBYTES[7:0] - 1 data bytes.

Caution: The PECBYTE bit has no effect when the RELOAD bit is set.

Figure 794. Transfer sequence flow for SMBus target transmitter N bytes + PEC

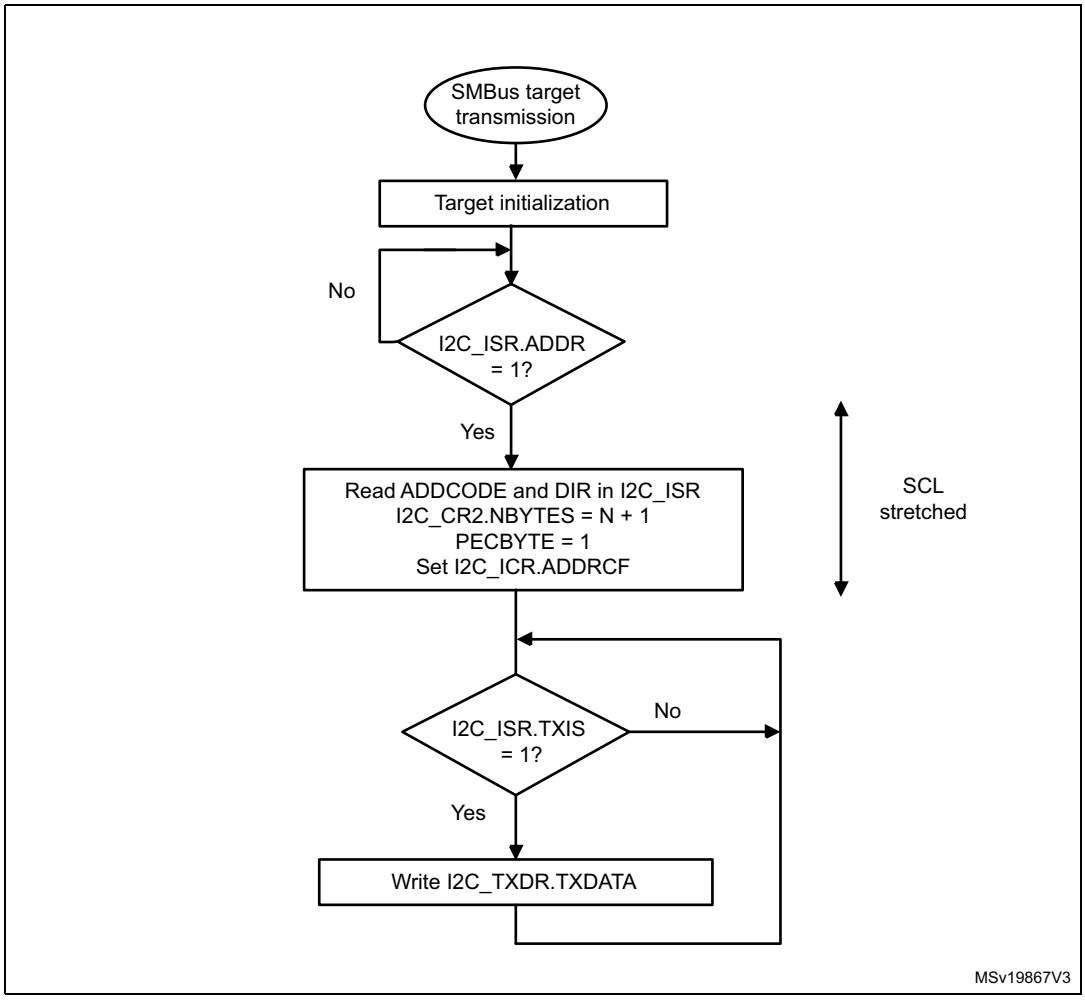
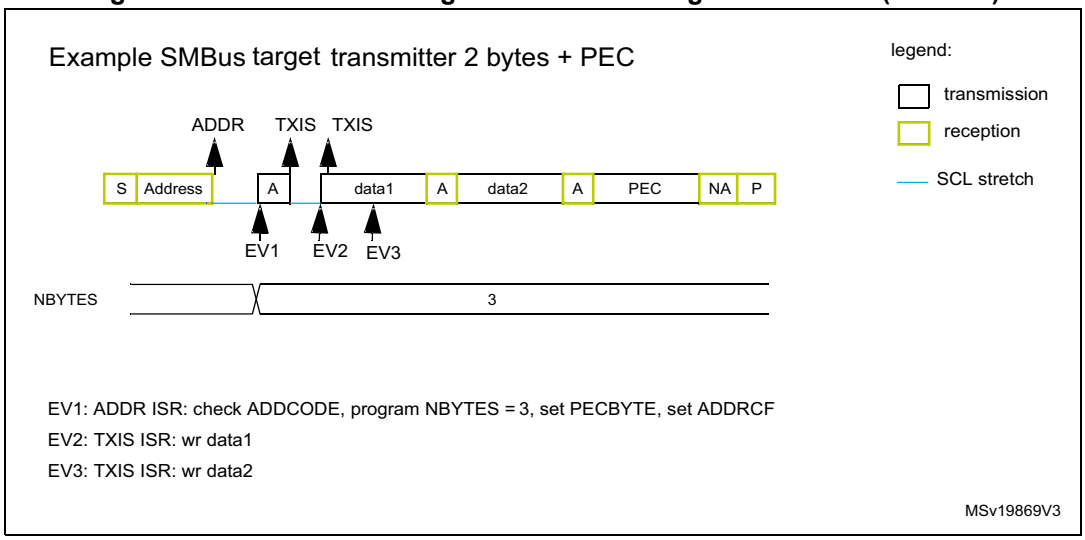


Figure 795. Transfer bus diagram for SMBus target transmitter (SBC = 1)



SMBus target receiver

When using the I2C peripheral in SMBus mode, set the SBC bit to enable the PEC checking at the end of the programmed number of data bytes. To allow the ACK control of each byte, the reload mode must be selected (RELOAD = 1). Refer to *Target byte control mode* for more details.

To check the PEC byte, the RELOAD bit must be cleared and the PECBYTE bit must be set. In this case, after the receipt of NBYTES[7:0] - 1 data bytes, the next received byte is compared with the internal I2C_PECR register content. A NACK is automatically generated if the comparison does not match, and an ACK is automatically generated if the comparison matches, whatever the ACK bit value. Once the PEC byte is received, it is copied into the I2C_RXDR register like any other data, and the RXNE flag is set.

Upon a PEC mismatch, the PECERR flag is set and an interrupt is generated if the ERRIE bit of the I2C_CR1 register is set.

If no ACK software control is required, the user can set the PECBYTE bit and, in the same write operation, load NBYTES[7:0] with the number of bytes to receive in a continuous flow. After the receipt of NBYTES[7:0] - 1 bytes, the next received byte is checked as being the PEC.

Caution: The PECBYTE bit has no effect when the RELOAD bit is set.

Figure 796. Transfer sequence flow for SMBus target receiver N bytes + PEC

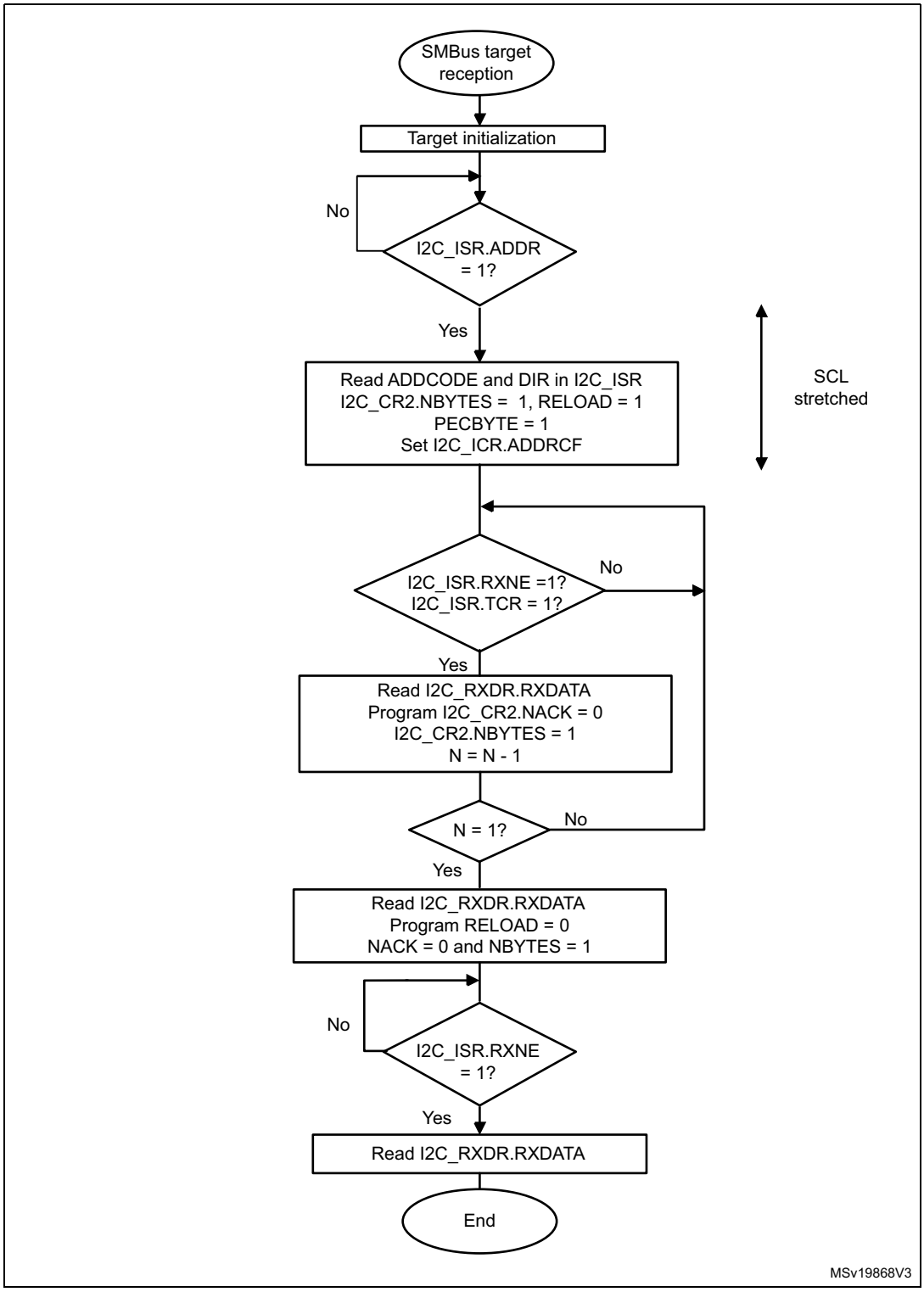
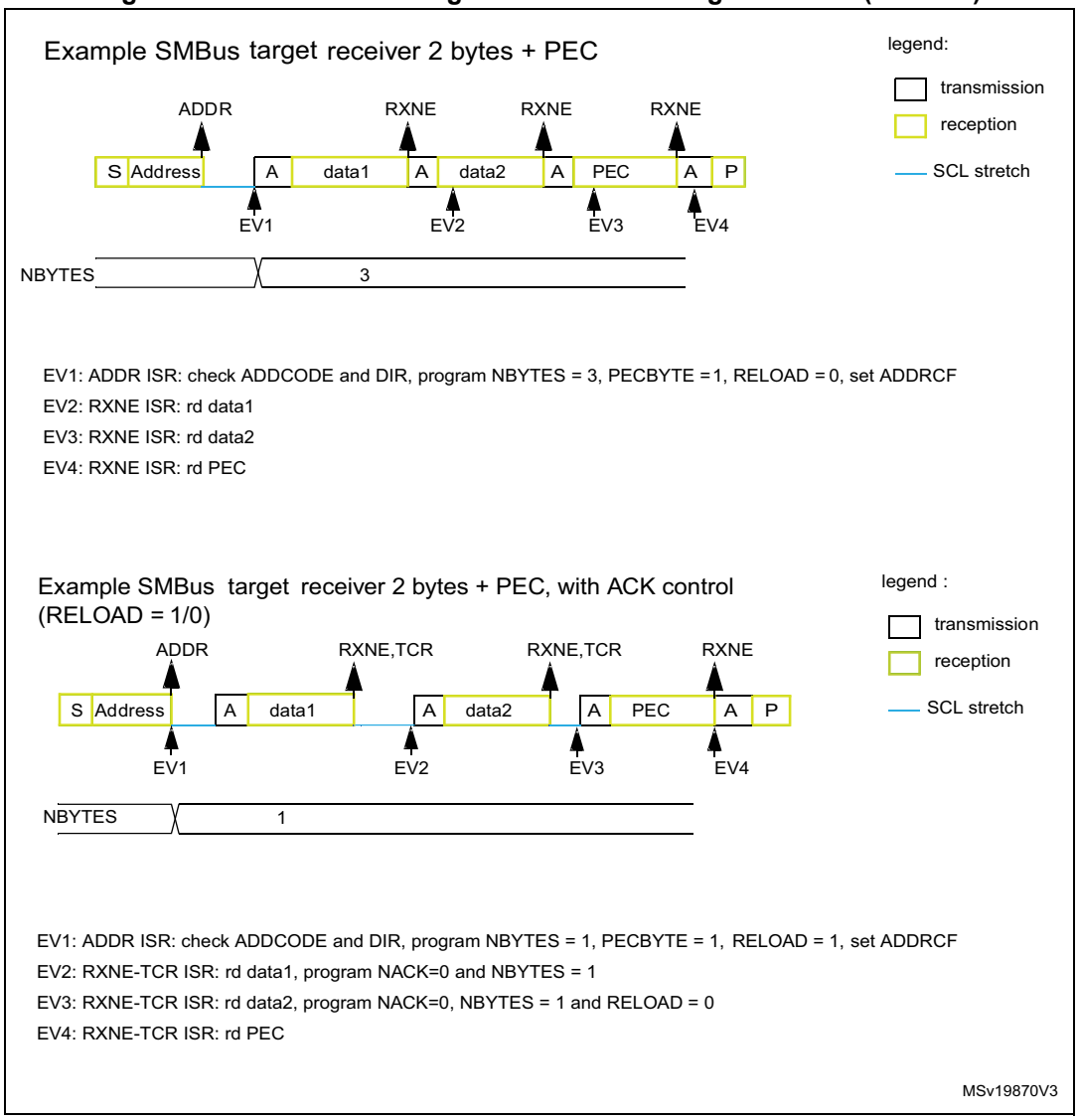


Figure 797. Bus transfer diagrams for SMBus target receiver (SBC = 1)



59.4.15 SMBus controller mode

In addition to I2C controller transfer management (refer to *Section 59.4.9: I2C controller mode*), this section provides extra software flowcharts to support SMBus.

SMBus controller transmitter

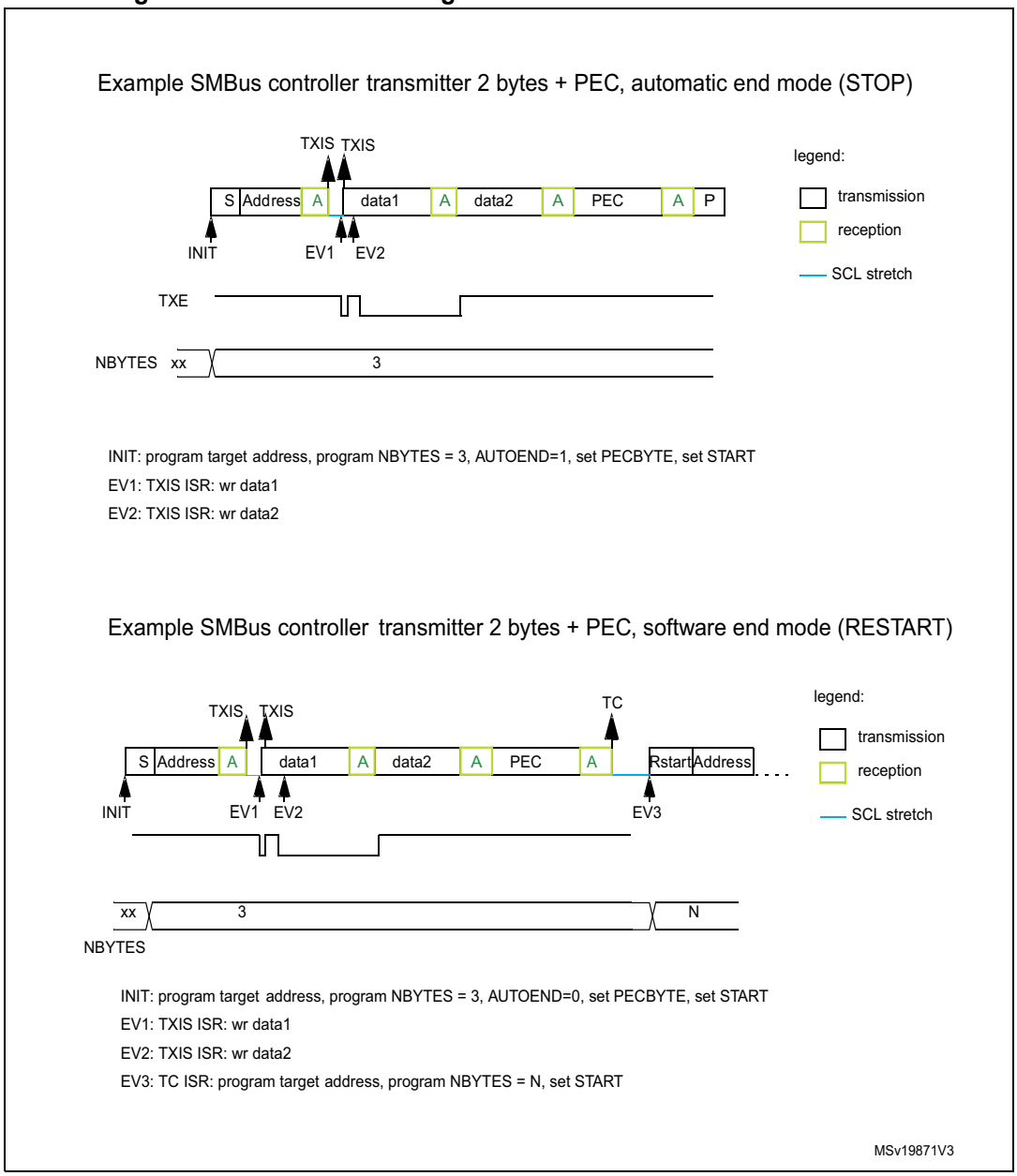
When the SMBus controller wants to transmit the PEC, the PECBYTE bit must be set and the number of bytes must be loaded in the NBYTES[7:0] bitfield, before setting the START bit. In this case, the total number of TXIS interrupts is NBYTES[7:0] - 1. So if the PECBYTE bit is set when NBYTES[7:0] = 0x1, the content of the I2C_PECR register is automatically transmitted.

If the SMBus controller wants to send a STOP condition after the PEC, the automatic end mode must be selected (AUTOEND = 1). In this case, the STOP condition automatically follows the PEC transmission.

When the SMBus controller wants to send a RESTART condition after the PEC, the software mode must be selected (AUTOEND = 0). In this case, once NBYTES[7:0] - 1 are transmitted, the I2C_PECR register content is transmitted. The TC flag is set after the PEC transmission, stretching the SCL line low. The RESTART condition must be programmed in the TC interrupt subroutine.

Caution: The PECBYTE bit has no effect when the RELOAD bit is set.

Figure 798. Bus transfer diagrams for SMBus controller transmitter



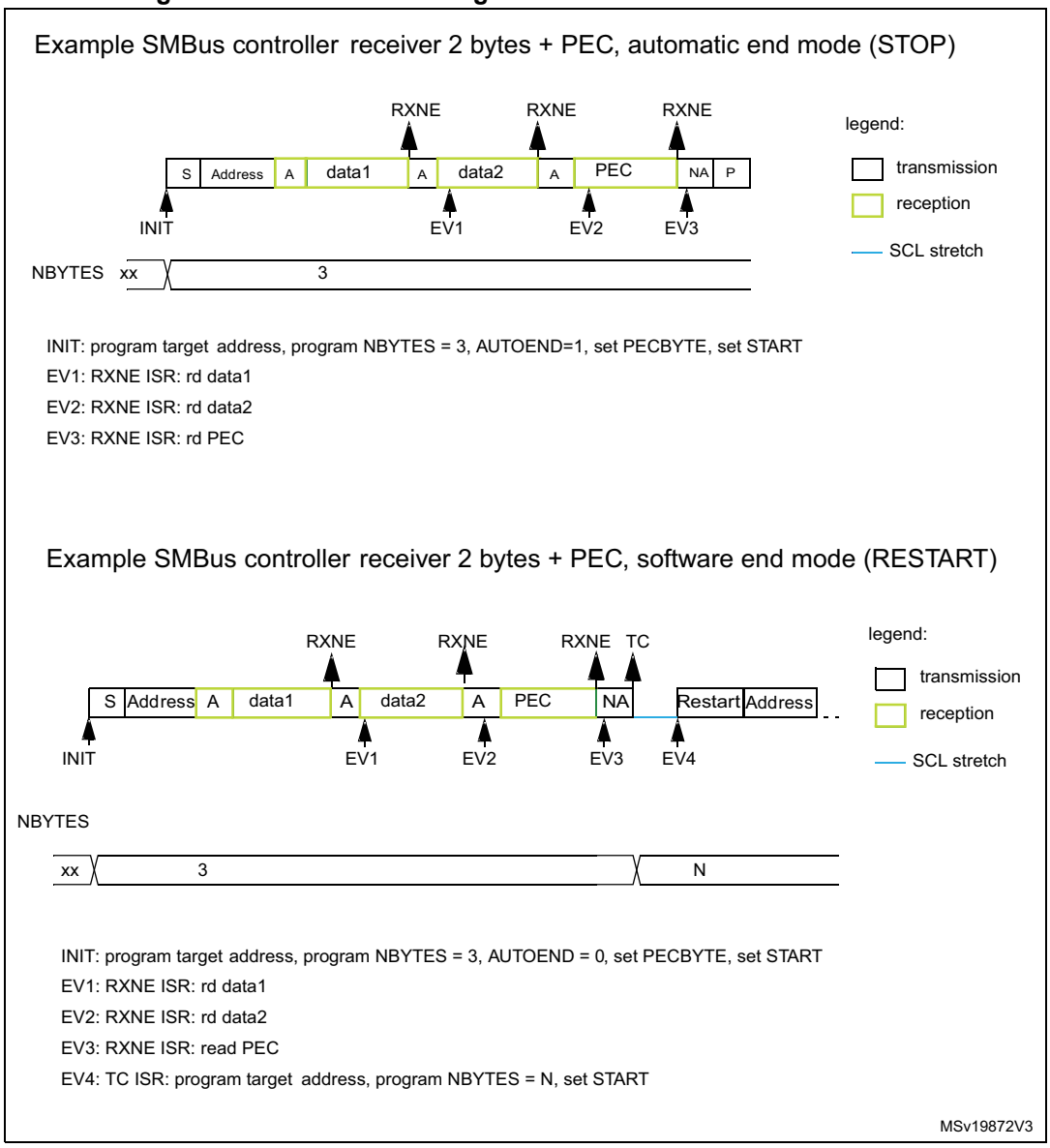
SMBus controller receiver

When the SMBus controller wants to receive, at the end of the transfer, the PEC followed by a STOP condition, the automatic end mode can be selected (AUTOEND = 1). The PECBYTE bit must be set and the target address programmed before setting the START bit. In this case, after the receipt of NBYTES[7:0] - 1 data bytes, the next received byte is automatically checked versus the I2C_PECR register content. A NACK response is given to the PEC byte, followed by a STOP condition.

When the SMBus controller receiver wants to receive, at the end of the transfer, the PEC byte followed by a RESTART condition, the software mode must be selected (AUTOEND = 0). The PECBYTE bit must be set and the target address programmed before setting the START bit. In this case, after the receipt of NBYTES[7:0] - 1 data bytes, the next received byte is automatically checked versus the I2C_PECR register content. The TC flag is set after the PEC byte reception, stretching the SCL line low. The RESTART condition can be programmed in the TC interrupt subroutine.

Caution: The PECBYTE bit has no effect when the RELOAD bit is set.

Figure 799. Bus transfer diagrams for SMBus controller receiver



59.4.16 Wake-up from Stop mode on address match

The I2C peripheral is able to wake up the device from Stop mode (APB clock is off), when the device is addressed. All addressing modes are supported.

The wake-up from Stop mode is enabled by setting the WUPEN bit of the I2C_CR1 register. The HSI and CSI only oscillator must be selected as the clock source for i2c_ker_ck to allow the wake-up from Stop mode.

In Stop mode, the HSI and CSI only oscillator is stopped. Upon detecting START condition, the I2C interface starts the HSI and CSI only oscillator and stretches SCL low until the oscillator wakes up.

HSI and CSI only is then used for the address reception.

If the received address matches the device own address, I2C stretches SCL low until the device wakes up. The stretch is released when the ADDR flag is cleared by software. Then the transfer goes on normally.

If the address does not match, the HSI and CSI only oscillator is stopped again and the device does not wake up.

Note: When the system clock is used as I2C clock, or when WUPEN = 0, the HSI and CSI only oscillator does not start upon receiving START condition.

Only an ADDR interrupt can wake the device up. Therefore, do not enter Stop mode when I2C is performing a transfer, either as a controller or as an addressed target after the ADDR flag is set. This can be managed by clearing the SLEEPDEEP bit in the ADDR interrupt routine and setting it again only after the STOPF flag is set.

Caution: The digital filter is not compatible with the wake-up from Stop mode feature. Before entering Stop mode with the WUPEN bit set, deactivate the digital filter, by writing zero to the DNF[3:0] bitfield.

Caution: The feature is only available when the HSI and CSI only oscillator is selected as the I2C clock.

Caution: Clock stretching must be enabled (NOSTRETCH = 0) to ensure proper operation of the wake-up from Stop mode feature.

Caution: If the wake-up from Stop mode is disabled (WUPEN = 0), the I2C peripheral must be disabled before entering Stop mode (PE = 0).

59.4.17 Error conditions

The following errors are the conditions that can cause the communication to fail.

Bus error (BERR)

A bus error is detected when a START or a STOP condition is detected and is not located after a multiple of nine SCL clock pulses. START or STOP condition is detected when an SDA edge occurs while SCL is high.

The bus error flag is set only if the I2C peripheral is involved in the transfer as controller or addressed target (that is, not during the address phase in target mode).

In case of a misplaced START or RESTART detection in target mode, the I2C peripheral enters address recognition state like for a correct START condition.

When a bus error is detected, the BERR flag of the I2C_ISR register is set, and an interrupt is generated if the ERRIE bit of the I2C_CR1 register is set.

Arbitration loss (ARLO)

An arbitration loss is detected when a high level is sent on the SDA line, but a low level is sampled on the SCL rising edge.

In controller mode, arbitration loss is detected during the address phase, data phase and data acknowledge phase. In this case, the SDA and SCL lines are released, the START control bit is cleared by hardware and the controller switches automatically to target mode.

In target mode, arbitration loss is detected during data phase and data acknowledge phase. In this case, the transfer is stopped and the SCL and SDA lines are released.

When an arbitration loss is detected, the ARLO flag of the I2C_ISR register is set and an interrupt is generated if the ERRIE bit of the I2C_CR1 register is set.

Overrun/underrun error (OVR)

An overrun or underrun error is detected in target mode when NOSTRETCH = 1 and:

- In reception when a new byte is received and the RXDR register has not been read yet. The new received byte is lost, and a NACK is automatically sent as a response to the new byte.
- In transmission:
  - When STOPF = 1 and the first data byte must be sent. The content of the I2C_TXDR register is sent if TXE = 0, 0xFF if not.
  - When a new byte must be sent and the I2C_TXDR register has not been written yet, 0xFF is sent.

When an overrun or underrun error is detected, the OVR flag of the I2C_ISR register is set and an interrupt is generated if the ERRIE bit of the I2C_CR1 register is set.

Packet error checking error (PECERR)

A PEC error is detected when the received PEC byte does not match the I2C_PECR register content. A NACK is automatically sent after the wrong PEC reception.

When a PEC error is detected, the PECERR flag of the I2C_ISR register is set and an interrupt is generated if the ERRIE bit of the I2C_CR1 register is set.

Timeout error (TIMEOUT)

A timeout error occurs for any of these conditions:

- TIDLE = 0 and SCL remains low for the time defined in the TIMEOUTA[11:0] bitfield: this is used to detect an SMBus timeout.
- TIDLE = 1 and both SDA and SCL remains high for the time defined in the TIMEOUTA [11:0] bitfield: this is used to detect a bus idle condition.
- Controller cumulative clock low extend time reaches the time defined in the TIMEOUTB[11:0] bitfield (SMBus $t_{LOW:MEXT}$ parameter).
- Target cumulative clock low extend time reaches the time defined in the TIMEOUTB[11:0] bitfield (SMBus $t_{LOW:SEXT}$ parameter).

When a timeout violation is detected in controller mode, a STOP condition is automatically sent.

When a timeout violation is detected in target mode, the SDA and SCL lines are automatically released.

When a timeout error is detected, the TIMEOUT flag is set in the I2C_ISR register and an interrupt is generated if the ERRIE bit of the I2C_CR1 register is set.

Alert (ALERT)

The ALERT flag is set when the I2C peripheral is configured as a host (SMBHEN = 1), the SMBALERT# signal detection is enabled (ALERTEN = 1), and a falling edge is detected on the SMBA pin. An interrupt is generated if the ERRIE bit of the I2C_CR1 register is set.

59.5 I2C in low-power modes

Table 650. Effect of low-power modes to I2C

Mode	Description
Sleep	No effect. I2C interrupts cause the device to exit the Sleep mode.
Stop(1)	The contents of I2C registers are kept. – WUPEN = 1 and I2C is clocked by an internal oscillator (HSI and CSI only). The address recognition is functional. The I2C address match condition causes the device to exit the Stop mode. – WUPEN = 0: I2C must be disabled before entering Stop mode.
Standby	The I2C peripheral is powered down. It must be reinitialized after exiting Standby mode.

1. Refer to *Section 59.3: I2C implementation* for information about the Stop modes supported by each instance. If the wake-up from a specific stop mode is not supported, the instance must be disabled before entering that specific Stop mode.

59.6 I2C interrupts

The following table gives the list of I2C interrupt requests.

Table 651. I2C interrupt requests

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit Sleep mode	Exit Stop modes	Exit Standby modes
I2C_EV	Receive buffer not empty	RXNE	RXIE	Read I2C_RXDR register	Yes	No	No
	Transmit buffer interrupt status	TXIS	TXIE	Write I2C_TXDR register			
	STOP detection interrupt flag	STOPF	STOPIE	Write STOPCF = 1			
	Transfer complete reload	TCR	TCIE	Write I2C_CR2 with NBYTES[7:0] ≠ 0			
	Transfer complete	TC		Write START = 1 or STOP = 1			
	Address matched	ADDR	ADDRIE	Write ADDRCF = 1		Yes(1)	
	NACK reception	NACKF	NACKIE	Write NACKCF = 1		No	
I2C_ERR	Bus error	BERR	ERRIE	Write BERRCF = 1	Yes	No	No
	Arbitration loss	ARLO		Write ARLOCF = 1			
	Overrun/underrun	OVR		Write OVRCF = 1			
I2C_ERR	PEC error	PECERR	ERRIE	Write PECERRCF = 1	Yes	No	No
	Timeout/ t_{LOW} error	TIMEOUT		Write TIMEOUTCF = 1			
	SMBus alert	ALERT		Write ALERTCF = 1			

1. The ADDR match event can wake up the device from Stop mode only if the I2C instance supports the wake-up from Stop mode feature. Refer to *Section 59.3: I2C implementation*.

59.7 I2C DMA requests

59.7.1 Transmission using DMA

DMA (direct memory access) can be enabled for transmission by setting the TXDMAEN bit of the I2C_CR1 register. Data is loaded from an SRAM area configured through the DMA peripheral (see *Section 16: General purpose direct memory access controller (GPDMA)*) to the I2C_TXDR register whenever the TXIS bit is set.

Only the data are transferred with DMA.

In controller mode, the initialization, the target address, direction, number of bytes and START bit are programmed by software (the transmitted target address cannot be transferred with DMA). When all data are transferred using DMA, DMA must be initialized before setting the START bit. The end of transfer is managed with the NBYTES counter. Refer to *Controller transmitter*.

In target mode:

- With NOSTRETCH = 0, when all data are transferred using DMA, DMA must be initialized before the address match event, or in ADDR interrupt subroutine, before clearing ADDR.
- With NOSTRETCH = 1, the DMA must be initialized before the address match event.

The PEC transfer is managed with the counter associated to the NBYTES[7:0] bitfield. Refer to *SMBus target transmitter* and *SMBus controller transmitter*.

Note: If DMA is used for transmission, it is not required to set the TXIE bit.

59.7.2 Reception using DMA

DMA (direct memory access) can be enabled for reception by setting the RXDMAEN bit of the I2C_CR1 register. Data is loaded from the I2C_RXDR register to an SRAM area configured through the DMA peripheral (refer to *Section 16: General purpose direct memory access controller (GPDMA)*) whenever the RXNE bit is set. Only the data (including PEC) are transferred with DMA.

In controller mode, the initialization, the target address, direction, number of bytes and START bit are programmed by software. When all data are transferred using DMA, DMA must be initialized before setting the START bit. The end of transfer is managed with the NBYTES counter.

In target mode with NOSTRETCH = 0, when all data are transferred using DMA, DMA must be initialized before the address match event, or in the ADDR interrupt subroutine, before clearing the ADDR flag.

The PEC transfer is managed with the counter associated to the NBYTES[7:0] bitfield. Refer to *SMBus target receiver* and *SMBus controller receiver*.

Note: If DMA is used for reception, it is not required to set the RXIE bit.

59.8 I2C debug modes

When the device enters debug mode (core halted), the SMBus timeout either continues working normally or stops, depending on the DBG_I2Cx_STOP bits in the DBG block.

59.9 I2C registers

Refer to *Section 1.2* for the list of abbreviations used in register descriptions.

The registers are accessed by words (32-bit).

59.9.1 I2C control register 1 (I2C_CR1)

Address offset: 0x00

Reset value: 0x0000 0000

Access: no wait states, except if a write access occurs while a write access is ongoing. In this case, wait states are inserted in the second write access, until the previous one is completed. The latency of the second write access can be up to 2 x i2c_pclk + 6 x i2c_ker_ck.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
STOPFACLR	ADDRACLR	Res.	Res.	Res.	Res.	Res.	FMP	PECEN	ALERTEN	SMBDEN	SMBHEN	GCEN	WUPEN	NOSTRETCH	SBC
rw	rw						rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXDMAEN	TXDMAEN	Res.	ANFOFF	DNF[3:0]				ERRIE	TCIE	STOPIE	NACKIE	ADDRIE	RXIE	TXIE	PE
rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **STOPFACLR**: STOP detection flag (STOPF) automatic clear

0: STOPF flag is set by hardware, cleared by software by setting STOPCF bit.

1: STOPF flag remains cleared by hardware. This mode can be used in NOSTRETCH target mode, to avoid the overrun error if the STOPF flag is not cleared before next data transmission. This allows a target data management by DMA only, without any interrupt from peripheral.

Bit 30 **ADDRACLR**: Address match flag (ADDR) automatic clear

0: ADDR flag is set by hardware, cleared by software by setting ADDRCF bit.

1: ADDR flag remains cleared by hardware. This mode can be used in target mode, to avoid the ADDR clock stretching if the I2C enables only one target address. This allows a target data management by DMA only, without any interrupt from peripheral.

Bits 29:25 Reserved, must be kept at reset value.

Bit 24 **FMP**: Fast-mode Plus drive enable

0: FMP I/O drive disabled

1: FMP I/O drive enabled

Bit 23 **PECEN:** PEC enable

0: PEC calculation disabled

1: PEC calculation enabled

Bit 22 **ALERTEN**: SMBus alert enable

0: The SMBALERT# signal on SMBA pin is not supported in host mode (SMBHEN = 1). In device mode (SMBHEN = 0), the SMBA pin is released and the alert response address header is disabled (0001100x followed by NACK).

1: The SMBALERT# signal on SMBA pin is supported in host mode (SMBHEN = 1). In device mode (SMBHEN = 0), the SMBA pin is driven low and the alert response address header is enabled (0001100x followed by ACK).

Note: When ALERTEN = 0, the SMBA pin can be used as a standard GPIO.

Bit 21 **SMBDEN**: SMBus device default address enable
0: Device default address disabled. Address 0b1100001x is NACKed.
1: Device default address enabled. Address 0b1100001x is ACKed.

Bit 20 **SMBHEN**: SMBus host address enable
0: Host address disabled. Address 0b0001000x is NACKed.
1: Host address enabled. Address 0b0001000x is ACKed.

Bit 19 **GCEN**: General call enable
0: General call disabled. Address 0b00000000 is NACKed.
1: General call enabled. Address 0b00000000 is ACKed.

Bit 18 **WUPEN**: Wake-up from Stop mode enable
0: Wake-up from Stop mode disabled.
1: Wake-up from Stop mode enabled.
Note: WUPEN can be set only when DNF[3:0] = 0000.

Bit 17 **NOSTRETCH**: Clock stretching disable
This bit is used to disable clock stretching in target mode. It must be kept cleared in controller mode.
0: Clock stretching enabled
1: Clock stretching disabled
Note: This bit can be programmed only when the I2C peripheral is disabled (PE = 0).

Bit 16 **SBC**: Target byte control
This bit is used to enable hardware byte control in target mode.
0: Target byte control disabled
1: Target byte control enabled

Bit 15 **RXDMAEN**: DMA reception requests enable
0: DMA mode disabled for reception
1: DMA mode enabled for reception

Bit 14 **TXDMAEN**: DMA transmission requests enable
0: DMA mode disabled for transmission
1: DMA mode enabled for transmission

Bit 13 Reserved, must be kept at reset value.

Bit 12 **ANFOFF:** Analog noise filter OFF
0: Analog noise filter enabled
1: Analog noise filter disabled
Note: This bit can be programmed only when the I2C peripheral is disabled (PE = 0).

Bits 11:8 **DNF[3:0]**: Digital noise filter
These bits are used to configure the digital noise filter on SDA and SCL input. The digital filter, filters spikes with a length of up to DNF[3:0] * t_{I2CCLK}
0000: Digital filter disabled
0001: Digital filter enabled and filtering capability up to one t_{I2CCLK}
...
1111: digital filter enabled and filtering capability up to fifteen t_{I2CCLK}
Note: If the analog filter is enabled, the digital filter is added to it. This filter can be programmed only when the I2C peripheral is disabled (PE = 0).

Bit 7 **ERRIE**: Error interrupts enable
0: Error detection interrupts disabled
1: Error detection interrupts enabled
Note: Any of these errors generates an interrupt:
- arbitration loss (ARLO)
- bus error detection (BERR)
- overrun/underrun (OVR)
- timeout detection (TIMEOUT)
- PEC error detection (PECERR)
- alert pin event detection (ALERT)

Bit 6 **TCIE**: Transfer complete interrupt enable
0: Transfer complete interrupt disabled
1: Transfer complete interrupt enabled
Note: Any of these events generates an interrupt:
Transfer complete (TC)
Transfer complete reload (TCR)

Bit 5 **STOPIE**: STOP detection interrupt enable
0: STOP detection (STOPF) interrupt disabled
1: STOP detection (STOPF) interrupt enabled

Bit 4 **NACKIE**: Not acknowledge received interrupt enable
0: Not acknowledge (NACKF) received interrupts disabled
1: Not acknowledge (NACKF) received interrupts enabled

Bit 3 **ADDRIE**: Address match interrupt enable (target only)
0: Address match (ADDR) interrupts disabled
1: Address match (ADDR) interrupts enabled

Bit 2 **RXIE**: RX interrupt enable
0: Receive (RXNE) interrupt disabled
1: Receive (RXNE) interrupt enabled

Bit 1 **TXIE**: TX interrupt enable
0: Transmit (TXIS) interrupt disabled
1: Transmit (TXIS) interrupt enabled

Bit 0 **PE**: Peripheral enable
0: Peripheral disabled
1: Peripheral enabled
Note: When PE = 0, the I2C SCL and SDA lines are released. Internal state machines and status bits are put back to their reset value. When cleared, PE must be kept low for at least three APB clock cycles.

59.9.2 I2C control register 2 (I2C_CR2)

Address offset: 0x04

Reset value: 0x0000 0000

Access: no wait states, except if a write access occurs while a write access is ongoing. In this case, wait states are inserted in the second write access until the previous one is completed. The latency of the second write access can be up to 2 x i2c_pclk + 6 x i2c_ker_ck.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	PECBYTE	AUTOEND	RELOAD	NBYTES[7:0]							
					rs	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NACK	STOP	START	HEAD10R	ADD10	RD_WRN	SADD[9:0]									
rs	rs	rs	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **PECBYTE**: Packet error checking byte

This bit is set by software, and cleared by hardware when the PEC is transferred, or when a STOP condition or an Address matched is received, also when PE = 0.

0: No PEC transfer

1: PEC transmission/reception is requested

Note: Writing 0 to this bit has no effect.

This bit has no effect when RELOAD is set, and in target mode when SBC = 0.

Bit 25 **AUTOEND**: Automatic end mode (controller mode)

This bit is set and cleared by software.

0: software end mode: TC flag is set when NBYTES data are transferred, stretching SCL low.

1: Automatic end mode: a STOP condition is automatically sent when NBYTES data are transferred.

Note: This bit has no effect in target mode or when the RELOAD bit is set.

Bit 24 **RELOAD**: NBYTES reload mode

This bit is set and cleared by software.

0: The transfer is completed after the NBYTES data transfer (STOP or RESTART follows).

1: The transfer is not completed after the NBYTES data transfer (NBYTES is reloaded). TCR flag is set when NBYTES data are transferred, stretching SCL low.

Bits 23:16 **NBYTES[7:0]**: Number of bytes

The number of bytes to be transmitted/received is programmed there. This field is don't care in target mode with SBC = 0.

Note: Changing these bits when the START bit is set is not allowed.

Bit 15 **NACK**: NACK generation (target mode)

The bit is set by software, cleared by hardware when the NACK is sent, or when a STOP condition or an Address matched is received, or when PE = 0.

0: an ACK is sent after current received byte.

1: a NACK is sent after current received byte.

Note: Writing 0 to this bit has no effect.

This bit is used only in target mode: in controller receiver mode, NACK is automatically generated after last byte preceding STOP or RESTART condition, whatever the NACK bit value.

When an overrun occurs in target receiver NOSTRETCH mode, a NACK is automatically generated, whatever the NACK bit value.

When hardware PEC checking is enabled (PECBYTE = 1), the PEC acknowledge value does not depend on the NACK value.

Bit 14 **STOP**: STOP condition generation

This bit only pertains to controller mode. It is set by software and cleared by hardware when a STOP condition is detected or when PE = 0.

0: No STOP generation

1: STOP generation after current byte transfer

Note: Writing 0 to this bit has no effect.

Bit 13 **START**: START condition generation

This bit is set by software. It is cleared by hardware after the START condition followed by the address sequence is sent, by an arbitration loss, by an address matched in target mode, by a timeout error detection, or when PE = 0.

0: No START generation

1: RESTART/START generation:

If the I2C is already in controller mode with AUTOEND = 0, setting this bit generates a repeated START condition when RELOAD = 0, after the end of the NBYTES transfer.

Otherwise, setting this bit generates a START condition once the bus is free.

Note: Writing 0 to this bit has no effect.

The START bit can be set even if the bus is BUSY or I2C is in target mode.

This bit has no effect when RELOAD is set.

Bit 12 **HEAD10R**: 10-bit address header only read direction (controller receiver mode)

0: The controller sends the complete 10-bit target address read sequence: START + 2 bytes 10-bit address in write direction + RESTART + first seven bits of the 10-bit address in read direction.

1: The controller sends only the first seven bits of the 10-bit address, followed by read direction.

Note: Changing this bit when the START bit is set is not allowed.

Bit 11 **ADD10**: 10-bit addressing mode (controller mode)

0: The controller operates in 7-bit addressing mode

1: The controller operates in 10-bit addressing mode

Note: Changing this bit when the START bit is set is not allowed.

Bit 10 **RD_WRN**: Transfer direction (controller mode)

0: Controller requests a write transfer

1: Controller requests a read transfer

Note: Changing this bit when the START bit is set is not allowed.

Bits 9:0 **SADD[9:0]**: Target address (controller mode)

Condition: In 7-bit addressing mode (ADD10 = 0):
SADD[7:1] must be written with the 7-bit target address to be sent. Bits SADD[9], SADD[8] and SADD[0] are don't care.

Condition: In 10-bit addressing mode (ADD10 = 1):
SADD[9:0] must be written with the 10-bit target address to be sent.

Note: Changing these bits when the START bit is set is not allowed.

59.9.3 I2C own address 1 register (I2C_OAR1)

Address offset: 0x08

Reset value: 0x0000 0000

Access: no wait states, except if a write access occurs while a write access is ongoing. In this case, wait states are inserted in the second write access until the previous one is completed. The latency of the second write access can be up to 2 x i2c_pclk + 6 x i2c_ker_ck.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OA1EN	Res.	Res.	Res.	Res.	OA1MODE	OA1[9:0]									
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **OA1EN**: Own address 1 enable

0: Own address 1 disabled. The received target address OA1 is NACKed.
1: Own address 1 enabled. The received target address OA1 is ACKed.

Bits 14:11 Reserved, must be kept at reset value.

Bit 10 **OA1MODE**: Own address 1 10-bit mode

0: Own address 1 is a 7-bit address.
1: Own address 1 is a 10-bit address.

Note: This bit can be written only when OA1EN = 0.

Bits 9:0 **OA1[9:0]**: Interface own target address

7-bit addressing mode: OA1[7:1] contains the 7-bit own target address. Bits OA1[9], OA1[8] and OA1[0] are don't care.
10-bit addressing mode: OA1[9:0] contains the 10-bit own target address.

Note: These bits can be written only when OA1EN = 0.

59.9.4 I2C own address 2 register (I2C_OAR2)

Address offset: 0x0C

Reset value: 0x0000 0000

Access: no wait states, except if a write access occurs while a write access is ongoing. In this case, wait states are inserted in the second write access, until the previous one is completed. The latency of the second write access can be up to 2x i2c_pclk + 6 x i2c_ker_ck.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OA2EN	Res.	Res.	Res.	Res.	OA2MSK[2:0]			OA2[7:1]							Res.
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **OA2EN**: Own address 2 enable
0: Own address 2 disabled. The received target address OA2 is NACKed.
1: Own address 2 enabled. The received target address OA2 is ACKed.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:8 **OA2MSK[2:0]**: Own address 2 masks
000: No mask
001: OA2[1] is masked and don't care. Only OA2[7:2] are compared.
010: OA2[2:1] are masked and don't care. Only OA2[7:3] are compared.
011: OA2[3:1] are masked and don't care. Only OA2[7:4] are compared.
100: OA2[4:1] are masked and don't care. Only OA2[7:5] are compared.
101: OA2[5:1] are masked and don't care. Only OA2[7:6] are compared.
110: OA2[6:1] are masked and don't care. Only OA2[7] is compared.
111: OA2[7:1] are masked and don't care. No comparison is done, and all (except reserved) 7-bit received addresses are acknowledged.

Note: These bits can be written only when OA2EN = 0.
As soon as OA2MSK ≠ 0, the reserved I2C addresses (0b0000xxx and 0b1111xxx) are not acknowledged, even if the comparison matches.

Bits 7:1 **OA2[7:1]**: Interface address
7-bit addressing mode: 7-bit address

Note: These bits can be written only when OA2EN = 0.

Bit 0 Reserved, must be kept at reset value.

59.9.5 I2C timing register (I2C_TIMINGR)

Address offset: 0x10

Reset value: 0x0000 0000

Access: no wait states

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRESC[3:0]				Res.	Res.	Res.	Res.	SCLDEL[3:0]				SDADEL[3:0]			
rw	rw	rw	rw					rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SCLH[7:0]								SCLL[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 **PRESC[3:0]**: Timing prescaler

This field is used to prescale i2c_ker_ck to generate the clock period t_{PRESC} used for data setup and hold counters (refer to section *I2C timings*), and for SCL high and low level counters (refer to section *I2C controller initialization*).

t_{PRESC} = (PRESC + 1) x t_{I2CCLK}

Bits 27:24 Reserved, must be kept at reset value.

Bits 23:20 **SCLDEL[3:0]**: Data setup time

This field is used to generate a delay t_{SCLDEL} = (SCLDEL + 1) x t_{PRESC} between SDA edge and SCL rising edge. In controller and in target modes with NOSTRETCH = 0, the SCL line is stretched low during t_{SCLDEL}.

Note: t_{SCLDEL} is used to generate $t_{SU:DAT}$ timing.

Bits 19:16 **SDADEL[3:0]**: Data hold time

This field is used to generate the delay t_{SDADEL} between SCL falling edge and SDA edge. In controller and in target modes with NOSTRETCH = 0, the SCL line is stretched low during t_{SDADEL}.

t_{SDADEL}= SDADEL x t_{PRESC}

Note: SDADEL is used to generate $t_{HD:DAT}$ timing.

Bits 15:8 **SCLH[7:0]**: SCL high period (controller mode)

This field is used to generate the SCL high period in controller mode.

t_{SCLH} = (SCLH + 1) x t_{PRESC}

Note: SCLH is also used to generate $t_{SU:STO}$ and $t_{HD:STA}$ timing.

Bits 7:0 **SCLL[7:0]**: SCL low period (controller mode)

This field is used to generate the SCL low period in controller mode.

t_{SCLL} = (SCLL + 1) x t_{PRESC}

Note: SCLL is also used to generate t_{BUF} and $t_{SU:STA}$ timings.

Note: This register must be configured when the I2C peripheral is disabled (PE = 0).

Note: The STM32CubeMX tool calculates and provides the I2C_TIMINGR content in the I2C Configuration window.

59.9.6 I2C timeout register (I2C_TIMEOUTR)

Address offset: 0x14

Reset value: 0x0000 0000

Access: no wait states, except if a write access occurs while a write access is ongoing. In this case, wait states are inserted in the second write access until the previous one is completed. The latency of the second write access can be up to 2 x i2c_pclk + 6 x i2c_ker_ck.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TEXTEN	Res.	Res.	Res.	TIMEOUTB[11:0]											
rw				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TIMOUTEN	Res.	Res.	TIDLE	TIMEOUTA[11:0]											
rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **TEXTEN**: Extended clock timeout enable

0: Extended clock timeout detection is disabled

1: Extended clock timeout detection is enabled. When a cumulative SCL stretch for more than $t_{LOW:EXT}$ is done by the I2C interface, a timeout error is detected (TIMEOUT = 1).

Bits 30:28 Reserved, must be kept at reset value.

Bits 27:16 **TIMEOUTB[11:0]**: Bus timeout B

This field is used to configure the cumulative clock extension timeout:

– Controller mode: the controller cumulative clock low extend time ($t_{LOW:MEXT}$) is detected

– Target mode: the target cumulative clock low extend time ($t_{LOW:SEXT}$) is detected

$t_{LOW:EXT}$ = (TIMEOUTB + TIDLE = 01) x 2048 x t_{I2CCLK}

Note: These bits can be written only when TEXTEN = 0.

Bit 15 **TIMOUTEN**: Clock timeout enable

0: SCL timeout detection is disabled

1: SCL timeout detection is enabled. When SCL is low for more than $t_{TIMEOUT}$ (TIDLE = 0) or high for more than t_{IDLE} (TIDLE = 1), a timeout error is detected (TIMEOUT = 1).

Bits 14:13 Reserved, must be kept at reset value.

Bit 12 **TIDLE**: Idle clock timeout detection

0: TIMEOUTA is used to detect SCL low timeout

1: TIMEOUTA is used to detect both SCL and SDA high timeout (bus idle condition)

Note: This bit can be written only when TIMOUTEN = 0.

Bits 11:0 **TIMEOUTA[11:0]**: Bus timeout A

This field is used to configure:

The SCL low timeout condition $t_{TIMEOUT}$ when TIDLE = 0

$t_{TIMEOUT}$= (TIMEOUTA + 1) x 2048 x t_{I2CCLK}

The bus idle condition (both SCL and SDA high) when TIDLE = 1

t_{IDLE}= (TIMEOUTA + 1) x 4 x t_{I2CCLK}

Note: These bits can be written only when TIMOUTEN = 0.

59.9.7 I2C interrupt and status register (I2C_ISR)

Address offset: 0x18

Reset value: 0x0000 0001

Access: no wait states

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDCODE[6:0]							DIR
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BUSY	Res.	ALERT	TIMEOUT	PECERR	OVR	ARLO	BERR	TCR	TC	STOPF	NACKF	ADDR	RXNE	TXIS	TXE
r		r	r	r	r	r	r	r	r	r	r	r	r	rs	rs

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:17 **ADDCODE[6:0]**: Address match code (target mode)

These bits are updated with the received address when an address match event occurs (ADDR = 1). In the case of a 10-bit address, ADDCODE provides the 10-bit header followed by the two MSBs of the address.

Bit 16 **DIR**: Transfer direction (target mode)

This flag is updated when an address match event occurs (ADDR = 1).

0: Write transfer, target enters receiver mode.

1: Read transfer, target enters transmitter mode.

Bit 15 **BUSY**: Bus busy

This flag indicates that a communication is in progress on the bus. It is set by hardware when a START condition is detected, and cleared by hardware when a STOP condition is detected, or when PE = 0.

Bit 14 Reserved, must be kept at reset value.

Bit 13 **ALERT**: SMBus alert

This flag is set by hardware when SMBHEN = 1 (SMBus host configuration), ALERTEN = 1 and an SMBALERT# event (falling edge) is detected on SMBA pin. It is cleared by software by setting the ALERTCF bit.

Note: This bit is cleared by hardware when PE = 0.

Bit 12 **TIMEOUT**: Timeout or t_{LOW} detection flag

This flag is set by hardware when a timeout or extended clock timeout occurred. It is cleared by software by setting the TIMEOUTCF bit.

Note: This bit is cleared by hardware when PE = 0.

Bit 11 **PECERR**: PEC error in reception

This flag is set by hardware when the received PEC does not match with the PEC register content. A NACK is automatically sent after the wrong PEC reception. It is cleared by software by setting the PECCF bit.

Note: This bit is cleared by hardware when PE = 0.

Bit 10 **OVR**: Overrun/underrun (target mode)

This flag is set by hardware in target mode with NOSTRETCH = 1, when an overrun/underrun error occurs. It is cleared by software by setting the OVRCF bit.

Note: This bit is cleared by hardware when PE = 0.

Bit 9 **ARLO**: Arbitration lost

This flag is set by hardware in case of arbitration loss. It is cleared by software by setting the ARLOCF bit.

Note: This bit is cleared by hardware when PE = 0.

Bit 8 **BERR**: Bus error

This flag is set by hardware when a misplaced START or STOP condition is detected whereas the peripheral is involved in the transfer. The flag is not set during the address phase in target mode. It is cleared by software by setting the BERRCF bit.

Note: This bit is cleared by hardware when PE = 0.

Bit 7 **TCR**: Transfer complete reload

This flag is set by hardware when RELOAD = 1 and NBYTES data have been transferred. It is cleared by software when NBYTES is written to a non-zero value.

Note: This bit is cleared by hardware when PE = 0.

This flag is only for controller mode, or for target mode when the SBC bit is set.

Bit 6 **TC**: Transfer complete (controller mode)

This flag is set by hardware when RELOAD = 0, AUTOEND = 0 and NBYTES data have been transferred. It is cleared by software when START bit or STOP bit is set.

Note: This bit is cleared by hardware when PE = 0.

Bit 5 **STOPF**: STOP detection flag

This flag is set by hardware when a STOP condition is detected on the bus and the peripheral is involved in this transfer:

- as a controller, provided that the STOP condition is generated by the peripheral.
- as a target, provided that the peripheral has been addressed previously during this transfer.

It is cleared by software by setting the STOPCF bit.

Note: This bit is cleared by hardware when PE = 0.

Bit 4 **NACKF**: Not acknowledge received flag

This flag is set by hardware when a NACK is received after a byte transmission. It is cleared by software by setting the NACKCF bit.

Note: This bit is cleared by hardware when PE = 0.

Bit 3 **ADDR**: Address matched (target mode)

This bit is set by hardware as soon as the received target address matched with one of the enabled target addresses. It is cleared by software by setting *ADDRCF bit.*

Note: This bit is cleared by hardware when PE = 0.

Bit 2 **RXNE**: Receive data register not empty (receivers)

This bit is set by hardware when the received data is copied into the I2C_RXDR register, and is ready to be read. It is cleared when I2C_RXDR is read.

Note: This bit is cleared by hardware when PE = 0.

Bit 1 **TXIS**: Transmit interrupt status (transmitters)

This bit is set by hardware when the I2C_TXDR register is empty and the data to be transmitted must be written in the I2C_TXDR register. It is cleared when the next data to be sent is written in the I2C_TXDR register.

This bit can be written to 1 by software only when NOSTRETCH = 1, to generate a TXIS event (interrupt if TXIE = 1 or DMA request if TXDMAEN = 1).

Note: This bit is cleared by hardware when PE = 0.

Bit 0 **TXE**: Transmit data register empty (transmitters)

This bit is set by hardware when the I2C_TXDR register is empty. It is cleared when the next data to be sent is written in the I2C_TXDR register.

This bit can be written to 1 by software in order to flush the transmit data register I2C_TXDR.

Note: This bit is set by hardware when PE = 0.

59.9.8 I2C interrupt clear register (I2C_ICR)

Address offset: 0x1C

Reset value: 0x0000 0000

Access: no wait states

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	ALERTCF	TIMOUTCF	PECCF	OVRCF	ARLOCF	BERRCF	Res.	Res.	STOPCF	NACKCF	ADDRCF	Res.	Res.	Res.
		w	w	w	w	w	w			w	w	w			

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **ALERTCF**: Alert flag clear
Writing 1 to this bit clears the ALERT flag in the I2C_ISR register.

Bit 12 **TIMOUTCF**: Timeout detection flag clear
Writing 1 to this bit clears the TIMEOUT flag in the I2C_ISR register.

Bit 11 **PECCF**: PEC error flag clear
Writing 1 to this bit clears the PECERR flag in the I2C_ISR register.

Bit 10 **OVRCF**: Overrun/underrun flag clear
Writing 1 to this bit clears the OVR flag in the I2C_ISR register.

Bit 9 **ARLOCF**: Arbitration lost flag clear
Writing 1 to this bit clears the ARLO flag in the I2C_ISR register.

Bit 8 **BERRCF**: Bus error flag clear
Writing 1 to this bit clears the BERRF flag in the I2C_ISR register.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **STOPCF**: STOP detection flag clear
Writing 1 to this bit clears the STOPF flag in the I2C_ISR register.

Bit 4 **NACKCF**: Not acknowledge flag clear
Writing 1 to this bit clears the NACKF flag in I2C_ISR register.

Bit 3 **ADDRCF**: Address matched flag clear
Writing 1 to this bit clears the ADDR flag in the I2C_ISR register. Writing 1 to this bit also clears the START bit in the I2C_CR2 register.

Bits 2:0 Reserved, must be kept at reset value.

59.9.9 I2C PEC register (I2C_PECR)

Address offset: 0x20

Reset value: 0x0000 0000

Access: no wait states

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PEC[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PEC[7:0]:** Packet error checking register
This field contains the internal PEC when PECEN=1.
The PEC is cleared by hardware when PE = 0.

59.9.10 I2C receive data register (I2C_RXDR)

Address offset: 0x24

Reset value: 0x0000 0000

Access: no wait states

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXDATA[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **RXDATA[7:0]:** 8-bit receive data
Data byte received from the I²C-bus.

59.9.11 I2C transmit data register (I2C_TXDR)

Address offset: 0x28

Reset value: 0x0000 0000

Access: no wait states

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXDATA[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **TXDATA[7:0]:** 8-bit transmit data

Data byte to be transmitted to the I²C-bus

Note: These bits can be written only when TXE = 1.

59.9.12 I2C register map

The table below provides the I2C register map and the reset values.

Table 652. I2C register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	I2C_CR1	STOPFACLR	ADDRACLR	Res.	Res.	Res.	Res.	Res.	FMP	PECEN	ALERTEN	SMBDEN	SMBHEN	GCEN	WUPEN	NOSTRETCH	SBC	RXDMAEN	TXDMAEN	Res.	ANFOFF	DNF[3:0]				ERRIE	TCIE	STOPIE	NACKIE	ADDRIE	RXIE	TXIE	PE
	Reset value	0	0						0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	I2C_CR2	Res.	Res.	Res.	Res.	Res.	PECBYTE	AUTOEND	RELOAD	NBYTES[7:0]								NACK	STOP	START	HEAD10R	ADD10	RD_WRN	SADD[9:0]									
	Reset value						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	I2C_OAR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OA1EN	Res.	Res.	Res.	Res.	OA1MODE	OA1[9:0]									
	Reset value																	0					0	0	0	0	0	0	0	0	0	0	0
0x0C	I2C_OAR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OA2EN	Res.	Res.	Res.	Res.	OA2MSK [2:0]			OA2[7:1]							Res.
	Reset value																	0					0	0	0	0	0	0	0	0	0	0	
0x10	I2C_TIMINGR	PRESC[3:0]				Res.	Res.	Res.	Res.	SCLDEL [3:0]				SDADEL [3:0]				SCLH[7:0]								SCLL[7:0]							
	Reset value	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	I2C_TIMEOUTR	TEXTEN	Res.	Res.	Res.	TIMEOUTB[11:0]												TIMOUTEN	Res.	Res.	TIDLE	TIMEOUTA[11:0]											
	Reset value	0				0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	I2C_ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDCODE[6:0]							DIR	BUSY	Res.	ALERT	TIMEOUT	PECERR	OVR	ARLO	BERR	TCR	TC	STOPF	NACKF	ADDR	RXNE	TXIS	TXE
	Reset value									0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x1C	I2C_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALERTCF	TIMOUTCF	PECCF	OVRCF	ARLOCF	BERRCF	Res.	Res.	STOPCF	NACKCF	ADDRCF	Res.	Res.	Res.
	Reset value																			0	0	0	0	0	0			0	0	0			
0x20	I2C_PECR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PEC[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x24	I2C_RXDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXDATA[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x28	I2C_TXDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXDATA[7:0]							
	Reset value																									0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

60 Improved inter-integrated circuit (I3C)

60.1 I3C introduction

The I3C interface handles communication with other devices such as sensor(s) and host processor.

An I3C bus is a two-wire, serial single-ended, multi-drop bus, intended to improve the legacy I^2C bus. The I3C interface improves the features of the I^2C interface (adding especially in-band interrupts, dynamic address assignment, energy-efficient data rates, power management) meanwhile preserving some backward compatibility: it allows an I^2C target to operate on an I3C bus in legacy I^2C standard-mode (Sm), fast-mode (Fm), or legacy I^2C fast-mode plus (Fm+), provided that the latter does not perform clock stretching.

The I3C SDR-only peripheral implements all the required features and many optional features of the MIPI® I3C specification v1.1 (see *Table 656: I3C peripheral controller/target features versus MIPI v1.1*). It can control all I3C bus-specific sequencing, protocol, arbitration, and timing.

After reset, the software can initialize the I3C peripheral as primary controller or as target:

- As I3C controller, the software can enable the I3C peripheral and initialize the I3C bus.
- As I3C target, the software can enable the I3C peripheral to operate on an I3C bus.

The I3C peripheral can be used with DMA, to off-load the CPU.

60.2 I3C main features

The I3C peripheral supports:

- MIPI® I3C specification v1.1 (see details in *Table 656*), as:
  - I3C SDR-only primary controller
  - I3C SDR-only secondary controller
  - I3C SDR-only target
- I3C SCL bus clock frequency up to 12.5 MHz
- Registers configuration from the host application via the APB slave port
- Queued data transfers:
  - Transmit FIFO (TX-FIFO) for data bytes/words to be transmitted on the I3C bus
  - Receive FIFO (RX-FIFO) for received data bytes/words on the I3C bus
  - For each FIFO, optional DMA mode with a dedicated DMA channel
- Queued control/status transfers, when controller:
  - Control FIFO (C-FIFO) for control words to be sent on the I3C bus
  - Optional status FIFO (S-FIFO) for status words as received on the I3C bus
  - For each FIFO, optional DMA mode with a dedicated DMA channel
- Messages:
  - Legacy I^2C read/write messages to legacy I^2C targets in Sm/Fm/Fm+
  - I3C SDR read/write private messages

  - I3C SDR broadcast CCC messages (see details in *Table 662*)
  - I3C SDR read/write direct CCC messages (see details in *Table 662*)
- Frame-level management, when controller:
  - Optional C-FIFO and TX-FIFO preload
  - Multiple messages encapsulation
  - Optional arbitrable header generation on the I3C bus
  - HDR exit pattern generation on the I3C bus for error recovery
- Programmable bus timing, when controller:
  - SCL high and low period
  - SDA hold time
  - Bus free (minimum) time
  - Bus available/idle condition time
  - Clock stall time
- Target-initiated requests management:
  - Simultaneous support up to four I3C targets, when controller
  - In-band interrupts, with programmable IBI payload (up to 4 bytes), with pending read notification support
  - Bus control request, with recovery flow support and hand-off delay
  - Hot-join mechanism
- HDR exit pattern detection, when target
- Bus error management:
  - CEx with x = 0, 1, 2, 3 when controller
  - TEx with x = 0, 1, ... , 6 when target
  - Bus control switch error and recovery
  - Target reset
- Individual programmable event-based management:
  - Per-event identification with flag reporting and clear control
  - Host application notification via flag polling, and/or via interrupt with a per-event programmable enable
  - Error type identification
- Multi-clock domain management:
  - Separate APB clock and kernel clock, driven from independently programmed clock sources via the RCC, in addition to SCL clock
  - Minimum operating frequency for the kernel clock and the APB clock vs. the application-driven SCL clock (see clocks constraints in *Section 60.6.2*)

60.3 I3C implementation

60.3.1 I3C instantiation

There are several I3C instances in the device, all with the same feature set:

Table 653. I3C instantiation

Instance(s)
I3C1, I3C2

60.3.2 I3C wake-up from low-power mode(s)

The I3C peripheral in this product cannot wake up from any Stop mode.

60.3.3 I3C FIFOs

The FIFOs are implemented as defined in *Table 654*.

Table 654. I3C FIFOs implementation

FIFO	Content	Unit	Size (in unit)	Used as controller/target (rationale)
C-FIFO	(32-bit) Control words	Word	2	Controller (a frame can be based on multiple control words; this is not the case as target)
S-FIFO	(32-bit) Status words			Controller (target: status only in register mode)
TX-FIFO	Transmitted data	Byte	8	Controller and target
RX-FIFO	Received data			

60.3.4 I3C triggers

This feature is not available in this product: no hardware trigger signal is connected as an input to the I3C peripheral.

60.3.5 I3C interrupt(s)

The interrupt mapping is implemented as detailed in *Table 655*.

Table 655. I3C interrupt(s)

Signal name	Signal type	Description
i3c_err_it	O	Error interrupt line
i3c_evt_it	O	Event interrupt line

60.3.6 I3C MIPI® support

The I3C peripheral supports the MIPI specification v1.1, as defined in *Table 656*.

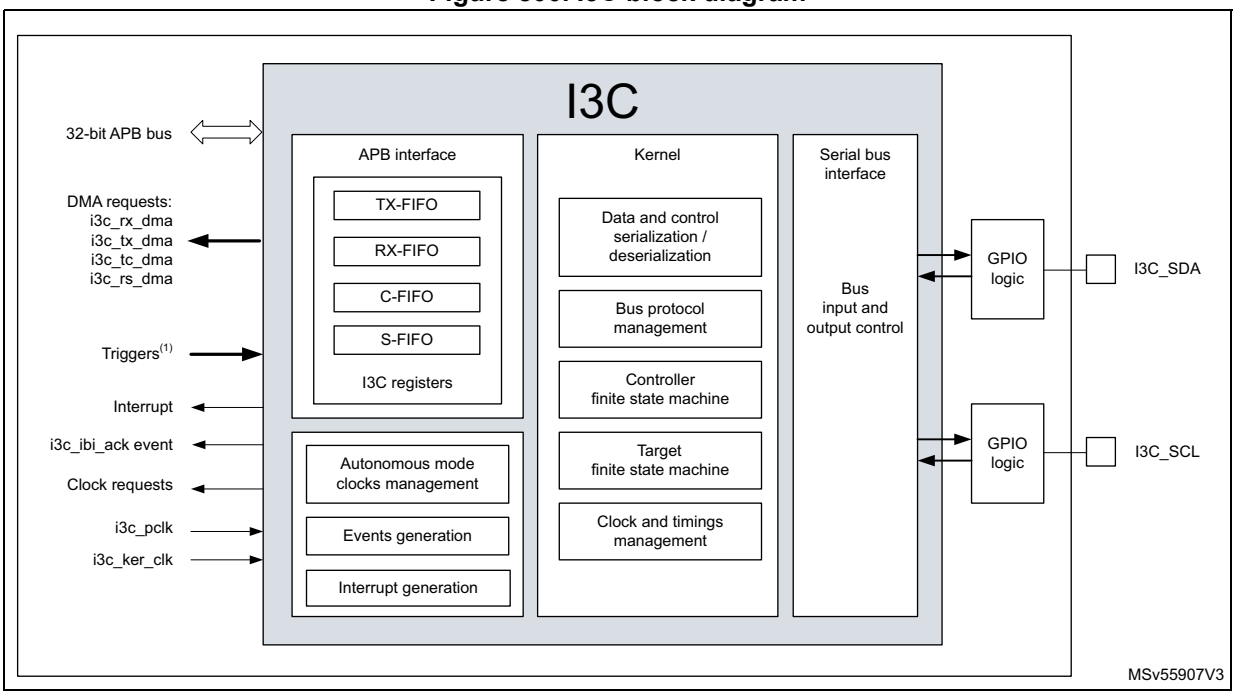
Table 656. I3C peripheral controller/target features versus MIPI v1.1

Feature	MIPI I3C v1.1	I3C peripheral		Comments
		When controller	When target	
I3C SDR message	X	X	X	-
Legacy I^2C message (Sm/Fm/Fm+)	X	X	-	Mandatory when controller if the I3C bus is mixed with (external) legacy I^2C target(s). Optional in MIPI v1.1 when target.
HDR DDR message	X	-	-	Optional in MIPI v1.1
HDR-TSL/TSP, HDR-BT	X	-	-	Optional in MIPI v1.1
Dynamic address assignment	X	X	X	Supported broadcast ENTDAA when controller and target. Supported broadcast SETAASA and direct SETDASA when controller.
7-bit static I^2C address	X	X	-	No support of the I3C peripheral as target on an I^2C bus.
Grouped addressing	X	X	-	Optional in MIPI v1.1
CCCs	X	X	X	Mandatory and some optional CCCs supported (refer to *Table 662* when controller/target).
Error detection and recovery	X	X	X	-
In-band interrupt (with MDB)	X	X	X	-
Secondary controller	X	X	X	-
Hot-join mechanism	X	X	X	-
Target reset	X	X	X	-
Synchronous timing control	X	X	-	Optional in MIPI v1.1
Asynchronous timing control 0	X	X	-	Mandatory in MIPI v1.1 when controller (refer to *Timing control and sensor acquisition timestamping when I3C controller*). Optional in MIPI v1.1 when target.
Asynchronous timing control 1, 2, 3	X	-	-	Optional in MIPI v1.1
Device to device tunneling	X	X	-	Optional in MIPI v1.1
Multi-lane data transfer	X	-	-	Optional in MIPI v1.1
Monitoring device early termination	X	-	-	Optional in MIPI v1.1

60.4 I3C block diagram

The I3C block diagram is illustrated in *Figure 800*.

Figure 800. I3C block diagram



1. Refer to *Section 60.3.4: I3C triggers*.

60.5 I3C pins and internal signals

Table 657. I3C input/output pins

Pin name	Pin type	Description
I3C_SDA	Input/output	Serial bus data line
I3C_SCL	Input/output	Serial bus clock line

Note: During initialization, the selected GPIOs for I3C_SCL and I3C_SDA should be configured as alternate function and no pull.

Table 658. I3C internal input/output signals

Signal name	Signal type	Description
i3c_pclk	I	APB clock
i3c_ker_clk	I	Kernel clock (also named as I3CCLK)
i3c_pclk_req	O	APB clock request
i3c_ker_clk_req	O	Kernel clock request
i3c_it(1)	O	Global interrupt line

Table 658. I3C internal input/output signals (continued)

Signal name	Signal type	Description
i3c_err_it(1)	O	Error interrupt line
i3c_evt_it(1)	O	Event interrupt line
i3c_rx_dma	O	DMA request for reading received bytes/words from RX-FIFO
i3c_tx_dma	O	DMA request for writing to be transmitted bytes/words to TX-FIFO
i3c_tc_dma	O	DMA request for writing to be transmitted control words to C-FIFO, when the I3C peripheral acts as controller
i3c_rs_dma	O	DMA request for reading status words from S-FIFO, when the I3C peripheral acts as controller
i3c_ibi_ack	O	IBI acknowledge event when the I3C peripheral acts as controller, for timing control with asynchronous mode 0

1. Refer to *Section 60.3.5: I3C interrupt(s)*.

60.6 I3C reset and clocks

60.6.1 I3C reset

On a system reset, the I3C peripheral is reset.

Alternatively, the software can reset specifically the I3C peripheral by writing the corresponding reset control bit (I3CxRST) of the reset and clock controller (RCC). Refer to the RCC section of this document for more details.

Additionally, when acting as target, the enabled I3C peripheral (EN = 1 in the I3C_CFGR register) can receive an in-band reset pattern on the I3C bus from the controller. The software is then notified (when RSTF = 1 in the I3C_EVR register and/or the corresponding interrupt is enabled) to perform the requested action, as registered in RSTACT[1:0] of the I3C_DEVR0 register, on the former reception of the broadcast or direct RSTACT CCC. Refer to *Table 662* and *Section 60.15.17* for more details.

For more details about the corresponding low-power mode(s), refer to the power management in the PWR section.

60.6.2 I3C clocks and requirements

As indicated in *Figure 800*, the I3C peripheral is implemented with several clock domains:

- SCL bus clock: for the I3C bus interface
  - When controller: the user must set and can adjust SCL/SDA timings by programming *I3C timing register 0 (I3C_TIMINGR0)*, *I3C timing register 1 (I3C_TIMINGR1)* and *I3C timing register 2 (I3C_TIMINGR2)*, as summarized in *Controller initialization* and *Updating the configuration for a transfer, as controller*.
  - When target: the user must set and comply with the bus available condition (t_{AVAL} for an in-band interrupt or controller-role request), and the bus idle condition (t_{IDLE} for a hot-join request), by programming *I3C timing register 1 (I3C_TIMINGR1)*, as summarized in *Target initialization*.

- I3CCLK kernel clock: for the I3C protocol management, data and control serialization/deserialization, controller and target finite state machines, bus clock and timings management
- APB clock: for the APB interface, DMA interface, events, and interrupt generation

APB clock and kernel clocks are driven from independently programmed clock sources via the RCC (refer to section Reset and clock control (RCC) for more details).

I3C kernel clock requirement, as controller

According to the intended value of the SCL clock on the bus, the application must guarantee that the frequency of the I3CCLK kernel clock be at least 2x the frequency of the SCL clock

Note: Sustaining $F_{SCL\ max}$ = 12.9 MHz means a frequency of the I3CCLK kernel clock > 25.8 MHz.

I3C kernel clock requirements, as target

According to the intended value of the SCL clock on the bus, the application must guarantee a minimum operating frequency for the I3CCLK kernel clock, meeting the following constraints:

1. Period of the I3CCLK kernel clock < t_{HIGH} (SCL clock high period)
   - $t_{HIGH\ min}$ = 24 ns. A frequency higher than 41.7 MHz guarantees this constraint, which can be relaxed, depending on the I3C bus/controller
2. Period of the I3CCLK kernel clock < t_{CASr} (clock after repeated start condition)
   - $t_{CASr\ min}$ = $t_{CAS\ min}$ / 2 = 19.2 ns. A frequency higher than 52 MHz guarantees this constraint, which can be relaxed, depending on the I3C bus/controller
3. Two periods of the I3CCLK kernel clock < t_{LOW_OD} (SCL clock low period in open drain)
   - $t_{LOW_OD\ min}$ = 200 ns. A frequency higher than 10 MHz guarantees this constraint, which can be relaxed, depending on the I3C bus/controller
4. Frequency of the I3CCLK kernel clock > 2.5x frequency of the SCL clock
   - $F_{SCL\ max}$ = 12.9 MHz. A frequency higher than 32.3 MHz guarantees this constraint, which can be relaxed, depending on the I3C controller

APB clock requirement

According to the intended value of the SCL clock on the bus, the application must guarantee a minimum operating frequency for the APB clock:

APB clock period < 3x (SCL clock period) - I3CCLK kernel clock period

This means that $F_{APB} > [F_{SCL} \times F_{I3CCLK} / (3x\ F_{I3CCLK} - F_{SCL})]$

Note: This equation can be simplified to a minimum value of 5 MHz for the APB frequency.

60.7 I3C peripheral state and programming

60.7.1 I3C peripheral state

The I3C peripheral plays the role of I3C bus controller, or the role of an I3C target. In any case (see *Figure 801* and *Figure 802*), the peripheral is in one of the following states:

- Disabled state:
  - After an I3C reset (system reset or I3C reset from RCC), the I3C peripheral is in disabled state.
  - When the software sets to 1 bit EN in the I3C_CFGR register, the I3C peripheral takes into account the value of the different initialized configuration registers, and switches to the (enabled and) idle state. The peripheral is initialized as I3C target or I3C controller.
  - As I3C controller, then software can enable the I3C peripheral and initialize the I3C bus.
  - As I3C target, then the software can enable the I3C peripheral to operate on an I3C bus.
- Idle state:
  - After being enabled (EN = 1), the I3C peripheral activates its I3CCLK and SCL clock domains, and is able to communicate on the I3C bus.
  - The software can partly update the I3C peripheral configuration, see *Updating the configuration for a transfer, as controller* and *Updating the configuration of the I3C peripheral, as target* for more details.
  - The I3C peripheral switches to the (enabled and) active state in either one of the following conditions:

    Once the software initiates a transfer (as controller: when the software initiates a frame transfer; as target: when the software initiates an IBI/CR/HJ request).

    Once the hardware receives a request from another I3C device on the bus (as controller: after a start request from a target and a maximum T_{CAS} time; as target: when receiving a broadcast/direct CCC or a private read/write).
- Active state:
  - The I3C peripheral executes the transfer(s) on the bus.
  - When the requested transfer(s) is(are) completed, the software is notified by an event from the *I3C event register (I3C_EVR)*, and the corresponding interrupt is enabled by *I3C interrupt enable register (I3C_IER)*. The I3C peripheral switches to idle state, is still able to communicate on the bus, and can be (partly) reconfigured:

    As controller: the raised event/flag can be frame completed (FCF), IBI/controller-role/hot-join request completed (IBIF/CRF/HJF), or transfer error (ERRF).

    As target: the raised event/flag can be dynamic address assignment completed (DAUPDF), IBI completed (IBIENDF), controller-role gaining completed (CRUPDF), broadcast/direct CCC completed (xxUPDF/RSTF/GETF/STAF), private read/write completed (FCF), or transfer error (ERRF).

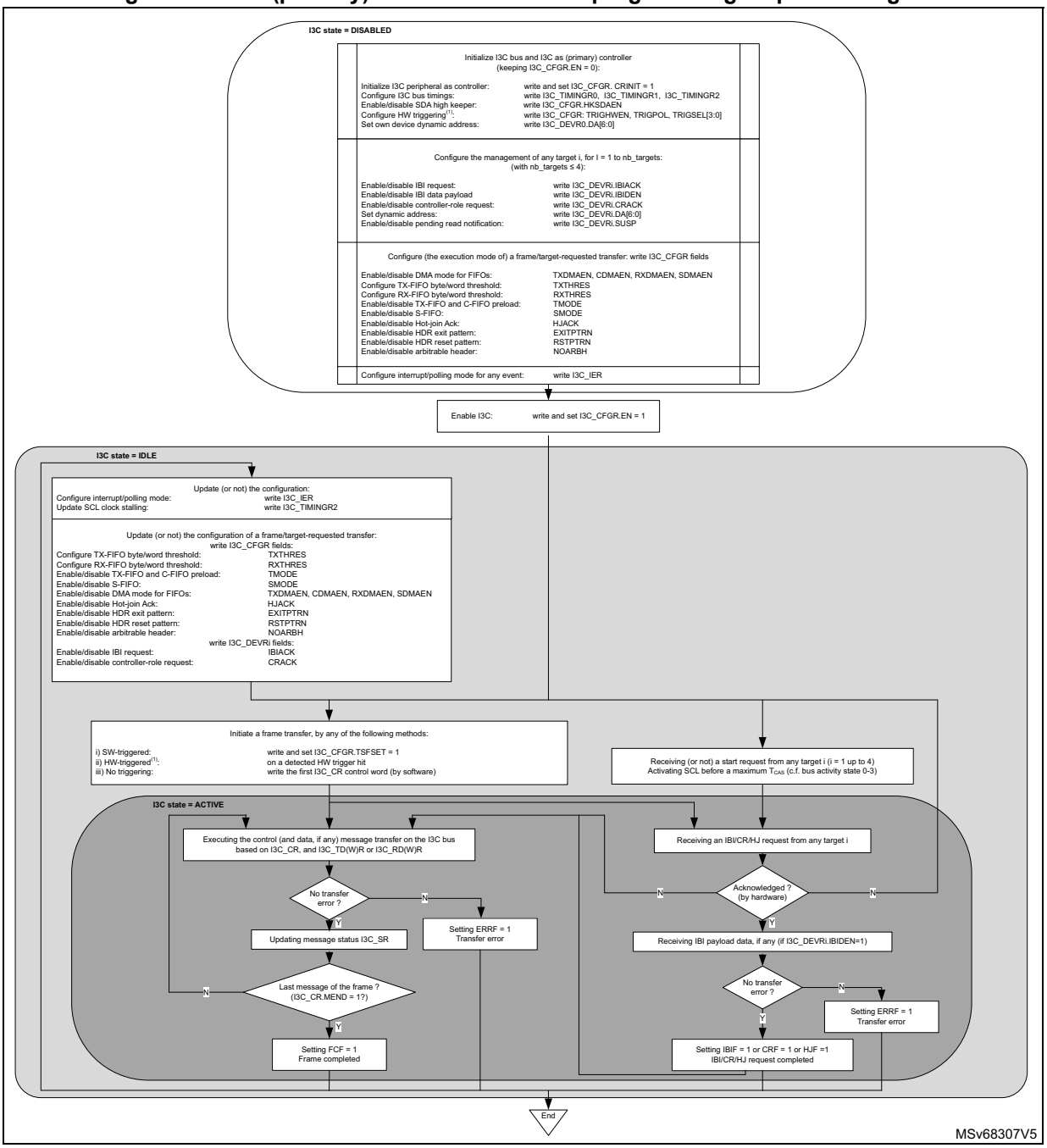
Note: The software can disable the I3C peripheral (write EN = 0), partially resetting it (subparts within the SCL clock domain and the I3CCLK kernel clock domain). Event, interrupt, and clock request generation are also impacted. The previously written configuration of the APB registers is kept and not modified.

Note: The software can disable the generation of the FCF flag by writing 1 into the FCFDIS bit of the I3C_CFGR register. This can be used with hardware triggers and autonomous DMA (if this feature is available, see Section 60.3), to stream a series of frames.

60.7.2 I3C controller state and programming sequence

Figure 801 illustrates the overall programming sequence of the I3C peripheral acting as (primary) controller, including state transitions, main subtasks, and conditions, as explained in this section.

Figure 801. I3C (primary) controller state and programming sequence diagram



1. This feature is implementation-dependent and can be unavailable. Refer to *Section 60.3.4: I3C triggers*.

Controller initialization

When the controller is in disabled state (EN = 0 in the I3C_CFGR register), the software must initialize as follows:

- Configure *I3C configuration register (I3C_CFGR)* with the following fields:
  - CRINIT = 1: as I3C bus controller
  - HKSDAEN: high keeper on SDA enable/disable
- Configure I3C bus timings:

  a) *I3C timing register 0 (I3C_TIMINGR0)*:
  - SCL clock high time period (t_{DIG_H}, $t_{DIG_H_MIXED}$) in legacy I^2C and I3C open-drain/push-pull
  - SCL clock low time period (t_{DIG_L}, $t_{DIG_OD_L}$) in legacy I^2C and I3C open-drain/push-pull

  b) *I3C timing register 1 (I3C_TIMINGR1)*:
  - SDA hold time in push-pull (t_{HD_PP})
  - bus free condition time (I3C $t_{CAS,}$ legacy I^2C t_{BUF})
  - I3C repeated start timing (t_{CASr}, t_{CBSr})
  - I3C stop timing (t_{CBP})
  - SCL clock low maximum stalling on the ENTDAA CCC ($t_{STALLDAA}$), or on the ACK/NACK of a legacy I^2C or address phase of an I3C transfer, or the parity bit of a write data transfer, or on the ACK/NACK data phase of a legacy I^2C write, or on the transition bit of an I3C read transfer, or on the ACK/NACK phase of a legacy I^2C write (t_{STALL}), to adjust SCL clock low stalling, if needed by the I3C peripheral itself, when used as controller
  - $t_{NEWCRLock}$ for controller-role hand-off procedure (after GETACCCR CCC)

  c) *I3C timing register 2 (I3C_TIMINGR2)*:
  - SCL clock low stalling time, with separated enable/disable for each phase, to adjust SCL clock low stalling, if needed on the SDA hand-off with the addressed I3C target or legacy I^2C target
- Configure its own dynamic address: DA [6:0] field of the *I3C own device characteristics register (I3C_DEVR0)*
- Configure the management of any device target x: *I3C device x characteristics register (I3C_DEVRx)*, for x = 1 to x ≤ 4
- Configure the execution mode of a frame transfer or a target-requested transfer: *I3C configuration register (I3C_CFGR)*, with the following fields:
  - TXDMAEN, CDMAEN, RXDMAEN, SDMAEN: DMA mode enable/disable for respectively, TX-FIFO, C-FIFO, RX-FIFO, S-FIFO
  - TXTHRES, RXTHRES: respectively TX-FIFO and RX-FIFO byte/world threshold
  - TMODE: transmit mode (enable/disable for both TX-FIFO and C-FIFO preload)
  - SMODE: S-FIFO enable/disable
  - EXITPTRN, RSTPTRN: exit, reset pattern enable/disable
  - HJACK: hot-join acknowledge enable/disable
  - NOARBH: arbitrable header disable/enable
  - FCFDIS: FCF generation enable/disable
- Configure interrupt generation or polling mode from any event: *I3C interrupt enable register (I3C_IER)*

Then, the software can enable the I3C peripheral (set EN = 1).

Note: The software can write once all the fields of the I3C_CFGR while enabling it.

Start a controller-initiated frame transfer

When the controller is in enabled state (EN = 1 in the I3C_CFGR register), the software can initiate a frame transfer by any of the following configuration methods:

- Software-triggering: on a write and set TSFSET = 1 in the I3C_CFGR register
  - This causes the hardware to raise the flag CFNFF = 1 in the I3C_EVR register, to request a first control word I3C_CR to be written.
- No triggering: on a write of the first control word I3C_CR by software.

Then, regardless of the frame starting method, the I3C peripheral switches to active state. While the control word is not the last message of the I3C frame (while MEND = 0 in the I3C_CR register), and while there is no transfer error (while ERRF = 1 in the I3C_EVR register), the hardware keeps requesting a next control word, and continuing the frame transfer:

- If the C-FIFO in not configured in DMA mode (CDMAEN = 0 in the I3C_CFGR register), the software writes a next control word following the flag CFNFF = 1 in the I3C_EVR register, or the corresponding interrupt if enabled (if CFNFIE = 1 in I3C_IER register)
- If the C-FIFO in configured in DMA mode (CDMAEN = 1), a next control word is automatically pushed and written by the allocated DMA channel consequently to the asserted I3C DMA request (i3c_tc_dma).

Start and receiving a target-initiated transfer

When the controller is in enabled state (EN = 1 in the I3C_CFGR register), concurrently to a possible controller-initiated transfer, a target can initiate a transfer by issuing a start request (drive SDA low), provided the controller has allowed a hot-join request, an IBI request, or a controller-role request via the I3C_DEVR0 register.

In this case, even though the controller software has no intent to start a frame transfer, the hardware switches to active state (activates the SCL clock before a maximum t_{CAS} time defined as 1 µs, 100 µs, 2 ms, or 50 ms, depending on, respectively, the bus activity state 0, 1, 2, or 3) to receive the hot-join/in-band interrupt/controller-role request from the target.

For more information about the execution of target-initiated I3C bus transfer and its related programming as a controller, refer to the relevant figures in *Section 60.9*:

- *Figure 813: IBI transfer, as controller/target*
- *Figure 814: Hot-join request transfer, as controller/target*
- *Figure 815: Controller-role request transfer, as controller/target*

Executing a (controller-initiated) frame transfer

The controller executes on the bus the frame transfer until the completion of the last message (FCF = 1 in the I3C_EVR register), or a transfer error (ERRF = 1 in the I3C_EVR register), and the corresponding interrupt, if enabled. This is based on I3C_CR and I3C_TD(W)R registers, written explicitly by software or pushed by the allocated DMA channel, and based on the I3C_RD(W)R, read explicitly by the software or by the allocated DMA channel. Then the I3C controller switches back to idle state.

For more information about the execution of controller-initiated I3C bus transfer and its related programming as a controller, refer to figures in *Section 60.9*:

- *Figure 803: I3C CCC messages, as controller*
- *Figure 804: I3C broadcast ENTDAA CCC, as controller*
- *Figure 805: I3C broadcast, direct read and direct write RSTACT CCC, as controller*
- *Figure 810: I3C private read/write messages, as controller*
- *Figure 812: Legacy I2C read/write messages, as controller*

Figure 801 does not include the management of the FIFOs (TX-FIFO, RX-FIFO, C-FIFO, and S-FIFO). This is detailed in *Section 60.10*.

For each completed message without transfer error, the hardware reports the exchanged transfer on the I3C bus by updating *I3C status register (I3C_SR)*, which can be read or not by the software when the S-FIFO is disabled (SMODE = 0 in the I3C_CFGR register).

- In the case of a direct CCC read or a private read transfer, in addition to the completion of the last message (FCF = 1 in the I3C_EVR register) or a transfer error (ERRF = 1 in the I3C_EVR register) and the corresponding interrupt if enabled, and provided that the S-FIFO is disabled for the status register I3C_SR (SMODE = 0 in the I3C_CFGR register), the software is notified if the read transfer is ended prematurely by the target by RXTGTENDF = 1 in the I3C_EVR register, and the corresponding interrupt, if enabled. The software can then read I3C_SR, to get more information about the executed transfer.

Alternatively, if the S-FIFO is enabled (SMODE = 1 in the I3C_CFGR register), the status register I3C_SR must be read for each executed message, either directly by the software (notified by SFNEF = 1 in the I3C_EVR register and the corresponding interrupt, if enabled), or via the DMA (if SDMAEN = 1 in the I3C_CFGR register), no matter if a read is prematurely ended by the target or not. Frame completion (FCF = 1 in the I3C_EVR register) occurs only after reading the status of the last message (S-FIFO is empty). For more information, refer to *Section 60.10.4*.

Updating the configuration for a transfer, as controller

Back in idle state, the software can update the configuration of the I3C peripheral before the next transfer:

- Modify SCL clock stalling via *I3C timing register 2 (I3C_TIMINGR2)*
- Modify the interrupt/polling mode policy via *I3C interrupt enable register (I3C_IER)*
- Modify the following fields of the *I3C configuration register (I3C_CFGR)*:
  - TXTHRES, RXTHRES
  - TMODE, SMODE
  - TXDMAEN, CDMAEN, RXDMAEN, SDMAEN
  - EXITPTRN, RSTPTRN
  - NOARBH
  - FCFDIS

- Modify/prepare the control words, status words, read/write data of the next frame transfer to be executed, by software and/or DMA
  - *I3C message control register (I3C_CR)*, *I3C message control register [alternate] (I3C_CR)*
  - *I3C status register (I3C_SR)*
  - *I3C transmit data byte register (I3C_TDR)*, *I3C transmit data word register (I3C_TDWR)*
  - *I3C receive data byte register (I3C_RDR)*, *I3C receive data word register (I3C_RDWR)*
- Typically after having issued and completed a broadcast/direct DISEC/ENEC CCC:
  - Modify the hot-join acknowledge policy via bit HJACK in the I3C_CFGR register
  - Modify IBI/CR acknowledge policy to any target x, via *I3C device x characteristics register (I3C_DEVRx)*

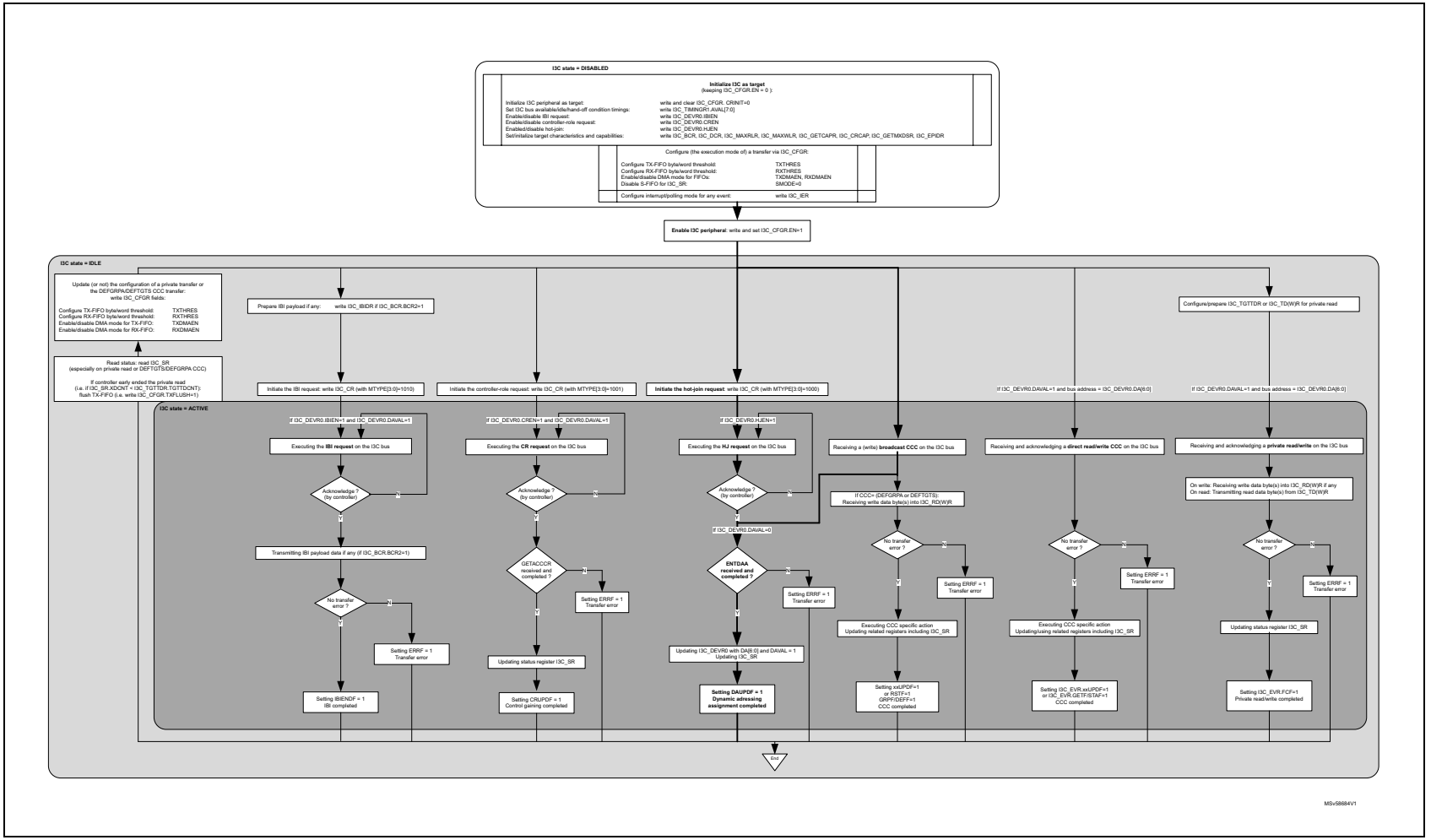
The registers usage versus the I3C peripheral role as controller is summarized in *Section 60.8.1*.

The static/dynamic registers fields usage when acting as controller is summarized in *Table 660*.

60.7.3 I3C target state and programming sequence

Figure 802 illustrates the overall programming sequence of the I3C peripheral acting as target, including state transitions, main subtasks, and conditions, as explained in this section.

Figure 802. I3C target state and programing sequence diagram



Target initialization

When the target is in disabled state (EN = 0 in the I3C_CFGR register), the software must initialize as follows:

- Set the I3C peripheral as target: write and clear CRINIT = 0 in the I3C_CFGR register
- Set the I3C bus timings via *I3C timing register 1 (I3C_TIMINGR1)*: write AVAL[7:0] for:
  - Bus available condition time (t_{AVAL}) for IBI or controller-role request
  - Bus idle condition time (t_{IDLE}) for hot-join request
  - $t_{NEWCRLock}$ for controller-role hand-off procedure (after GETACCCR CCC)
- Configure target-initiated requests: write *I3C own device characteristics register (I3C_DEVR0)* with
  - IBIEN: in-band interrupt (also known as IBI) request enable/disable
  - CREN: controller-role request enable/disable
  - HJEN: hot-join request enable/disable
- Initialize target characteristics and capabilities: write
  - *I3C bus characteristics register (I3C_BCR)*
  - *I3C device characteristics register (I3C_DCR)*
  - *I3C maximum read length register (I3C_MAXRLR)*
  - *I3C maximum write length register (I3C_MAXWLR)*
  - *I3C get capability register (I3C_GETCAPR)*
  - *I3C controller-role capability register (I3C_CRCAPR)*
  - *I3C get max data speed register (I3C_GETMXDSR)*
  - *I3C extended provisioned ID register (I3C_EPIDR)*
- Configure the execution mode of a transfer: *I3C configuration register (I3C_CFGR)*, with the following fields:
  - TXDMAEN, RXDMAEN: DMA mode enable/disable for, respectively, TX-FIFO and RX-FIFO
  - TXTHRES, RXTHRES: respectively TX-FIFO and RX-FIFO byte/world threshold
  - Disable S-FIFO: SMODE = 0 (default/reset value)
- Configure interrupt generation or polling mode from any event: *I3C interrupt enable register (I3C_IER)*

Then, the software can enable the I3C peripheral (write and set EN = 1).

Note: The software can write once all the fields of the I3C_CFGR register while enabling it.

Receiving a (broadcast CCC, direct read/write CCC or private read/write) message on the I3C bus

When the target is in idle state (EN = 1 in the I3C_CFGR register), the target is ready to receive a communication message on the I3C bus from the controller, and is ready to switch to the active state.

Typically, first, the active target is receiving a broadcast ENTDAA CCC, possibly after optional received broadcast ENEC/DISEC CCC(s), and is then assigned a dynamic address. The event DAUPF in the I3C_EVR register is raised to 1, the related interrupt is generated if enabled, and the target goes back to idle state.

After that, the idle target is ready to receive any other broadcast CCC message, or direct read/write CCC, or private read/write message from the controller.

For more information about the execution of controller-initiated I3C bus transfers and its related programming as a target, including the updated I3C registers and fields, refer to figures in *Section 60.9*:

- *Figure 806: I3C CCC messages, as target*
- *Figure 807: I3C broadcast ENTDAA CCC, as target*
- *Figure 808: I3C broadcast DEFTGTS CCC, as target*
- *Figure 809: I3C broadcast DEFGRPA CCC, as target*
- *Figure 811: I3C private read/write messages, as target*

Figure 802 does not include the FIFOs management (TX-FIFO, RX-FIFO). This is detailed in *Section 60.10*.

Read the message status register

For each received and completed message without transfer error, the hardware reports the exchanged transfer on the bus by updating the *I3C status register (I3C_SR)*, which can be read by the software after being notified by the corresponding flag in the *I3C event register (I3C_EVR)*, or by the corresponding interrupt if enabled in the *I3C interrupt enable register (I3C_IER)*.

I3C status register (I3C_SR) must be read by the software after the following messages:

- A private read: to get the number of exchanged data bytes, as the controller can have ended the transfer earlier than expected by the target (if XDCNT[15:0] in the I3C_SR register is lower than TGTTDCNT[15:0] in the I3C_TGTTDR register). If so, software must flush the TX-FIFO (write TXFLUSH = 1 in the I3C_CFGR register).
- A DEFTGTS CCC or a DEFGRPA CCC: to get the number of received data bytes in the RX-FIFO

Start a (target-initiated) transfer on the I3C bus

When the target goes first from disabled to idle state (software writes EN = 1 in the I3C_CFGR register), concurrently to be able to receive a broadcast CCC from the controller, the software can initiate a hot-join request (the software writes MTYPE[3:0] = 1000 in the I3C_CR register) to be eligible to participate to a next ENTDAA CCC, provided it is allowed to do so (HJEN = 1 in the I3C_DEVR0 register).

Once a dynamic address is assigned (DAUPF = 1 in the I3C_EVR register), more generally and possibly concurrently to a frame transfer emitted by the controller, the software can initiate an IBI (in-band interrupt request) to the controller, or a controller-role request by writing the related control word into the I3C_CR register.

For more information about the execution of target-initiated I3C bus transfer, and its related programming as a target, refer to figures in *Section 60.9*:

- *Figure 813: IBI transfer, as controller/target*
- *Figure 814: Hot-join request transfer, as controller/target*
- *Figure 815: Controller-role request transfer, as controller/target*

Updating the configuration of the I3C peripheral, as target

Back in idle state, the software can update the configuration of the I3C target before a next transfer:

- Modify the interrupt/polling mode policy via *I3C interrupt enable register (I3C_IER)*
- Modify following fields of the *I3C configuration register (I3C_CFGR)*:
  - TXTHRES, RXTHRES
  - TXDMAEN, RXDMAEN
- Modify/prepare the *I3C IBI payload data register (I3C_IBIDR)*, if any payload (if BCR2 = 1 in the I3C_BCR register), before initiating an IBI transfer (write *I3C message control register [alternate] (I3C_CR)* with MTYPE[3:0] = 1010)
- Modify/prepare *I3C target transmit configuration register (I3C_TGTTDR)*, to disable or enable the TX-FIFO to be preloaded with a defined number of data bytes to be transmitted, before receiving a private read or a direct CCC read (out of the GETSTATUS CCC)

The registers usage vs. the I3C peripheral role as target is summarized in *Section 60.8.1*.

The static/dynamic registers fields usage, when acting as target, is summarized in *Table 661*.

60.8 I3C registers and programming

60.8.1 I3C register set, as controller/target

Table 659 lists the registers and their usage versus the I3C peripheral role.

Table 659. I3C register usage

Register	Used as controller	Used as target
I3C_CR	X	X
I3C_CFGR	X	X
I3C_RDR	X	X
I3C_RDWR	X	X
I3C_TDR	X	X
I3C_TDWR	X	X
I3C_IBIDR	X	X
I3C_TGTTDR	-	X
I3C_SR	X	X
I3C_SER	X	X
I3C_RMR	X	X
I3C_EVR	X	X
I3C_IER	X	X
I3C_CEVR	X	X
I3C_MISR	X	X

Table 659. I3C register usage (continued)

Register	Used as controller	Used as target
I3C_DEVR0	X	X
I3C_DEVRx (x = 1 to 4)	X	-
I3C_MAXRLR	-	X
I3C_MAXWLR	-	X
I3C_TIMINGR0	X	-
I3C_TIMINGR1	X	X
I3C_TIMINGR2	X	-
I3C_BCR	-	X
I3C_DCR	-	X
I3C_GETCAPR	-	X
I3C_CRCAPR	-	X
I3C_GETMXDSR	-	X
I3C_EPIDR	-	X

60.8.2 I3C registers and fields use versus peripheral state, as controller

When the I3C peripheral acts as controller, *Table 660* lists the registers and their usage versus the controller state (disabled, idle, and active).

Table 660. I3C registers/fields usage versus controller state

Register	Used as controller	Writable only in disabled state	Typically written/read in idle state	Typically written/read in idle or active state
I3C_CR	X	-	-	X

Table 660. I3C registers/fields usage versus controller state (continued)

Register	Used as controller	Writable only in disabled state	Typically written/read in idle state	Typically written/read in idle or active state
I3C_CFGR	X	CRINIT HKSDAEN EN(1)	Write: any used field except {CRINIT, HKSDAEN}, namely {CDMAEN SDMAEN TXDMAEN RXDMAEN TMODE SMODE TXTHRES RXTHRES HJACK EXITPTRN RSTPTRN NOARBH}(2) FCFDIS CFLUSH SFLUSH TXFLUSH RXFLUSH TSFSET	-
I3C_RDR	X	-	-	Read
I3C_RDWR	X	-	-	Read
I3C_TDR	X	-	-	Write
I3C_TDWR	X	-	-	Write
I3C_IBIDR	X	-	-	Read
I3C_TGTTDR	-			
I3C_SR	X	-	-	Read
I3C_SER	X	-	Read	-
I3C_RMR	X	-	-	Read RADD[6:0] IBIRDCNT[2:0]

Table 660. I3C registers/fields usage versus controller state (continued)

Register	Used as controller	Writable only in disabled state	Typically written/read in idle state	Typically written/read in idle or active state
I3C_EVR	X	-	-	Read (controller-role fields): HJF CRF IBIF FCF ERRF RXTGTENDF RXFNEF TXFNFF SFNEF CFNFF RXLASTF TXLASTF TXFEF CFEF
I3C_IER	X	Write xIE with x = HJ, CR, IBI, FC, ERR, RXTGTEND, RXFNE, TXFNF, SFNE, CFNF(2)		
I3C_CEVR	X	-	-	Write (controller-role fields, refer to I3C_EVR)
I3C_MISR	X	-	-	Read (controller-role fields): HJMIS CRMIS IBIMIS FCMIS ERRMIS RXTGTENDMIS RXFNEMIS TXFNFMIS SFNEMIS CFNFMIS
I3C_DEVR0	X	Write DA[6:0](2)		-
I3C_DEVRx x = 1..4	X	Write SUSP, IBIDEN, IBIACK, CRACK, DA[6:0](2)		-
I3C_MAXRLR	-			
I3C_MAXWLR	-			
I3C_TIMINGR0	X	X	-	-
I3C_TIMINGR1	X	X	-	-
I3C_TIMINGR2	X	Write(2)		
I3C_BCR	-			
I3C_DCR	-			
I3C_GETCAPR	-			
I3C_CRCAPR	-			

Table 660. I3C registers/fields usage versus controller state (continued)

Register	Used as controller	Writable only in disabled state	Typically written/read in idle state	Typically written/read in idle or active state
I3C_GETMXDSR	-			
I3C_EPIDR	-			

1. Bit EN in the I3C_CFGR register is written and set in disabled state (when the same bit is 0). This field can be also written and de-asserted in idle state.
2. These fields are typically written and initialized in disabled state during bus configuration. They are not write-protected when EN = 0, and can be also written and updated in other state(s).

60.8.3 I3C registers and fields usage versus peripheral state, as target

When the I3C peripheral acts as target, *Table 661* lists the registers and their usage versus the I3C target state (disabled, idle, and active).

Table 661. I3C registers/fields usage versus target state

Register	Used as target	Writable only in disabled state	Typically written/read in idle state	Typically written/read in idle or active state
I3C_CR	X	-	MTYPE[3:0] DCNT[2:0]	-
I3C_CFGR	X	CRINIT EN(1)	Write: any used field except CRINIT, namely: {TXDMAEN RXDMAEN TXTHRES RXTHRES}(2) TXFLUSH RXFLUSH	-
I3C_RDR	X	-	-	Read
I3C_RDWR	X	-	-	Read
I3C_TDR	X	-	-	Write
I3C_TDWR	X	-	-	Write
I3C_IBIDR	X	-	Write	-
I3C_TGTTDR	X	-	Write	-
I3C_SR	X	-	-	Read DIR, XDCNT[15:0]
I3C_SER	X	-	Read DOVR, STALL, PERR, CODERR[3:0]	-
I3C_RMR	X	-	-	Read RCODE[7:0]

Table 661. I3C registers/fields usage versus target state (continued)

Register	Used as target	Writable only in disabled state	Typically written/read in idle state	Typically written/read in idle or active state
I3C_EVR	X	-	-	Read (target-role fields): GRPF DEFF INTUPDF ASUPDF RSTF MRLUPDF MWLUPDF DAUPDF STAF GETF WKPF CRUPDF IBIENDF ERRF FCF RXFNEF TXFNFF TXLASTF TXFEF
I3C_IER	X	Write xIE with x = GRP, DEF, INTUPD, ASUPD, RST, MRLUPD, MWLUPD, DAUPD, STA, GET, WKP, CRUPD, IBIEND, ERR, FC, RXFNE, TXFNF(2)		
I3C_CEVR	X	-	-	Write (target-role fields, refer to I3C_EVR)
I3C_MISR	X			Read (target-role fields): GRPMIS DEFMIS INTUPDMIS ASUPDMIS RSTMIS MRLUPDMIS MWLUPDMIS DAUPDMIS STAMIS GETMIS WKPMIS CRUPDMIS IBIENDMIS ERRMIS FCMIS RXFNEMIS TXFNFMIS

Table 661. I3C registers/fields usage versus target state (continued)

Register	Used as target	Writable only in disabled state	Typically written/read in idle state	Typically written/read in idle or active state
I3C_DEVR0	X	HJEN CREN IBIEN	Read RSTVAL, RSTACT[1:0], and AS[1:0]	-
I3C_DEVRx x = 1..4	-			
I3C_MAXRLR	X	X	-	-
I3C_MAXWLR	X	X	-	-
I3C_TIMINGR0	-			
I3C_TIMINGR1	X	AVAL[7:0]	-	-
I3C_TIMINGR2	-			
I3C_BCR	X	X	-	-
I3C_DCR	X	X	-	-
I3C_GETCAPR	X	X	-	-
I3C_CRCAPR	X	X	-	-
I3C_GETMXDSR	X	X	-	-
I3C_EPIDR	X	X	-	-

1. Bit EN in the I3C_CFGR register is written and set in disabled state (when the same bit is 0). This field can be also written and de-asserted in idle state.
2. These fields are typically written and initialized in disabled state during I3C bus configuration. They are not write-protected when EN = 0.

60.9 I3C bus transfers and programming

60.9.1 I3C command set (CCCs), as controller/target

The list of the supported I3C command set (for example, list of CCCs, common command codes) and the overview of how they are handled by the I3C peripheral acting as controller or target, is specified in *Table 662*.

Table 662. List of supported I3C CCCs, as controller/target

CCC name	CCC value	Read /write	With/without defining byte With/without sub-command byte	With/without optional data byte(s)	Use as controller	Use as target, raised I3C_EVR event	When target: specific action
Broadcast CCCs							
ENEC	0x00	Write	No defining/sub-command byte	With one data byte (enable target events byte)	X	X, INTUPDF	Update and enable I3C_DEVR0: HJEN, CREN, IBIEN if any
DISEC	0x01			With one data byte (disable target events byte)	X	X, INTUPDF	Update and disable I3C_DEVR0: HJEN, CREN, IBIEN if any
ENTASx x = 0...3	0x02 ... 0x05			No data byte	X	X, ASUPDF	Update I3C_DEVR0.AS[1:0]
RSTDAA	0x06			-	X	X, DAUPDF	Clear I3C_DEVR0.DAVAL = 0
ENTDAA	0x07			-	X	X, DAUPDF if DAVAL = 0	Update I3C_DEVR0: DA[6:0] and set DAVAL = 1
DEFTGTS	0x08			With [1+ 4x (1+ number_of_targets)] x data bytes	X	X, DEFF	Update I3C_RDR/ I3C_RDWR. Refer to *Figure 808*.
SETMWL	0x09			With two data byte	X	X, MWLUPDF	Update I3C_MAXWLR
SETMRL	0x0A			With 2 or 3 data bytes	X	X, MRLUPDF	Update I3C_MAXRLR
ENTTM	0x0B			With one data byte	X	-	-
SETXTIME	0x28		With sub-command byte	Without or with one or more data bytes	X	-	-
SETAASA	0x29		No defining/sub-command byte	No data byte	X	-	-
RSTACT	0x2A		With defining byte (0x00, 0x01 or 0x02)		X	X, RSTF after detected reset pattern	Update I3C_DEVR0: RSTACT[1:0] and set RSTVAL = 1
DEFGRPA	0x2B		No defining/sub-command byte	With several data bytes	X	X, GRPF	Update I3C_RDR/ RDWR. Refer to *Figure 809*.
RSTGRPA	0x2C			No data byte	X	-	-

Table 662. List of supported I3C CCCs, as controller/target (continued)

CCC name	CCC value	Read /write	With/without defining byte With/without sub-command byte	With/without optional data byte(s)	Use as controller	Use as target, raised I3C_EVR event	When target: specific action
Direct CCCs							Action if ACK (if I3C target Address = I3C_DEVR0.DA[6:0] and I3C_DEVR0.DAVAL = 1) (else NACK)
ENEC	0x80	Write	No defining/sub-command byte	With one data byte (enable target events byte)	X	X, INTUPDF	Update and enable I3C_DEVR0: HJEN, CREN, IBIEN if any
DISEC	0x81			With one data byte (disable target events byte)	X	X, INTUPDF	Update and disable I3C_DEVR0: HJEN, CREN, IBIEN if any
ENTASx x = 0...3	0x82...0x85			No data byte	X	X, ASUPDF	Update I3C_DEVR0.AS[1:0]
SETDASA	0x87			No data byte	X	-	-
SETNEWDA	0x88			With one data byte	X	X, DAUPDF if DAVAL = 1	Update I3C_DEVR0: DA[6:0] (and keep DAVAL = 1)
SETMWL	0x89			With two data bytes	X	X, MWLUPDF	Update I3C_MAXWLR
SETMRL	0x8A			With two or three data bytes	X	X, MRLUPDF	Update I3C_MAXRLR
GETMWL	0x8B	Read	No defining/sub-command byte	With two data bytes	X	X, GETF	Return data bytes from I3C_MAXWLR[15:0]. Refer to *Section 60.15.20*.
GETMRL	0x8C			With two or three data bytes	X	X, GETF	Return data bytes from I3C_MAXRLR[15:0] and if I3C_BCR.BCR2 = 1 return third byte from I3C_MAXRLR.IBIP[2:0]. Refer to *Section 60.15.19*.

Table 662. List of supported I3C CCCs, as controller/target (continued)

CCC name	CCC value	Read /write	With/without defining byte With/without sub-command byte	With/without optional data byte(s)	Use as controller	Use as target, raised I3C_EVR event	When target: specific action
GETPID	0x8D	Read	No defining/sub-command byte	With six data bytes	X	X, GETF	Return data bytes from I3C_EPIDR. Refer to *Section 60.15.29*.
GETBCR	0x8E			With one data byte	X	X, GETF	Return data byte from I3C_BCR[7:0]. Refer to *Section 60.15.24*.
GETDCR	0x8F				X	X, GETF	Return I3C_DCR[7:0]. Refer to *Section 60.15.25*.
GETSTATUS	0x90		With or without defining byte (TGTSTAT, PRECR)	With two data bytes (format 1 or format 2 with PRECR)	X	X, STAF if format 1 X, GETF if format 2	Return 2 data bytes, as detailed in *Section 60.9.9*.
GETACCCR	0x91		No defining/sub-command byte	With one data byte	X	X, CRUPDF	Return data byte from I3C_DEVR0.DA[6:0] with parity bit
GETMXDS	0x94		With or without defining byte (WRRDTURN, CRHDLY)	With two data bytes (format 1) or 5 data bytes (format 2 or format 3 with WRRDTURN) or 1 data byte (format 3 with CRHDLY)	X	X, GETF	Return data byte(s) from I3C_GETMXDSR. Refer to *Section 60.15.28*.
GETCAPS	0x95		With or without defining byte (TGTSTAT, CRCAPS)	With 3 data bytes (format 1 or format 2 with TGTSTAT) or two data bytes (format 2 with CRCAPS)	X	X, GETF	Return 3 GETCAPx data bytes from I3C_GETCAPR (refer to *Section 60.15.26*) or Return 2 CRCAPx data bytes from I3C_CRCAPR (refer to *Section 60.15.27*)
D2DXFER	0x97	Write	With defining byte	With defining byte	X	-	-
SETXTIME	0x98		With sub-command byte	With sub-command byte	X		
GETXTIME	0x99	Read	No defining/sub-command byte	No defining/sub-command byte	X		

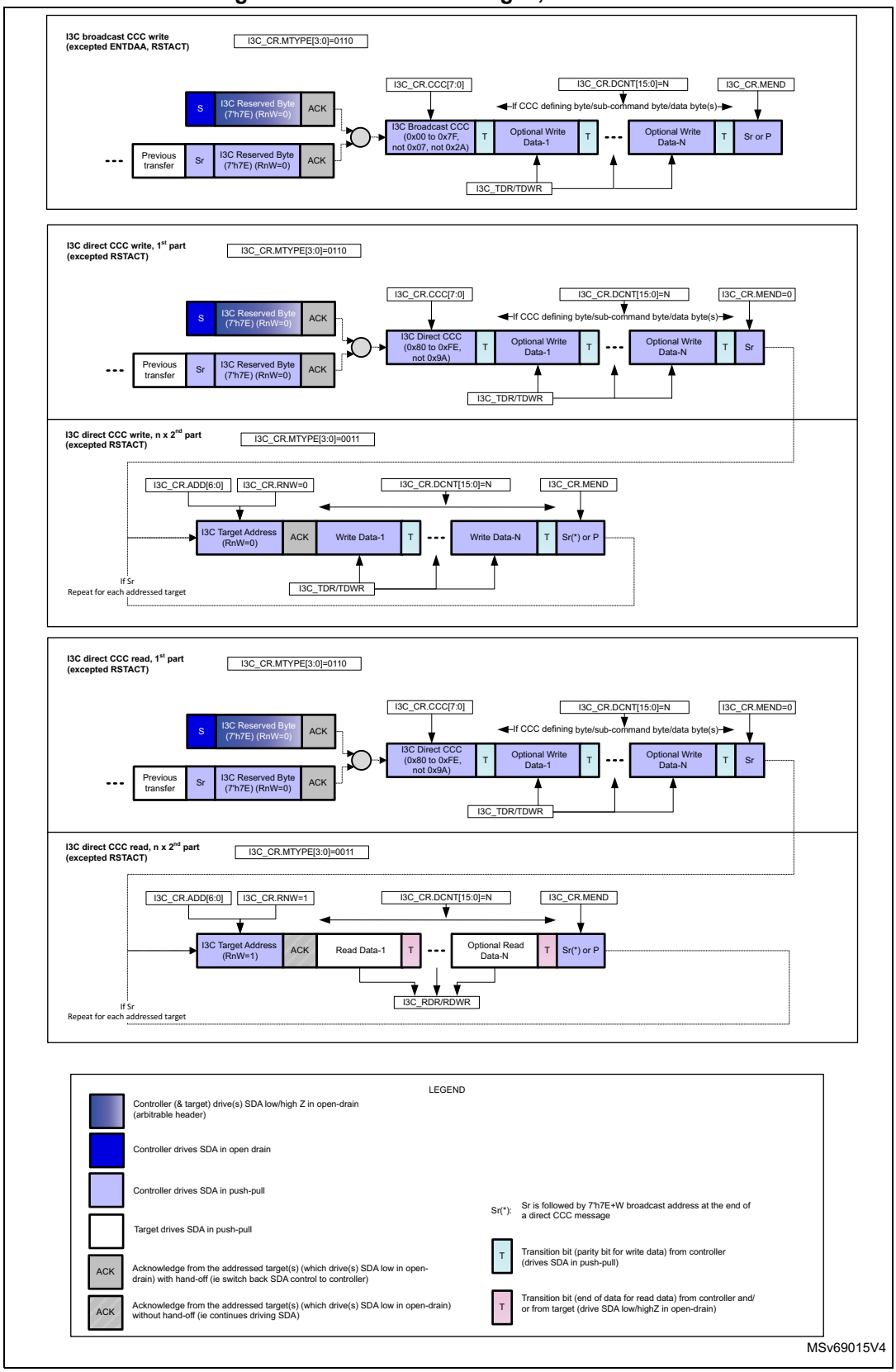
Table 662. List of supported I3C CCCs, as controller/target (continued)

CCC name	CCC value	Read /write	With/without defining byte With/without sub-command byte	With/without optional data byte(s)	Use as controller	Use as target, raised I3C_EVR event	When target: specific action
RSTACT	0x9A	Read/ Write	With defining byte (0x00, 0x01, or 0x02)	With defining byte (0x00, 0x01, or 0x02)	X	X, RSTF if detected reset pattern	Read: return data byte from RSTACT[1:0] in the I3C_DEVR0 register. Write: update I3C_DEVR0: RSTACT[1:0] and set RSTVAL = 1
SETGRPA	0x9B	Write	No defining/sub-command byte	No defining/sub-command byte	X	-	-
RSTGRPA	0x9C				X		

60.9.2 I3C broadcast/direct CCC transfer (except ENTDAA, RSTACT), as controller

Figure 803 illustrates I3C broadcast CCC write transfer (except ENTDAA, RSTACT), and direct CCC read/write transfer, as communicated on the I3C bus, and as programmed when acting as controller.

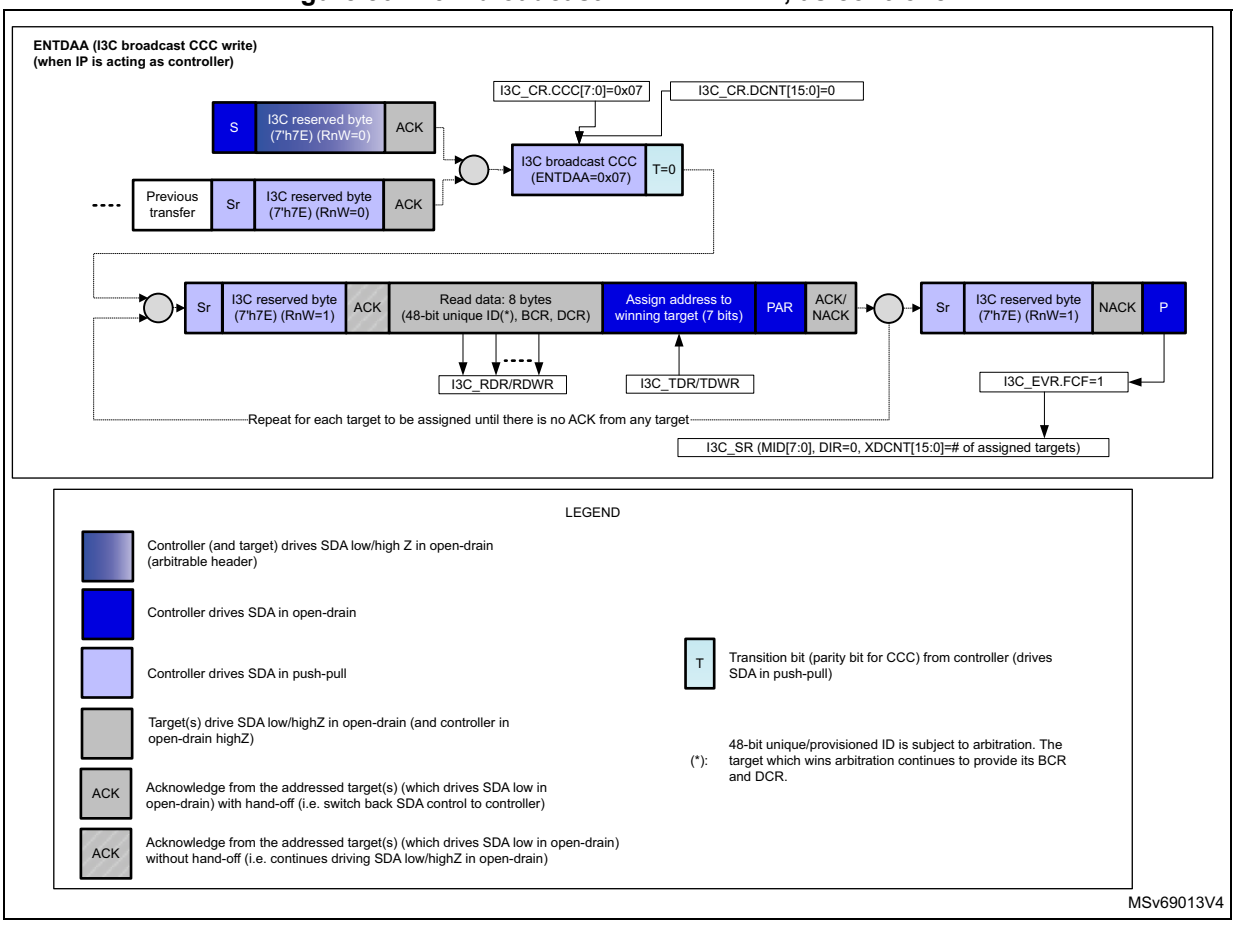
Figure 803. I3C CCC messages, as controller



60.9.3 I3C broadcast ENTDAA CCC transfer, as controller

Figure 804 illustrates I3C broadcast ENTDAA CCC, as communicated on the I3C bus, and as programmed when acting as controller.

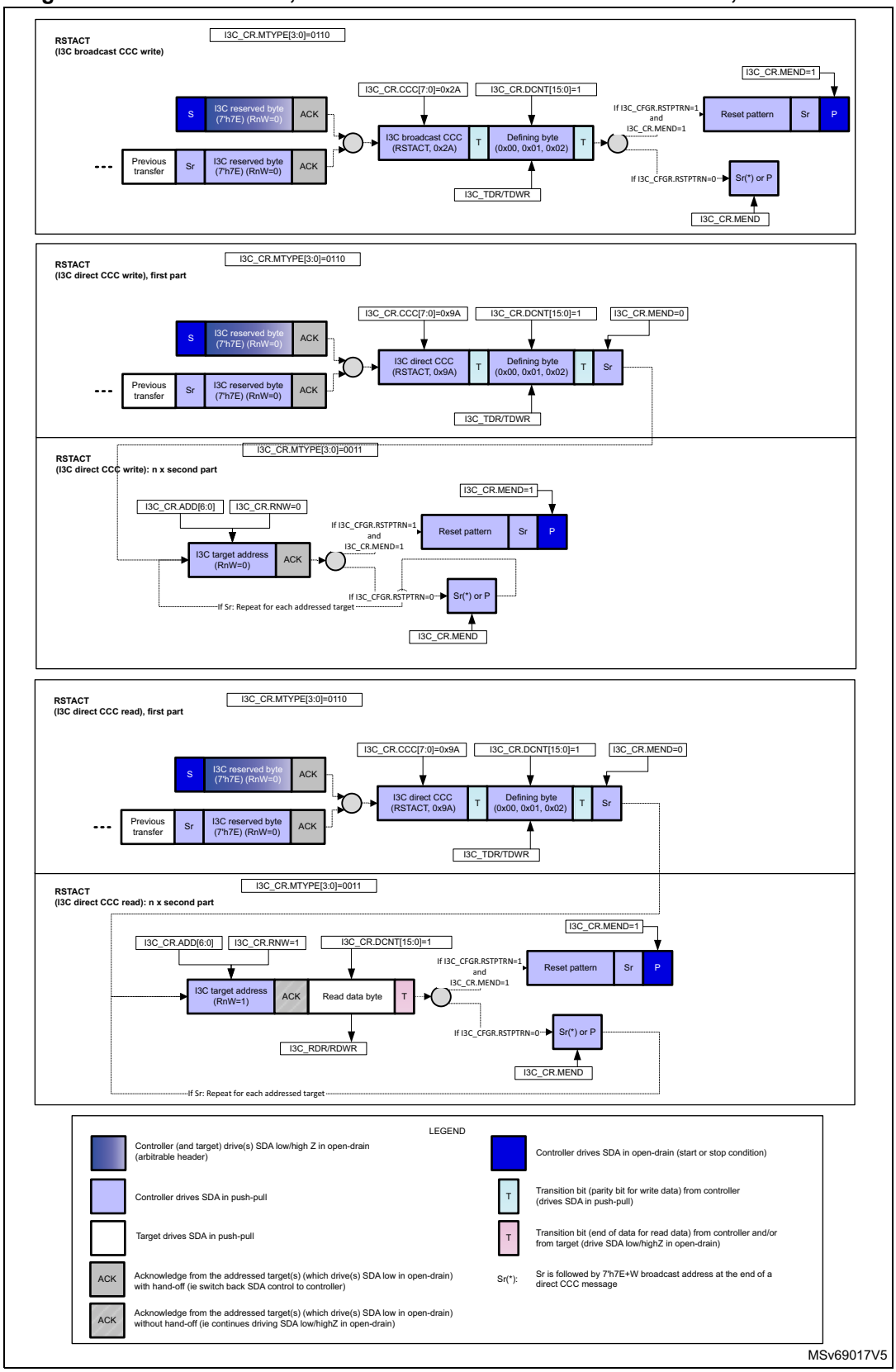
Figure 804. I3C broadcast ENTDAA CCC, as controller



60.9.4 I3C broadcast/direct RSTACT CCC transfer, as controller

Figure 805 illustrates I3C broadcast (write), direct write and read RSTACT CCC, as communicated on the I3C bus, and as programmed when acting as controller.

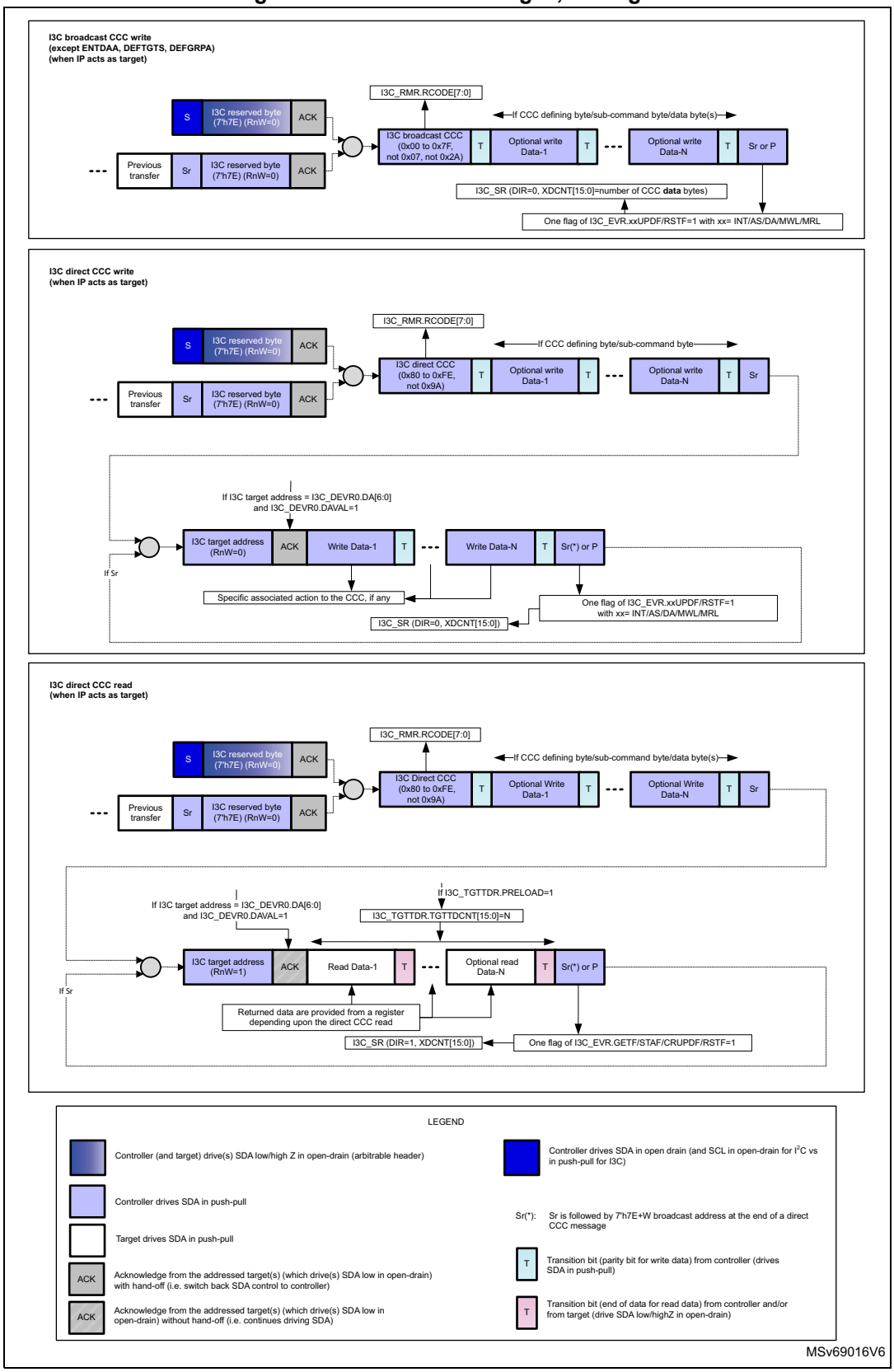
Figure 805. I3C broadcast, direct read and direct write RSTACT CCC, as controller



60.9.5 I3C broadcast/direct CCC transfer (except ENTDAA, DEFTGTS, DEFGRPA), as target

Figure 806 illustrates I3C broadcast CCC write transfer (except ENTDAA, DEFTGTS, DEFGRPA), direct CCC read/write transfer, as communicated on the I3C bus, and as programmed when acting as target.

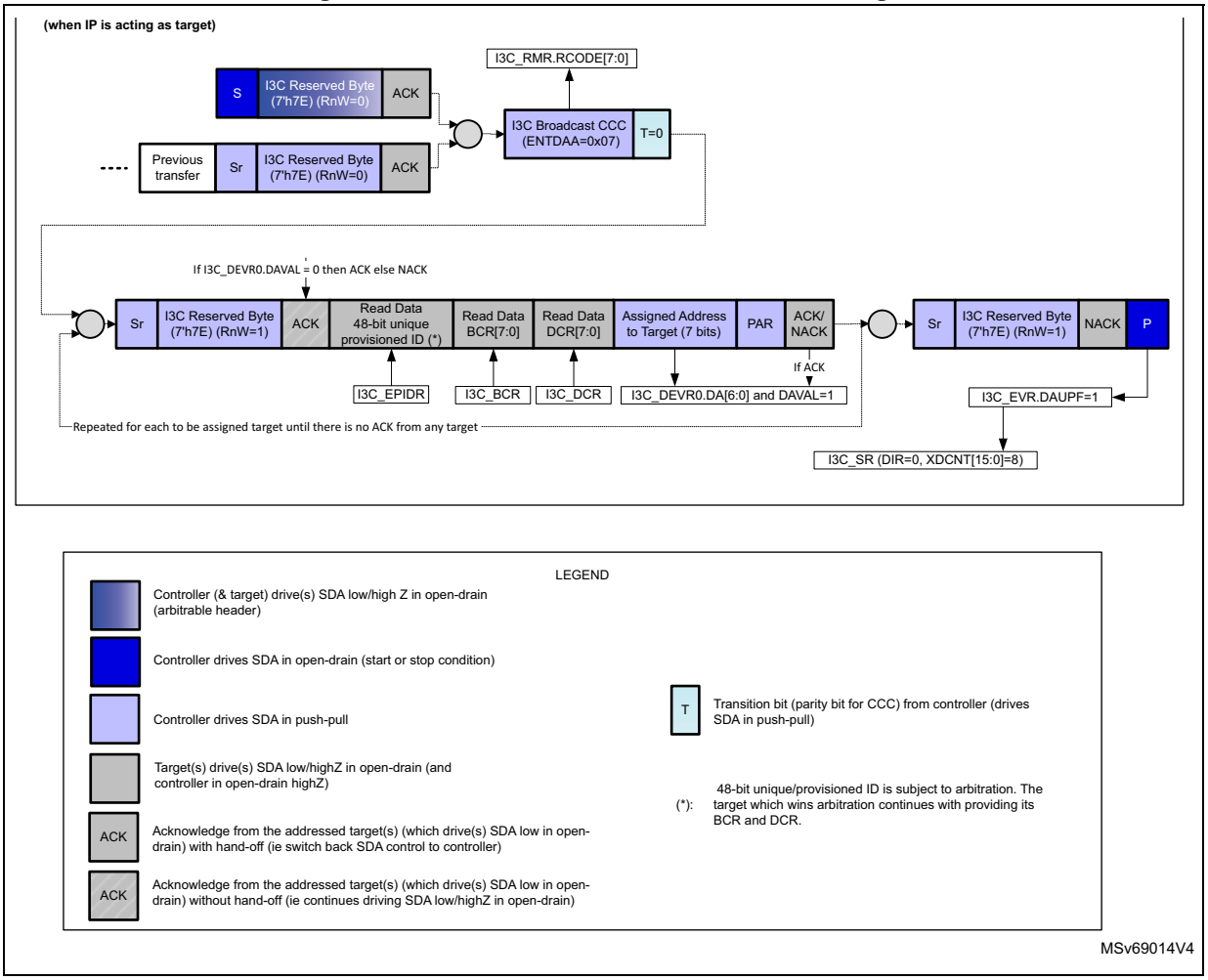
Figure 806. I3C CCC messages, as target



60.9.6 I3C broadcast ENTDAA CCC transfer, as target

Figure 807 illustrates I3C broadcast ENTDAA CCC, as communicated on the I3C bus, and as programmed when acting as target.

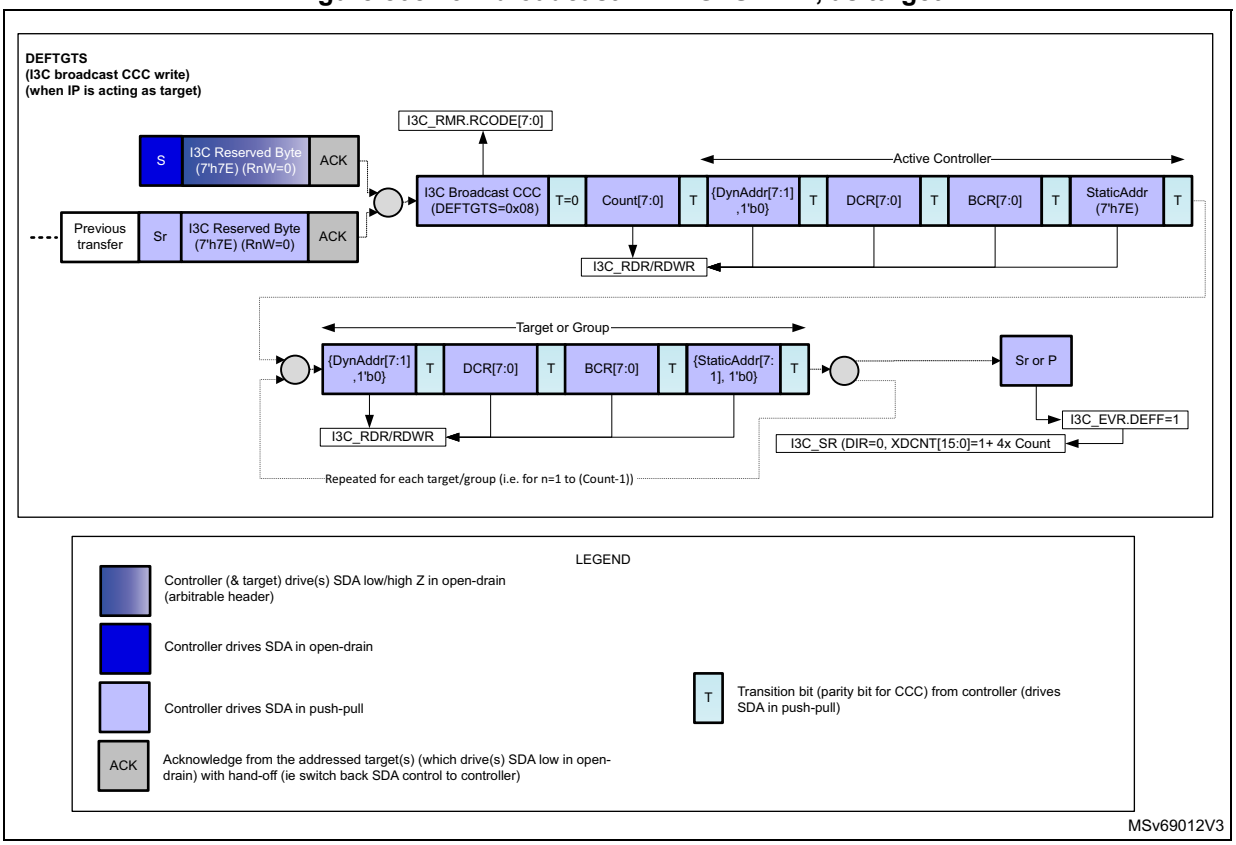
Figure 807. I3C broadcast ENTDAA CCC, as target



60.9.7 I3C broadcast DEFTGTS CCC transfer, as target

Figure 808 illustrates I3C broadcast DEFTGTS CCC, as communicated on the I3C bus, and as programmed when acting as target.

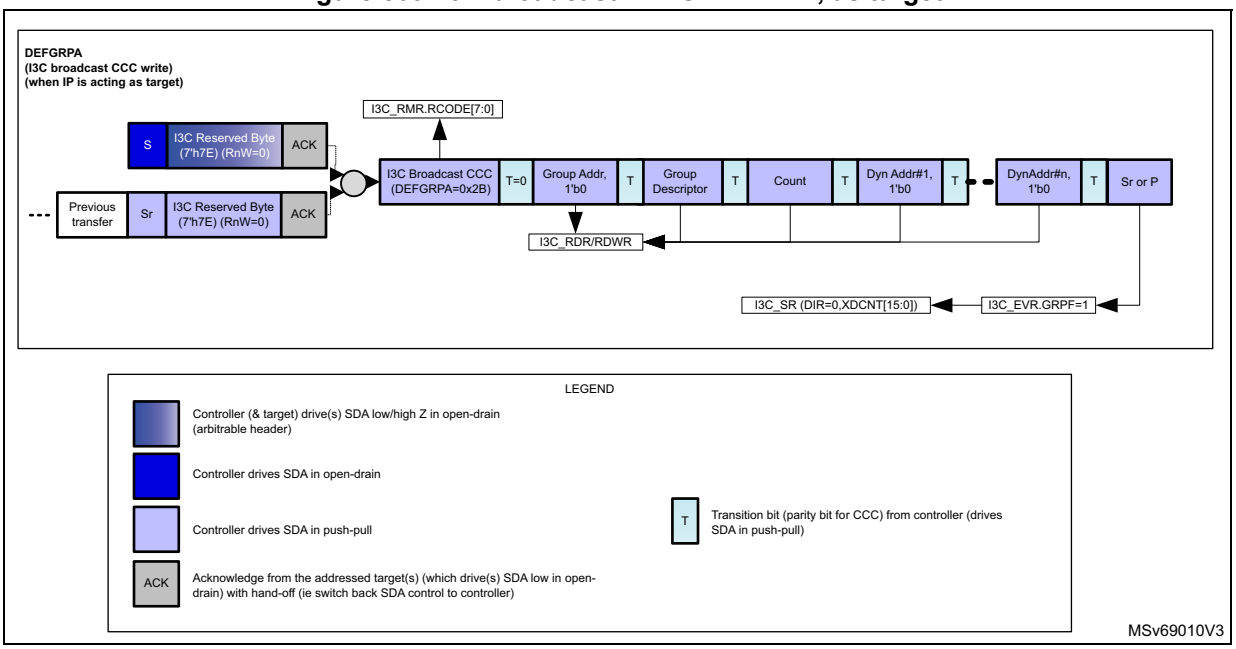
Figure 808. I3C broadcast DEFTGTS CCC, as target



60.9.8 I3C broadcast DEFGRPA CCC transfer, as target

Figure 809 illustrates I3C broadcast DEFGRPA CCC, as communicated on the I3C bus, and as programmed when acting as target.

Figure 809. I3C broadcast DEFGRPA CCC, as target



60.9.9 I3C direct GETSTATUS CCC response, as target

When the I3C acts as target, the hardware returns two data bytes on reception of GETSTATUS CCC, with format 1 (without defining byte or with defining byte TGTSTAT = 0x00), or format 2 (with defining byte PRECR = 0x91).

The returned 2-byte STATUS[15:0] with format 1 on the I3C bus is then as follows:

- STATUS[15:14] = 00 (unused)
- STATUS[13] = 1 if a missed start was detected since the former GETSTATUS CCC, else 0
- STATUS[12] = 1 if an overrun/underrun error was detected since the former GETSTATUS CCC, else 0
- STATUS[11] = 1 if an SCL stable for more than 125 µs was detected during an SDR read since the former GETSTATUS CCC, else 0
- STATUS[10:8] = 000 to 110: encoded value x = 0 to 6, corresponding to a target error TEx if a protocol error was detected since the former GETSTATUS CCC (if STATUS[5] = 1), else 000
- STATUS[7:6] = 00 (ready to prepare for hand-off procedure)
- STATUS[5] = 1 if a protocol error was detected since the former GETSTATUS CCC, else 0
- STATUS[4] = 0 (reserved)
- STATUS[3:1] = 000 (unused)
- STATUS[0] = 1 if there is a pending interrupt (if an IBI is configured in the I3C_CR register, and IBIEN = 1 and DAVAL = 1 in the I3C_DEVR0.register, and the IBI is not yet acknowledged by the controller neither disabled via DISEC), else 0

The returned 2-byte STATUS[15:0] with format 2 on the I3C bus is then as follows:

- STATUS[15:8] = 0000 0000 (unused)
- STATUS[7:2] = 00000 (unused)
- STATUS[1] = 1 if a received DEFTGTS or a received DEFGRPA CCC is still under software processing, and the related event is not yet cleared by software (DEFF = 1 or GRPF = 1 in the I3C_EVR register); the controller must wait before issuing a GETACCR CCC (else it is not acknowledged)
- STATUS[0] = 1 if a DEFTGTS or DEFGRPA CCC may have been missed. This bit is asserted if a missed start is detected (WKPF = 1 in the I3C_EVR register), de-asserted if DEFF = 1 or GRPF = 1 in the I3C_EVR register.

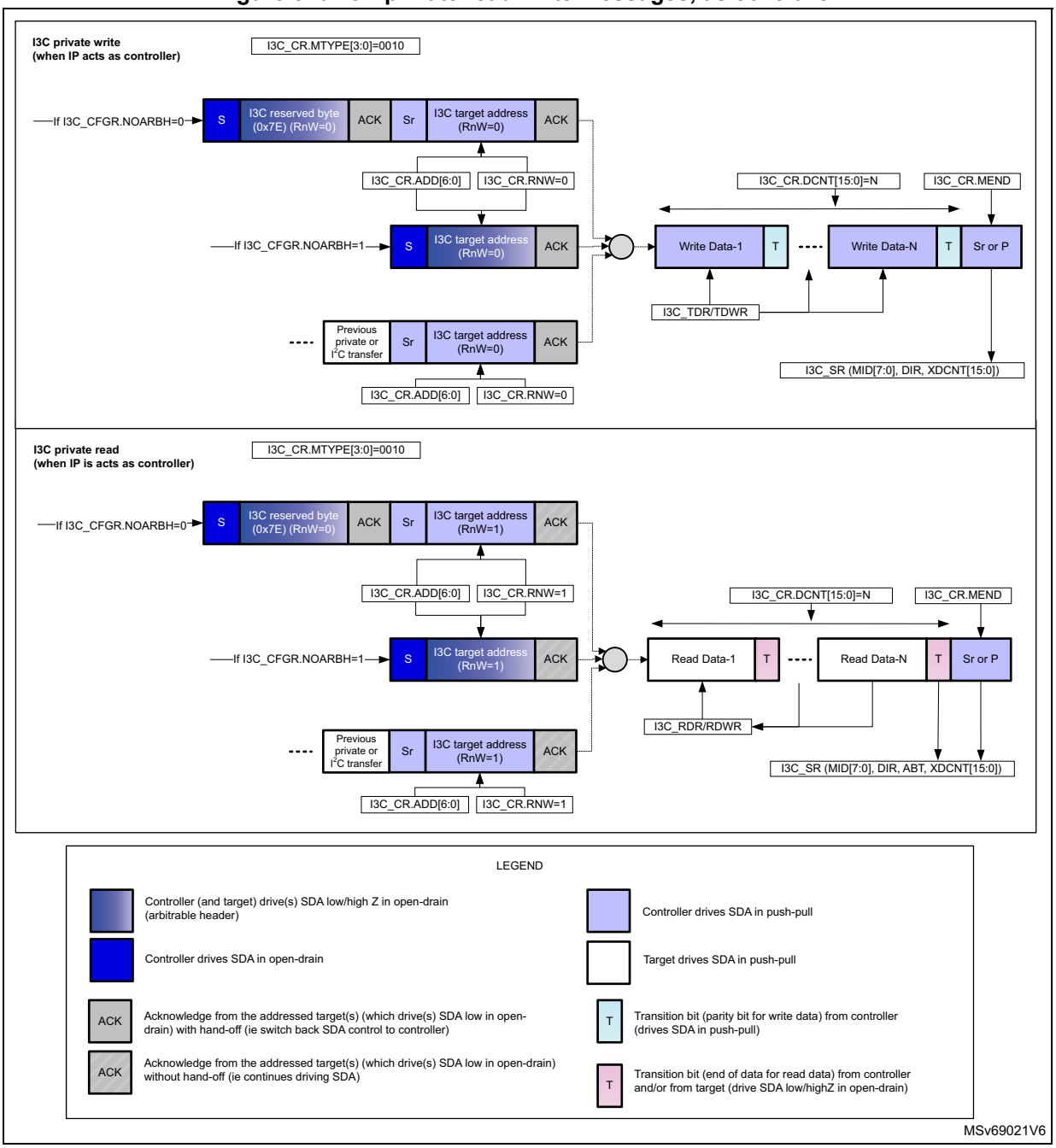
Completion of a GETSTATUS CCC of format 1 is reported by STAF = 1 in the I3C_EVR register, and the corresponding interrupt if enabled (if STAIE = 1 in the I3C_IER register).

Completion of a GETSTATUS CCC of format 2 is reported by GETF = 1 in the I3C_EVR register, and the corresponding interrupt if enabled (if GETIE = 1 in the I3C_IER register).

60.9.10 I3C private read/write transfer, as controller

Figure 810 illustrates private read/write transfer, as communicated on the I3C bus, and as programmed when acting as controller.

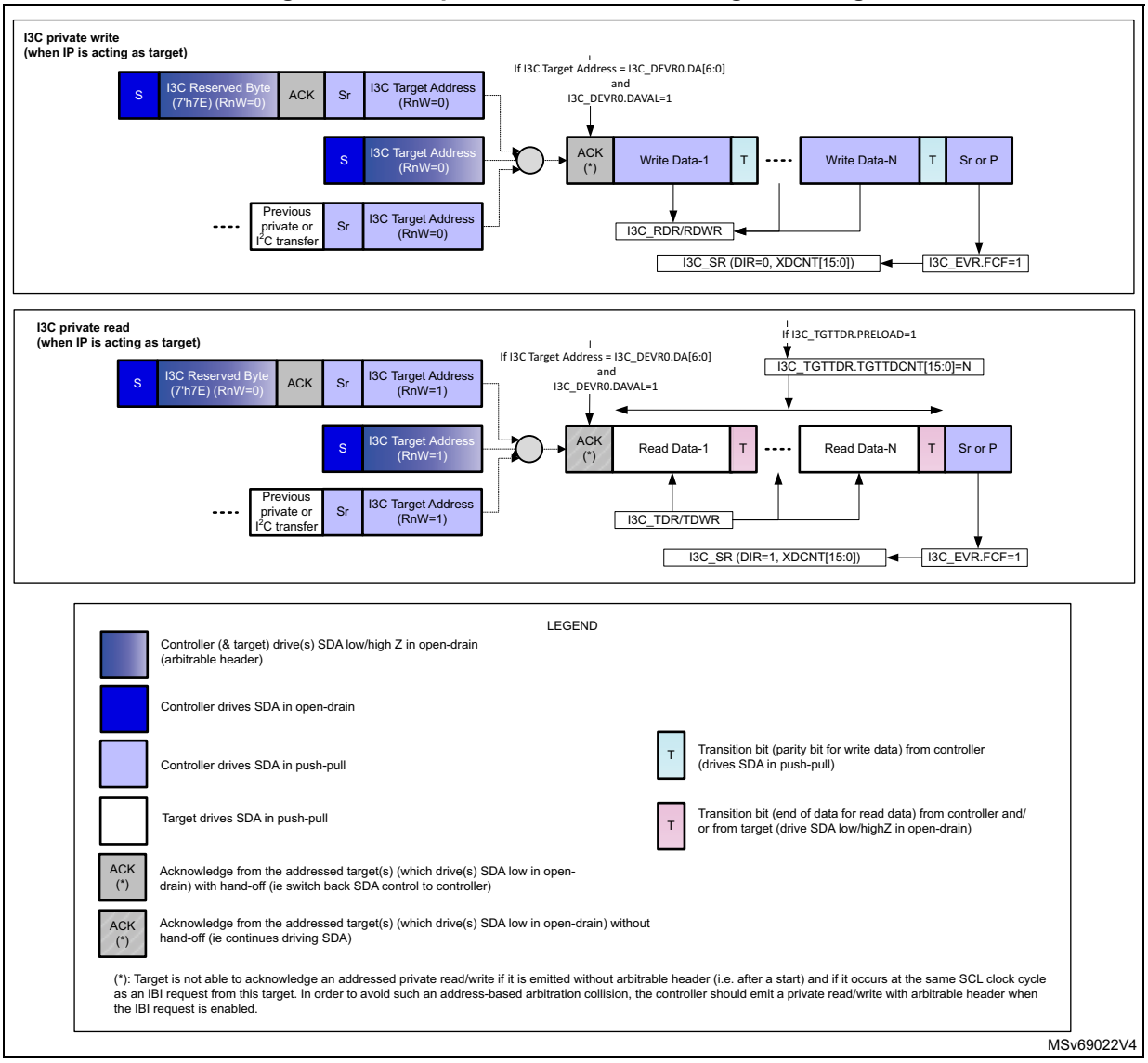
Figure 810. I3C private read/write messages, as controller



60.9.11 I3C private read/write transfer, as target

Figure 811 illustrates I3C private read/write transfer, as communicated on the I3C bus, and as programmed when acting as target.

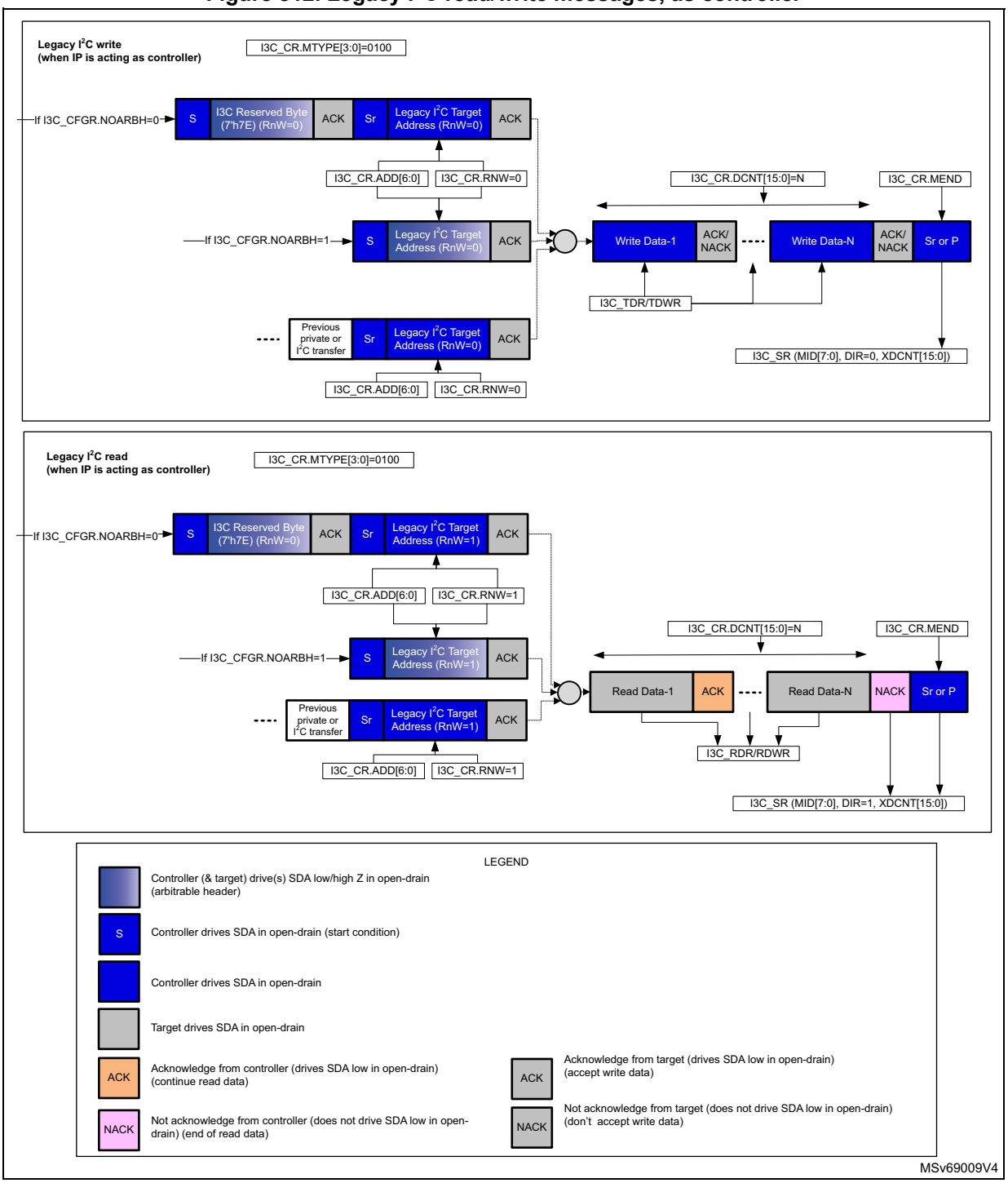
Figure 811. I3C private read/write messages, as target



60.9.12 Legacy I²C read/write transfer, as controller

Figure 812 illustrates legacy I²C read/write transfer, as communicated on the I3C bus, and as programmed when acting as controller.

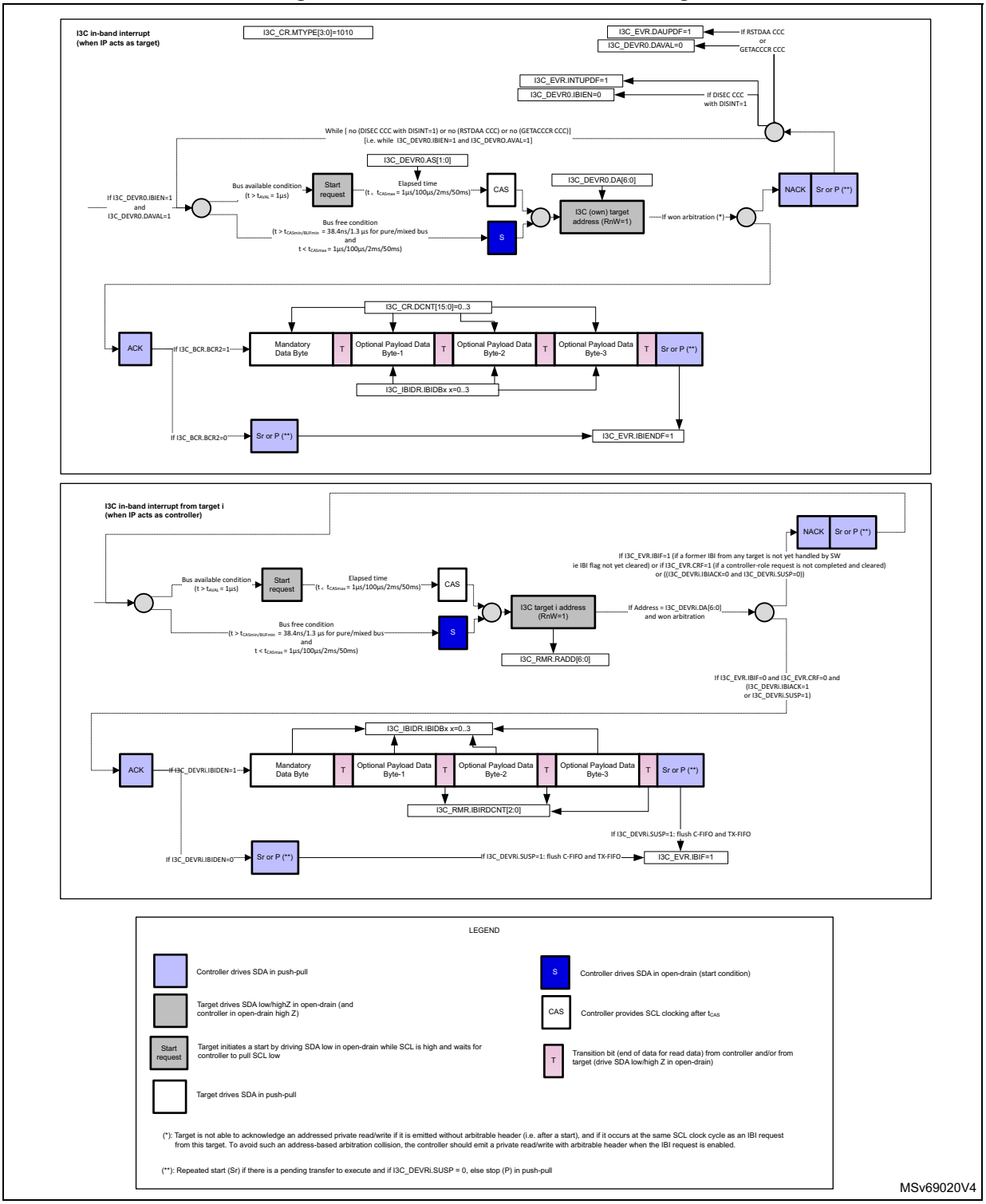
Figure 812. Legacy I²C read/write messages, as controller



60.9.13 I3C IBI transfer, as controller/target

Figure 813 illustrates IBI (in-band interrupt) transfer, as communicated on the I3C bus, and as programmed when acting as target or received as controller.

Figure 813. IBI transfer, as controller/target



When the I3C peripheral acts as controller, the I3C_IBIDR register is used to receive the IBI data payload. Consequently, the IBI request from the target must not exceed a 4-byte data payload. If there is more information to be exchanged in the context of this in-band interrupt, the controller software must issue a private read.

Timing control and sensor acquisition timestamping when I3C controller

When the I3C peripheral acts a controller, it can use timing control and asynchronous mode 0 to timestamp the moment at which the target(s) acquired sampled data, and to time-correlate them.

To do this, the software must go through the following sequence:

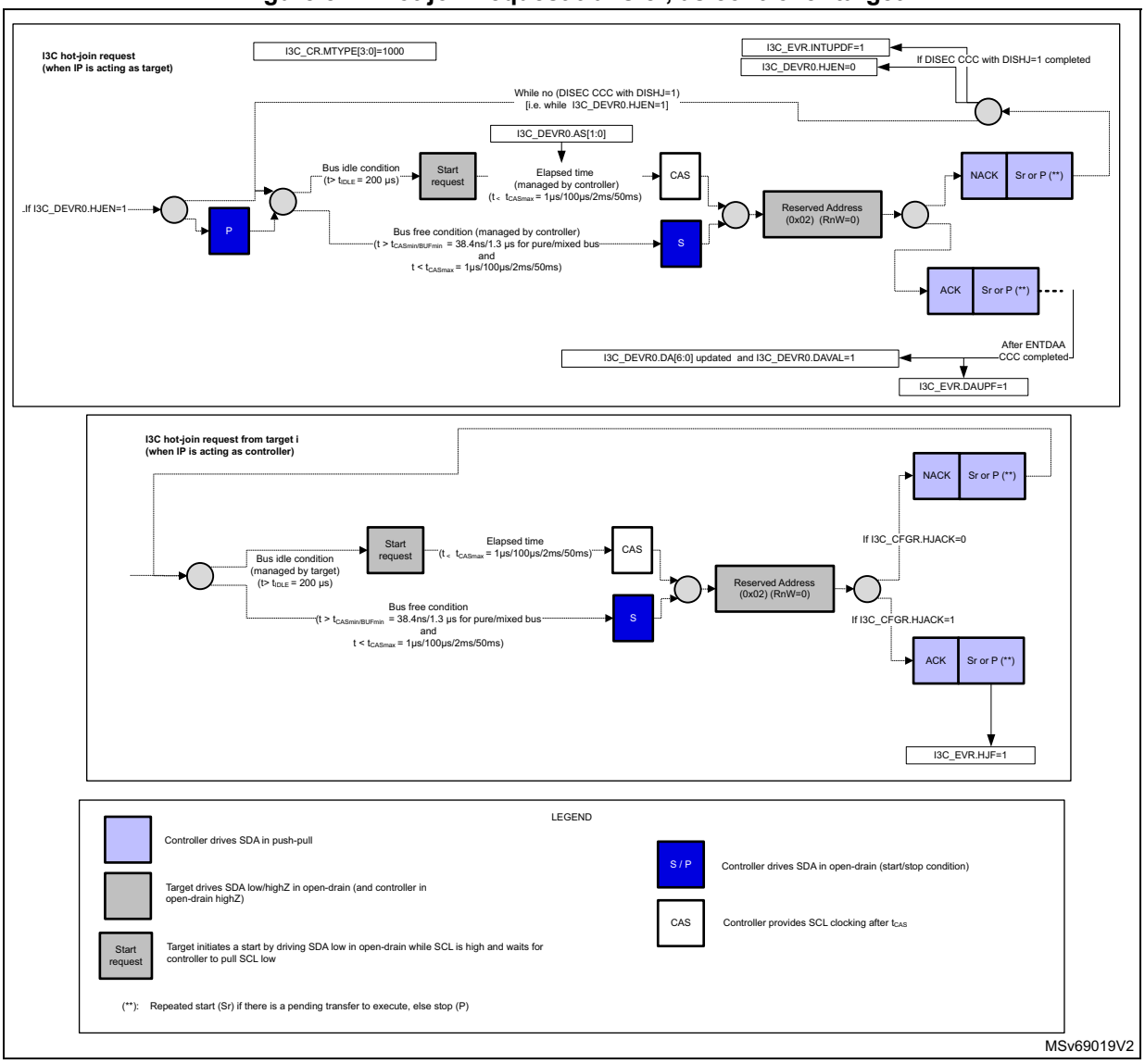
1. Allocate and configure a timer in capture mode, to be connected to the I3C generated event i3c_ibi_ack so that for each IBI acknowledge the counter of the timer can be captured.
2. Program a broadcast/direct SETXTIME CCC with sub-command byte 0xDT to enter asynchronous mode 0 on the target(s) side.
3. After being notified of the command completion by the flag and/or the related interrupt (FCF flag is set in I3C_EVR register), reset and enable the timer to start the counter on the controller side.
4. After being notified that an IBI is complete by the flag and/or the related interrupt (IBIF = 1 in the I3C_EVR register), and if the IBI is with timing info (if IBIDB0[7:5] = 100 in the I3C_IBIDR register), read the captured value of the timer, as C_TIM. Given that:
   a) C_C2 = 9 × (SCLL_PP[7:0] + 1 + SCLH_I3C[7:0] + 1) × T_{I3CCLK}
   b) T_C1 (16-bit value) = {IBIDB2, IBIDB1} in the I3C_IBIDR register
   c) T_C2 (8-bit value) = IBID3 in the I3C_IBIDR register

   Compute the timestamp of the sampled data received from the target, as follows (see MIPI spec formula for more details): C_TS = C_TIM - C_C2 x T_C1 / T_C2.
5. Repeat step *4*, for each received IBI.
6. Generate a broadcast/direct SETXTIME CCC with subcommand byte 0xFF to exit asynchronous mode 0 and disable/deallocate the timer resource.

60.9.14 I3C hot-join request transfer, as controller/target

Figure 814 illustrates hot-join request transfer, as communicated on the I3C bus, and as programmed when acting as target or received as controller.

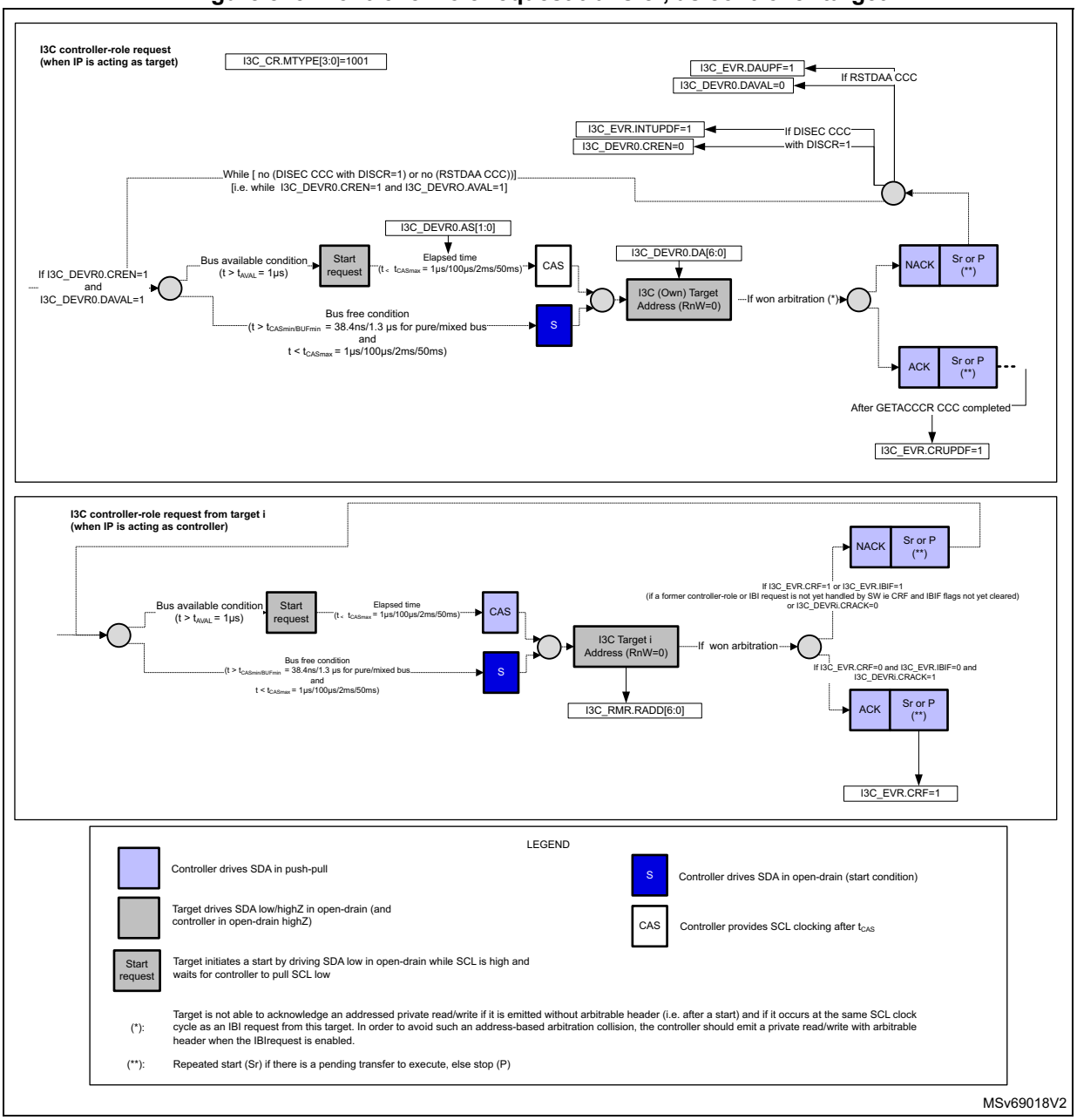
Figure 814. Hot-join request transfer, as controller/target



60.9.15 I3C controller-role request transfer, as controller/target

Figure 815 illustrates controller-role request transfer, as communicated on the I3C bus, and as programmed when acting as target or received as controller.

Figure 815. Controller-role request transfer, as controller/target



60.10 I3C FIFOs management, as controller

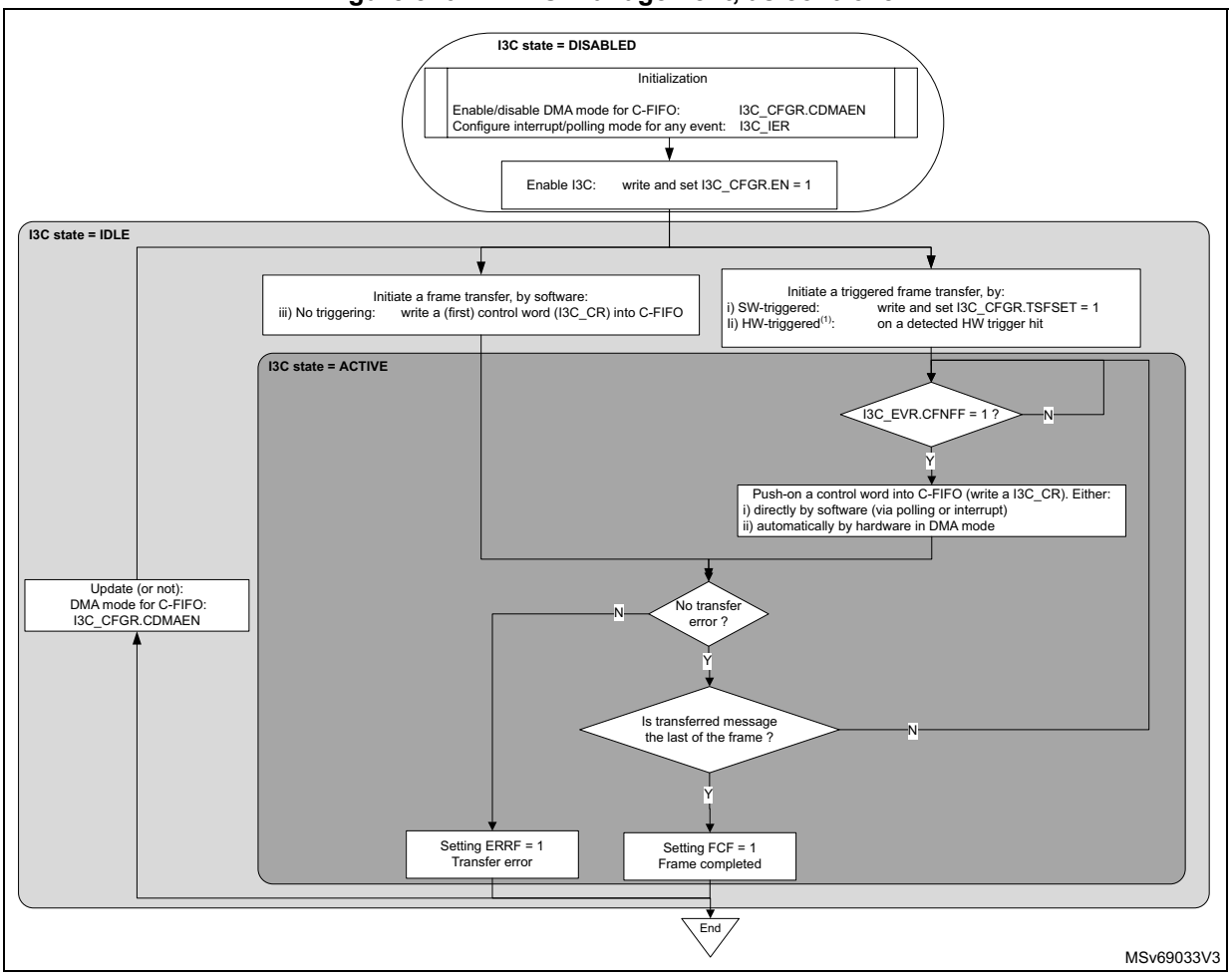
60.10.1 C-FIFO management, as controller

When controller, as illustrated in figures of *Section 60.9*, C-FIFO can be used during any of the following transfers:

- broadcast CCC (*Figure 803*, *Figure 804*, *Figure 805*)
- direct read/write CCC (*Figure 805*)
  - command part, first message
  - data part, next message(s)
- private read/write (*Figure 810*)
- legacy I2C read/write (*Figure 812*)
- software-initiated error recovery (SCL forced to be stopped until next header message followed by HDR exit pattern)

Figure 816 illustrates the management of the C-FIFO for queuing control word(s) on the I3C bus, when the I3C peripheral acts as controller.

Figure 816. C-FIFO management, as controller



1. This feature is implementation-dependent and can be unavailable. Refer to *Section 60.3.4*.

Note: The software can disable the generation of FCF flag by writing 1 into the FCFDIS bit of the I3C_CFGR register. This can be used with hardware triggers and autonomous DMA (if this feature is available, see Section 60.3) to stream a series of frames.

First, the software must initialize the C-FIFO management via CDMAEN in the I3C_CFGR register, to be written either:

- directly by the software (if CDMAEN = 0) at the control word level:
  - via polling mode (CFNFIE = 0 in the I3C_IER register): waiting for a next control word is requested by the hardware (CFNFF = 1 in the I3C_IER register) before an explicit write to the I3C_CR register
  - via enabled interrupt notification if CFNFIE = 1
- by the allocated DMA channel (if CDMAEN = 1) to the corresponding DMA request from the I3C peripheral (i3c_tc_dma):
  - as configured at block level, the DMA is automatically pushing-on/writing control word(s) into the I3C_CR register from its memory source buffer, until the frame completion (a stop is emitted on the I3C bus after the last message of the frame), unless a transfer error occurs.

In any case, if C-FIFO is empty and a restart must be emitted with a new control word, a C-FIFO underrun is reported (ERRF = 1 in the I3C_EVR register and COVR = 1 in the I3C_SER register). If enabled by ERRIE = 1 in the I3C_IER register, an interrupt is generated.

The DMA mode for the C-FIFO management can be modified when the I3C peripheral is not in active state.

When controller, if a transfer error occurs (ERRF = 1 in the I3C_EVR register), the C-FIFO is flushed automatically by the hardware.

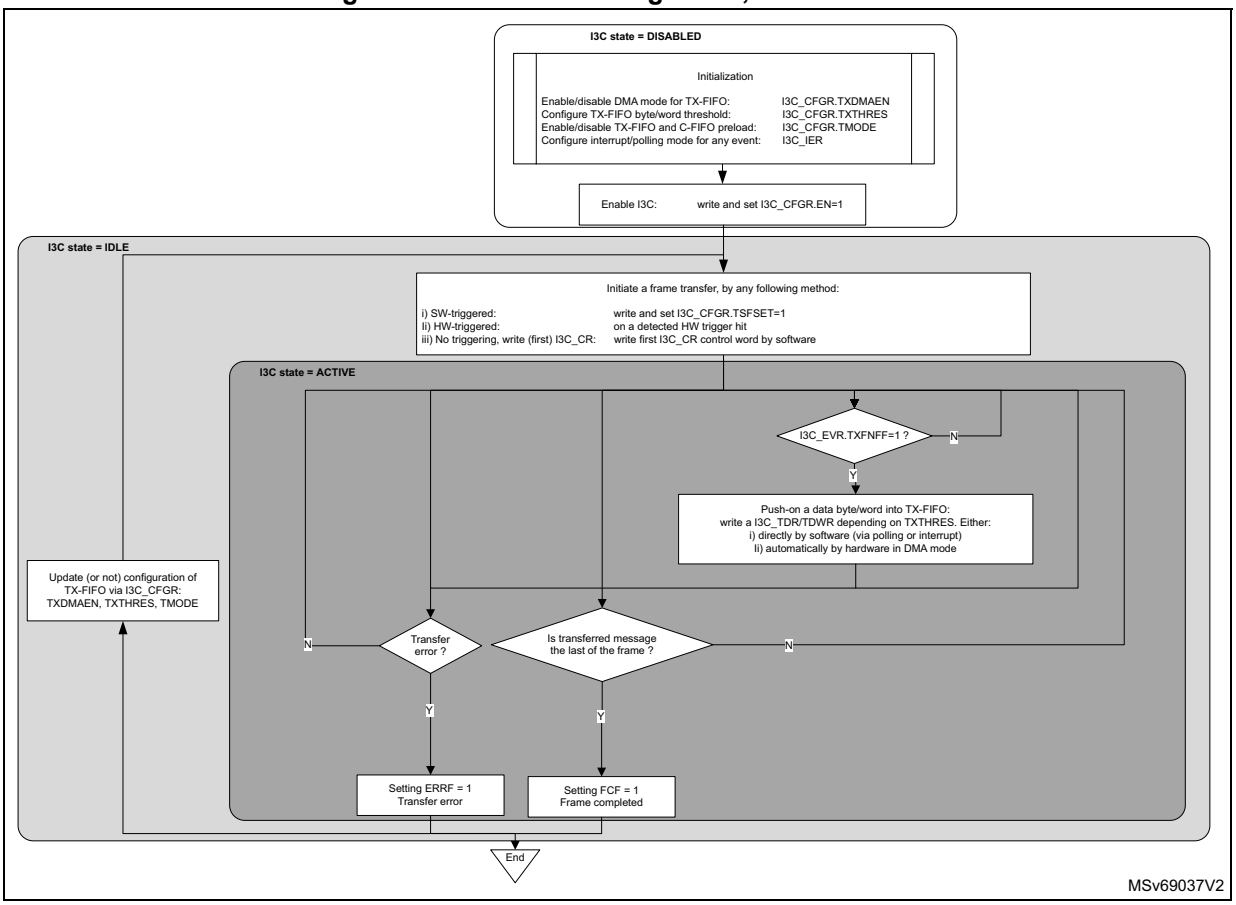
60.10.2 TX-FIFO management, as controller

When controller, as shown in figures of *Section 60.9*, TX-FIFO can be used during any of the following transfers:

- broadcast or direct CCC (including ENTDAA and RSTACT), if a defining/sub-command byte or if data byte(s) are present (*Figure 803*, *Figure 804*, *Figure 805*)
- private write (*Figure 810*)
- legacy I2C write (*Figure 812*)

Figure 817 illustrates the management of the TX-FIFO for queuing data bytes or word(s) to be transmitted on the I3C bus, when the I3C peripheral acts as controller.

Figure 817. TX-FIFO management, as controller



First, the software must initialize the TX-FIFO management via the following fields in the I3C_CFGR register:

- TXDMAEN: enable/disable DMA mode for TX-FIFO
- TXTHRES: push-on data byte(s) or word(s) into TX-FIFO
- TMODE: enable/disable TX-FIFO and C-FIFO preload

Then, depending upon bit TXDMAEN in the I3C_CFGR register, the TX-FIFO is written either:

- directly by the software (if TXDMAEN = 0) at the byte/word level:
  - via polling mode (TXFNFIE = 0 in the I3C_IER register): waiting for a next data byte/word is requested by the hardware (TXFNFF = 1 in the I3C_IER register) before an explicit write to the I3C_TDR or I3C_TDWR register, depending upon bit TXTHRES in the I3C_CGFR register
  - via enabled interrupt notification if TXFNFIE = 1
- by the allocated DMA channel (if TXDMAEN = 1) to the corresponding DMA request from the I3C peripheral (i3c_tx_dma):
  - as configured at DMA block level, the DMA is automatically pushing-on/writing data bytes/words to the I3C_TDR or I3C_TDWR register (depending upon bit TXTHRES in the I3C_CGFR. register) from its memory source buffer, until the frame completion (a stop is emitted on the I3C bus after the last message of the frame), unless a transfer error occurs.

An I3C message begins from a start or a repeated start, and ends with a stop or a repeated start. At message level, the last data byte/word to be transmitted is flagged by TXLASTF = 1 in the I3C_EVR register. When an I3C frame is described with multiple messages (separated by a repeated start), this event can be used by the software to update the pointer to the buffer where the byte(s)/word(s) of the next message is/are stored.

When frame completion is reported (FCF = 1 in the I3C_EVR register, and the corresponding interrupt is enabled), the TX-FIFO is empty.

If the TX-FIFO is empty and a data byte must be transmitted on the I3C bus, a TX-FIFO underrun is reported (ERRF = 1 in the I3C_EVR register and DOVR = 1 in the I3C_SER register). If enabled by ERRIE = 1 in the I3C_IER register, an interrupt is generated.

The configuration for the TX-FIFO management can be modified when the I3C peripheral is not in active state.

When controller, if a transfer error occurs (ERRF = 1), the TX-FIFO is automatically flushed by the hardware.

No C-FIFO/TX-FIFO preload

As defined in *Table 654*, C-FIFO size is two words, TX-FIFO size is 8 bytes.

When no C-FIFO/TX-FIFO preload is configured (TMODE = 0 in the I3C_CFGR register), the I3C peripheral emits a start on the I3C bus as soon as the first control word is written into the C-FIFO. Then, it decodes the I3C_CR register, and requires a next data byte/word to be written, if needed within this message. As soon as a next control word is detected as required by the hardware to be transmitted on the I3C bus (if a repeated start must be emitted on the I3C bus or if the C-FIFO gets available room), this control word is requested to be written into the C-FIFO until the last message (MEND = 1 in the I3C_CR register).

Similarly, as soon as another data byte/word is detected as required by the hardware to be transmitted on the I3C bus (if a repeated start must be emitted on the I3C bus, and if TX-FIFO is not full, and if data byte(s)/word(s) must be transmitted during this I3C message), this data byte/word must be written in the TX-FIFO.

C-FIFO and TX-FIFO preload

When C-FIFO/TX-FIFO preload is configured (TMODE = 1 in the I3C_CFGR register), before emitting a start on the bus, the I3C peripheral waits for loading as much as possible both the C-FIFO and the TX-FIFO, as follows:

1. Wait for a first control word to be written into the C-FIFO.
2. Wait for data byte(s)/word(s) to be written in the TX-FIFO, if any, as defined by the first control word (if RNW = 0 and DCNT[15:0] = 0 in the I3C_CR register), and up to the TX-FIFO size.
3. If TX-FIFO is not full and if the first control word is not the last of the frame (MEND = 0 in the I3C_CR register):
   a) Wait for a second control word to be written into the C-FIFO, then C-FIFO is full.
   b) If TX-FIFO is not full, wait for data byte(s)/word(s) to be written in the TX-FIFO, if any, as defined by the second control word (RNW = 0 and DCNT[15:0] = 0 in the I3C_CR register), and up to the TX-FIFO size.

Then, as soon as a next control word is detected as required by the hardware to be transmitted on the I3C bus (if a repeated start must be emitted on the I3C bus), this control

word is requested to be written into the C-FIFO until the last message (MEND = 1 in the I3C_CR register).

Similarly, as soon as a next data byte/word is detected as required by the hardware to be transmitted on the I3C bus (if a repeated start must be emitted on the I3C bus and if TX-FIFO is not full and if data byte(s)/word(s) are to be transmitted during this I3C message), this data byte/word must be written in the TX-FIFO.

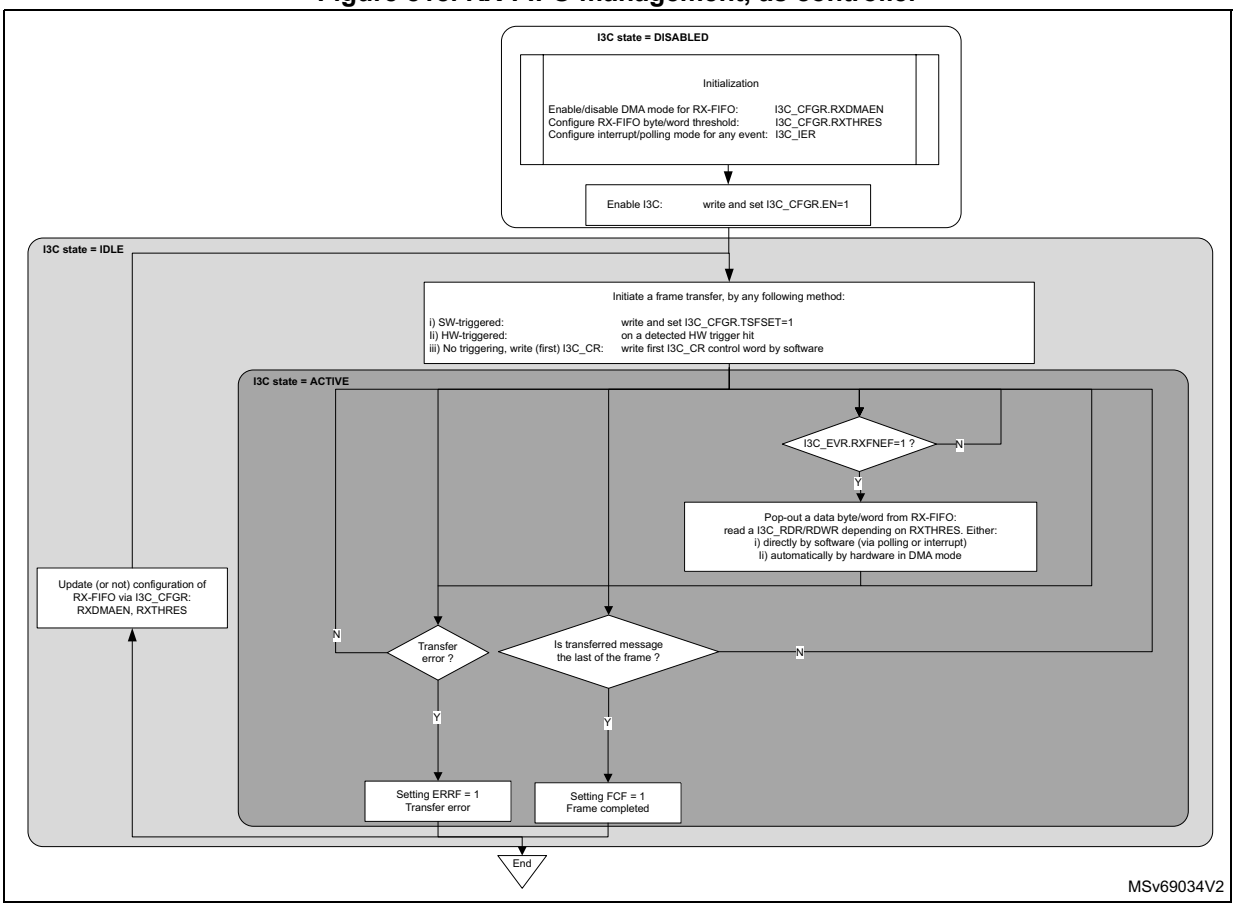
60.10.3 RX-FIFO management, as controller

When controller, as shown in figures of *Section 60.9*, RX-FIFO is used during any of the following transfers:

- broadcast ENTDAA CCC (*Figure 804*)
- direct CCC read (*Figure 803*), including direct RSTACT CCC read (*Figure 805*)
- private read (*Figure 810*)
- legacy I2C read (*Figure 812*)

Figure 818 illustrates the management of the RX-FIFO for queuing and popping-out data bytes or word(s) as received from the I3C bus, when the I3C peripheral acts as controller.

Figure 818. RX-FIFO management, as controller



First, the software must initialize the RX-FIFO management via the following fields of the I3C_CFGR register:

- RXDMAEN: enable/disable DMA mode for RX-FIFO
- RXTHRES: pop-out data byte(s) or word(s) from RX-FIFO

Then, depending on RXDMAEN, the RX-FIFO is read either:

- directly by the software (RXDMAEN = 0) at the byte/word level:
  - via polling mode (RXFNEIE = 0 in the I3C_IER register): waiting for a next data byte/word is requested by the hardware (RXFNEF = 1 in the I3C_IER register) before an explicit read to the I3C_RDR or I3C_RDWR register, depending upon bit RXTHRES in the I3C_CGFR register
  - via enabled interrupt notification if RXFNEIE = 1 in the I3C_IER register
- by the allocated DMA channel (if RXDMAEN = 1) to the corresponding DMA request from the I3C peripheral (i3c_rx_dma):
  - as configured at DMA block level, the DMA automatically pops-out/reads data bytes/words from the I3C_RDR or I3C_RDWR register (depending upon bit RXTHRES), and writes them into its memory destination buffer, until the frame completion (a stop is emitted on the I3C bus after the last message of the frame), unless a transfer error occurs.

An I3C message begins from a start or a repeated start, and ends with a stop or a repeated start. At message level, the last received data byte/word from the I3C bus is flagged by IRXLASTF = 1 in the I3C_EVR register. When an I3C frame is described with multiple messages (separated by a repeated start), this event can be used by the software for updating the pointer to the buffer where is/are stored the data byte(s)/word(s) of the next message.

If RX-FIFO is full and a data byte is received on the I3C bus, an RX-FIFO overrun is reported (ERRF = 1 in the I3C_EVR register and DOVR = 1 in the I3C_SER register). If enabled by ERRIE = 1 in the I3C_IER register, an interrupt is generated.

The configuration for the RX-FIFO management can be modified when the I3C peripheral is not in active state.

Early read termination from the target

A private read message can be early completed (also known as prematurely ended) by the addressed target.

- If RXDMAEN = 1:
  - the software must allocate, for the DMA request i3c_rx_dma, a DMA channel x, capable of peripheral early termination (refer to DMA implementation section).
  - The software must configure the DMA channel x to enable the DMA peripheral-flow control mode via PFREQ = 1 in the DMA_CxTR2 register, to be able to perform a(n) (early or not) DMA block completion.
  - Then, on block completion, the software can read BR1.BNDT[15:0] in DMA_Cx and/or DMA_CxSAR register(s), to get the effective number of DMA transferred bytes.
- If RXDMAEN = 0:
  - at message level, the last received data byte/word from the I3C bus is flagged by RXFNEF = 1 and RXLASTF = 1 in the I3C_EVR register.

In any case, if the S-FIFO is disabled (if SMODE = 0 in the I3C_CFGR register), the software is notified that an early read termination occurs by RXTGTENDF = 1 in the I3C_EVR register, and the corresponding interrupt if enabled. Then, software can read the status register I3C_SR to check information related to the last message ,and get the number of received data bytes on the prematurely ended read transfer (XDCNT[15:0] in the I3C_SR register).

In any case, if the S-FIFO is enabled (SMODE = 1 in the I3C_CFGR register), the software or the DMA (depending upon SDMAEN in the I3C_CFGR register) must read for each message the status register I3C_SR. The number of effective received data bytes on the prematurely ended read message is reported by XDCNT[15:0] (and then ABT = 1) in the I3C_SR register.

For more information, refer to *I3C status register (I3C_SR)* and *Section 60.10.4*.

60.10.4 S-FIFO management, as controller

When controller, S-FIFO can be used by the software to be able to read the *I3C status register (I3C_SR)* for each transferred message.

Reading status register with disabled S-FIFO

If SMODE = 0 in the I3C_CFGR register, the S-FIFO is disabled and the status register can be read as a usual register:

- the register content is overwritten by hardware when is transferee a new message
- I3C_SR contains the status of the last transferred message
- SCL clock is not stalled if status register is not read.

If SMODE = 0, for the specific case of a private read prematurely ended by the target:

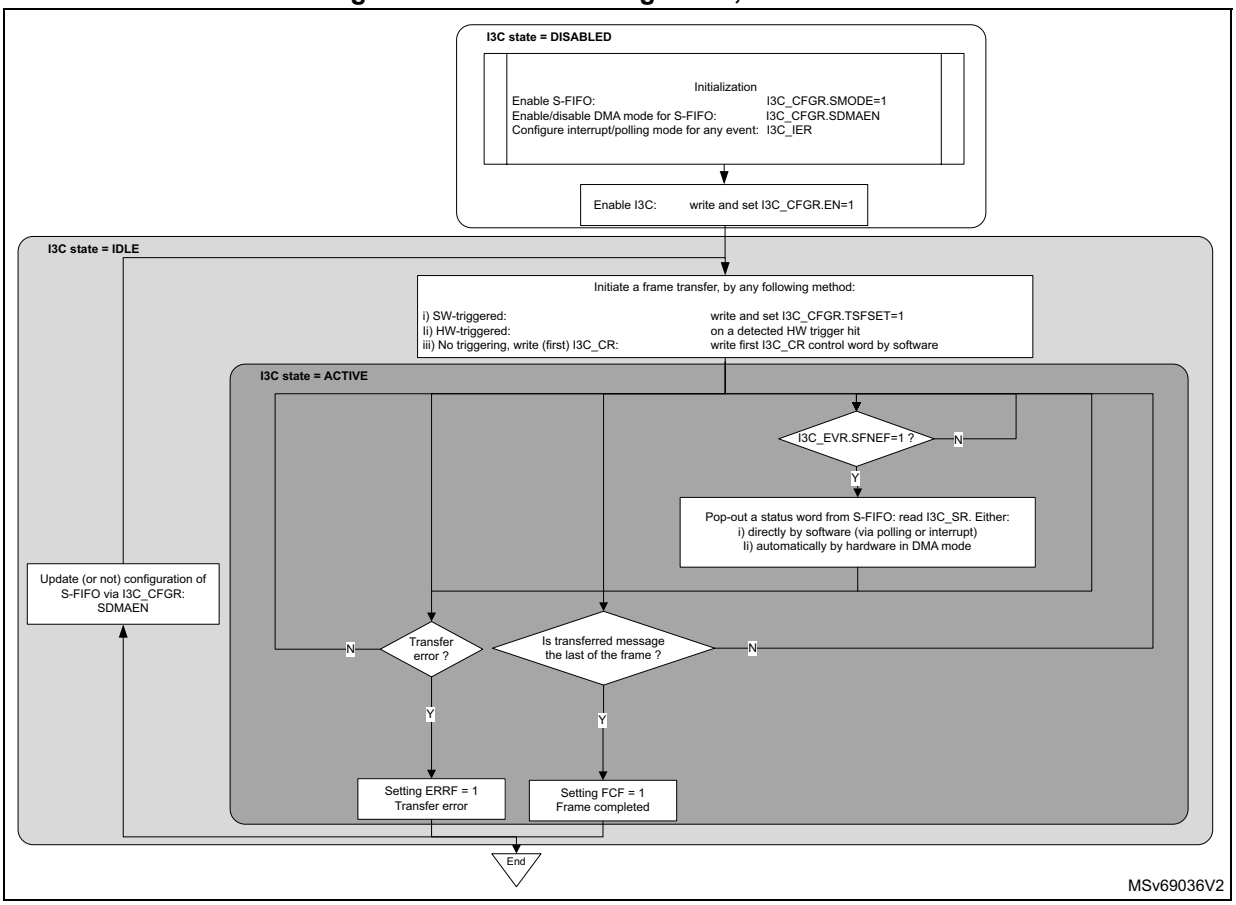
- the software is notified by the flag RXTGTENDF = 1 in the I3C_EVR register and the corresponding interrupt if enabled.
- Then, until that the software has cleared the event flag write and set CRXTGTENDF = 1 in the I3C_CEVR register:
  - no more data byte can be received on the I3C bus and written by the hardware into I3C_RDR/I3C_RDWR registers
  - I3C_SR cannot be updated
  - SCL clock is stalled if needed

Typically, I3C_SR can be read when FCF = 1, or ERRF = 1, or RXTGTENDF = 1 in the I3C_EVR register. XDCNT[15:0] in the I3C_SR register can be read to get the effective number of received data bytes on a private read, after an early termination from the target (refer to *Section 60.10.3*).

Reading status register with enabled S-FIFO

If SMODE = 1 in the I3C_CFGR register, the S-FIFO is enabled. *Figure 819* illustrates the management of the S-FIFO for queuing and popping-out a status word for each executed message on the I3C bus, when the I3C peripheral acts as controller.

Figure 819. S-FIFO management, as controller



First, the software must initialize the S-FIFO management via the SDMAEN field (enable/disable DMA mode for S-FIFO) in the I3C_CFGR register. Then, depending on SDMAEN, the S-FIFO is read either:

- directly by the software (if SDMAEN = 0):
  - via polling mode (SFNEIE = 0 in the I3C_IER register): waiting for a next status word is requested by the hardware (SFNEF = 1 in the I3C_IER register) before an explicit read to the I3C_SR register
  - via enabled interrupt notification (SFNEIE = 1)
- by the allocated DMA channel (if SDMAEN = 1) to the corresponding DMA request from the I3C peripheral (i3c_rs_dma):
  - as configured at DMA block level, the DMA is automatically popping-out/reading status words from the I3C_SR register and writing them into its memory destination buffer, until the frame completion (a stop is emitted on the I3C bus after the last message of the frame), unless a transfer error occurs.

Each message status must be read, else an overrun error is asserted by the hardware (ERRF = 1 in the I3C_EVR register and COVR = 1 in the I3C_SER register) when the S-FIFO is full and a next message status must be written. The corresponding interrupt is raised if enabled by ERRIE = 1 in the I3C_IER register.

The frame completion (FCF = 1 in the I3C_EVR register) is reported only when the S-FIFO is empty.

The configuration for the S-FIFO management can be modified when the I3C peripheral is not in active state.

60.11 I3C FIFOs management, as target

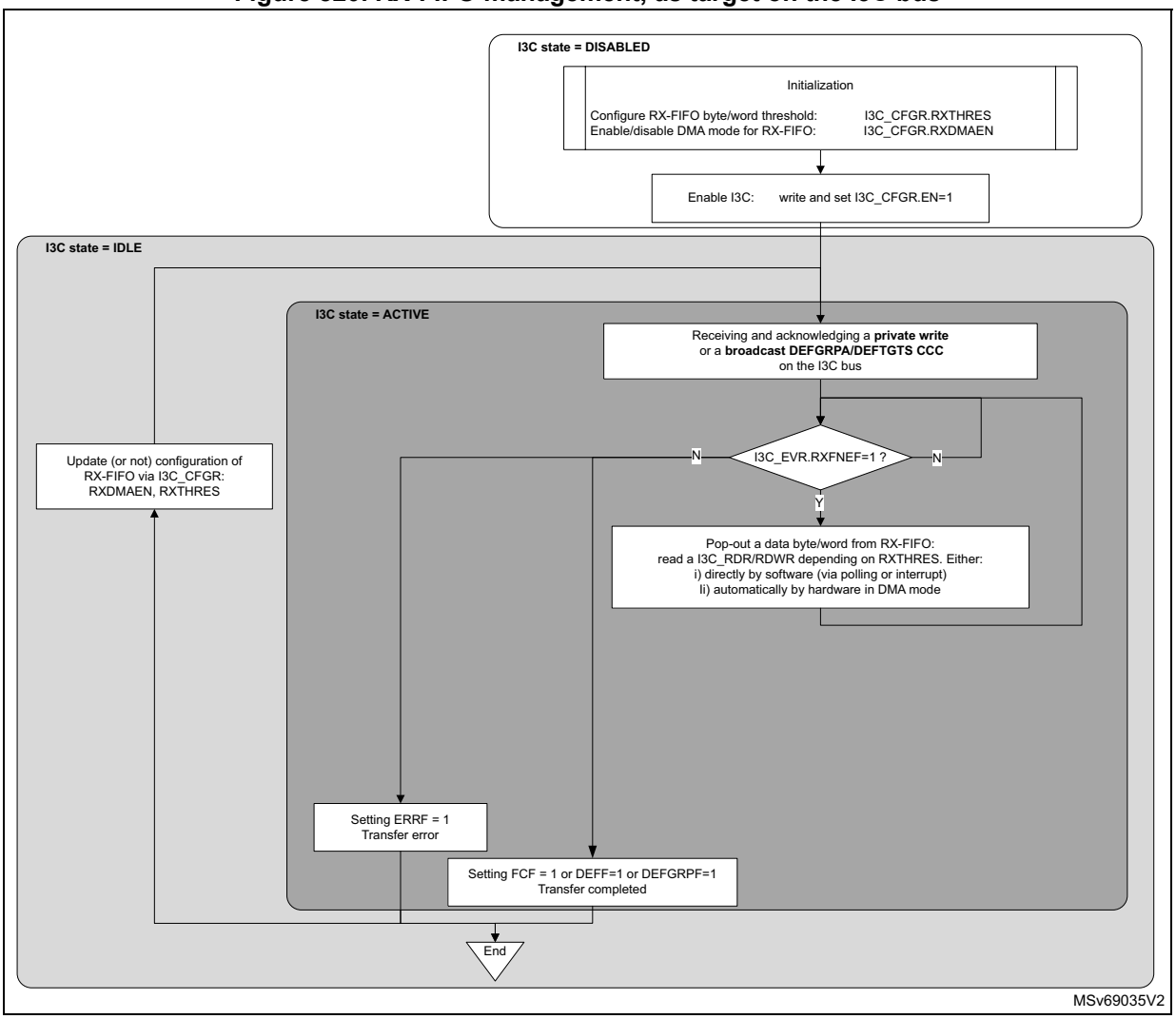
60.11.1 RX-FIFO management, as target

When target, as shown in figures of *Section 60.9*, the RX-FIFO is used during any of the following received and acknowledged transfers:

- broadcast DEFTGTS CCC (*Figure 808*)
- broadcast DEFGRPA CCC (*Figure 809*)
- private write (*Figure 811*)

Figure 820 illustrates the management of the RX-FIFO for queuing and popping-out data bytes or word(s) as received on the I3C bus, when the I3C peripheral acts as target.

Figure 820. RX-FIFO management, as target on the I3C bus



First, the software must initialize the RX-FIFO management via the following I3C_CFGR register fields:

- RXDMAEN: enable/disable DMA mode for RX-FIFO
- RXTHRES: pop-out data byte(s) or word(s) from RX-FIFO

Then, depending on RXDMAEN, the RX-FIFO is read either:

- directly by the software (if RXDMAEN = 0) at the byte/word level:
  - via polling mode (RXFNEIE = 0 in the I3C_IER register): waiting for a next data byte/word is requested by the hardware (RXFNEF = 1 in the I3C_IER register) before an explicit read to the I3C_RDR or I3C_RDWR registers, depending upon RXTHRES in the I3C_CGFR register
  - via enabled interrupt notification if RXFNEIE = 1
- by the allocated DMA channel (if RXDMAEN = 1) to the corresponding DMA request from the I3C peripheral (i3c_rx_dma):
  - as configured at DMA block level, the DMA is automatically popping-out/reading data bytes/words from the I3C_RDR or I3C_RDWR register (depending upon RXTHRES) and writing them into its memory destination buffer, until the transfer completion (in the I3C_EVR register, FCF = 1 in case of private write, or GRPF = 1 in case of a DEFGRPA CCC, or DEFF = 1 in case of DEFTGTS CCC), unless a transfer error occurs.

If RX-FIFO is full and a new data byte is received on the I3C bus, a RX-FIFO overrun is reported (ERRF = 1 in the I3C_EVR register and DOVR = 1 in the I3C_SER register) and the corresponding interrupt if enabled.

When the transfer is completed (in the I3C_EVR register, FCF = 1, or GRPF = 1, or DEFF = 1):

- RX-FIFO is empty
- Until software has not processed the RX data buffer corresponding to the completed or private write / DEFTGTS / DEFGRPA transfer (meaning until software has not cleared the corresponding flag write and set CFCF / CDEFF / CGRPF to 1 in the I3C_CEVR register), if a next private write / DEFTGTS CCC / DEFGRPA CCC is received and a data byte must be written by the hardware into the RX-FIFO, a transfer error is reported with a RX-FIFO overrun (ERRF = 1 in the I3C_EVR register and DOVR = 1 in the I3C_SER register) and the corresponding interrupt if enabled.

The configuration for the RX-FIFO management can be modified when the I3C peripheral is not in active state.

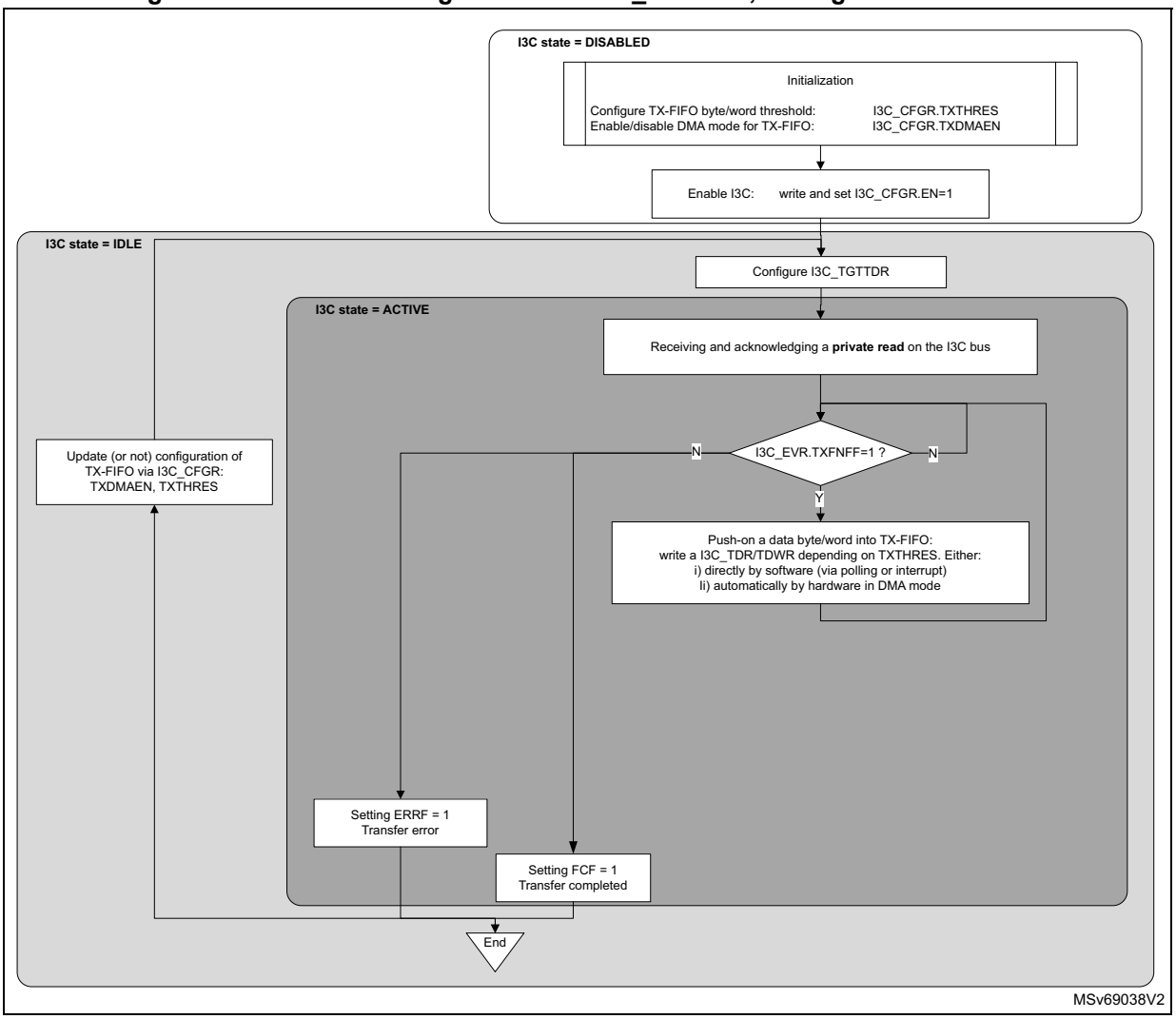
60.11.2 TX-FIFO management, as target

Main scheme

When target, as shown in figures of *Section 60.9*, the TX-FIFO is used only during a private read (*Figure 811*).

Figure 821 illustrates the management of the TX-FIFO for queuing and pushing-on data bytes or word(s) to be transmitted on the I3C bus, when the I3C peripheral acts as target.

Figure 821. TX-FIFO management with I3C_TGTTDR, as target on the I3C bus



First, the software must initialize the TX-FIFO management and write I3C_CFGR with

- TXDMAEN: enable/disable DMA mode for TX-FIFO
- TXTHRES: push-on data byte(s) or word(s) to TX-FIFO

Then, before receiving a private read on the I3C bus , the software must configure the *I3C target transmit configuration register (I3C_TGTTDR)* to preload the TX-FIFO with a number of data bytes (write TGTTDCNT[15:0] and PRELOAD = 1 in a single access), so that data bytes from the target are ready to be transmitted on the serial bus:

- If PRELOAD = 1 and TGTTDCNT[15:0] > TX-FIFO size, TX-FIFO is first preloaded up to the FIFO size.
- If PRELOAD = 1 and TGTTDCNT[15:0] ≤ TX-FIFO size, TX-FIFO is preloaded up to TGTTDCNT[15:0].

Note: TX-FIFO size is 8 bytes (refer to Table 654).

Depending upon TXDMAEN, the TX-FIFO is preloaded either:

- directly by the software (TXDMAEN = 0) at the byte/word level:
  - via polling mode (TXFNFIE = 0 in the I3C_IER register): waiting for a next data byte/word is requested by the hardware (TXFNFF = 1 in the I3C_IER register) before an explicit write to the I3C_TDR or I3C_TDWR register, depending upon TXTHRES in the I3C_CGFR register
  - via enabled interrupt notification if TXFNFIE = 1
- by the allocated DMA channel (TXDMAEN = 1) to the corresponding DMA request from the I3C peripheral (i3c_tx_dma):
  - as configured at DMA block level, the DMA is automatically pushing-on/writing data bytes/words to the I3C_TDR or I3C_TDWR register (depending upon TXTHRES) from its memory source buffer, until the transfer completion (FCF = 1 in the IEC_EVR register), unless a transfer error occurs.

Then, in the same way, either directly by the software or by the allocated DMA channel, if there are remaining TGTTDCNT[15:0] in the I3C_TGTTDR register to be loaded into TX-FIFO for continuing the private read (set PRELOAD = 1 and TGTTDCNT[15:0] > TX-FIFO size), and provided that the private read is not yet completed by the controller:

- If TXTHRES = 0: when a byte is transmitted on the serial bus, a next byte is preloaded into TX-FIFO
- If TXTHRES = 1: when four bytes are transmitted on the serial bus, the next word is preloaded into TX-FIFO.

The private read transfer is completed (FCF = 1 in the I3C_EVR register) when either the target or the controller first terminates the data byte transfer.

On transfer completion, the software can:

- read XDCNT[15:0] in the I3C_SR register: the effective number of transmitted data bytes
- read TGTTDCNT[15:0] in the I3C_TGTTDR register: the remaining number of bytes to be loaded and transmitted on the serial bus
- flush TX-FIFO: write and set (or not) TXFLUSH = 1 in the I3C_CFGR register, continue (or not) for another read, depending upon the user application

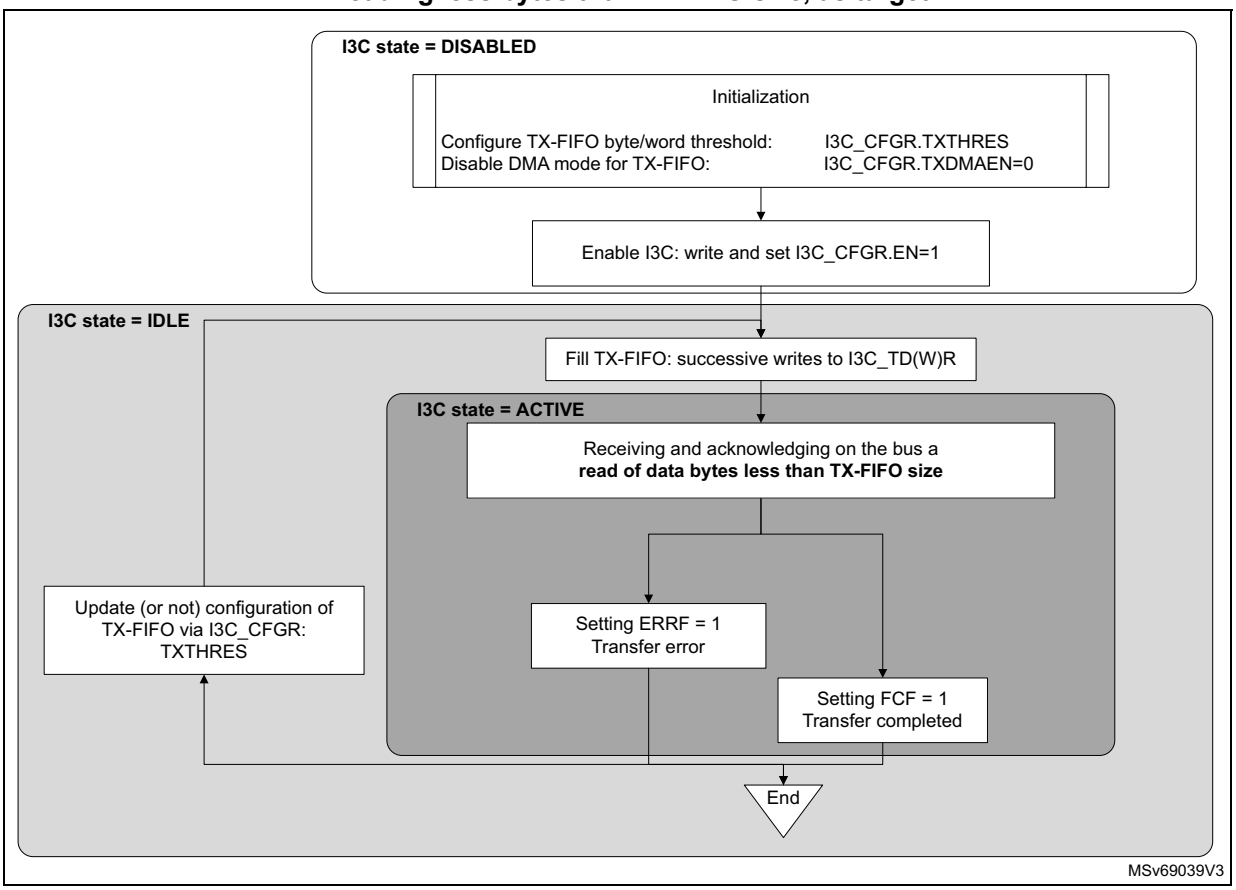
If TX-FIFO is empty and a data byte must be transmitted on the serial bus, a TX-FIFO underrun is reported (ERRF = 1 in the I3C_EVR register and DOVR = 1 in the I3C_SER register). If enabled by ERRIE = 1 in the I3C_EVR register, an interrupt is generated.

The configuration for the TX-FIFO management can be modified when the I3C peripheral is not in active state.

Alternative without I3C_TGTTDR, if less bytes than the TX-FIFO size

Alternatively to the use of the I3C_TGTTDR register, as shown in the *Figure 822*, when the DMA is not used (TDMAEN = 0), provided that the number of data bytes to be read on the serial bus is less that the TX-FIFO size, the software can directly prepare and fill the TX-FIFO with the number of bytes to be read directly by the software, by successive writes to the I3C_TDR or I3C_I3C_TDWR, depending upon TXTHRES.

Figure 822. TX-FIFO management by software without I3C_TGTTDR if reading less bytes than TX-FIFO size, as target



60.12 I3C error management

60.12.1 Controller error management

Table 663 enumerates the I3C bus error conditions, and, for each of them, the corresponding detection, action and reporting when the I3C peripheral acts as controller.

Table 663. I3C controller error management

Error type	Description	Error detection	Controller action	Reported error(1)
CE0	Illegally formatted CCC (e.g. less returned data byte(s))	Prematurely ended read data by target on a direct CCC read(2)	Hardware emits a stop.	ERRF = 1 and PERR = 1 and CODERR[3:0] = 0000

Table 663. I3C controller error management (continued)

Error type	Description	Error detection	Controller action	Reported error(1)
CE1	Monitoring error	An incorrect ACK is detected at the end of a legacy I^2C read	Hardware keeps SCL running for nine clock cycles and another byte to be possibly exchanged, then emits again a NACK, followed by a stop.	ERRF = 1 and PERR = 1 and CODERR[3:0] = 0001
		Restart or stop cannot be generated at the end of an I3C SDR read	SCL is kept running. Software can stop SCL by writing a control word with MTYPE[3:0] = 0000 in the I3C_CR register (header message), then must typically wait at least 150 µs before emitting another message.	
		After a CE1 error, a start cannot be generated		
CE2	No response to broadcast address (0b111_1110)	Header (0b111_1110 + RnW = 0) is detected as NACK-ed during a message different from escalation fault or reset pattern message	Hardware emits an HDR exit pattern followed by a stop.	ERRF = 1 and PERR = 1 and CODERR[3:0] = 0010
CE3	Failed controller hand-off	New controller has not driven SCL low after having SDA low (after a start via a test header or a start request from a target) and after the delay time defined by its activity state has elapsed	Hardware emits a start + 0b111_1110 + RnW = 0, followed by ACK/NACK from target(s), then stops.	ERRF = 1 and PERR = 1 and CODERR[3:0] = 0011
-	Incorrect returned 7-bit target address with parity bit on a GETACCCR CCC	Incorrect dynamic address and/or parity bit is detected	Hardware cancels the GETACCCR CCC by emitting a Restart + 0b111_1110 + RnW = 0, followed by ACK/NACK from target(s), then stops.	ERRF = 1 and DERR = 1
-	Addressed target is NACK-ed on a direct CCC read for the first time	NACK is detected	Hardware performs a single-retry by emitting a Restart + 7-bit same target address + RnW = 1.	-
-	Addressed target is NACK-ed on either a direct CCC write, an I3C private read/write, a legacy I^2C, or a direct CCC read for the second time	NACK is detected	Hardware emits a stop.	ERRF = 1 and ANACK= 1

Table 663. I3C controller error management (continued)

Error type	Description	Error detection	Controller action	Reported error(1)
-	Assigned/transmitted dynamic address with parity bit is NACK-ed on a ENTDAA CCC for the first time	NACK is detected	Hardware performs a single-retry assignation loop by emitting a Restart + 0b111_1110 + RnW = 1, followed by an ACK and 8-byte read data from the (most-priority) target, followed by the assigned address + parity bit.	-
-	Assigned/transmitted dynamic address with parity bit is NACK-ed on a ENTDAA CCC for the second time	NACK is detected	Hardware emits a stop.	ERRF = 1 and DNACK= 1
-	Write data is NACK-ed on a legacy I2C write			
-	Control word, status word, transmitted data or read data is not written/read in time vs. I3C bus timings	SCL stall timeout	Hardware emits a stop.	ERRF = 1 and (COVR = 1 or DOVR = 1)

1. ERRF in the I3C_EVR register, PERR, CODERR[3:0], DERR, ANACK, DNACK, COVR, and DOVR in the I3C_SER register.
2. MIPI v1.1: on a GETCAPS CCC, the number of received data bytes can be 2, 3 or 4. However a target compliant with MIPI v1.0 can return only the first byte as per previously named GETHDRCAP CCC. As a result, CE0 is not generated if the number is lower than 4.
On a GETMXDS CCC, the number of received data bytes can be 2 or 5. CE0 is not generated if the number is lower than 5.

60.12.2 Target error management

Table 664 enumerates the I3C bus error conditions, the corresponding detection, action, and reporting when the I3C peripheral acts as target.

Table 664. I3C target error management

Error type	Description	Error detection	Next (when emitted by the controller)	Reported error(1)
TE0	Invalid broadcast address (0b111_1110+RnW = 0) or Invalid 7-bit dynamic address + RnW = 1 after DAA assignment	A forbidden address is detected after a start or a repeated start	Hardware waits for an HDR exit pattern	ERRF = 1 and PERR = 1 and ODERR[3:0] = 1000
TE1	CCC code	A CCC code is detected with a parity error		ERRF = 1 and PERR = 1 and ODERR[3:0] = 1001

Table 664. I3C target error management (continued)

Error type	Description	Error detection	Next (when emitted by the controller)	Reported error(1)
TE2	Write data	A write data byte is detected with a parity error on an I3C private write message	Hardware waits for a stop or a repeated start	ERRF = 1 and PERR = 1 and ODERR[3:0] = 1010
TE3	Assigned address during dynamic address arbitration	Assigned dynamic address is detected with a parity error on a ENTDAA CCC		ERRF = 1 and PERR = 1 and ODERR[3:0] = 1011
TE4	0b111_1110 + RnW = 1 missing after Sr during dynamic address arbitration	Missing {0b111_1110 + RnW = 1} after Sr during dynamic address arbitration is detected		ERRF = 1 and PERR = 1 and ODERR[3:0] = 1100
TE5	Transaction after detecting CCC	Invalid CCC direction is detected vs. direction provided during address phase, on a CCC direct read/write		ERRF = 1 and PERR = 1 and ODERR[3:0] = 1101
TE6	Monitoring error of I3C bus	SDA is detected as driven at unexpected value on an data read (during a CCC direct read or a private read or an IBI)	Hardware releases SDA, then waits for a stop or a repeated start	ERRF = 1 and PERR = 1 and ODERR[3:0] = 1110
-	Monitoring SCL on an SDR data read	SCL is detected as stable for more than 125 µs on an SDR data read (during a CCC direct read or a private read or an IBI)		ERRF = 1 and STALL = 1
-	Data to be transmitted not written/available in time vs. I3C bus timings	Data to be transmitted not written by software or DMA in due time on a private read	Hardware detects a stop or a repeated start	ERRF = 1 and DOVR = 1
-	Received data cannot be registered in time vs. I3C bus timings	Received data is not read by software or DMA in due time on a private write or a DEFTGTS or a DEFGRPA CCC		

1. ERRF in the I3C_EVR register, PERR, ODERR[3:0], STALL, and DOVR in the I3C_SER register.

60.13 I3C in low-power modes

Table 665. Effect of low-power modes

Mode	Description
Sleep	No effect. I3C interrupts cause the device to exit Sleep mode.
Stop(1)	The content of the I3C registers is kept when entering Stop mode. I3C hardware manages automatically its own clocks gating and generates, for its kernel clock and APB clock, a clock request output signal to the RCC.
Standby	The I3C peripheral is powered down and must be reinitialized after exiting Standby mode.

1. Refer to *Section 60.3.2: I3C wake-up from low-power mode(s)* to see which, if any, Stop modes are supported.

60.14 I3C interrupts

60.15 I3C registers

The I3C registers must be accessed with a 32-bit word aligned address.

Note: I3C_RDR and I3C_TDR registers must be accessed with a single significant LSB data byte for, respectively, reading RX-FIFO and writing TX-FIFO.

60.15.1 I3C message control register (I3C_CR)

Address offset: 0x000

Reset value: 0x0000 0000

This register must be used to control the message to emit on the I3C bus:

- when I3C acts as controller (bit[30] = MTYPE[3] = 0): if there is no CCC code to be emitted bits[29:27] = MTYPE[2:0] differ from 110; else the alternate register description *Section 60.15.2* must be considered.
- when I3C acts as target (bit[30] = MTYPE[3] = 1).

When I3C acts as controller:

- If the control FIFO (C-FIFO) is not full (CFNFF = 1 in the I3C_EVR register), writing into this register means pushing a new control word into the C-FIFO; either by software, or automatically by DMA, as defined by CDMAEN in the I3C_CFGR register.
- If C-FIFO is empty and a restart must be emitted with a new control word, the I3C hardware asserts the control FIFO error underrun flag (COVR = 1 in the I3C_SER register). If enabled by ERRIE = 1 in the I3C_IER register, an interrupt is generated.
- After the last message of the frame is completed (a message with MEND = 1 in the I3C_CR register), the I3C hardware asserts the frame completed flag (FCF = 1 in the I3C_EVR register) and the corresponding interrupt, if enabled.

When I3C acts as target, this register is used in register mode:

- Software writes into this register to initiate a command (IBI, controller-role or hot-join request) on the I3C bus.
- C-FIFO is disabled, and there is no DMA mode neither for control words.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MEND	MTYPE[3:0]				Res.	Res.	Res.	ADD[6:0]							RNW
w	w	w	w	w				w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DCNT[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bit 31 **MEND**: Message end type/last message of a frame (when the I3C acts as controller)

0: this message from controller is followed by a repeated start (Sr), before another message must be emitted

1: this message from controller ends with a stop (P), being the last message of a frame

Bits 30:27 **MTYPE[3:0]**: Message type (whatever I3C acts as controller/target)

Condition: when I3C acts as I3C controller

0000: **SCL clock is forced to stop** until a next control word is executed

Bits[26:0] are ignored. On a CE1 error detection (ERRF = 1 in the I3C_EVR register and CODERR[3:0] = 0001 in the I3C_SER register) where a start/restart/stop is prevented from being generated, the software must use this message type for SCL “stuck at” recovery. Refer to *Table 663*.

0001: **header message**

Bits[26:0] are ignored. If the addressed target is not responding with an ACK to a private/direct message, as an escalation stage after a failed GETSTATUS tentative, the software must program this with EXITPTRN = 1 in the I3C_CFGR register, so that an HDR exit pattern is emitted on the bus, whatever the header is ACK-ed or NACK-ed (to avoid the target to consider that the I3C bus is in HDR mode). Refer to *Table 663* and MIPI specification about escalation handling.

If the fields of the I3C_CFGR register are programmed with EXITPTRN= 0 and RSTPTRN=1, a target reset pattern is sent on the I3C bus after the header message, whatever the header is ACK-ed or NACK-ed. This can be used to generate and broadcast a target reset pattern, especially in the case of an I3C bus topology with a single I3C target in deep sleep. Alternatively, and more generally, a target reset pattern can be encapsulated within a RSTACT CCC command (refer to *Figure 805*).

0010: **private message** (refer to *Figure 810*)

Bits[23:17] (ADD[6:0]) are the emitted 7-bit dynamic address.
Bit[16] (RNW) is the emitted RnW bit.
Bits[15:0] (DCNT[15:0]) are the number of programmed data bytes.
The transferred private message is:

– {S / S + 0b111_1110 + RnW = 0 + Sr/Sr+*} + 7-bit DynAddr + RnW + (8-bit Data + T)* + Sr/P.
– After an S (start), depending upon bit NOARBH in the I3C_CFGR register, the arbitrable header (0b111_1110 + RnW = 0) is inserted or not.
– Sr+*: after an Sr (repeated start), the hardware automatically inserts (0b111_1110 + RnW = 0) if needed, if it follows a previous message without ending by a P (stop).

0011: **direct message (second part of an I3C SDR direct CCC command)** (refer to *Figure 803*)

Bits[23:17] (ADD[6:0]) are the emitted 7-bit dynamic address.
Bit[16] (RNW) is the emitted RnW bit.
Bits[15:0] (DCNT[15:0]) are the number of programmed data bytes.
The transferred direct message is: Sr + 7-bit DynAddr + RnW + (8-bit Data + T)* + Sr/P

0100: **legacy I^2C message** (refer to *Figure 812*)

Bits[23:17] (ADD[6:0]) are the emitted 7-bit static address.
Bit[16] (RNW) is the emitted RnW bit.
Bits[15:0] (DCNT[15:0]) are the number of programmed data bytes.
The transferred legacy I^2C message is:

– {S / S + 0b111_1110 + RnW = 0 + Sr/Sr+*} + 7-bit StaAddr + RnW + (8-bit data + T)* + Sr/P.
– After an S, depending on NOARBH, the arbitrable header (0b111_1110 + RnW = 0) is inserted or not.
– Sr+*: after an Sr (repeated start), the hardware automatically inserts (0b111_1110 + RnW = 0) if needed (if it follows a previous message without ending by a P (stop)).

Others: reserved

Condition: when I3C acts as I3C target

1000: **hot-join request** (W) (refer to *Figure 814*)

The transferred hot-join request is {S +} 0b000_0010 addr + RnW = 0.
Writing the control word initiates the hot-join request if target is allowed to do so (HJEN = 1 in the I3C_DEVR0 register), either actively after a bus idle condition via the hardware issuing a start request (SDA low) and waiting for the controller to activate SCL clock, or passively if the controller initiates a concurrent message.

1001: **controller-role request** (W) (refer to *Figure 815*)

The transferred controller-role request is {S +} DA[6:0] + RnW = 0 (DA in the I3C_DEVR0 register)
Writing the control word initiates the controller-role request if target is allowed to do so (CREN = 1 and DAVAL = 1 in the I3C_DEVR0 register), either actively after a bus idle condition via the hardware issuing a start request (SDA low) and waiting for the controller to activate SCL clock, or passively if the controller initiates a concurrent message.

1010: **IBI (in-band interrupt) request** (R) (refer to *Figure 813*)

Bits[15:0] (DCNT[15:0]) are the number of the IBI data payload (including the first MDB), if any.
The transferred IBI request is {S +} DA[6:0] + RnW = 1 + optional IBI data payload. Writing the control word initiates the IBI request if target is allowed to do so (IBIEN = 1 and DAVAL = 1 in the I3C_DEVR0.register), either actively after a bus idle condition via the hardware issuing a start request (SDA low) and waiting for the controller to activate SCL clock, or passively if the controller initiates a concurrent message.
When acknowledged from controller, the transmitted IBI payload data (optional, depending upon BCR2 in the I3C_BCR register) is defined by DCNT[15:0] in the I3C_CR register and I3C_IBIDR, and must be consistently programmed vs. the IBI payload data size defined by IBIP[2:0] in the I3C_IBIDR register.

Others: reserved

Bits 26:24 Reserved, must be kept at reset value.

Bits 23:17 **ADD[6:0]**: 7-bit I3C dynamic / I^2C static target address (when I3C acts as controller)

When I3C acts as controller, this field is used if MTYPE[3:0] = 0010 (private message), or MTYPE[3:0] = 0011 (direct message), or MTYPE[3:0] = 0100 (legacy I^2C message)

Bit 16 **RNW**: Read / non-write message (when I3C acts as controller)

When I3C acts as controller, this field is used if MTYPE[3:0] = 0010 (private message), or MTYPE[3:0] = 0011 (direct message), or MTYPE[3:0] = 0100 (legacy I^2C message), to emit the RnW bit on the I3C bus.

0: write message

1: read message

Bits 15:0 **DCNT[15:0]**: Count of data to transfer during a read or write message, in bytes (whatever I3C acts as controller/target)

When I3C acts as controller, this field is used if MTYPE[3:0] = 0010 (private message), or MTYPE[3:0] = 0011 (direct message), or MTYPE[3:0] = 0100 (legacy I^2C message), to set the number of exchanged data bytes on the bus. In case of a private or legacy I^2C read/write message, this field must be non-null.

When I3C acts as target, this field is used if MTYPE[3:0] = 1010 (IBI request) and if any IBI data payload (data to be transmitted if BCR2 = 1 in the I3C_BCR register), to set the number of bytes of the IBI data payload (1, 2, 3, or 4).

Linear encoding up to 64 Kbytes - 1

0x0000: no data to transfer

0x0001: 1 byte

0x0002: 2 bytes

...

0xFFFF: 64 Kbytes - 1 byte

60.15.2 I3C message control register [alternate] (I3C_CR)

Address offset: 0x000

Reset value: 0x0000 0000

This write register description must be used to control the message for when the controller has to emit a CCC (whatever is the type of the CCC: for a CCC broadcast, a CCC direct, or a CCC Enter HDR).

This is the alternate description of register I3C_CR, for when MTYPE[3:0] = 0110. Else refer to *I3C message control register (I3C_CR)*.

If the control FIFO (also known as C-FIFO) is not full (CFNFF = 1 in the I3C_EVR register), writing into this register means pushing a new control word into the C-FIFO; either by the software or automatically by DMA, as defined by the CDMAEN bit in the I3C_CFGR register.

When the last message of the frame is completed (a message with MEND = 1 in the I3C_CR register), the I3C hardware asserts the frame completed flag (FCF = 1 in the I3C_EVR register) and the corresponding interrupt, if enabled.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MEND	MTYPE[3:0]				Res.	Res.	Res.	CCC[7:0]							
w	w	w	w	w				w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DCNT[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bit 31 **MEND**: Message end type/last message of a frame (when I3C acts as controller)

0: this message from controller is followed by a repeated start (Sr), before another message must be emitted

1: the message from the controller ends with a stop (P), being the last message of a frame

Bits 30:27 **MTYPE[3:0]**: Message type (when I3C acts as controller)

Condition: when I3C acts as I3C controller

0110: broadcast/direct CCC command (refer to *Table 662*, *Figure 803*, *Figure 804*, *Figure 805*)

Bits[23:16] (CCC[7:0]) are the emitted 8-bit CCC code

Bits[15:0] (DCNT[15:0]) are the number of the CCC defining bytes, or CCC sub-command bytes, or CCC data bytes.

If Bit[23] = CCC[7] = 1: this is the first part of an I3C SDR direct CCC command

The transferred direct CCC command (first part) message is:

– {S / S + 0b111_1110 +RnW = 0 / Sr+*} + (direct CCC + T) + (8-bit Data + T)* + Sr
– After an S (start), depending upon NOARBH in the I3C_CFGR register, the arbitrable header (0b111_1110 + RnW = 0) is inserted or not.
– Sr+*: after an Sr (repeated start), the hardware automatically inserts (0b111_1110 + R/W).

If Bit[23] = CCC[7] = 0: this is an I3C SDR broadcast CCC command (including specific ENTDAA, refer to *Figure 804*)

The transferred broadcast CCC command message is:

– {S / S + 0b111_1110 + RnW = 0 / Sr+*} + (broadcast CCC + T) + (8-bit Data + T)* + Sr/P
– After an S (start), depending on NOARBH, the arbitrable header (0b111_1110 + RnW = 0) is inserted or not.
– Sr+*: after an Sr (repeated start), the hardware automatically inserts (0b111_1110 + R/W).

Others: reserved

Bits 26:24 Reserved, must be kept at reset value.

Bits 23:16 **CCC[7:0]**: 8-bit CCC code (when I3C acts as controller)

If bit[23] = CCC[7] = 1, this is the first part of an I3C SDR direct CCC command.

If bit[23] = CCC[7] = 0, this is an I3C SDR broadcast CCC command (including ENTDAA).

Bits 15:0 **DCNT[15:0]**: Count of related data to the CCC command to transfer as CCC defining bytes, or CCC sub-command bytes, or CCC data bytes, in bytes

Linear encoding up to 64 Kbytes - 1.

0x0000: no data to transfer.

Note: Value mandatory when emitting ENTDAA broadcast CCC (refer to Figure 804).

0x0001: 1 byte

Note: Value mandatory when emitting RSTACT direct/broadcast CCC (refer to Figure 805).

0x0002: 2 bytes

...

0xFFFF: 64 Kbytes - 1 byte

60.15.3 I3C configuration register (I3C_CFGR)

Address offset: 0x004

Reset value: 0x0000 0000

This register is used to configure:

- features that apply when the I3C acts as controller or target: RX-FIFO and TX-FIFO management (RXDMAEN, RXTHRES, RXFLUSH, TXDMAEN, TXTHRES, TXFLUSH), I3C peripheral role (CRINIT)
- dedicated features when the I3C acts as a controller: frame-based control-word triggering (TSFSET), FIFOs management (TMODE, SMODE, SFLUSH, SDMAEN, CDMAEN), and miscellaneous ones (HJACK, HKSDAEN, EXITPTRN, RSTPATRN, NOARBH, FCFDIS)

The configuration fields CRINIT, HKSDAEN can be modified only when EN = 0. This condition is respected if they are modified at the same time when EN is set to 1 (it is not necessary to set EN later on, with another write operation).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	TSFSET	Res.	Res.	Res.	Res.	Res.	Res.	FCFDIS	Res.	CFLUSH	CDMA EN	TMODE	SMODE	SFLUSH	SDMA EN
	w							rw		w	rw	rw	rw	w	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TX THRES	TX FLUSH	TX DMAEN	Res.	RX THRES	RX FLUSH	RX DMAEN	HJACK	Res.	HK SDAEN	EXIT PTRN	RST PTRN	NO ARBH	CRINIT	EN
	rw	w	rw		rw	w	rw	rw		rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **TSFSET**: Frame transfer set (software trigger) (when I3C acts as controller)

This bit can only be written. When I3C acts as I3C controller:

0: no action

1: setting this bit initiates a frame transfer by causing the hardware to assert the flag CFNFF in the I3C_EVR register (C-FIFO not full and a control word is needed)

Note: If this bit is not set, the other alternative for the software to initiate a frame transfer is to directly write the first control word register (I3C_CR) while C-FIFO is empty (CFEF = 1 in the I3C_EVR register). Then, if the first written control word is not tagged as a message end (MEND = 0 in the I3C_CR register), it causes the hardware to assert CFNFF.

Bits 29:24 Reserved, must be kept at reset value.

Bit 23 **FCFDIS**: FCF generation disable (when I3C acts as controller)

When the IP acts as controller, the generation of the FCF flag in the register I3C_EVR can be disabled. The software can avoid clearing this flag between two generated I3C frames (by writing 1 into CFCF in the I3C_CEVR register), especially in hardware-triggered autonomous mode.

0: enable the generation of the flag FCF in the I3C_EVR register

1: disable the generation of the flag FCF in the I3C_EVR register

Bit 22 Reserved, must be kept at reset value.

Bit 21 **CFLUSH**: C-FIFO flush (when I3C acts as controller)

This bit can only be written.

0: no action

1: flush C-FIFO

Bit 20 **CDMAEN**: C-FIFO DMA request enable (when I3C acts as controller)

When I3C acts as controller:

0: DMA mode is disabled for C-FIFO

- Software writes and pushes control word(s) into C-FIFO (writes I3C_CR register), as needed for a given frame
- A next control word transfer can be written by software either via polling on the flag CFNFF = 1 in the I3C_EVR register, or via interrupt notification (enabled by CFNFIE = 1 in the I3C_IER register).

1: DMA mode is enabled for C-FIFO

- DMA writes and pushes control word(s) into C-FIFO (writes I3C_CR register), as needed for a given frame.
- A next control word transfer is automatically written by the programmed hardware (via the asserted C-FIFO DMA request from the I3C and the programmed DMA channel).

Bit 19 **TMODE**: Transmit mode (when I3C acts as controller)

When I3C acts as controller, this bit is used for the C-FIFO and TX-FIFO management vs. the emitted frame on the I3C bus.

0: C-FIFO and TX-FIFO are not preloaded before starting to emit a frame transfer.

A frame transfer starts as soon as the first control word is present in C-FIFO.

1: C-FIFO and TX-FIFO are first preloaded (also TX-FIFO if needed, depending on the frame format) before starting to emit a frame transfer. Refer to *Section 60.10.2* for more details.

Bit 18 **SMODE**: S-FIFO enable / status receive mode (when I3C acts as controller)

When I3C acts as controller, this bit is used to enable the FIFO for the status (S-FIFO) of the exchanged message on the I3C bus.

When I3C acts as target, this bit must be cleared.

0: S-FIFO is disabled

- Status register (I3C_SR) is used without FIFO mechanism.
- There is no SCL stalling if a new status register content is not read.
- Status register must be read before being overwritten by the hardware.
- Must have SDMAEN = 0 in the I3C_CFGR register.

1: S-FIFO is enabled.

- Each message status must be read.
- There is SCL stalling when the S-FIFO is full and a next message status must be read.
- S-FIFO overrun error is reported after the maximum SCL clock stalling time.

Bit 17 **SFLUSH**: S-FIFO flush (when I3C acts as controller)

This bit can be written and used only when I3C acts as controller.

0: no action

1: flush S-FIFO

Bit 16 **SDMAEN**: S-FIFO DMA request enable (when I3C acts as controller)

This bit must be cleared if SMODE = 0 in the I3C_CFGR register (S-FIFO is disabled). In other words, DMA mode cannot be used if S-FIFO is disabled. Then the status register I3C_SR can be read or not.

This bit can be set or cleared if SMODE = 1 (S-FIFO is enabled). In other words, status register I3C_SR must be read for each message, either by software, or via an allocated DMA channel.

0: DMA mode is disabled for reading status register I3C_SR

- SMODE = 0: software can read the I3C_SR register after a completed frame (FCF = 1 in the I3C_EVR register) or an error (ERRF = 1 in the I3C_EVR register). Via polling on these register flags or via interrupt notification (enabled by FCIE = 1 and ERRIE = 1 in the I3C_IER register).
- SMODE = 1: software must read and pop a status word from S-FIFO (read I3C_SR register) after each asserted flag SFNEF = 1. Via polling on this register flag or via interrupt notification (enabled by SFNEIE = 1 in the I3C_IER register).

1: DMA mode is enabled for reading status register I3C_SR

- Must have SMODE = 1 in the I3C_CFGR register (S-FIFO enabled)
- DMA reads and pops status word(s) from S-FIFO (it reads I3C_SR register)
- Status word(s) are automatically read by the programmed hardware (via the asserted S-FIFO DMA request from the I3C and the programmed DMA channel).

Bit 15 Reserved, must be kept at reset value.

Bit 14 **TXTHRES**: TX-FIFO threshold (whatever I3C acts as controller/target)

This threshold defines, compared to the TX-FIFO level, when the TXFNFF flag is set in the I3C_EVR register (and consequently if TXDMAEN = 1 when is asserted a DMA TX request).

0: 1-byte threshold

TXFNFF is set when 1 byte must be written in TX-FIFO (in I3C_TDR).

1: 1-word / 4-byte threshold

TXFNFF is set when 1 word / 4 bytes must be written in TX-FIFO (in the I3C_TDWR register). If the a number of the last transmitted data is not a multiple of 4 bytes (XDCNT[1:0] = 00 in the I3C_SR register), only the relevant 1, 2, or 3 valid LSB bytes of the last word are taken into account by the hardware, and sent on the I3C bus.

Bit 13 **TXFLUSH**: TX-FIFO flush (whatever I3C acts as controller/target)

This bit can only be written.

When the I3C acts as target, this bit can be used to flush the TX-FIFO on a private read if the controller has aborted the data read (driven low the T bit), and there is/are remaining data in the TX-FIFO (ABT = 1, and XDCNT[15:0] in the I3C_SR register < TGTTDCNT[15:0] in the I3C_TGTTDR register).

0: no action

1: flush TX-FIFO

Bit 12 **TXDMAEN**: TX-FIFO DMA request enable (whatever I3C acts as controller/target)

0: DMA mode is disabled for TX-FIFO

- Software writes and pushes a data byte/word into TX-FIFO (writes I3C_TDR or I3C_TDWR register), to be transmitted over the I3C bus.
- A next data byte/word must be written by the software either via polling on the flag TXFNFF = 1 or via interrupt notification (enabled by TXFNFIE = 1).

1: DMA mode is enabled for TX-FIFO

- DMA writes and pushes data byte(s)/word(s) into TX-FIFO (writes I3C_TDR or I3C_TDWR register).
- A next data byte/word transfer is automatically pushed by the programmed hardware (via the asserted TX-FIFO DMA request from the I3C and the programmed DMA channel).

Bit 11 Reserved, must be kept at reset value.

Bit 10 **RXTHRES**: RX-FIFO threshold (whatever I3C acts as controller/target)

This threshold defines, compared to the RX-FIFO level, when the RXFNEF flag in the I3C_EVR register is set (and consequently if RXDMAEN = 1 when is asserted a DMA RX request).

0: 1-byte threshold

RXFNEF is set when 1 byte must be read in RX-FIFO (in the I3C_RDR register).

1: 1-word/4-bytes threshold

RXFNEF is set when 1 word / 4 bytes is/are to be read in RX-FIFO (in I3C_RDWR). In the case of a number of last received data being not a multiple of 4 bytes, only the relevant 1, 2 or 3 valid LSB bytes of the last word are to be considered by the software. The number of effective received data bytes is reported by XDCNT[15:0] in the I3C_SR register.

Bit 9 **RXFLUSH**: RX-FIFO flush (whatever I3C acts as controller/target)

This bit can only be written.

0: no action

1: flush RX-FIFO

Bit 8 **RXDMAEN**: RX-FIFO DMA request enable (whatever I3C acts as controller/target)

0: DMA mode is disabled for RX-FIFO

- Software reads and pops a data byte/word from RX-FIFO (it reads I3C_RDR or I3C_RDWR register).
- A next data byte/word must be read by the software either via polling flag RXFNEF = 1 in the I3C_EVR register, or via interrupt notification (enabled by RXFNEIE = 1 in the I3C_IER register).

1: DMA mode is enabled for RX-FIFO

- DMA reads and pops data byte(s)/word(s) from RX-FIFO (reads I3C_RDR or I3C_RDWR register).
- A next data byte/word is automatically read by the programmed hardware (via the asserted RX-FIFO DMA request from the I3C and the programmed DMA channel).

Bit 7 **HJACK**: Hot-join request acknowledge (when I3C acts as a controller)

0: hot-join request is not acknowledged

After the NACK, the controller continues as initially programmed (the hot-joining target is aware of the NACK and must emit another hot-join request later on).

1: hot-join request is acknowledged

After the ACK, the controller continues as initially programmed. The software is notified by the HJ interrupt (flag HJF is set in the I3C_EVR register), and must initiate the ENTDAA sequence later on, potentially preventing other hot-join requests with a disable target events command (DISEC, with DISHJ = 1).

Bit 6 Reserved, must be kept at reset value.

Bit 5 **HKSDAEN:** High-keeper enable on SDA line (when I3C acts as a controller)

0: High-keeper is disabled

1: High-keeper is enabled, and the weak pull-up is effective on the T bit, instead of the open-drain class pull-up.

Note: This bit can be modified only when EN = 0 in the I3C_CFGR register.

Bit 4 **EXITPTRN:** HDR exit pattern enable (when I3C acts as a controller)

This bit can be modified only when there is no on-going frame.

0: HDR exit pattern is not sent after the issued message header (MTYPE[3:0] = 0001 in the I3C_CR register). This is used to send the header, to test ownership of the bus when there is a suspicion of a problem after controller-role hand-off (new controller did not assert its controller-role by accessing the previous one in less than the delay defined by the activity state).

1: HDR exit pattern is sent after the issued message header (MTYPE[3:0] = 0001). This is used on a controller error detection and escalation handling, in case of a not responding target to a private message or a direct read CCC.

The HDR exit pattern is sent whatever the message header {S/Sr + 0x7E addr + W} is ACK-ed or NACK-ed..

Bit 3 **RSTPTRN:** HDR reset pattern enable (when I3C acts as a controller)

This bit can be modified only when there is no on-going frame.

0: standard stop emitted at the end of a frame

1: HDR reset pattern is inserted before the stop of any emitted frame that includes a RSTACT CCC command

Additionally, if RSTPTRN = 1 and EXITPTRN = 0, a reset pattern is sent after the issued message header (MTYPE[3:0] = 0001 in the I3C_CR register), whatever the message header is ACK-ed or NACK-ed.

Bit 2 **NOARBH**: No arbitrable header after a start (when I3C acts as a controller)

This bit can be modified only when there is no on-going frame.

0: An arbitrable header (0b111_1110 + RnW = 0) is emitted after a start and before a legacy I^2C message or an I3C SDR private read/write message (default).

1: No arbitrable header

- The target address is emitted directly after a start in case of a legacy I^2C message or an I3C SDR private read/write message.

- This is a more performing option (when the emission of the 0x7E arbitrable header is useless), but must be used only when the controller is sure that the addressed target device cannot emit concurrently an IBI or a controller-role request (to ensure no misinterpretation and no potential conflict between the address emitted by the controller in open-drain mode and the same address a target device can emit after a start, for IBI or MR).

Bit 1 **CRINIT**: Initial controller/target role

This bit can be modified only when EN = 0 in the I3C_CFGR register.

0: target role

Once enabled by setting EN = 1, the I3C peripheral initially acts as a target. I3C does not drive SCL line and does not enable SDA pull-up, until it eventually acquires the controller role.

1: controller role

Once enabled by setting EN = 1, the I3C peripheral initially acts as a controller. It has the I3C controller role, so drives SCL line and enables SDA pull-up, until it eventually offers the controller role to an I3C secondary controller.

Bit 0 **EN**: I3C enable (whatever I3C acts as controller/target)

0: I3C is disabled

- Except registers, the I3C peripheral is under reset (partial reset).
- Before clearing EN, when I3C acts as a controller, all the possible target requests must be disabled using DISEC CCC.
- When I3C acts as a target, software must not disable the I3C, unless a partial reset is needed.

1: I3C is enabled

In this state, some register fields cannot be modified (like CRINIT, HKSDAEN for the I3C_CFGR)

60.15.4 I3C receive data byte register (I3C_RDR)

Address offset: 0x010

Reset value: 0x0000 0000

This register is used to read received data bytes from the I3C bus if the RX-FIFO is configured with a byte-based read access (RXTHRES = 0 in the I3C_CFGR register). Then:

- On read, I3C_RDR returns a 32-bit data word, with the received data byte in LSB position, and other reserved bits read as 0.
- When RXDMAEN = 1 in the I3C_CFGR register: programmed I3C and DMA automatically manage by hardware the relevant and successive reads.
- When RXDMAEN = 0: before a read, the software must wait to be notified that a next received data byte must be read via the RX-FIFO non empty flag (RXFNEF = 1 in the I3C_EVR register) or via the corresponding interrupt if enabled. Last received byte of a given message to be read is also marked with RXLASTF = 1 in the I3C_EVR register when acting as controller.
- If the RX-FIFO is full, a new byte is received and cannot be pushed into the RX-FIFO without waiting anymore, the software is notified by error flag ERRF = 1 in the I3C_EVR register and by a data overrun flag DOVRF = 1 in the I3C_SER register (and corresponding interrupt if enabled).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDB0[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **RDB0[7:0]**: 8-bit received data on I3C bus.

60.15.5 I3C receive data word register (I3C_RDWR)

Address offset: 0x014

Reset value: 0x0000 0000

This register is used to read received data bytes from the I3C bus if the RX-FIFO is configured with a 32-bit word-based read access (RXTHRES = 1 in the I3C_CFGR register). Then:

- When RXDMAEN = 1 in the I3C_CFGR register: programmed I3C and DMA automatically manage by hardware the relevant and successive reads.
- When RXDMAEN = 0: before a read, the software must first wait to be notified that must be read a next received data word via the RX-FIFO non empty flag (RXFNEF = 1 in the I3C_EVR register) or via the corresponding interrupt if enabled. Last received word/byte(s) of a given message to be read is also marked with RXLASTF = 1 in the I3C_EVR register when acting as controller.
- If the RX-FIFO holds less than four bytes, a read on I3C_RDWR returns a data word padded with null byte(s): the available byte(s) in LSB position(s) is (are) padded with zero byte(s) in MSB position(s).
- If the RX-FIFO is full and a new byte is received and cannot be pushed into the RX-FIFO without waiting anymore, the software is notified by an error flag ERRF = 1 in the I3C_EVR register and a data overrun DOVR = 1 in the I3C_SER register (and corresponding interrupt if enabled).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDB3[7:0]								RDB2[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDB1[7:0]								RDB0[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 **RDB3[7:0]**: 8-bit received data (latest byte on I3C bus).

Bits 23:16 **RDB2[7:0]**: 8-bit received data (next byte after RDB1 on I3C bus).

Bits 15:8 **RDB1[7:0]**: 8-bit received data (next byte after RDB0 on I3C bus).

Bits 7:0 **RDB0[7:0]**: 8-bit received data (earliest byte on I3C bus).

60.15.6 I3C transmit data byte register (I3C_TDR)

Address offset: 0x018

Reset value: 0x0000 0000

This register is used to write data bytes to be transmitted over the I3C bus.

This register implements a byte-based write access to the transmit FIFO (TX-FIFO), and is used when TXTHRES = 0 in the I3C_CFGR register.

When the I3C acts as controller:

- When TXDMAEN = 1 and if TXTHRES = 0 in the I3C_CFGR register: programmed I3C and DMA automatically manage by hardware the relevant and successive writes.
- When TXDMAEN = 0 and if TXTHRES = 0: before a write, the software must wait to be notified that must be written a next data byte via the TX-FIFO non full flag (TXFNFF = 1 in the I3C_EVR register) or via the corresponding interrupt if enabled. Last transmitted byte of a given message to be written is also marked with TXLASTF = 1 in the I3C_EVR register.

When the I3C acts as target:

- When TXDMAEN = 1 and if TXTHRES = 0 and if PRELOAD = 1 in the I3C_TGTTDR register: programmed I3C and DMA automatically manage by hardware the relevant and successive number of writes to I3C_TDR register, according to TGTTDCNT[15:0] in the I3C_TGTDR register.
- When TXDMAEN = 0 and if TXTHRES = 0:
  - when PRELOAD = 1 in the I3C_TGTTDR register: before a write, the software must wait to be notified that must be written a next data byte via the TX-FIFO non full flag (TXFNFF = 1) or via the corresponding interrupt, if enabled. The last transmitted byte of the initially programmed TGTTDCNT[15:0] is also marked with TXLASTF = 1 in the I3C_EVR register.
  - when PRELOAD = 0: before a write, the software must wait to be notified that can be written up to 8 next data bytes (TX-FIFO size) via the TX-FIFO empty flag (TXFEF = 1 in the I3C_EVR register), or via the corresponding interrupt if enabled. If the software needs to write another data byte, it must wait for the TX-FIFO be empty (TXFEF = 1), and then write this data byte to be transmitted before nine SCL clock periods elapse, to avoid a data underrun error flag (ERRF = 1 in the I3C_EVR register and DOVR = 1 in the I3C_SER register).

If the TX-FIFO is empty and the controller cannot wait longer a data byte to be transmitted, the software is notified by an error flag ERRF = 1 in the I3C_EVR register and a data underrun flag DOF = 1 (and corresponding interrupt if enabled) in the I3C_SER register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDB0[7:0]							
								w	w	w	w	w	w	w	w

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **TDB0[7:0]**: 8-bit data to transmit on I3C bus.

60.15.7 I3C transmit data word register (I3C_TDWR)

Address offset: 0x01C

Reset value: 0x0000 0000

This register is used to write 32-bit data words to be transmitted over the I3C bus.

This register implements a word-based write access to the transmit FIFO (TX-FIFO), and is used when TXTHRES = 1 in the I3C_CFGR register.

When the I3C acts as controller:

- When TXDMAEN = 1 and if TXTHRES = 1 in the I3C_CFGR register, programmed I3C and DMA automatically manage by hardware the relevant and successive writes.
- When TXDMAEN = 0 and if TXTHRES = 1: before a write, the software must wait to be notified that next data word/byte(s) must be written via the TX-FIFO non full flag (TXFNFF = 1 in the I3C_EVR register), or via the corresponding interrupt if enabled. Last transmitted word/byte(s) of a given message to be written in TX-FIFO is also marked with TXLASTF = 1 in the I3C_EVR register.

When the I3C acts as target:

- When TXDMAEN = 1 and if TXTHRES = 1 and if PRELOAD = 1 in the I3C_TGTTDR register: programmed I3C and DMA automatically manage by hardware the relevant and successive number of writes to the I3C_TDWR register, as per TGTTDCNT[15:0] in the I3C_TGTDR register.
- When TXDMAEN = 0 and if TXTHRES = 1:
  - when PRELOAD = 1: before a write, the software must wait to be notified that must be written a next data word via the TX-FIFO non full flag (TXFNFF = 1 in the I3C_EVR register) or via the corresponding interrupt, if enabled. Last transmitted word of the initially programmed TGTTDCNT[15:0] in the I3C_TGTTDR register is also marked with TXLASTF = 1 in the I3C_EVR register.
  - when PRELOAD = 0: before a write, the software must wait to be notified that can be written up to two next data words (TX-FIFO size) via the TX-FIFO empty flag (TXFEF = 1 in the I3C_EVR register) or via the corresponding interrupt if enabled. If the software needs to write another data word, it must wait for TX-FIFO to be empty (TXFEF = 1), and then write the next data word to be transmitted before nine SCL clock periods elapse, to avoid a data underrun error flag (ERRF = 1 in the I3C_EVR register and DOVR = 1 in the I3C_SER register).

If the TX-FIFO is empty and the controller/target cannot wait longer a data byte to be transmitted, the software is notified by an error flag ERRF = 1 in the I3C_EVR register and a data underrun flag DOF = 1 in the I3C_SER register (and corresponding interrupt if enabled).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TDB3[7:0]								TDB2[7:0]							
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TDB1[7:0]								TDB0[7:0]							
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:24 **TDB3[7:0]**: 8-bit transmit data (latest byte on I3C bus).

Bits 23:16 **TDB2[7:0]**: 8-bit transmit data (next byte after TDB1[7:0] on I3C bus).

Bits 15:8 **TDB1[7:0]**: 8-bit transmit data (next byte after TDB0[7:0] on I3C bus).

Bits 7:0 **TDB0[7:0]**: 8-bit transmit data (earliest byte on I3C bus)

60.15.8 I3C IBI payload data register (I3C_IBIDR)

Address offset: 0x020

Reset value: 0x0000 0000

This register is used for the IBI payload data.

When I3C acts as target:

- if BCR2 = 0 in the I3C_BCR register, this register is useless.
- if BCR2 = 1, this register must be written by software
  - to be emitted on the I3C bus as the IBI payload data, after that the IBI request (MTYPE[3:0] = 1010 in the I3C_CR register) is acknowledged by the controller; with the IBI data payload size defined by DCNT[15:0] in the I3C_CR register.
  - Maximum (static) payload data size is given by IBIP[2:0] in the I3C_MAXRLR register. it can be 1, 2, 3 or 4 bytes.
  - DCNT[15:0] must be set between 1 (for the mandatory data byte MDB[7:0]) and the maximum IBIP[2:0].

When I3C acts as controller: if IBIACK= 1 in the I3C_DEVRx register, once it acknowledges on the I3C bus the IBI request from the target x:

- if IBIDEN = 0 (BCR[2] = 0 received from target x) in the I3C_DEVRx register, this register is useless.
- if IBIDEN = 1 (BCR[2] = 1 received from target x):
  - This register is internally written by hardware from the IBI payload data received on the I3C bus (including the first mandatory data byte MDB[7:0]).
  - When the last byte of the payload is received in I3C_IBIDR (when target drives T-bit = 0), IBIF flag is set (and corresponding interrupt if enabled) in the I3C_EVR register.
  - Then, the software can identify the target x via the received and logged 7-bit address in RADD[6:0] in the I3C_RMR register.
  - The software can read this register and interpret byte(s) according to the number of bytes effectively received and logged in IBIRDCNT[2:0] in the I3C_RMR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IBIDB3[7:0]								IBIDB2[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IBIDB1[7:0]								IBIDB0[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **IBIDB3[7:0]**: 8-bit IBI payload data (latest byte on I3C bus).

Bits 23:16 **IBIDB2[7:0]**: 8-bit IBI payload data (next byte on I3C bus after IBIDB1[7:0]).

Bits 15:8 **IBIDB1[7:0]**: 8-bit IBI payload data (next byte on I3C bus after IBIDB0[7:0]).

Bits 7:0 **IBIDB0[7:0]**: 8-bit IBI payload data (earliest byte on I3C bus, MDB[7:0] mandatory data byte).

60.15.9 I3C target transmit configuration register (I3C_TGTTDR)

Address offset: 0x024

Reset value: 0x0000 0000

When I3C acts as target, this register must be used to preload a number of data bytes in the TX-FIFO, so that they are ready to be transmitted on the I3C bus, when they are accepted/acknowledged by the controller, whatever the DMA mode is used or not (independently from TXDMAEN in the I3C_CFGR register).

When I3C acts as target, alternatively, if the number of data bytes to be transmitted is less than or equal to the TX-FIFO size (8 bytes), the software can directly use and write byte(s) into the I3C_TDR register (or I3C_TDWR register, depending upon TXTHRES in the I3C_CFGR register), via polling on the TX-FIFO empty flag (TXFEF = 1 in the I3C_EVR register), or via the corresponding enabled interrupt.

In any case, since an I3C target is unable to stretch/stall the SCL line, the software can identify a TX-FIFO underrun via DOR = 1 in the I3C_EVR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRELOAD
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TGTTDCNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **PRELOAD**: Preload of the TX-FIFO (when I3C is configured as target)

This bit must be written and asserted by software in the same access when is written and defined the number of bytes to preload into the TX-FIFO and to transmit.

This bit is cleared by hardware when all the data bytes to transmit are loaded into the TX-FIFO.

0: no TX-FIFO preload

1: TX-FIFO preload

Bits 15:0 **TGTTDCNT[15:0]**: Transmit data counter, in bytes (when I3C is configured as target)

This bitfield must be written by software in the same access when is asserted PRELOAD, in order to define the number of bytes to preload and to transmit.

This bitfield is updated by hardware and reports, when read, the remaining number of bytes to be loaded into the TX-FIFO.

60.15.10 I3C status register (I3C_SR)

Address offset: 0x030

Reset value: 0x0000 0000

This register is used to read the status about the exchanged message on the I3C bus:

- in FIFO mode: when the I3C acts as controller and if S-FIFO is enabled via SMODE = 1 in the I3C_CFGR register:
  - Software is notified via SFNEF = 1 in the I3C_EVR register if there is a status register to be read (and corresponding interrupt if enabled), when not in DMA mode (SDMAEN = 0)
  - In DMA mode (SDMAEN = 1), programmed I3C and DMA automatically manage by hardware the relevant and successive reads.
  - Software is notified via COVR = 1 in the I3C_SER register on an S-FIFO overflow (and ERRF = 1 in the I3C_EVR register and corresponding interrupt if enabled)
- in register mode: if SMODE = 0 in the I3C_CFGR register
  - Software can use the flags FCF in the I3C_SER register and ERRF = 1 in the I3C_EVR register (and corresponding interrupt if enabled) to read this register
  - This register can be overwritten by hardware on a new message completion, without any notification.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MID[7:0]								Res.	Res.	Res.	Res.	Res.	DIR	ABT	Res.
r	r	r	r	r	r	r	r						r	r	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XDCNT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 **MID[7:0]**: Message identifier/counter of a given frame (when the I3C acts as controller)

When I3C acts as controller, this fbitield identifies the control word message (I3C_CR) to whom the I3C_SR status register refers.

First message of a frame is identified with MID[7:0] = 0.

This bitfield is incremented (by hardware) on the completion of a new message control word (I3C_CR) over I3C bus. This field is reset for every new frame start.

Bits 23:19 Reserved, must be kept at reset value.

Bit 18 **DIR**: Message direction

Whatever the I3C acts as controller or target, this bit indicates the direction of the related message on the I3C bus

0: write

1: read

Note: ENTDAA CCC is considered as a write command.

Bit 17 **ABT**: A private read message is ended prematurely by the target (when the I3C acts as controller)

When the I3C acts as controller, this bit indicates if the private read data transmitted by the target early terminates (the target drives T bit low earlier vs. what the controller expects in terms of programmed number of read data bytes DCNT[15:0] in the I3C_CR register).

0: no early completion from the target

1: early completion from the target

Bit 16 Reserved, must be kept at reset value.

Bits 15:0 **XDCNT[15:0]**: Data counter

Condition: during the dynamic address assignment process (ENTDAA CCC)

- When the I3C acts as controller: number of targets detected on the bus
- When the I3C acts as target: number of transmitted bytes

Condition: for other transfers, during the message

- Whatever the I3C acts as controller or target: number of data bytes read from or transmitted on the I3C bus during the message

60.15.11 I3C status error register (I3C_SER)

Address offset: 0x034

Reset value: 0x0000 0000

This read register is used to get more information about the error when an error is raised by hardware and notified to the software via the error flag ERRF = 1 in the I3C_EVR register (and corresponding interrupt if enabled).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	DERR	DNACK	ANACK	COVR	DOVR	STALL	PERR	CODERR[3:0]			
					r	r	r	r	r	r	r	r	r	r	r

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **DERR**: Data error (when the I3C acts as controller)

0: no detected error

1: controller detected a data error during the controller-role hand-off procedure (GETACCCR CCC, formerly known as GETACCMST) when the received target address or/and the parity bit do no match. Active controller keeps controller-role.

Bit 9 **DNACK**: Data not acknowledged (when the I3C acts as controller)

0: no detected error

1: controller detected that a data byte is not acknowledged by a target, either during:

i) a legacy I2C write transfer

ii) the second trial when sending dynamic address during ENTDAA procedure

Bit 8 **ANACK**: Address not acknowledged (when the I3C is configured as controller)

0: no detected error

1: controller detected that the static/dynamic address was not acknowledged by a target, either during:

i) a legacy I2C read/write transfer

ii) a direct CCC write transfer

iii) the second trial of a direct CCC read transfer

iv) a private read/write transfer

Bit 7 **COVR**: C-FIFO underrun or S-FIFO overrun (when the I3C acts as controller)

0: no detected error

1: controller detected either:

i) a C-FIFO underrun: control FIFO is empty and a restart must be emitted

ii) an S-FIFO overrun: S-FIFO is full and a new message ends

Bit 6 **DOVR**: RX-FIFO overrun or TX-FIFO underrun

0: no detected error

1: whatever controller or target, hardware detected either:

i) a TX-FIFO underrun: TX-FIFO is empty and a write data byte must be transmitted

ii) a RX-FIFO overrun: RX-FIFO is full and a new data byte is received

Bit 5 **STALL**: SCL stall error (when the I3C acts as target)

0: no detected error

1: target detected that SCL was stable for more than 125 µs during an I3C SDR data read (during a direct CCC read, a private read, or an IB)

Bit 4 **PERR**: Protocol error

0: no detected error

1: whatever controller or target, hardware detected a protocol error, as detailed in CODERR[3:0]

Bits 3:0 **CODERR[3:0]**: Protocol error code/type
0000: CE0 error (transaction after sending CCC):
controller detected an illegally formatted CCC
0001: CE1 error (monitoring error):
controller detected that transmitted data on the bus is different from expected
0010: CE2 error (no response to broadcast address):
controller detected a not acknowledged broadcast address (0b111_1110)
0011: CE3 error (failed controller-role hand-off):
controller detected the new controller did not drive bus after controller-role hand-off
1000: TE0 error (invalid broadcast address 0b111_1110 + W):
target detected an invalid broadcast address 0b111_1110 + W
1001: TE1 error (CCC code):
target detected a parity error on a CCC code via a parity check (vs. T bit)
1010: TE2 error (write data):
target detected a parity error on a write data via a parity check (vs. T bit)
1011: TE3 error (assigned address during dynamic address arbitration):
target detected a parity error on the assigned address during dynamic address arbitration via a parity check (vs. PAR bit)
1100: TE4 error (0b111_1110 + R missing after Sr during dynamic address arbitration):
target detected a 0b111_1110 + R missing after Sr during dynamic address arbitration
1101: TE5 error (transaction after detecting CCC):
target detected an illegally formatted CCC
1110: TE6 error (monitoring error):
target detected that transmitted data on the bus is different from expected
others: reserved

60.15.12 I3C received message register (I3C_RMR)

Address offset: 0x040

Reset value: 0x0000 0000

When the I3C acts as controller, this read register is used to log the received target address, and the IBI received payload data size.

When the I3C acts as target, this read register is used to log the received CCC code

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RADD[6:0]							Res.
								r	r	r	r	r	r	r	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RCODE[7:0]								Res.	Res.	Res.	Res.	Res.	IBIRDCNT[2:0]		
r	r	r	r	r	r	r	r						r	r	r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:17 **RADD[6:0]**: Received target address (when the I3C is configured as controller)
When the I3C is configured as controller, this field logs the received dynamic address from the target during acknowledged IBI or controller-role request.

Bit 16 Reserved, must be kept at reset value.

Bits 15:8 **RCODE[7:0]**: Received CCC code (when the I3C is configured as target)
When the I3C is configured as target, this field logs the received CCC code.

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **IBIRDCNT[2:0]**: IBI received payload data count (when the I3C is configured as controller)
When the I3C is configured as controller, this field logs the number of data bytes effectively received in the I3C_IBIDR register.

60.15.13 I3C event register (I3C_EVR)

Address offset: 0x050

Reset value: 0x0000 0003

This is a read register, used for reporting event flags.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GRPF	DEFF	INT UPDF	AS UPDF	RSTF	MRL UPDF	MWL UPDF	DA UPDF	STAF	GETF	WKPF	Res.	HJF	CR UPDF	CRF	IBI ENDF
r	r	r	r	r	r	r	r	r	r	r		r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IBIF	Res.	Res.	Res.	ERRF	RXTGT ENDF	FCF	Res.	RX LASTF	TX LASTF	RX FNEF	TX FNFF	SFNEF	CFNFF	TXFEF	CFEF
r				r	r	r		r	r	r	r	r	r	r	r

Bit 31 **GRPF**: Group addressing flag (when the I3C acts as target)
When the I3C acts as target (and is typically controller-capable), this flag is asserted by hardware to indicate that the broadcast DEFGRPA CCC (define list of group addresses) has been received. Then, software can store the received data for when getting controller role.
The flag is cleared when software writes 1 into the corresponding CGRPF bit in the I3C_CR register.

Bit 30 **DEFF**: DEFTGTS flag (when the I3C acts as target)
When the I3C acts as target (and is typically controller capable), this flag is asserted by hardware to indicate that the broadcast DEFTGTS CCC (define list of targets) has been received. Then, software can store the received data for when getting the controller role.
The flag is cleared when software writes 1 into the corresponding CDEFF bit in the I3C_CEVR register.

Bit 29 **INTUPDF**: Interrupt/controller-role/hot-join update flag (when the I3C acts as target)
When the I3C acts as target, this flag is asserted by hardware to indicate that the direct or broadcast ENEC/DISEC CCC (enable/disable target events) has been received, where a target event is either an interrupt/IBI request, a controller-role request, or an hot-join request. Then, software must read respectively IBIEN, CREN, or HJEN in the I3C_DEVR0 register.
The flag is cleared when software writes 1 into the corresponding CINTUPDF bit in the I3C_CEVR register.

Bit 28 **ASUPDF**: Activity state update flag (when the I3C acts as target)
When the I3C acts as target, this flag is asserted by hardware to indicate that the direct or broadcast ENTASx CCC (with x = 0...3) has been received. Then, software must read AS[1:0] in the I3C_DEVR0 register.
The flag is cleared when software writes 1 into the corresponding CASUPDF bit in the I3C_CEVR register.

Bit 27 **RSTF**: Reset pattern flag (when the I3C acts as target)

When I3C acts as target, this flag is asserted by hardware to indicate that a reset pattern has been detected (14 SDA transitions while SCL is low, followed by repeated start, then stop).

Then, when not in Stop mode, software must read RSTACT[1:0] and RSTVAL in the I3C_DEVR0 register, to know the required reset level.

- If RSTVAL = 1: when the RSTF is asserted (and/or the corresponding interrupt if enabled), RSTACT[1:0] in the I3C_DEVR0 register dictates the reset action to be performed by the software, if any.
- If RSTVAL = 0: when the RSTF is asserted (and/or the corresponding interrupt if enabled), the software must issue an I3C reset after a first detected reset pattern, and a system reset on the second one.

The flag is cleared when software writes 1 into the corresponding CRSTF bit in the I3C_CEVR register.

Bit 26 **MRLUPDF**: Maximum read length update flag (when the I3C acts as target)

When the I3C acts as target, this flag is asserted by hardware to indicate that a direct SETMRL CCC (set max read length) has been received. Then, software must read MRL[15:0] in the I3C_MAXRLR register to get the maximum read length value.

The flag is cleared when software writes 1 into the corresponding CMRLUPDF bit in the I3C_CEVR register.

Bit 25 **MWLUPDF**: Maximum write length update flag (when the I3C acts as target)

When the I3C acts as target, this flag is asserted by hardware to indicate that a direct SETMWL CCC (set max write length) has been received. Then, software must read MWL[15:0] in the I3C_MAXRLR register to get the maximum write length value.

The flag is cleared when software writes 1 into the corresponding CMWLUPDF bit in the I3C_CEVR register.

Bit 24 **DAUPDF**: Dynamic address update flag (when the I3C acts as target)

When the I3C acts as target, this flag is asserted by hardware to indicate that a dynamic address update has been received via any of the broadcast ENTDAA, RSTDAA and direct SETNEWDA CCC. Then, software must read DA[6:0] and DAVAL in the I3C_DEVR0 register to get the dynamic address update.

The flag is cleared when software writes 1 into the corresponding CDAUPDF bit in the I3C_CEVR register.

Bit 23 **STAF**: Get status flag (when the I3C acts as target)

When the I3C acts as target, this flag is asserted by hardware to indicate that a direct GETSTATUS CCC of format 1 (without defining byte or with defining byte TGTSTAT) has been received.

The flag is cleared when software writes 1 into the corresponding CSTAF bit in the I3C_CEVR register.

Bit 22 **GETF**: Get flag (when the I3C acts as target)

When the I3C acts as target, this flag is asserted by hardware to indicate that any direct CCC of get type (GET*** CCC) except the GETSTATUS of format 1 (but including GETSTATUS of format 2) has been received.

The flag is cleared when software writes 1 into the corresponding CGETF bit in the I3C_CEVR register.

Bit 21 **WKPF**: Wake-up/missed start flag (when the I3C acts as target)

When the I3C acts as target, this flag is asserted by hardware to indicate that a start has been detected (an SDA falling edge followed by an SCL falling edge) but on the next SCL falling edge, the I3C kernel clock is (still) gated. Thus an I3C bus transaction may have been lost by the target.

The flag is cleared when software writes 1 into the corresponding CWKPF bit in the I3C_CEVR register.

Bit 20 Reserved, must be kept at reset value.

Bit 19 **HJF**: Hot-join flag (when the I3C acts as controller)

When the I3C acts as controller, this flag is asserted by hardware to indicate that an hot join request has been received.

The flag is cleared when software writes 1 into the corresponding CHJF bit in the I3C_CEVR register.

Bit 18 **CRUPDF**: Controller-role update flag (when the I3C acts as target)

When the I3C acts as target, this flag is asserted by hardware to indicate that it has now gained the controller role after the completed controller-role hand-off procedure.

The flag is cleared when software writes 1 into the corresponding CCRUPDF bit in the I3C_CEVR register.

Bit 17 **CRF**: Controller-role request flag (when the I3C acts as controller)

When the I3C acts as controller, this flag is asserted by hardware to indicate that a controller-role request has been acknowledged and completed (by hardware). The software must then issue a GETACCCR CCC (get accept controller role) for the controller-role hand-off procedure.

The flag is cleared when software writes 1 into the corresponding CCRF bit in the I3C_CEVR register.

Bit 16 **IBIENDF**: IBI end flag (when the I3C acts as target)

When the I3C acts as target, this flag is asserted by hardware to indicate that an IBI transfer has been received and completed (IBI acknowledged and IBI data bytes read by controller if any).

The flag is cleared when software writes 1 into the corresponding CIBIENDF bit in the I3C_CEVR register.

Bit 15 **IBIF**: IBI flag (when the I3C acts as controller)

When the I3C acts as controller, this flag is asserted by hardware to indicate that an IBI request has been received.

The flag is cleared when software writes 1 into the corresponding CIBIF bit in the I3C_CEVR register.

Bits 14:12 Reserved, must be kept at reset value.

Bit 11 **ERRF**: Flag (whatever the I3C acts as controller/target)

This flag is asserted by hardware to indicate that an error occurred.Then, software must read I3C_SER to get the error type.

The flag is cleared when software writes 1 into the corresponding CERRF bit in the I3C_CEVR register.

Bit 10 **RXTGTENDF**: Target-initiated read end flag (when the I3C acts as controller)

When the I3C acts as controller, and only if the S-FIFO is disabled (SMODE = 0 in the I3C_CFGR register), this flag is asserted by hardware to indicate that the target has prematurely ended a read transfer. Then, software must read the status register I3C_SR to check information related to the last message and get the number of received data bytes on the prematurely read transfer (XDCNT in the I3C_SR register).

The flag is cleared when software writes 1 into the corresponding CRXTGTENDF bit in the I3C_CEVR register.

Bit 9 **FCF**: Frame complete flag (whatever the I3C acts as controller/target)

When the I3C acts as controller, this flag is asserted by hardware to indicate that a frame has been (normally) completed on the I3C bus, for example, when a stop is issued.

When the I3C acts as target, this flag is asserted by hardware to indicate that a message addressed to/by this target has been (normally) completed on the I3C bus, for example, when a next stop or repeated start is then issued by the controller.

The flag is cleared when software writes 1 into the corresponding CFCF bit in the I3C_CEVR register.

Bit 8 Reserved, must be kept at reset value.

Bit 7 **RXLASTF**: Last read data byte/word flag (when the I3C acts as controller)

When the I3C acts as controller, this flag is asserted by hardware to indicate that the last data byte/word (depending upon RXTHRES in the I3C_CFGR register) of a message must be read from the RX-FIFO. The flag is de-asserted by hardware when the last data byte/word of a message is read.

Bit 6 **TXLASTF**: Last written data byte/word flag (whatever the I3C acts as controller/target)

This flag is asserted by hardware to indicate that the last data byte/word (depending upon TXTHRES in the I3C_CFGR register) of a message must be written to the TX-FIFO. The flag is de-asserted by hardware when the last data byte/word of a message is written.

Bit 5 **RXFNEF**: RX-FIFO not empty flag (whatever the I3C acts as controller/target)

This flag is asserted/de-asserted by hardware to indicate that a data byte must/must not be read from the RX-FIFO.

Note: The software must wait for RXFNEF = 1 (by polling or via the enabled interrupt) before reading from RX-FIFO (reading from I3C_RDR or I3C_RDWR, depending upon RXTHRES).

Bit 4 **TXFNFF**: TX-FIFO not full flag (whatever the I3C acts as controller/target)

This flag is asserted/de-asserted by hardware to indicate that a data byte/word must/must not be written to the TX-FIFO.

Note: The software must wait for TXFNFF = 1 (by polling or via the enabled interrupt) before writing to TX-FIFO (writing to I3C_TDR or I3C_TDWR, depending upon TXTHRES).

Note: When the I3C acts as target, if the software intends to use the TXFNFF flag for writing into I3C_TDR/I3C_TDWR, it must have configured and set the TX-FIFO preload (write PRELOAD in the I3C_TGTTDR register).

Bit 3 **SFNEF**: S-FIFO not empty flag (when the I3C acts as controller)

When the I3C acts as controller, if the S-FIFO is enabled (SMODE = 1 in the I3C_CFGR register), this flag is asserted by hardware to indicate that a status word must be read from the S-FIFO. The flag is de-asserted by hardware to indicate that a status word is not to be read from the S-FIFO.

Bit 2 **CFNFF**: C-FIFO not full flag (when the I3C acts as controller)

When the I3C acts as controller, this flag is asserted by hardware to indicate that a control word must be written to the C-FIFO. The flag is de-asserted by hardware to indicate that a control word is not to be written to the C-FIFO.

Note: The software must wait for CFNFF = 1 (by polling or via the enabled interrupt) before writing to C-FIFO (writing to I3C_CR).

Bit 1 **TXFEF**: TX-FIFO empty flag (whatever the I3C acts as controller/target)

This flag is asserted by hardware to indicate that the TX-FIFO is empty.

This flag is de-asserted by hardware to indicate that the TX-FIFO is not empty.

Bit 0 **CFEF**: C-FIFO empty flag (whatever the I3C acts as controller)

This flag is asserted by hardware to indicate that the C-FIFO is empty when controller, and that the I3C_CR register contains no control word (none IBI/CR/HJ request) when target.

This flag is de-asserted by hardware to indicate that the C-FIFO is not empty when controller, and that the I3C_CR register contains one control word (a pending IBI/CR/HJ request) when target.

Note: When the I3C acts as controller, if the C-FIFO and TX-FIFO preload is configured (TMODE = 1 in the I3C_CFGR register), the software must wait for TXFEF = 1 and CFEF = 1 before starting a new frame transfer.

60.15.14 I3C interrupt enable register (I3C_IER)

Address offset: 0x054

Reset value: 0x0000 0000

This register is used to enable/disable, at bit level, an interrupt, for each of the following event/flag.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GRPIE	DEFIE	INTUPDIE	ASUPDIE	RSTIE	MRLUPDIE	MWLUPDIE	DAUPDIE	STAIE	GETIE	WKPIE	Res.	HJIE	CRUPDIE	CRIE	IBIENDIE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IBIIE	Res.	Res.	Res.	ERRIE	RXTGTENDIE	FCIE	Res.	Res.	Res.	RXFNEIE	TXFNFIE	SFNEIE	CFNFIE	Res.	Res.
rw				rw	rw	rw				rw	rw	rw	rw		

Bit 31 **GRPIE**: DEFGRPA CCC interrupt enable (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 30 **DEFIE**: DEFTGTS CCC interrupt enable (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 29 **INTUPDIE**: ENEC/DISEC CCC interrupt enable (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 28 **ASUPDIE**: ENTASx CCC interrupt enable (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 27 **RSTIE**: reset pattern interrupt enable (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 26 **MRLUPDIE**: SETMRL CCC interrupt enable (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 25 **MWLUPDIE**: SETMWL CCC interrupt enable (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 24 **DAUPDIE**: ENTDAA/RSTDAA/SETNEWDA CCC interrupt enable (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 23 **STAIE**: format 1 GETSTATUS CCC interrupt enable (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 22 **GETIE**: GETxxx CCC interrupt enable (except GETSTATUS of format 1) (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 21 **WKPIE**: Wake-up interrupt enable (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 20 Reserved, must be kept at reset value.

Bit 19 **HJIE**: Hot-join interrupt enable (when the I3C acts as controller)
0: interrupt disabled
1: interrupt enabled

Bit 18 **CRUPDIE**: Controller-role update interrupt enable (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 17 **CRIE**: Controller-role request interrupt enable (when the I3C acts as controller)
0: interrupt disabled
1: interrupt enabled

Bit 16 **IBIENDIE**: IBI end interrupt enable (when the I3C acts as target)
0: interrupt disabled
1: interrupt enabled

Bit 15 **IBIIE**: IBI request interrupt enable (when the I3C acts as controller)
0: interrupt disabled
1: interrupt enabled

Bits 14:12 Reserved, must be kept at reset value.

Bit 11 **ERRIE**: error interrupt enable (whatever the I3C acts as controller/target)
0: interrupt disabled
1: interrupt enabled

Bit 10 **RXTGTENDIE**: target-initiated read end interrupt enable (when the I3C acts as controller)
0: interrupt disabled
1: interrupt enabled

Bit 9 **FCIE**: frame complete interrupt enable (whatever the I3C acts as controller/target)
0: interrupt disabled
1: interrupt enabled

Bits 8:6 Reserved, must be kept at reset value.

Bit 5 **RXFNEIE**: RX-FIFO not empty interrupt enable (whatever the I3C acts as controller/target)
0: interrupt disabled
1: interrupt enabled

Bit 4 **TXFNFIE**: TX-FIFO not full interrupt enable (whatever the I3C acts as controller/target)
0: interrupt disabled
1: interrupt enabled

Bit 3 **SFNEIE**: S-FIFO not empty interrupt enable when the I3C acts as controller
0: interrupt disabled
1: interrupt enabled

Bit 2 **CFNFIE**: C-FIFO not full interrupt enable when the I3C acts as controller
0: interrupt disabled
1: interrupt enabled

Bits 1:0 Reserved, must be kept at reset value.

60.15.15 I3C clear event register (I3C_CEVR)

Address offset: 0x058

Reset value: 0x0000 0000

This write register is used to clear individually, at bit level, the corresponding event flag of the I3C_EVR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CGRPF	CDEFF	CINTUPDF	CASUPDF	CRSTF	CMRLUPDF	CMWLUPDF	CDAUPDF	CSTAF	CGETF	CWKPF	Res.	CHJF	CCRUPDF	CCRF	CIBIENDF
w	w	w	w	w	w	w	w	w	w	w		w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CIBIF	Res.	Res.	Res.	CERRF	CRXTGTENDF	CFCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
w				w	w	w									

Bit 31 **CGRPF**: Clear DEFGRPA CCC flag (when the I3C acts as target)
0: no effect
1: clear GRPF

Bit 30 **CDEFF**: Clear DEFTGTS CCC flag (when the I3C acts as target)
0: no effect
1: clear DEFF

Bit 29 **CINTUPDF**: Clear ENEC/DISEC CCC flag (when the I3C acts as target)
0: no effect
1: clear CINTUPDF

Bit 28 **CASUPDF**: Clear ENTASx CCC flag (when the I3C acts as target)
0: no effect
1: clear ASUPDF

Bit 27 **CRSTF**: Clear reset pattern flag (when the I3C acts as target)
0: no effect
1: clear RSTF

Bit 26 **CMRLUPDF**: Clear SETMRL CCC flag (when the I3C acts as target)
0: no effect
1: clear MRLUPDF

Bit 25 **CMWLUPDF**: Clear SETMWL CCC flag (when the I3C acts as target)
0: no effect
1: clear MWLUPDF

Bit 24 **CDAUPDF**: Clear ENTDAA/RSTDAA/SETNEWDA CCC flag (when the I3C acts as target)
0: no effect
1: clear DAUPDF

Bit 23 **CSTAF**: Clear format 1 GETSTATUS CCC flag (when the I3C acts as target)
0: no effect
1: clear STAF

Bit 22 **CGETF**: Clear GETxxx CCC flag (except GETSTATUS of format 1) (when the I3C acts as target)
0: no effect
1: clear GETF

Bit 21 **CWKPF**: Clear wake-up flag (when the I3C acts as target)
0: no effect
1: clear WKPF

Bit 20 Reserved, must be kept at reset value.

Bit 19 **CHJF**: Clear hot-join flag (when the I3C acts as controller)
0: no effect
1: clear HJF

Bit 18 **CCRUPDF**: Clear controller-role update flag (when the I3C acts as target)
0: no effect
1: clear CRUPDF

Bit 17 **CCRF**: Clear controller-role request flag (when the I3C acts as controller)
0: no effect
1: clear CRF

Bit 16 **CIBIENDF**: Clear IBI end flag (when the I3C acts as target)
0: no effect
1: clear IBIENDF

Bit 15 **CIBIF**: Clear IBI request flag (when the I3C acts as controller)
0: no effect
1: clear IBIF

Bits 14:12 Reserved, must be kept at reset value.

Bit 11 **CERRF**: Clear error flag (whatever the I3C acts as controller/target)
0: no effect
1: clear ERRF

Bit 10 **CRXTGTENDF**: Clear target-initiated read end flag (when the I3C acts as controller)
0: no effect
1: clear RXTGTENDF

Bit 9 **CFCF**: Clear frame complete flag (whatever the I3C acts as controller/target)
0: no effect
1: clear FCF

Bits 8:0 Reserved, must be kept at reset value.

60.15.16 I3C masked interrupt status register (I3C_MISR)

Address offset: 0x05C

Reset value: 0x0000 0000

This is a read register, containing the masked interrupt status for each individual event flag bit. Each bit is the logical AND of the corresponding interrupt enable bit of the I3C_IER register and the event flag bit of the I3C_EVR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GRPMIS	DEFMIS	INTUPDMIS	ASUPDMIS	RSTMIS	MRLUPDMIS	MWLUPDMIS	DAUPDMIS	STAMIS	GETMIS	WKPMIS	Res.	HJMIS	CRUPDMIS	CRMIS	IBIENDMIS
r	r	r	r	r	r	r	r	r	r	r		r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IBIMIS	Res.	Res.	Res.	ERRMIS	RXTGTENDMIS	FCMIS	Res.	Res.	Res.	RXFNEMIS	TXFNFMIS	SFNEMIS	CFNFMIS	Res.	Res.
r				r	r	r				r	r	r	r		

Bit 31 **GRPMIS**: DEFGRPA CCC masked interrupt status (when the I3C acts as target)

Bit 30 **DEFMIS**: DEFTGTS CCC masked interrupt status (when the I3C acts as target)

Bit 29 **INTUPDMIS**: ENEC/DISEC CCC masked interrupt status (when the I3C acts as target)

Bit 28 **ASUPDMIS**: ENTASx CCC masked interrupt status (when the I3C acts as target)

Bit 27 **RSTMIS**: reset pattern masked interrupt status (when the I3C acts as target)

Bit 26 **MRLUPDMIS**: SETMRL CCC masked interrupt status (when the I3C acts as target)

Bit 25 **MWLUPDMIS**: SETMWL CCC masked interrupt status (when the I3C acts as target)

Bit 24 **DAUPDMIS**: ENTDAA/RSTDAA/SETNEWDA CCC masked interrupt status (when the I3C acts as target)

Bit 23 **STAMIS**: format 1 GETSTATUS CCC masked interrupt status (when the I3C acts as target)

Bit 22 **GETMIS**: GETxxx CCC masked interrupt status, except GETSTATUS of format 1 (when the I3C acts as target)

Bit 21 **WKPMIS**: Wake-up/missed start masked interrupt status (when the I3C acts as target)

Bit 20 Reserved, must be kept at reset value.

Bit 19 **HJMIS**: Hot-join masked interrupt status (when the I3C acts as controller)

Bit 18 **CRUPDMIS**: Controller-role update masked interrupt status (when the I3C acts as target)

Bit 17 **CRMIS**: Controller-role request masked interrupt status (when the I3C acts as controller)

Bit 16 **IBIENDMIS**: IBI end masked interrupt status (when the I3C acts as target)

Bit 15 **IBIMIS**: IBI request masked interrupt status (when the I3C acts as controller)

Bits 14:12 Reserved, must be kept at reset value.

Bit 11 **ERRMIS**: error masked interrupt status (whatever the I3C acts as controller/target)

Bit 10 **RXTGTENDMIS**: target-initiated read end masked interrupt status (when the I3C acts as controller)

Bit 9 **FCMIS**: frame complete masked interrupt status (whatever the I3C acts as controller/target)

Bits 8:6 Reserved, must be kept at reset value.

Bit 5 **RXFNEMIS**: RX-FIFO not empty masked interrupt status (whatever the I3C acts as controller/target)

Bit 4 **TXFNFMIS**: TX-FIFO not full masked interrupt status (whatever the I3C acts as controller/target)

Bit 3 **SFNEMIS**: S-FIFO not empty masked interrupt status (when the I3C acts as controller)

Bit 2 **CFNFMIS**: C-FIFO not full masked interrupt status (when the I3C acts as controller)

Bits 1:0 Reserved, must be kept at reset value.

60.15.17 I3C own device characteristics register (I3C_DEVR0)

Address offset: 0x060

Reset value: 0x0000 0000

When the I3C peripheral acts as target, this register is used to write or read its own device characteristics.

When the I3C peripheral acts as controller, the field DA[6:0] is used to write and store its own dynamic address.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	RSTVAL	RSTACT[1:0]		AS[1:0]		HJEN	Res.	CREN	IBIEN
							r	r	r	r	r	rw		rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DA[6:0]							DAVAL
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **RSTVAL**: Reset action is valid (when the I3C acts as target)

This bit is asserted by hardware to indicate that the RSTACT[1:0] field has been updated on the reception of a broadcast or direct write RSTACT CCC (target reset action) and is valid.

This bit is cleared by hardware when the target receives a frame start.

When the device is not in Stop mode:

– If RSTVAL = 1: when RSTF in the I3C_EVR register is asserted (and/or the corresponding interrupt if enabled), RSTACT[1:0] in the I3C_DEVR0 register dictates the reset action to be performed by the software, if any.

If RSTVAL = 0: when RSTF is asserted (and/or the corresponding interrupt if enabled), the software must issue an I3C reset after a first detected reset pattern, and a system reset on the second one.

Bits 23:22 **RSTACT[1:0]**: Reset action/level on received reset pattern (when the I3C acts as target)

This read field is used by hardware on the reception of a direct read RSTACT CCC in order to return the corresponding data byte on the I3C bus.

This read field is updated by hardware on the reception of a broadcast or direct write RSTACT CCC (target reset action).

Only the defining bytes 0x00, 0x01 and 0x02 are mapped, and RSTACT[1:0] = Defining Byte[1:0].

00: no reset action

01: first level of reset: the application software must either:

a) partially reset the I3C peripheral, by a write and clear of the enable bit of the I3C configuration register (write EN = 0). This resets the I3C bus interface and the I3C kernel sub-parts, without modifying the content of the I3C APB registers (except the EN bit).

b) fully reset the I3C peripheral, including all its registers, via a write and set of the I3C reset control bit of the RCC (reset and clock controller) register.

10: second level of reset: the application software must issue a warm reset, also known as a system reset:

– the software writes and sets the SYSRESETREQ control bit of the AIRCR register, when the device is controlled by a Cortex®-M.

11: no reset action

Bits 21:20 **AS[1:0]**: Activity state (when the I3C acts as target)

This read field is updated by hardware on the reception of a ENTASx CCC (enter activity state, with x = 0-3):

00: activity state 0

01: activity state 1

10: activity state 2

11: activity state 3

Bit 19 **HJEN**: Hot-join request enable (when the I3C acts as target)

This bit is initially written by software when EN = 0, and is updated by hardware on the reception of DISEC CCC with DISHJ= 1 (cleared) and the reception of ENEC CCC with ENHJ= 1 (set). This bit can only be written by software when EN = 0 in the I3C_CFGR register.

0: hot-join request disabled

1: hot-join request enabled

Bit 18 Reserved, must be kept at reset value.

Bit 17 **CREN**: Controller-role request enable (when the I3C acts as target)

This bit is initially written by software when EN = 0, and is updated by hardware on the reception of DISEC CCC with DISCR = 1 (cleared) and the reception of ENEC CCC with ENCR = 1 (set). This bit can only be written by software when EN = 0 in the I3C_CFGR register.

0: controller-role request disabled

1: controller-role request enabled

Bit 16 **IBIEN**: IBI request enable (when the I3C acts as target)

This bit is initially written by software when EN = 0, and is updated by hardware on the reception of DISEC CCC with DISINT = 1 (cleared) and the reception of ENEC CCC with ENINT = 1 (set). This bit can only be written by software when EN = 0 in the I3C_CFGR register.

0: IBI request disabled

1: IBI request enabled

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:1 **DA[6:0]**: 7-bit dynamic address

When the I3C acts as controller, this field can be written by software, for defining its own dynamic address.

When the I3C acts as target, this field is updated by hardware on the reception of either the broadcast ENTDAA CCC or the direct SETNEWDA CCC.

Bit 0 **DAVAL**: Dynamic address is valid (when the I3C acts as target)

When the I3C acts as controller, this bit can be written by software, for validating its own dynamic address, for example before a controller-role hand-off.

When the I3C acts as target, this bit is asserted by hardware on the acknowledge of the broadcast ENTDAA CCC or the direct SETNEWDA CCC, and this field is cleared by hardware on the acknowledge of the broadcast RSTDAA CCC.

60.15.18 I3C device x characteristics register (I3C_DEVRx)

Address offset: 0x060 + 0x4 * x, (x = 1 to 4)

Reset value: 0x0000 0000

When the I3C peripheral acts as controller, this register is used to define and store some characteristics of a device target x with their related management from the controller, to communicate accordingly with any of this target x over the I3C bus. Then, the hardware can autonomously identify and acknowledge an allowed IBI or/and controller-role request from a target x, receive the expected IBI payload data if any, and notify the software via the corresponding flag IBIF/CRF (and the corresponding interrupt if enabled) in the I3C_EVR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUSP	IBIDEN	CRACK	IBIACK
r												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DA[6:0]							Res.
								rw	rw	rw	rw	rw	rw	rw	

Bit 31 **DIS**: Disables writes to DA[6:0] (when the I3C acts as controller)

When the I3C acts as controller, once the software sets IBIACK= 1 or CRACK= 1, this read bit is set by hardware (DIS= 1) to lock the configured DA[6:0] and IBIDEN values.

Then, to be able to modify DA[6:0], IBIDEN or SUSP, the software must wait for DIS to be de-asserted by hardware (polling on DIS= 0) before modifying these three assigned values to the target x. Indeed, the target can request an IBI or a controller-role while the controller intends to modify DA[6:0], IBIDEN or SUSP.

0: write to DA[7:0] and to IBIDEN in the I3C_DEVRx register is allowed

1: write to DA[7:0] and to IBIDEN is disabled/locked

Bits 30:20 Reserved, must be kept at reset value.

Bit 19 **SUSP**: Suspend/stop I3C transfer on received IBI (when the I3C acts as controller)

When the I3C acts as controller, this bit can be used to receive an IBI from target x with pending read notification feature (received MDB[7:5] = 3'b101).

If this bit is set, when an IBI is received and completed (IBIF = 1 in the I3C_EVR register), a stop is emitted on the I3C bus and both C-FIFO and TX-FIFO are automatically flushed by hardware. The controller execution flow is stopped, even if a next control message is programmed. When the IBI is completed, the controller software can issue a new control word, such as a private read, to the target device that initiated the IBI request.

0: C-FIFO and TX-FIFO are not flushed after an IBI request from target x is acknowledged and completed, and depending on the presence or absence of a next control word, a repeated start or a stop is emitted

1: I3C transfer is stopped and both C-FIFO and TX-FIFO are flushed after receiving an IBI request from target x

Bit 18 **IBIDEN**: IBI data enable (when the I3C acts as controller)

When the I3C acts as controller, this bit must be written by software to store the BCR[2] bit as received from the target x during broadcast ENTDAA or direct GETBCR CCC via the received I3C_RDR.

Writing to this field has no impact when the DIS = 1 in the I3C_DEVRx register.

0: no data byte follows the acknowledged IBI from target x

1: the mandatory data byte MDB[7:0] follows the acknowledged IBI from target x

Bit 17 **CRACK**: Controller-role request acknowledge (when the I3C acts as controller)

When the I3C acts as controller, this bit is written by software to define the acknowledge policy to be applied on the I3C bus on the reception of a controller-role request from target x:

0: a controller-role request from target x must be NACK-ed

After the NACK, the message continues as initially programmed (the target is aware of the NACK and can emit another controller-role request later on)

1: a controller-role request (with 7-bit dynamic address DA[6:0]) from target x must be ACKed

- The field DIS is asserted by hardware to protect DA[6:0] from being modified by software meanwhile the hardware can store internally the current DA[6:0] into the kernel clock domain.

- After the ACK, the message continues as initially programmed. The software is notified by the controller-role request flag (CRF = 1 in the I3C_EVR register) and/or the corresponding interrupt if enabled; For effectively granting the controller-role to the requesting secondary controller, software must issue a GETACCCR (formerly known as GETACCMST), followed by a stop.

- Independently of CRACK configuration for this or other devices, further controller-role request(s) are NACK-ed until controller-role request flag (CRF) and IBI flag (IBIF) in the I3C_EVR register are both cleared.

Bit 16 **IBIACK**: IBI request acknowledge (when the I3C acts as controller)

When the I3C acts as controller, this bit is written by software to define the acknowledge policy to be applied on the I3C bus on the reception of an IBI request from target x:

0: an IBI request from target x must be NACK-ed

- After the NACK, the message continues as initially programmed (the target is aware of the NACK and can emit another IBI request later on)

1: an IBI request (with 7-bit dynamic address DA[6:0]) from target x must be ACKed

- The field DIS is asserted by hardware to protect DA[6:0] from being modified by software meanwhile the hardware can store internally the current DA[6:0] into the kernel clock domain.
- After the ACK, the controller logs the IBI payload data, if any, depending on I3C_DEVRx.IBIDEN.
- The software is notified by the IBI flag (IBIF = 1) and/or the corresponding interrupt if enabled;
- Independently from IBIACK configuration for this or other devices, further IBI request(s) are NACK-ed until IBI request flag (IBIF) and controller-role request flag (CRF) are both cleared.

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:1 **DA[6:0]**: Assigned I3C dynamic address to target x (when the I3C acts as controller)

When the I3C acts as controller, this field must be written by software to store the 7-bit dynamic address that the controller sends via a broadcast ENTDAA or a direct SETNEWDA CCC acknowledged by the target x.

Writing to this field has no impact when the read field DIS = 1 in the I3C_DEVRx register.

Bit 0 Reserved, must be kept at reset value.

60.15.19 I3C maximum read length register (I3C_MAXRLR)

Address offset: 0x090

Reset value: 0x0000 0000

When the I3C acts as target, this register is used to set or get the maximum read length value exchanged with the controller during respectively GETMRL or SETMRL CCC. This register is also used to set the IBI data payload size.

This register can be written by the software when EN = 0 in the I3C_CFGR register.

When receiving a private read message, the target ends the data transmission (by driving T-bit = 0) when the count of transmitted data reaches MRL[15:0] in the I3C_MAXRLR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IBIP[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MRL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **IBIP[2:0]**: IBI payload data maximum size, in bytes (when I3C acts as target)
This field is initially written by software when EN = 0 to set the maximum number of data bytes to be sent to the controller after an IBI request has been acknowledged.This field can be updated by hardware on the reception of SETMRL command (which potentially also updated IBIP[2:0]).
Software is notified of an MRL update by MRLUPF in the I3C_EVR register and the corresponding interrupt, if enabled.
000: null payload data size (only allowed when BCR2 = 0 in the I3C_BCR register)
001: 1 byte (mandatory data byte MDB[7:0]
010: 2 bytes (including first MDB[7:0])
011: 3 bytes (including first MDB[7:0])
100: 4 bytes (including first MDB[7:0])
others: same as 100

Bits 15:0 **MRL[15:0]**: Maximum data read length (when I3C acts as target)
This field is initially written by software when EN = 0 and updated by hardware on the reception of SETMRL command (with potentially also updated IBIP[2:0]).
Software is notified of an MRL update by MRLUPF and the corresponding interrupt, if enabled.
This field is used by hardware to return the value on the I3C bus when the target receives a GETMRL CCC.

60.15.20 I3C maximum write length register (I3C_MAXWLR)

Address offset: 0x094

Reset value: 0x0000 0000

When the I3C acts as target, this register is used to set or get the maximum write length value exchanged with the controller during respectively GETMWL or SETMWL CCC.

This register can be written by the software when EN = 0 in the I3C_CFGR register.

On receiving a private write message, the target stops the data reception (extra received data are not written into RX-FIFO) when the count of received data reaches MWL[15:0] in the I3C_MAXWLR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MWL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **MWL[15:0]**: Maximum data write length (when I3C acts as target)
This field is initially written by software when EN = 0 and updated by hardware on the reception of SETMWL command.
Software is notified of an MWL update by MWLUPF in the I3C_EVR register and the corresponding interrupt, if enabled.
This field is used by hardware to return the value on the I3C bus when the target receives a GETMWL CCC.

60.15.21 I3C timing register 0 (I3C_TIMINGR0)

Address offset: 0x0A0

Reset value: 0x0000 0000

When the I3C acts as controller, this register is used to configure the SCL clock signal waveform.

This register can be written by the software when EN = 0 in the I3C_CFGR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SCLH_I2C[7:0]								SCLL_OD[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SCLH_I3C[7:0]								SCLL_PP[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **SCLH_I2C[7:0]**: SCL high duration, used for legacy I^2C messages, in number of kernel clocks cycles:

t_{SCLH_I2C} = (SCLH_I2C + 1) x t_{I3CCLK}

Note: SCLH_I2C is used to generate t_{DIG_H} (I^2C) timing when communicating with I^2C devices.

Note: With I^2C Fm+ device t_{DIG_Hmin} = 260 ns, with I^2C Fm+ device t_{DIG_Hmin} = 600 ns.

Bits 23:16 **SCLL_OD[7:0]**: SCL low duration in open-drain phases, used for legacy I^2C messages and for I3C open-drain phases (address phase following a start, ACK phase during controller-initiated messages, and T bit phase during direct/private/IBI payload), in number of kernel clocks cycles:

t_{SCLL_OD} = (SCLL_OD + 1) x t_{I3CCLK}

Note: SCLL_OD is used to generate both t_{DIG_L} (I^2C) and $t_{DIG_OD_L}$(I3C) timings.

Note: With I^2C Fm+ device t_{DIG_Lmin} = 500 ns, with I^2C Fm device t_{DIG_Lmin} = 1320 ns.

Note: I3C messages: $t_{DIG_OD_Lmin}$ = 200 ns.

Note: If a single I3C frame is gathering I^2C and I3C messages, the SCL low duration during I3C open-drain phases is increased to fit I^2C timings.

Bits 15:8 **SCLH_I3C[7:0]**: SCL high duration, used for I3C messages (both in push-pull and open-drain phases), in number of kernel clocks cycles:

t_{SCLH_I3C} = (SCLH_I3C + 1) x t_{I3CCLK}

Note: SCLH_I3C is used to generate both t_{DIG_H} (I3C) and $t_{DIG_H_MIXED}$ timings.

Note: For mixed bus (with at least one I^2C target): $t_{DIG_H_MIXEDmin}$ = 32 ns and $t_{DIG_H_MIXEDmax}$ = 45 ns (due to I^2C 50 ns spike filter).

Note: For pure I3C bus (with no I^2C targets): t_{DIG_Hmin} = 32 ns.

Bits 7:0 **SCLL_PP[7:0]**: SCL low duration in I3C push-pull phases, in number of kernel clocks cycles:

t_{SCLL_PP} = (SCLL_PP + 1) x t_{I3CCLK}

Note: SCLL_PP is used to generate t_{DIG_L} (I3C in PP) timing.

Note: t_{DIG_Lmin} = 32 ns (max 40/60 duty cycle at 12.5 MHz).

60.15.22 I3C timing register 1 (I3C_TIMINGR1)

Address offset: 0x0A4

Reset value: 0x0000 0000

When the I3C acts as controller, this register is used to configure some I3C timing settings.

When the I3C acts as target and is controller-capable, this register is used to configure a timing for the controller-role hand-off procedure.

This register can be written by the software when EN = 0 in the I3C_CFGR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	SDA_HD[1:0]		Res.	Res.	Res.	Res.	Res.	FREE[6:0]						
		rw	rw						rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	ASNCR[1:0]		AVAL[7:0]							
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:28 **SDA_HD[1:0]**: SDA hold time (when the I3C acts as controller), in number of kernel clocks cycles (refer to MIPI timing SDA hold time in push-pull t_{HD_PP}):

SDA hold time = (SDA_HD[1:0] + 0.5) x t_{I3CCLK}

Note: when controller: t_{HD_PPmiN} = min (t_{CR} , t_{CF}) + 3 ns.

Bits 27:23 Reserved, must be kept at reset value.

Bits 22:16 **FREE[6:0]**: Number of kernel clocks cycles that is used to set some MIPI timings like bus free condition time (when the I3C acts as controller)

When the I3C acts as controller:

1. for I3C start timing: it must wait for (bus free condition) time to be elapsed after a stop and before a start, refer to MIPI timings (I3C) t_{CAS} and (I^2C) t_{BUF}. These timings are defined by: t_{BUF} = t_{CAS} = [(FREE[6:0] + 1) x 2 - (0.5 + SDA_HD[1:0])] x t_{I3CCLK}

Note: For pure I3C bus: t_{CASmin} = 38.4 ns, and t_{CASmax} = 1 µs, 100 µs, 2 ms, 50 ms for, respectively, ENTAS0, 1, 2, and 3.

Note: For mixed bus with I^2C Fm+ device t_{BUFmin} = 0.5 µs, for mixed bus with I^2C Fm device t_{BUFmin} = 1.3 µs.

2. for I3C repeated start timing: must wait for time to be elapsed after a repeated start (SDA is de-asserted) and before driving SCL low, refer to. MIPI timing t_{CASr}. This timing is defined by: t_{CASr} = [(FREE[6:0] + 1) x 2 - (0.5 + SDA_HD[1:0])] x t_{I3CCLK}.

Note: $t_{CASr,\ miN}$ = 19.2 ns.

3. for I3C stop timing: must wait for time to be elapsed after that the SCL clock is driven high, and before the stop condition (SDA is asserted). This timing is defined by: t_{CBP} = (FREE[6:0] + 1) x t_{I3CCLK}.

Note: t_{CBPmiN} = 19.2 ns.

4. for I3C repeated start timing (T-bit when controller ends read with repeated start followed by stop): must wait for time to be elapsed after that the SCL clock is driven high, and before the repeated start condition (SDA is de-asserted). This timing is defined by: t_{CBSr} = (FREE[6:0] + 1) x t_{I3CCLK}.

Note: $t_{CBSr,\ miN}$ = 19.2 ns.

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **ASNCR[1:0]**: Activity state of the new controller (when I3C acts as active controller)

This field indicates the time to wait before being accessed as new target, refer AVAL[7:0].

This field can be modified only when the I3C acts as controller.

Bits 7:0 **AVAL[7:0]**: Number of kernel clock cycles to set a time unit of 1 µs, whatever I3C acts as controller or target.

This time unit is then used by the hardware to build some internal timers, corresponding to the following MIPI I3C timings:

When the I3C acts as target:

1. for bus available condition time: it must wait for (bus available condition) time to be elapsed after a stop and before issuing a start request for an IBI or a controller-role request (bus free condition is sustained for at least t_{AVAL}). Refer to MIPI timing t_{AVAL} = 1 µs. This timing is defined by: t_{AVAL} = (AVAL[7:0] + 2) x t_{I3CCLK}
2. for bus idle condition time: it must wait for (bus idle condition) time to be elapsed after that both SDA and SCL are continuously high and stable before issuing a hot-join event. Refer to MIPI v1.1 timing t_{IDLE} = 200 µs . This timing is defined by: t_{IDLE} = (AVAL[7:0] + 2) x 200 x t_{I3CCLK}

When the I3C acts as controller, it cannot stall the clock beyond a maximum stall time (stall the SCL clock low), as follows:

1. on first bit of assigned address during dynamic address assignment: it cannot stall the clock beyond the MIPI timing $t_{STALLDAA}$ = 15 ms. This timing is defined by: $t_{STALLDAAmax}$ = (AVAL[7:0] + 1) x 15000 x t_{I3CCLK}
2. on ACK/NACK phase of I3C/I^2C transfer, on parity bit of write data transfer, on transition bit of I3C read transfer: it cannot stall the clock beyond the MIPI timing t_{STALL} = 100 µs. This timing is defined by: $t_{STALLmax}$ = (AVAL[7:0] + 1) x 100 x t_{I3CCLK}

Whatever the I3C acts as controller or as (controller-capable) target, during a controller-role hand-off procedure:

1. The new controller must wait for $t_{NEWCRLock}$ before pulling SDA low (issuing a start) after a completed GETACCR CCC. Then the new controller, within t_{CAS}, can pull SCL low to activate SCL clock. The active controller must wait for the same $t_{NEWCRLock}$ time, or at least 100 µs, before testing if the new controller has gained control of the bus by pulling SDA low. The time to wait depends upon the value of ANSCR[1:0] in the I3C_TIMINGR1 register:
   - ASNCR[1:0] = 00: $t_{NEWCRLock}$ = (AVAL[7:0] + 1) x t_{I3CCLK}
   - ASNCR[1:0] = 01: $t_{NEWCRLock}$ = (AVAL[7:0] + 1) x 100 x t_{I3CCLK}
   - ASNCR[1:0] = 10: $t_{NEWCRLock}$ = (AVAL[7:0] + 1) x 2000 x t_{I3CCLK}
   - ASNCR[1:0] = 11: $t_{NEWCRLock}$ = (AVAL[7:0] + 1) x 50000 x t_{I3CCLK}

60.15.23 I3C timing register 2 (I3C_TIMINGR2)

Address offset: 0x0A8

Reset value: 0x0000 0000

When the I3C acts as controller, this register is used to configure and enable SCL clock stalling, to enable SCL clock low stalling, if needed by the addressed I3C or legacy I^2C target(s).

This register can be written only when the I3C acts as controller.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STALL[7:0]								Res.	STALLL	STALLS	STALLR	STALLA	STALLC	STALLD	STALLT
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **STALL[7:0]**: Controller clock stall time, in number of kernel clock cycles

t_{SCLL_STALL} = STALL x t_{I3CCLK}

Bit 7 Reserved, must be kept at reset value.

Bit 6 **STALLL:** Controller clock stall enable in the address ACK/NACK phase (before the ninth bit) of a legacy I2C read/write message. This allows the I2C target to prepare the next data byte to send/receive.

0: no stall

1: stall enabled

Bit 5 **STALLS:** Controller clock stall enable in the data ACK/NACK phase of a legacy I2C write message. This allows the I2C target to prepare the next data byte to receive.

0: no stall

1: stall enabled

Bit 4 **STALLR:** Controller clock stall enable in the data ACK/NACK phase of a legacy I2C read message. This allows the I2C target to prepare the next data byte to send.

0: no stall

1: stall enabled

Bit 3 **STALLA:** Controller clock stall enable on ACK phase

The SCL is stalled (during t_{SCLL_STALL}as defined by STALL) in the address ACK/NACK phase (before the ninth bit). This allows the target to prepare data. The ACK driven by the controller itself on a target-initiated request (IBI/HJ/CR) is not impacted by this control bit.

0: no stall

1: stall enabled

Bit 2 **STALLC:** Controller clock stall enable on PAR phase of CCC

The SCL is stalled during STALL x t_{SCLL_PP} in the T-bit phase of common command code (before the ninth bit). This allows the target to decode the command.

0: no stall

1: stall enabled

Note: t_{SCLL_PP} = (I3C_TIMINGR0.SCLL_PP[7:0] + 1) x t_{I3CCLK}

Bit 1 **STALLD:** Controller clock stall enable on PAR phase of Data

The SCL is stalled during STALL x t_{SCLL_PP} in the T-bit phase (before the ninth bit). This allows the target to read received data.

0: no stall

1: stall enabled

Note: t_{SCLL_PP} = (I3C_TIMINGR0.SCLL_PP[7:0] + 1) x t_{I3CCLK}

Bit 0 **STALLT:** Controller clock stall enable on T-bit phase of data

The SCL is stalled during STALL x t_{SCLL_PP} in the T-bit phase (before the ninth bit). This allows the target to prepare the data to be sent.

0: no stall

1: stall enabled

Note: t_{SCLL_PP} = (I3C_TIMINGR0.SCLL_PP[7:0] + 1) x t_{I3CCLK}

60.15.24 I3C bus characteristics register (I3C_BCR)

Address offset: 0x0C0

Reset value: 0x0000 0000

When the I3C acts as target, this register is used to configure three bits used by hardware to return the data byte BCR[7:0] on reception of GETBCR or ENTDAA CCC. The returned byte BCR[7:0] on the I3C bus is then as follows:

- BCR[7] = 0 (reserved)
- BCR[6] = I3C_BCR6 (controller capable)
- BCR[5] = 1 (advanced capabilities, use GETCAPS CCC to determine which ones)
- BCR[4] = 0 (not a virtual target)
- BCR[3] = 1 (offline capable)
- BCR[2] = I3C_BCR2 (IBI payload)
- BCR[1] = 1 (IBI request capable)
- BCR[0] = I3C_BCR0 (max data speed limitation)

This register can be written by software only when EN = 0 in the I3C_CFGR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BCR6	Res.	Res.	Res.	BCR2	Res.	BCR0
									rw				rw		rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **BCR6**: Controller capable

0: I3C target (no controller capable)

1: I3C controller capable

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **BCR2**: in-band interrupt (IBI) payload
0: no data byte follows the accepted IBI
1: at least one mandatory data byte follows the accepted IBI (and at most 4 data bytes)

Bit 1 Reserved, must be kept at reset value.

Bit 0 **BCR0**: max data speed limitation
0: no limitation
1: limitation, as described by I3C_GETMXDSR.

60.15.25 I3C device characteristics register (I3C_DCR)

Address offset: 0x0C4

Reset value: 0x0000 0000

When the I3C acts as target, this register is used to configure the device characteristics ID, which is used by hardware to return the data byte DCR[7:0] on reception of GETDCR, ENTDAA, or DEFTGTS CCC.

This register can be written by software only when EN = 0 in the I3C_CFGR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCR[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **DCR[7:0]**: device characteristics ID
0x00: generic device (for v1.0 devices)
others: ID to describe the type of the I3C sensor/device
Note: The latest MIPI DCR ID assignments are available on https://www.mipi.org.

60.15.26 I3C get capability register (I3C_GETCAPR)

Address offset: 0x0C8

Reset value: 0x0000 0000

When the I3C acts as target, this register is used to set the IBI MDB support for pending read notification support, and is used by hardware to return the GETCAP3 byte on reception of GETCAPS CCC, format 1.

The returned byte GETCAP1[7:0] on the I3C bus is then as follows:

- GETCAP1[7:0] = 0 (no HDR)

The returned byte GETCAP2[7:0] on the I3C bus is then as follows:

- GETCAP2[7:6] = 00 (no HDR)
- GETCAP2[5:4] = 00 (no group addressing)
- GETCAP2[3:0] = 0001 (compliant with MIPI specification v1.1)

The returned byte GETCAP3[7:0] on the I3C bus is then as follows:

- GETCAP3[7] = 0 (reserved)
- GETCAP3[6] = CAPPEND in the I3C_GETCAPR register (IBI MDB support for pending read notification)
- GETCAP3[5] = 0 (no HDR)
- GETCAP3[4] = 1 (defining byte support in GETSTATUS)
- GETCAP3[3] = 1 (defining byte support in GETCAPS)
- GETCAP3[2] = 0 (no device-to-device transfer)
- GETCAP3[1] = 0 (no device-to-device transfer)
- GETCAP3[0] = 0 (no multi-lane data transfer)

This register can be written by software only when EN = 0 in the I3C_CFGR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	CAPPEND	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw														

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **CAPPEND**: IBI MDB support for pending read notification

This bit is written by software during bus initialization (EN = 0), and indicates the support (or not) of the pending read notification via the IBI MDB[7:0] value.

This bit is used to return the GETCAP3 byte in response to the GETCAPS CCC format 1.

0: this I3C when acting as target sends an IBI request without a mandatory data byte value indicating a pending read notification

1: this I3C when acting as target sends an IBI request with a mandatory data byte value (MDB[7:5] = 101), indicating a pending read notification

Bits 13:0 Reserved, must be kept at reset value.

60.15.27 I3C controller-role capability register (I3C_CRCAPR)

Address offset: 0x0CC

Reset value: 0x0000 0000

When the I3C acts as target, this register is used to set features the I3C supports as a secondary controller after controller-role hand-off, and is used by hardware to return the CRCAP1 byte and the CRCAP2 byte on reception of GETCAPS CCC, format 2 with the defining byte CRCAPS (0x91).

The returned CRCAP1[7:0] on the I3C bus is then as follows:

- CRCAP1[7:3] = 00000 (reserved)
- CRCAP1[2] = 0 (no multi-lane)
- CRCAP1[1] = CAPGRP in the I3C_CRCAPR register (group management)
- CRCAP1[0] = 1 (hot-join)

The returned CRLCAP2[7:0] on the I3C bus is then as follows:

- CRCAP2[7:4] = 0000 (reserved)
- CRCAP2[3] = CAPDHOFF in the I3C_CRCAPR register (delayed controller-role handoff)
- CRCAP2[2] = 1 (deep sleep capable)
- CRCAP2[1] = 0 (no automatic controller-role pass-back)
- CRCAP2[0] = 1 (IBI ack capable)

This register can be written by software only when EN = 0 in the I3C_CFGR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CAP GRP	Res.	Res.	Res.	Res.	Res.	CAP DHOFF	Res.	Res.	Res.
						rw						rw			

Bits 31:10 Reserved, must be kept at reset value.

Bit 9 **CAPGRP**: group management support (when acting as controller)

This bit is written by software during bus initialization (EN = 0), and indicates if the I3C is able to support group management when it acts as a controller (after controller-role hand-off) via emitted DEFGRPA, RSTGRPA, and SETGRPA CCC.

This bit is used to return the CRCAP1 byte in response to the GETCAPS CCC format 2.

0: this I3C does not support group address capabilities

1: this I3C supports group address capabilities (when becoming controller)

Bits 8:4 Reserved, must be kept at reset value.

Bit 3 **CAPDHOFF**: delayed controller-role hand-off

This bit is written by software during bus initialization (EN = 0), and indicates if this target I3C needs additional time to process a controller-role hand-off requested by the current controller.

This bit is used to return the CRCAP2 byte in response to the GETCAPS CCC format 2.

0: this I3C does not needs additional time to process a controller-role hand-off

1: this I3C needs additional time to process a controller-role hand-off

Bits 2:0 Reserved, must be kept at reset value.

60.15.28 I3C get max data speed register (I3C_GETMXDSR)

Address offset: 0x0D0

Reset value: 0x0000 0000

When the I3C acts as target, this register is used to set its capabilities and limitations if any. This register is used by hardware to return data byte(s) on reception of GETMXDS CCC, with format 1 (2 bytes, without maxRdTurn), format 2 (5 bytes, with MaxRdTurn), or format 3 (with defining byte WRRDTURN = 0x00: same 5 bytes as format 2, or with defining byte CRHDLY = 0x91: single byte CRHDLY1).

The returned byte MaxWr[7:0] on the I3C bus is then as follows:

- MaxWr[7:4] = 0000 (reserved)
- MaxWr[3] = 1 (defining byte WRRDTURN and CRHDLY support)
- MaxWr[2:0] = 000 (max sustained data rate for non-CCC messages sent by the controller to the target is designed to operate at 12.5 MHz)

The returned byte MaxRd[7:0] on the I3C bus is then as follows:

- MaxRd[7] = 0 (reserved)
- MaxRd[6] = 1 (stop is allowed between write and read)
- MaxRd[5:3] = 100 if TSCO = 0 (clock to data turnaround time t_{SCO} ≤ 12 ns) in the I3C_GETMXDSR register, else 111 (t_{SCO} > 12 ns, refer to the datasheet for more details)
- MaxRd[2:0] = 000 (max sustained data rate for non-CCC messages sent by the target to the controller is designed to operate at 12.5 MHz)

The returned 3-byte MaxRdTurn[23:0], if FMT[1:0] = 00 in the I3C_GETMXDSR register, on the I3C bus is then as follows:

- MaxRdTurn[23:0], with either the MSB (between 65 ms and 16 s), the middle byte (between 256 µs and 65 ms), or the LSB (less than 256 µs) from RDTURN[7:0] in the I3C_GETMXDSR register (others bits are 0), and depending upon FMT[1:0] in the same register.

The returned byte CRHDLY1[7:0] on the I3C bus is then as follows:

- CRHDLY1[7:3] = 00000 (reserved)
- CRHDLY1[2] = 0 if HOFFAS[1:0] = 00 in the I3C_GETMXDSR register, else 1 (set bus activity state)
- CRHDLY1[1:0] = HOFFAS[1:0] (controller-role hand-off activity state)

This register can be written by software only when EN = 0 in the I3C_CFGR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSCO	RDTURN[7:0]							
							rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	FMT[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	HOFFAS[1:0]	
						rw	rw							rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **TSCO**: clock-to-data turnaround time (t_{SCO})

This bit is written by software during bus initialization (EN = 0 in the I3C_CFGR register) and is used to specify the clock-to-data turnaround time t_{SCO} (vs. the value of 12 ns). This bit is used by the hardware in response to the GETMXDS CCC to return the encoded clock-to-data turnaround time via the returned MaxRd[5:3] bits.

0: $t_{SCO} \leq 12$ ns

1: $t_{SCO} > 12$ ns (refer to the datasheet for more details)

Bits 23:16 **RDTURN[7:0]**: programmed byte of the 3-byte MaxRdTurn (maximum read turnaround byte)

This bit is written by software during bus initialization (EN = 0) and writes the value of the selected byte (via the FMT[1:0] field) of the 3-byte MaxRdTurn, which is returned in response to the GETMXDS CCC format 2 to encode the maximum read turnaround time.

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **FMT[1:0]**: GETMXDS CCC format

This field is written by software during bus initialization (EN = 0) and indicates how is returned the GETMXDS format 1 (without MaxRdTurn) and format 2 (with MaxRdTurn).

This field is used to return the 2-byte format 1 (MaxWr, MaxRd) or 5-byte format 2 (MaxWr, MaxRd, 3-byte MaxRdTurn) byte in response to the GETCAPS CCC.

00: format 1 (2 bytes with MaxWr with no defining byte, MaxRd)

01: format 2: (5 bytes w.ith MaxWr with no defining byte, MaxRd, MaxRdTurn)

- 3-byte MaxRdTurn is returned with MSB = 0, middle byte = 0 and LSB = RDTURN[7:0].
- Max read turnaround time is less than 256 µs.

10: format 2 (5 bytes with MaxWr with no defining byte, MaxRd, and middle byte of MaxRdTurn)

- 3-byte MaxRdTurn is returned with MSB = 0, middle byte = RDTURN[7:0] and LSB = 0.
- Max read turnaround time is between 256 and 65535 µs

11: format 2 (5 bytes with MaxWr with no defining byte, MaxRd, MSB of MaxRdTurn)

- 3-byte MaxRdTurn is returned with MSB = RDTURN[7:0], middle byte = 0 and LSB = 0.
- Max read turnaround time is between 65535 µs and 16 s.

Bits 7:2 Reserved, must be kept at reset value.

Bits 1:0 **HOFFAS[1:0]**: Controller hand-off activity state

This field is written by software during bus initialization (EN = 0), and indicates in which initial activity state the (other) current controller must expect the I3C bus after a controller-role hand-off to this controller-capable I3C, when returning the defining byte CRHDLY (0x91) to a GETMXDS CCC.

This 2-bit field is used to return the CRHDLY1 byte in response to the GETCAPS CCC format 3, to state the activity state of this I3C when becoming controller after a controller-role hand-off, and consequently the time the former controller must wait before testing this I3C to be confirmed its ownership.

00: activity state 0 is the initial activity state of this I3C before and when becoming controller

01: activity state 1 is the initial activity state of this I3C when becoming controller

10: activity state 2 is the initial activity state of this I3C when becoming controller

11: activity state 3 is the initial activity state of this I3C when becoming controller

60.15.29 I3C extended provisioned ID register (I3C_EPIDR)

Address offset: 0xD4

Reset value: 0x0208 0000

When the I3C acts as target, this register is used to set the 4-bit MIPI instance ID by software, and some other constant bits used for the 48-bit provisioned ID. It is also used by hardware to return the six bytes for the 48-bit provisioned ID on reception of GETPID and ENTDAA CCC.

The 48-bit provisioned ID on the I3C bus is then returned as:

- provisioned ID [47:32] = 0x0208
- provisioned ID [31:16] = 0x1381
- provisioned ID [15:0] = {MIPIID[3:0], 0x000}

This register can be written by software only when EN = 0 in the I3C_CFGR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MIPIMID[14:0]															IDTSEL
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MIPIID[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw												

Bits 31:17 **MIPIMID[14:0]**: 15-bit MIPI manufacturer ID
This read field is the 15-bit STMicroelectronics MIPI ID (0x0104).
This field represents bits[47:33] of the 48-bit provisioned ID.

Bit 16 **IDTSEL**: provisioned ID type selector
This field is set as 0 (vendor fixed value).
This field represents bit[32] of the 48-bit provisioned ID.
Note: Bits[31:16] of the provisioned ID can be 0.

Bits 15:12 **MIPIID[3:0]**: 4-bit MIPI Instance ID
This field is written by software to set and identify individually each instance of this I3C IP with a specific number on a single I3C bus.
This field represents bits[15:12] of the 48-bit provisioned ID.
Note: Bits[11:0] of the provisioned ID can be 0.

Bits 11:0 Reserved, must be kept at reset value.

60.15.30 I3C register map

Table 666. I3C register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	I3C_CR	MEND	MTYPE[3:0]				Res.	Res.	Res.	ADD[6:0] / CCC[7:0]							RNW	DCNT[15:0]																
	Reset value	0	0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x004	I3C_CFGR	Res.	TSFSET	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FCFDIS	CFLUSH	CDMAEN	TMODE	SMODE	SFLUSH	SDMAEN	Res.	TXTHRES	TXFLUSH	TXDMAEN	Res.	RXTHRES	RXFLUSH	RXDMAEN	HJACK	Res.	HKSDAEN	EXITPTRN	RSTPTRN	NOARBH	CRINIT	EN
	Reset value		0								0	0	0	0	0	0	0		0	0	0		0	0	0	0		0	0	0	0	0	0
0x010	I3C_RDR	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	RDB0[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x014	I3C_RDWR	RDB3[7:0]								RDB2[7:0]								RDB1[7:0]								RDB0[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x018	I3C_TDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDB0[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x01C	I3C_TDWR	TDB3[7:0]								TDB2[7:0]								TDB1[7:0]								TDB0[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	I3C_IBIDR	IBIDB3[7:0]								IBIDB2[7:0]								IBIDB1[7:0]								IBIDB0[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	I3C_TGTTDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRELOAD	TGTTDCNT[15:0]																
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x030	I3C_SR	MID[7:0]								Res.	Res.	Res.	Res.	Res.	DIR	ABT	Res.	XDCNT[15:0]																
	Reset value	0	0	0	0	0	0	0	0						0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x034	I3C_SER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DERR	DNACK	ANACK	COVR	DOVR	STALL	PERR	CODERR[3:0]			
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x040	I3C_RMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RADD[6:0]							s_e_TP	RCODE[7:0]								Res.	Res.	Res.	Res.	Res.	IBIRDCNT[2:0]		
	Reset value									0	0	0	0	0	0	0		0	0	0	0	0	0	0	0						0	0	0

Table 666. I3C register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x050	I3C_EVR	GRPF	DEFF	INTUPDF	ASUPDF	RSTF	MRLUPDF	MWLUPDF	DAUPDF	STAF	GETF	WKPF	Res.	HJF	CRUPDF	CRF	IBIENDF	IBIF	Res.	Res.	Res.	ERRF	RXTGTENDF	FCF	Res.	RXLASTF	TXLASTF	RXFNEF	TXFNFF	SFNEF	CFNFF	TXFEF	CFEF
	Reset value	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0				0	0	0		0	0	0	0	0	0	1	1
0x054	I3C_IER	GRPIE	DEFIE	INTUPDIE	ASUPDIE	RSTIE	MRLUPDIE	MWLUPDIE	DAUPDIE	STAIE	GETIE	WKPIE	Res.	HJIE	CRUPDIE	CRIE	IBIENDIE	IBIIE	Res.	Res.	Res.	ERRIE	RXTGTENDIE	FCIE	Res.	Res.	Res.	RXFNEIE	TXFNFIE	SFNEIE	CFNFIE	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0				0	0	0				0	0	0	0		
0x058	I3C_CEVR	CGRPF	CDEFF	CINTUPDF	CASUPDF	CRSTF	CMRLUPDF	CMWLUPDF	CDAUPDF	CSTAF	CGETF	CWKPF	Res.	CHJF	CRRUPDF	CCRF	CIBIENDF	CIBIF	Res.	Res.	Res.	CERRF	CRXTGTENDF	CFCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0				0	0	0									
0x05C	I3C_MISR	GRPMIS	DEFMIS	INTUPDMIS	ASUPDMIS	RSTMIS	MRLUPDMIS	MWLUPDMIS	DAUPDMIS	STAMIS	GETMIS	WKPMIS	Res.	HJMIS	CRUPDMIS	CRMIS	IBIENDMIS	IBIMIS	Res.	Res.	Res.	ERRMIS	RXTGTENDMIS	FCMIS	Res.	Res.	Res.	RXFNEMIS	TXFNFMIS	SFNEMIS	CFNFMIS	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0				0	0	0				0	0	0	0		
0x060	I3C_DEVR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RSTVAL	RSTACT [1:0]		AS [1:0]		HJEN	Res.	CREN	IBIEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DA[6:0]							DAVAL
	Reset value								0	0	0	0	0	0		0	0									0	0	0	0	0	0	0	0
0x060 + 4 * x, (x = 1 to 4)	I3C_DEVRx	DIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUSP	IBIDEN	CRACK	IBIACK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DA[6:0]							Res.
	Reset value	0												0	0	0	0									0	0	0	0	0	0	0	
0x090	I3C_MAXRLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IBIP [2:0]			MRL15:0]															
	Reset value														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x094	I3C_MAXWLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MWL15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A0	I3C_TIMINGR0	SCLH_I2C[7:0]								SCLL_OD[7:0]								SCLH_I3C[7:0]								SCLL_PP[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A4	I3C_TIMINGR1	Res.	Res.	SDA_HD		Res.	Res.	Res.	Res.	Res.	FREE[6:0]							Res.	Res.	Res.	Res.	Res.	Res.	ASNCR[1:0]		AVAL[7:0]							
	Reset value			0	0						0	0	0	0	0	0	0							0	0	0	0	0	0	0	0	0	0
0x0A8	I3C_TIMINGR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AVAL[7:0]								Res.	STALLL	STALLS	STALLR	STALLA	STALLC	STALLD	STALLT
	Reset value																	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0

Table 666. I3C register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0C0	I3C_BCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BCR6	Res.	Res.	Res.	BCR2	Res.	BCR0
	Reset value																										0				0		0
0x0C4	I3C_DCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCR[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x0C8	I3C_GETCAPR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CAPPEND	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																		0														
0x0CC	I3C_CRCAPR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CAPGR	Res.	Res.	Res.	Res.	Res.	CAPDHOFF	Res.	Res.	Res.
	Reset value																							0						0			
0x0D0	I3C_GETMXDSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSCO	RDTURN[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	FMT[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	HOFFAS [1:0]	
	Reset value								0	0	0	0	0	0	0	0	0							0	0							0	0
0x0D4	I3C_EPIDR	MIPIMID[14:0]															IDTSEL	MIPIID[3:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0												

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

61 Universal synchronous/asynchronous receiver transmitter (USART/UART)

61.1 USART introduction

The USART offers a flexible means to perform full-duplex data exchange with external equipments requiring an industry standard NRZ asynchronous serial data format. A very wide range of baud rates can be achieved through a fractional baud rate generator.

The USART supports both synchronous one-way and half-duplex single-wire communications, as well as LIN (local interconnection network), smartcard protocol, IrDA (infrared data association) SIR ENDEC specifications, and modem operations (CTS/RTS). Multiprocessor communications are also supported.

High-speed data communications are possible by using the DMA (direct memory access) for multibuffer configuration.

61.2 USART main features

- Full-duplex asynchronous communication
- NRZ standard format (mark/space)
- Configurable oversampling method by 16 or 8 to achieve the best compromise between speed and clock tolerance
- Baud rate generator systems
- Two internal FIFOs for transmit and receive data

  Each FIFO can be enabled/disabled by software and come with a status flag.
- A common programmable transmit and receive baud rate
- Dual clock domain with dedicated kernel clock for peripherals independent from PCLK
- Auto baud rate detection
- Programmable data word length (7, 8 or 9 bits)
- Programmable data order with MSB-first or LSB-first shifting
- Configurable stop bits (1 or 2 stop bits)
- Synchronous master/slave mode and clock output/input for synchronous communications
- SPI slave transmission underrun error flag
- Single-wire half-duplex communications
- Continuous communications using DMA
- Received/transmitted bytes are buffered in reserved SRAM using centralized DMA.
- Separate enable bits for transmitter and receiver
- Separate signal polarity control for transmission and reception
- Swappable Tx/Rx pin configuration
- Hardware flow control for modem and RS-485 transceiver
- Communication control/error detection flags
- Parity control:
  – Transmits parity bit

  - Checks parity of received data byte
- Interrupt sources with flags
- Multiprocessor communications: wake-up from mute mode by idle line detection or address mark detection
- Wake-up from Stop mode

61.3 USART extended features

- LIN master synchronous break send capability and LIN slave break detection capability
  - 13-bit break generation and 10/11 bit break detection when USART is hardware configured for LIN
- IrDA SIR encoder decoder supporting 3/16 bit duration for normal mode
- Smartcard mode
  - Supports the T = 0 and T = 1 asynchronous protocols for smartcards as defined in the ISO/IEC 7816-3 standard
  - 0.5 and 1.5 stop bits for smartcard operation
- Support for Modbus communication
  - Timeout feature
  - CR/LF character recognition

61.4 USART implementation

The following tables describe the USART implementation. LPUART is included for comparison.

Table 667. Instance implementation on STM32H5E4/5F4 and STM32H5E5/5F5

Instance	STM32H5Ex/H5Fx
USART1	Full
USART2	Full
USART3	Full
USART6	Full
USART10	Full
USART11	Full
UART4	Basic
UART5	Basic
UART7	Basic
UART8	Basic
UART12	Basic
LPUART1	Low-power

Table 668. USART/LPUART features

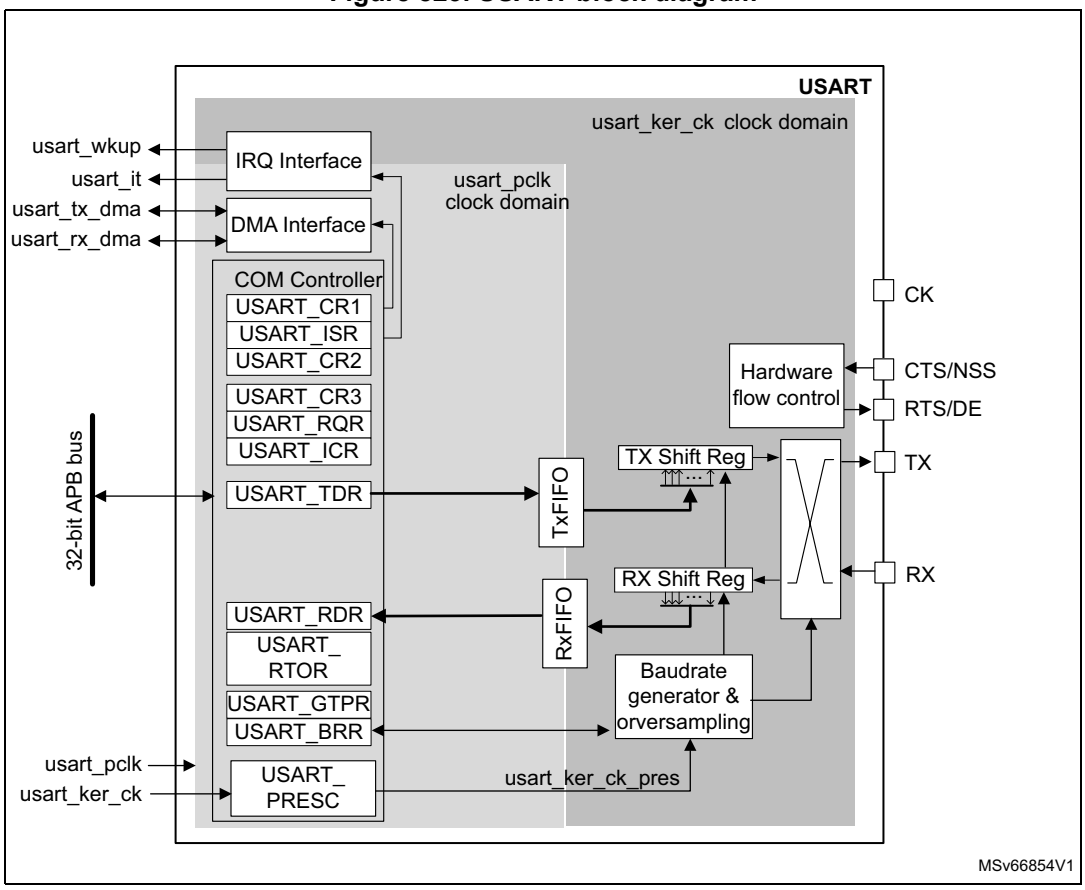
Modes/features[1]	Full feature set	Basic feature set	Low-power feature set
Hardware flow control for modem	X	X	X
Continuous communication using DMA	X	X	X
Multiprocessor communication	X	X	X
Synchronous mode (master/slave)	X	-	-
Smartcard mode	X	-	-
Single-wire half-duplex communication	X	X	X
IrDA SIR ENDEC block	X	X	-
LIN mode	X	X	-
Dual clock domain	X	X	X
Receiver timeout interrupt	X	X	-
Modbus communication	X	X	-
Auto baud rate detection	X	X	-
Driver enable	X	X	X
USART data length	7, 8 and 9 bits		
Tx/Rx FIFO	X	X	X
Tx/Rx FIFO size (bytes)	8		
Wake-up from low-power mode	X[2]	X[2]	X[2]

1. “X” = supported, “-” = not supported.
2. Wake-up supported from Stop mode.

61.5 USART functional description

61.5.1 USART block diagram

Figure 823. USART block diagram



61.5.2 USART pins and internal signals

Description of USART input/output pins

- USART bidirectional communications

  USART bidirectional communications require a minimum of two pins: Receive Data In (RX) and Transmit Data Out (TX):

  – **RX** (Receive Data Input)

    RX is the serial data input. Oversampling techniques are used for data recovery. They discriminate between valid incoming data and noise.

  – **TX** (Transmit Data Output)

    When the transmitter is disabled, the output pin returns to its I/O port configuration. When the transmitter is enabled and no data needs to be transmitted, the TX pin is High. In single-wire and smartcard modes, this I/O is used to transmit and receive data.

- RS232 hardware flow control mode

  The following pins are required in RS232 hardware flow control mode:

  – **CTS** (Clear To Send)

    When driven high, this signal blocks the data transmission at the end of the current transfer.

  – **RTS** (Request To Send)

    When it is low, this signal indicates that the USART is ready to receive data.

- RS485 hardware control mode

  The **DE** (Driver Enable) pin is required in RS485 hardware control mode. This signal activates the transmission mode of the external transceiver.

- Synchronous SPI master/slave mode and smartcard mode

  The following pins are required in synchronous master/slave mode and smartcard mode:

  – **CK**

    This pin acts as clock output in synchronous SPI master and smartcard modes.

    It acts as clock input in synchronous SPI slave mode.

    In synchronous master mode, this pin outputs the transmitter data clock for synchronous transmission corresponding to SPI master mode (no clock pulses on start bit and stop bit, and a software option to send a clock pulse on the last data bit). In parallel, data can be received synchronously on RX pin. This mechanism can be used to control peripherals featuring shift registers (such as LCD drivers). The clock phase and polarity are software programmable.

    In smartcard mode, CK output provides the clock to the smartcard.

  – **NSS**

    This pin acts as Slave Select input in synchronous slave mode.

Refer to *Table 669* and *Table 670* for the list of USART input/output pins and internal signals.

Table 669. USART/UART input/output pins

Pin name	Signal type	Description
USART_RX/UART_RX	Input	Serial data receive input
USART_TX/UART_TX	Output	Transmit data output
USART_CTS/UART_CTS	Input	Clear to send
USART_RTS/UART_RTS	Output	Request to send
USART_DE(1)/UART_DE(2)	Output	Driver enable
USART_CK	Output	Clock output in synchronous master and smartcard modes.
USART_NSS(3)	Input	Slave select input in synchronous slave mode.

1. USART_DE and USART_RTS share the same pin.
2. UART_DE and UART_RTS share the same pin.
3. USART_NSS and USART_CTS share the same pin.

Description of USART input/output signals

Table 670. USART internal input/output signals

Signal name	Signal type	Description
usart_pclk	Input	APB clock
usart_ker_ck	Input	USART kernel clock
usart_wkup	Output	USART provides a wake-up interrupt
usart_it	Output	USART global interrupt
usart_tx_dma	Input/output	USART transmit DMA request
usart_rx_dma	Input/output	USART receive DMA request

61.5.3 USART clocks

The simplified block diagram given in *Section 61.5.1: USART block diagram* shows two fully-independent clock domains:

- The **usart_pclk** clock domain

  The **usart_pclk** clock signal feeds the peripheral bus interface. It must be active when accesses to the USART registers are required.
- The **usart_ker_ck** kernel clock domain.

  The **usart_ker_ck** is the USART clock source. It is independent from **usart_pclk** and delivered by the RCC. The USART registers can consequently be written/read even when the **usart_ker_ck** clock is stopped.

  When the dual clock domain feature is not supported, the **usart_ker_ck** clock is the same as the **usart_pclk** clock.

There is no constraint between **usart_pclk** and **usart_ker_ck**: **usart_ker_ck** can be faster or slower than **usart_pclk**. The only limitation is the software ability to manage the communication fast enough.

When the USART operates in SPI slave mode, it handles data flow using the serial interface clock derived from the external CK signal provided by the external master SPI device. The **usart_ker_ck** clock must be at least 3 times faster than the clock on the CK input.

61.5.4 USART character description

The word length can be set to 7, 8 or 9 bits, by programming the M bits (M0: bit 12 and M1: bit 28) in the USART_CR1 register (see *Figure 824*):

- 7-bit character length: M[1:0] = 10
- 8-bit character length: M[1:0] = 00
- 9-bit character length: M[1:0] = 01

Note: In 7-bit data length mode, the smartcard mode, LIN master mode and Auto baud rate (0x7F and 0x55 frames detection) are not supported.

By default, the signal (TX or RX) is in low state during the start bit. It is in high state during the stop bit.

These values can be inverted, separately for each signal, through polarity configuration control.

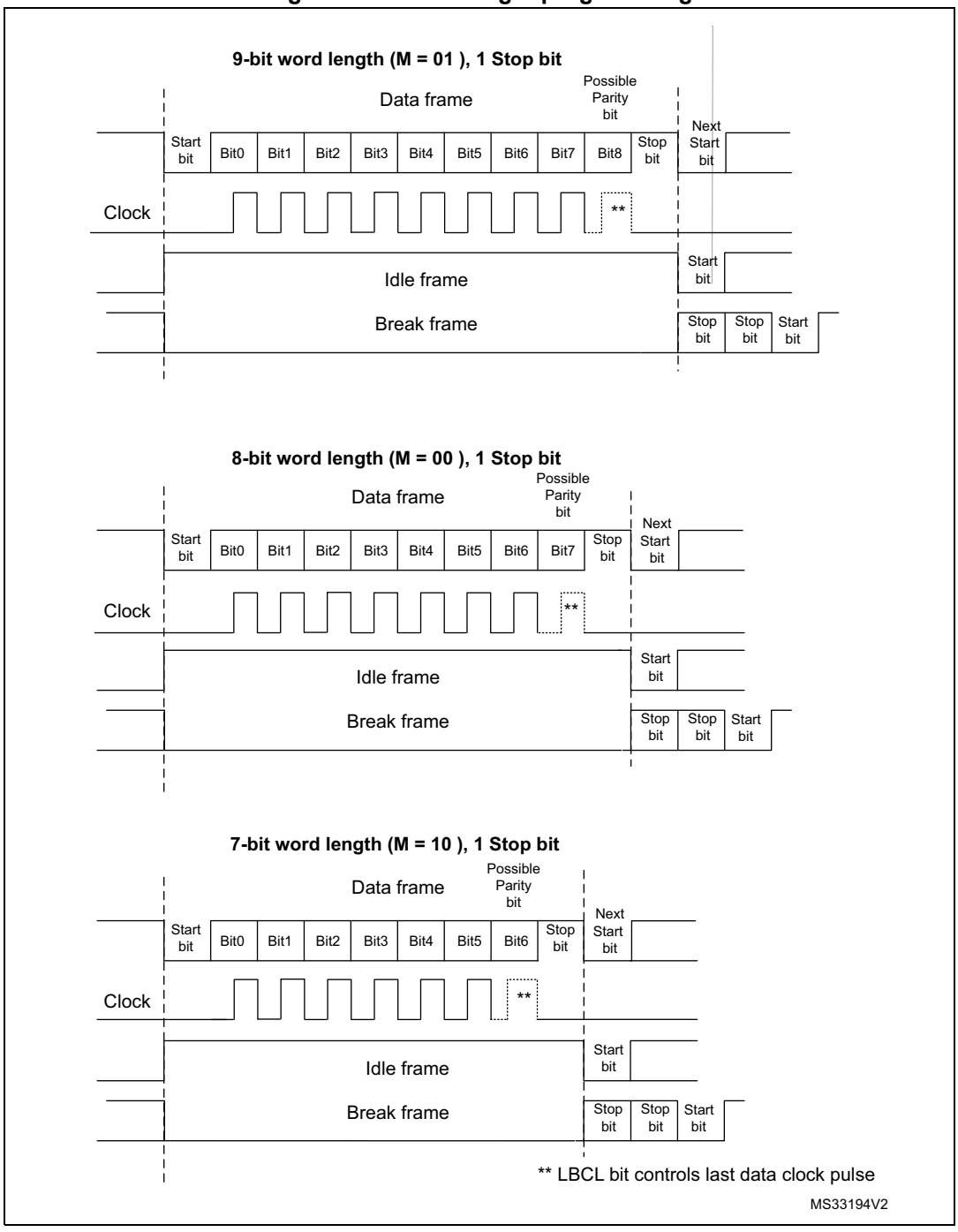
An ***Idle character*** is interpreted as an entire frame of “1”s (the number of “1”s includes the number of stop bits).

A ***Break character*** is interpreted on receiving “0”s for a frame period. At the end of the break frame, the transmitter inserts 2 stop bits.

Transmission and reception are driven by a common baud rate generator. The transmission and reception clock are generated when the enable bit is set for the transmitter and receiver, respectively.

A detailed description of each block is given below.

Figure 824. Word length programming



61.5.5 USART FIFOs and thresholds

The USART can operate in FIFO mode.

The USART comes with a Transmit FIFO (TXFIFO) and a Receive FIFO (RXFIFO). The FIFO mode is enabled by setting FIFOEN in USART_CR1 register (bit 29). This mode is supported only in UART, SPI and smartcard modes.

Since the maximum data word length is 9 bits, the TXFIFO is 9-bit wide. However the RXFIFO default width is 12 bits. This is due to the fact that the receiver does not only store the data in the FIFO, but also the error flags associated to each character (Parity error, Noise error and Framing error flags).

Note: The received data is stored in the RXFIFO together with the corresponding flags. However, only the data are read when reading the RDR.

The status flags are available in the USART_ISR register.

It is possible to configure the TXFIFO and RXFIFO levels at which the Tx and RX interrupts are triggered. These thresholds are programmed through the RXFTCFG[2:0] and TXFTCFG[2:0] bitfields of the USART_CR3 control register.

In this case:

- The Rx interrupt is generated when the number of received data in the RXFIFO reaches the threshold programmed in the RXFTCFG[2:0] bitfield.

  In this case, the RXFT flag is set in the USART_ISR register. This means that RXFTCFG[2:0] data have been received: 1 data in USART_RDR and (RXFTCFG[2:0] – 1) data in the RXFIFO. As an example, when RXFTCFG[2:0] is programmed to 101, the RXFT flag is set when a number of data corresponding to the FIFO size has been received (FIFO size – 1 data in the RXFIFO and 1 data in the USART_RDR). As a result, the next received data does not set the overrun flag.
- The Tx interrupt is generated when the number of empty locations in the TXFIFO is greater than the threshold programmed in the TXFTCFG[2:0] bitfield of the USART_CR3 register.

61.5.6 USART transmitter

The transmitter can send data words of either 7 or 8 or 9 bits, depending on the M bit status. The Transmit Enable bit (TE) must be set in order to activate the transmitter function. The data in the transmit shift register is output on the TX pin while the corresponding clock pulses are output on the CK pin.

Character transmission

During an USART transmission, data shifts out the least significant bit first (default configuration) on the TX pin. In this mode, the USART_TDR register consists of a buffer (TDR) between the internal bus and the transmit shift register.

When FIFO mode is enabled, the data written to the transmit data register (USART_TDR) are queued in the TXFIFO.

Every character is preceded by a start bit which corresponds to a low logic level for one bit period. The character is terminated by a configurable number of stop bits.

The number of stop bits can be configured to 0.5, 1, 1.5 or 2.

Note: The TE bit must be set before writing the data to be transmitted to the USART_TDR.

The TE bit must not be reset during data transmission. Resetting the TE bit during the transmission corrupts the data on the TX pin as the baud rate counters get frozen. The current data being transmitted are then lost.

An idle frame is sent when the TE bit is enabled.

Configurable stop bits

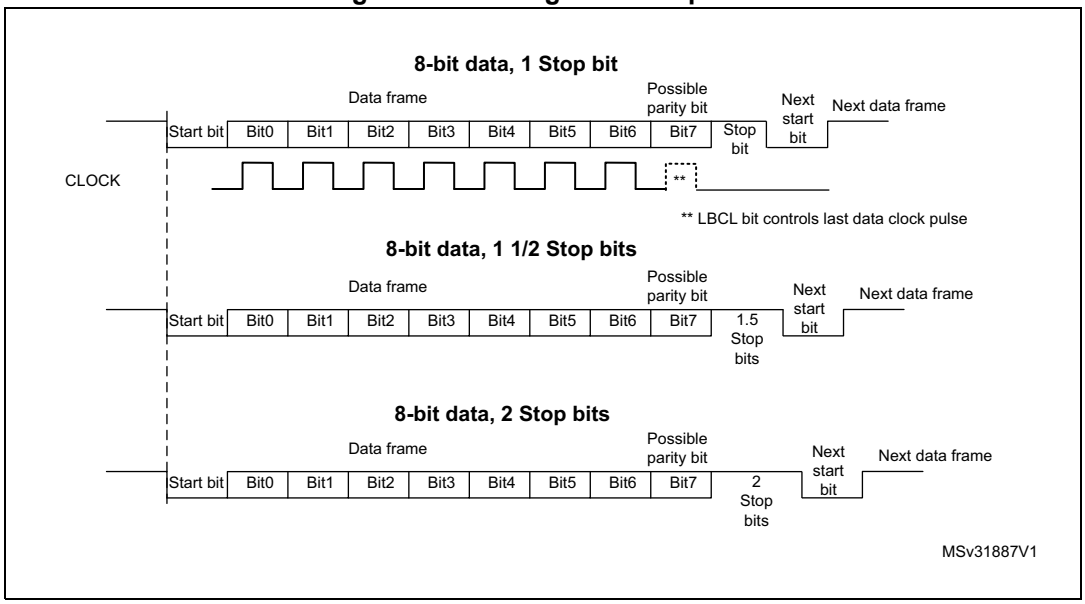
The number of stop bits to be transmitted with every character can be programmed in USART_CR2, bits 13,12.

- ***1 stop bit***: This is the default value of number of stop bits.
- ***2 stop bits***: This is supported by normal USART, single-wire and modem modes.
- ***1.5 stop bits***: To be used in smartcard mode.

An idle frame transmission includes the stop bits.

A break transmission is 10 low bits (when M[1:0] = 00) or 11 low bits (when M[1:0] = 01) or 9 low bits (when M[1:0] = 10) followed by 2 stop bits (see *Section 61.5.1: USART block diagram*). It is not possible to transmit long breaks (break of length greater than 9/10/11 low bits).

Figure 825. Configurable stop bits



Character transmission procedure

To transmit a character, follow the sequence below:

1. Program the M bits in USART_CR1 to define the word length.
2. Select the desired baud rate using the USART_BRR register.
3. Program the number of stop bits in USART_CR2.
4. Enable the USART by writing the UE bit in USART_CR1 register to 1.
5. Select DMA enable (DMAT) in USART_CR3 if multibuffer communication must take place. Configure the DMA register as explained in *Section 61.5.20: Continuous communication using USART and DMA*.
6. Set the TE bit in USART_CR1 to send an idle frame as first transmission.

7. Write the data to send in the USART_TDR register. Repeat this for each data to be transmitted in case of single buffer.
   – When FIFO mode is disabled, writing a data to the USART_TDR clears the TXE flag.
   – When FIFO mode is enabled, writing a data to the USART_TDR adds one data to the TXFIFO. Write operations to the USART_TDR are performed when TXFNF flag is set. This flag remains set until the TXFIFO is full.
8. When the last data is written to the USART_TDR register, wait until TC = 1.
   – When FIFO mode is disabled, this indicates that the transmission of the last frame has completed.
   – When FIFO mode is enabled, this indicates that both TXFIFO and shift register are empty.

   This check is required to avoid corrupting the last transmission when the USART is disabled or enters Halt mode.

Single byte communication

- When FIFO mode is disabled

  Writing to the transmit data register always clears the TXE bit. The TXE flag is set by hardware. It indicates that:
  – the data have been moved from the USART_TDR register to the shift register and the data transmission has started;
  – the USART_TDR register is empty;
  – the next data can be written to the USART_TDR register without overwriting the previous data.

  This flag generates an interrupt if the TXEIE bit is set.

  When a transmission is ongoing, a write instruction to the USART_TDR register stores the data in the TDR buffer. It is then copied in the shift register at the end of the current transmission.

  When no transmission is ongoing, a write instruction to the USART_TDR register places the data in the shift register, the data transmission starts, and the TXE bit is set.
- When FIFO mode is enabled, the TXFNF (TXFIFO not full) flag is set by hardware to indicate that:
  – the TXFIFO is not full;
  – the USART_TDR register is empty;
  – the next data can be written to the USART_TDR register without overwriting the previous data. When a transmission is ongoing, a write operation to the USART_TDR register stores the data in the TXFIFO. Data are copied from the TXFIFO to the shift register at the end of the current transmission.

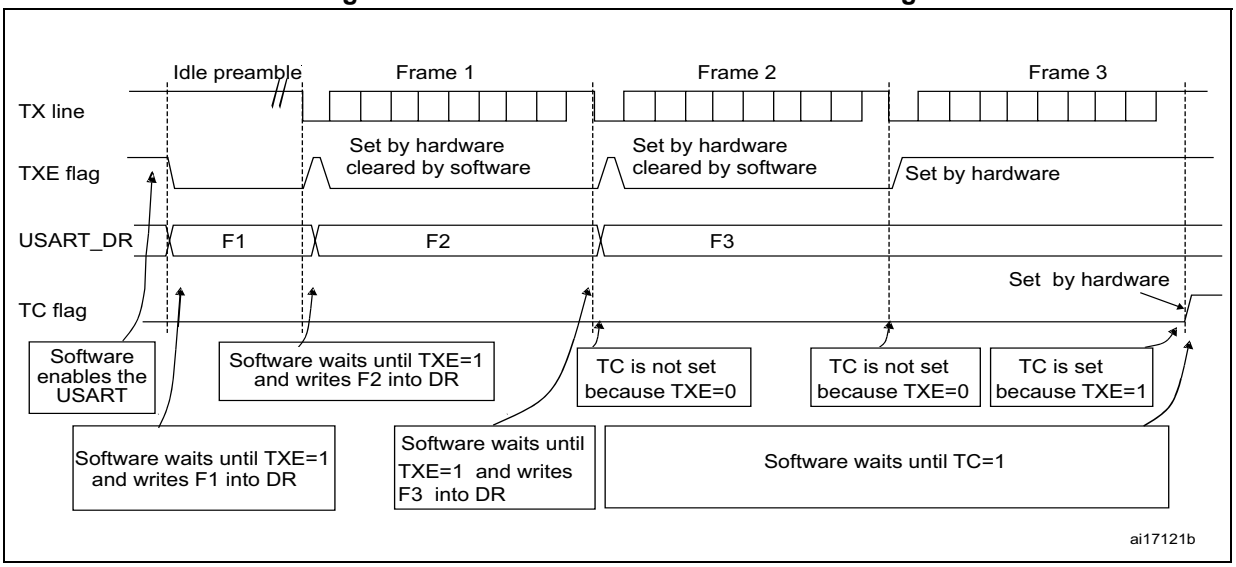
  When the TXFIFO is not full, the TXFNF flag stays at 1 even after a write operation to USART_TDR register. It is cleared when the TXFIFO is full. This flag generates an interrupt if the TXFNFIE bit is set.

  Alternatively, interrupts can be generated and data can be written to the FIFO when the TXFIFO threshold is reached. In this case, the CPU can write a block of data defined by the programmed trigger level.

  If a frame is transmitted (after the stop bit) and the TXE flag (TXFE in case of FIFO mode) is set, the TC flag goes high. An interrupt is generated if the TCIE bit is set in the USART_CR1 register.

After writing the last data to the USART_TDR register, it is mandatory to wait until TC is set before disabling the USART or causing the microcontroller to enter the low-power mode (see *Figure 826*).

Figure 826. TC/TXE behavior when transmitting



Note: When FIFO management is enabled, the TXFNF flag is used for data transmission.

Break characters

Setting the SBKRQ bit transmits a break character. The break frame length depends on the M bit (see *Figure 824*).

If a 1 is written to the SBKRQ bit, a break character is sent on the TX line after completing the current character transmission. The SBKF bit is set by the write operation and it is reset by hardware when the break character is complete (during the stop bits after the break character). The USART inserts a logic 1 signal (stop) for the duration of 2 bits at the end of the break frame to guarantee the recognition of the start bit of the next frame.

When the SBKRQ bit is set, the break character is sent at the end of the current transmission.

When FIFO mode is enabled, sending the break character has priority on sending data even if the TXFIFO is full.

Idle characters

Setting the TE bit drives the USART to send an idle frame before the first data frame.

61.5.7 USART receiver

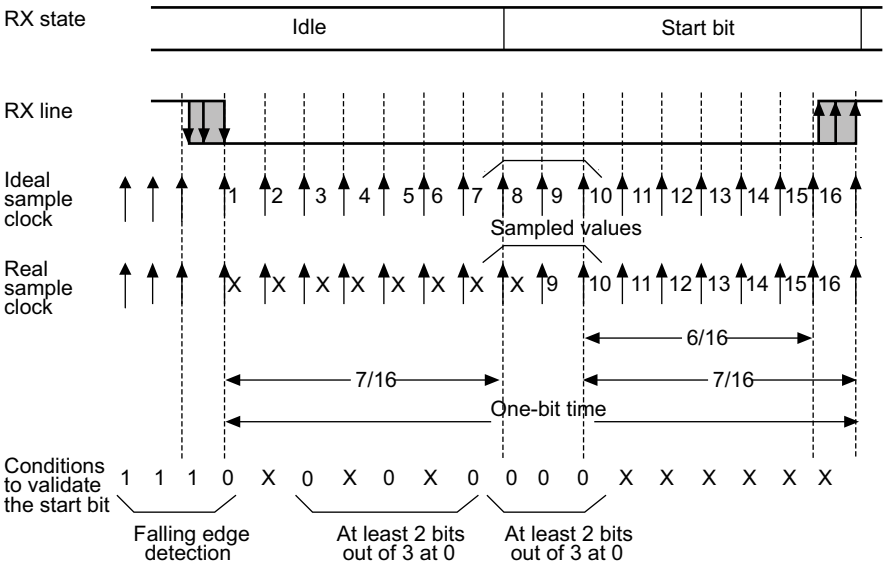
The USART can receive data words of either 7 or 8 or 9 bits depending on the M bits in the USART_CR1 register.

Start bit detection

The start bit detection sequence is the same when oversampling by 16 or by 8.

In the USART, the start bit is detected when a specific sequence of samples is recognized. This sequence is: 1 1 1 0 X 0 X 0X 0X 0 X 0X 0.

Figure 827. Start bit detection when oversampling by 16 or 8



Note: If the sequence has not completed, the start bit detection aborts and the receiver returns to the idle state (no flag is set), where it waits for a falling edge.

The start bit is confirmed (RXNE flag set and interrupt generated if RXNEIE = 1, or RXFNE flag set and interrupt generated if RXFNEIE = 1 if FIFO mode enabled) if the 3 sampled bits are at 0 (first sampling on the 3rd, 5th and 7th bits finds the 3 bits at 0 and second sampling on the 8th, 9th and 10th bits also finds the 3 bits at 0).

The start bit is validated but the NE noise flag is set if,

- for both samplings, 2 out of the 3 sampled bits are at 0 (sampling on the 3rd, 5th and 7th bits and sampling on the 8th, 9th and 10th bits), or
- for one of the samplings (sampling on the 3rd, 5th and 7th bits or sampling on the 8th, 9th and 10th bits), 2 out of the 3 bits are found at 0.

If neither of the above conditions are met, the start detection aborts and the receiver returns to the idle state (no flag is set).

Character reception

During an USART reception, data are shifted out least significant bit first (default configuration) through the RX pin.

Character reception procedure

To receive a character, follow the sequence below:

1. Program the M bits in USART_CR1 to define the word length.
2. Select the desired baud rate using the baud rate register USART_BRR
3. Program the number of stop bits in USART_CR2.
4. Enable the USART by writing the UE bit in USART_CR1 register to 1.
5. Select DMA enable (DMAR) in USART_CR3 if multibuffer communication is to take place. Configure the DMA register as explained in *Section 61.5.20: Continuous communication using USART and DMA*.
6. Set the RE bit USART_CR1. This enables the receiver which begins searching for a start bit.

When a character is received:

- When FIFO mode is disabled, the RXNE bit is set to indicate that the content of the shift register is transferred to the RDR. In other words, data have been received and can be read (as well as their associated error flags).
- When FIFO mode is enabled, the RXFNE bit is set to indicate that the RXFIFO is not empty. Reading the USART_RDR returns the oldest data entered in the RXFIFO. When a data is received, it is stored in the RXFIFO together with the corresponding error bits.
- An interrupt is generated if the RXNEIE (RXFNEIE when FIFO mode is enabled) bit is set.
- The error flags can be set if a frame error, noise, parity or an overrun error was detected during reception.
- In multibuffer communication mode:
  - When FIFO mode is disabled, the RXNE flag is set after every byte reception. It is cleared when the DMA reads the Receive data Register.
  - When FIFO mode is enabled, the RXFNE flag is set when the RXFIFO is not empty. After every DMA request, a data is retrieved from the RXFIFO. A DMA request is triggered when the RXFIFO is not empty, that is when there are data to be read from the RXFIFO.
- In single-buffer mode:
  - When FIFO mode is disabled, clearing the RXNE flag is done by performing a software read from the USART_RDR register. The RXNE flag can also be cleared by programming RXFRQ bit to 1 in the USART_RQR register. The RXNE flag must be cleared before the end of the reception of the next character to avoid an overrun error.
  - When FIFO mode is enabled, the RXFNE is set when the RXFIFO is not empty. After every read operation from USART_RDR, a data is retrieved from the RXFIFO. When the RXFIFO is empty, the RXFNE flag is cleared. The RXFNE flag can also be cleared by programming RXFRQ bit to 1 in USART_RQR. When the RXFIFO is full, the first entry in the RXFIFO must be read before the end of the reception of the next character, to avoid an overrun error. The RXFNE flag generates an interrupt if the RXFNEIE bit is set. Alternatively, interrupts can be

generated and data can be read from RXFIFO when the RXFIFO threshold is reached. In this case, the CPU can read a block of data defined by the programmed threshold.

Break character

When a break character is received, the USART handles it as a framing error.

Idle character

When an idle frame is detected, it is handled in the same way as a data character reception except that an interrupt is generated if the IDLEIE bit is set.

Overrun error

- FIFO mode disabled

  An overrun error occurs if a character is received and RXNE has not been reset.

  Data can not be transferred from the shift register to the RDR register until the RXNE bit is cleared. The RXN E flag is set after every byte reception.

  An overrun error occurs if RXNE flag is set when the next data is received or the previous DMA request has not been serviced. When an overrun error occurs:

  – the ORE bit is set;
  – the RDR content is not lost. The previous data is available by reading the USART_RDR register.
  – the shift register is overwritten. After that, any data received during overrun is lost.
  – an interrupt is generated if either the RXNEIE or the EIE bit is set.

- FIFO mode enabled

  An overrun error occurs when the shift register is ready to be transferred and the receive FIFO is full.

  Data can not be transferred from the shift register to the USART_RDR register until there is one free location in the RXFIFO. The RXFNE flag is set when the RXFIFO is not empty.

  An overrun error occurs if the RXFIFO is full and the shift register is ready to be transferred. When an overrun error occurs:

  – The ORE bit is set.
  – The first entry in the RXFIFO is not lost. It is available by reading the USART_RDR register.
  – The shift register is overwritten. After that point, any data received during overrun is lost.
  – An interrupt is generated if either the RXFNEIE or EIE bit is set.

The ORE bit is reset by setting the ORECF bit in the USART_ICR register.

Note: The ORE bit, when set, indicates that at least 1 data has been lost.

When the FIFO mode is disabled, there are two possibilities

- *if RXNE = 1, then the last valid data is stored in the receive register (RDR) and can be read,*
- *if RXNE = 0, the last valid data has already been read and there is nothing left to be read in the RDR register. This case can occur when the last valid data is read in the RDR register at the same time as the new (and lost) data is received.*

Selecting the clock source and the appropriate oversampling method

The choice of the clock source is done through the Clock Control system (see *Section : Reset and Clock Control (RCC)*). The clock source must be selected through the UE bit before enabling the USART.

The clock source must be selected according to two criteria:

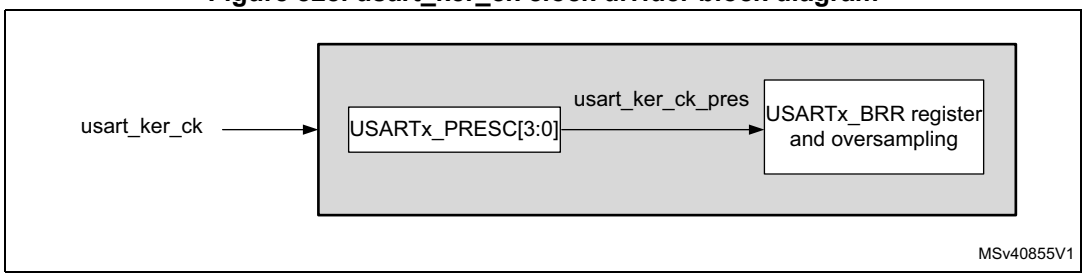
- Possible use of the USART in low-power mode
- Communication speed.

The clock source frequency is usart_ker_ck.

When the dual clock domain and the wake-up from low-power mode features are supported, the usart_ker_ck clock source can be configurable in the RCC (see *Section : Reset and Clock Control (RCC)*). Otherwise the usart_ker_ck clock is the same as usart_pclk.

The usart_ker_ck clock can be divided by a programmable factor, defined in the USART_PRESC register.

Figure 828. usart_ker_ck clock divider block diagram



Some usart_ker_ck sources enable the USART to receive data while the MCU is in low-power mode. Depending on the received data and wake-up mode selected, the USART wakes up the MCU, when needed, in order to transfer the received data, by performing a software read to the USART_RDR register or by DMA.

For the other clock sources, the system must be active to enable USART communications.

The communication speed range (specially the maximum communication speed) is also determined by the clock source.

The receiver implements different user-configurable oversampling techniques (except in synchronous mode) for data recovery by discriminating between valid incoming data and noise. This enables obtaining the best a trade-off between the maximum communication speed and noise/clock inaccuracy immunity.

The oversampling method can be selected by programming the OVER8 bit in the USART_CR1 register either to 16 or 8 times the baud rate clock (see *Figure 829* and *Figure 830*).

Depending on the application:

- select oversampling by 8 (OVER8 = 1) to achieve higher speed (up to usart_ker_ck_pres/8). In this case the maximum receiver tolerance to clock deviation is reduced (refer to *Section 61.5.9: Tolerance of the USART receiver to clock deviation*)
- select oversampling by 16 (OVER8 = 0) to increase the tolerance of the receiver to clock deviations. In this case, the maximum speed is limited to maximum usart_ker_ck_pres/16 (where usart_ker_ck_pres is the USART input clock divided by a prescaler).

Programming the ONEBIT bit in the USART_CR3 register selects the method used to evaluate the logic level. Two options are available:

- The majority vote of the three samples in the center of the received bit. In this case, when the 3 samples used for the majority vote are not equal, the NE bit is set.
- A single sample in the center of the received bit

  Depending on the application:

  – select the three sample majority vote method (ONEBIT = 0) when operating in a noisy environment and reject the data when a noise is detected (refer to *Table 671*) because this indicates that a glitch occurred during the sampling.

  – select the single sample method (ONEBIT = 1) when the line is noise-free to increase the receiver tolerance to clock deviations (see *Section 61.5.9: Tolerance of the USART receiver to clock deviation*). In this case the NE bit is never set.

When noise is detected in a frame:

- The NE bit is set at the rising edge of the RXNE bit (RXFNE in case of FIFO mode enabled).
- The invalid data is transferred from the Shift register to the USART_RDR register.
- No interrupt is generated in case of single byte communication. However this bit rises at the same time as the RXNE bit (RXFNE in case of FIFO mode enabled) which itself generates an interrupt. In case of multibuffer communication an interrupt is issued if the EIE bit is set in the USART_CR3 register.

The NE bit is reset by setting NFCF bit in ICR register.

Note: Noise error is not supported in SPI and IrDA modes.

Oversampling by 8 is not available in the smartcard, IrDA and LIN modes. In those modes, the OVER8 bit is forced to 0 by hardware.

Figure 829. Data sampling when oversampling by 16

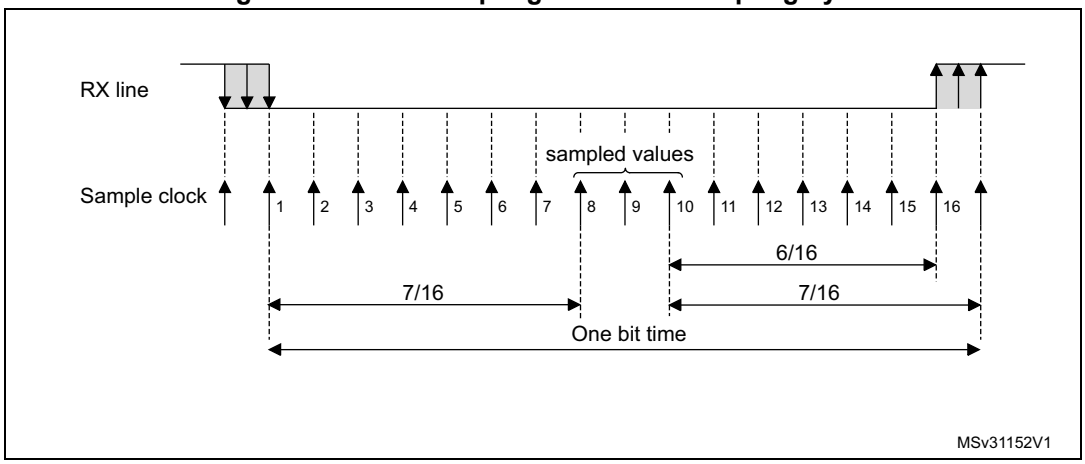


Figure 830. Data sampling when oversampling by 8

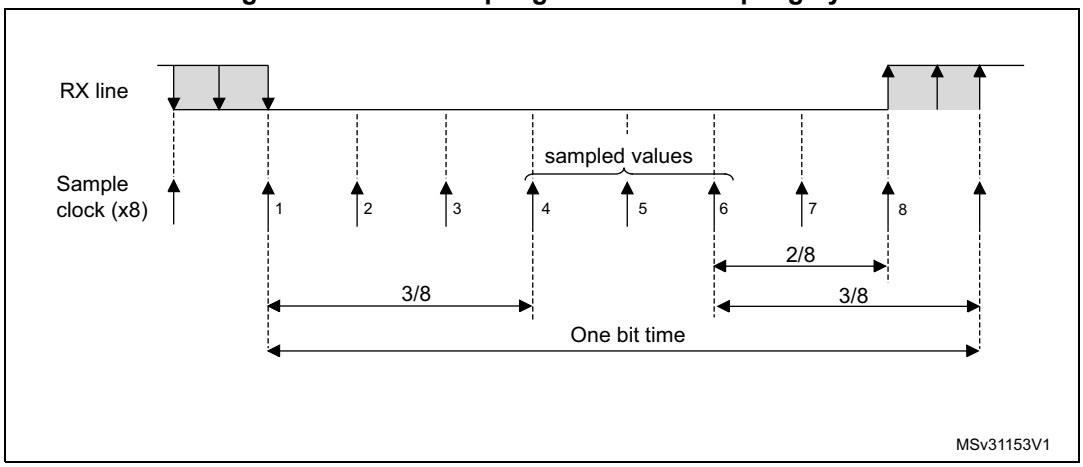


Table 671. Noise detection from sampled data

Sampled value	NE status	Received bit value
000	0	0
001	1	0
010	1	0
011	1	1
100	1	0
101	1	1
110	1	1
111	0	1

Framing error

A framing error is detected when the stop bit is not recognized on reception at the expected time, following either a de-synchronization or excessive noise.

When the framing error is detected:

- the FE bit is set by hardware.
- the invalid data is transferred from the Shift register to the USART_RDR register (RXFIFO in case FIFO mode is enabled).
- no interrupt is generated in case of single byte communication. However this bit rises at the same time as the RXNE bit (RXFNE in case FIFO mode is enabled) which itself generates an interrupt. In case of multibuffer communication an interrupt is issued if the EIE bit is set in the USART_CR3 register.

The FE bit is reset by writing 1 to the FECF in the USART_ICR register.

Note: Framing error is not supported in SPI mode.

Configurable stop bits during reception

The number of stop bits to be received can be configured through the control bits of USART_CR: it can be either 1 or 2 in normal mode and 0.5 or 1.5 in smartcard mode.

- **0.5 stop bit (reception in smartcard mode)**: no sampling is done for 0.5 stop bit. As a consequence, no framing error and no break frame can be detected when 0.5 stop bit is selected.
- **1 stop bit**: sampling for 1 stop bit is done on the 8th, 9th and 10th samples.
- **1.5 stop bits (smartcard mode)**

  When transmitting in smartcard mode, the device must check that the data are correctly sent. The receiver block must consequently be enabled (RE = 1 in USART_CR1) and the stop bit is checked to test if the smartcard has detected a parity error.

  In the event of a parity error, the smartcard forces the data signal low during the sampling (NACK signal), which is flagged as a framing error. The FE flag is then set through RXNE flag (RXFNE if the FIFO mode is enabled) at the end of the 1.5 stop bit. Sampling for 1.5 stop bits is done on the 16th, 17th and 18th samples (1 baud clock period after the beginning of the stop bit). The 1.5 stop bit can be broken into 2 parts: one 0.5 baud clock period during which nothing happens, followed by 1 normal stop bit period during which sampling occurs halfway through (refer to *Section 61.5.17: USART receiver timeout* for more details).
- **2 stop bits**

  Sampling for 2 stop bits is done on the 8th, 9th and 10th samples of the first stop bit.

  The framing error flag is set if a framing error is detected during the first stop bit.

  The second stop bit is not checked for framing error. The RXNE flag (RXFNE if the FIFO mode is enabled) is set at the end of the first stop bit.

61.5.8 USART baud rate generation

The baud rate for the receiver and transmitter (Rx and Tx) are both set to the value programmed in the USART_BRR register.

Equation 1: baud rate for standard USART (SPI mode included) (OVER8 = 0 or 1)

In case of oversampling by 16, the baud rate is given by the following formula:

$$\text{Tx/Rx baud} = \frac{\text{usart_ker_ck_pres}}{\text{USARTDIV}}$$

In case of oversampling by 8, the baud rate is given by the following formula:

$$\text{Tx/Rx baud} = \frac{2 \times \text{usart_ker_ck_pres}}{\text{USARTDIV}}$$

Equation 2: baud rate in smartcard, LIN and IrDA modes (OVER8 = 0)

The baud rate is given by the following formula:

$$\text{Tx/Rx baud} = \frac{\text{usart_ker_ck_pres}}{\text{USARTDIV}}$$

USARTDIV is an unsigned fixed point number that is coded on the USART_BRR register.

- When OVER8 = 0, BRR = USARTDIV.
- When OVER8 = 1
  - BRR[2:0] = USARTDIV[3:0] shifted 1 bit to the right.
  - BRR[3] must be kept cleared.
  - BRR[15:4] = USARTDIV[15:4]

Note: The baud counters are updated to the new value in the baud registers after a write operation to USART_BRR. Hence the baud rate register value must not be changed during communication.

In case of oversampling by 16 and 8, USARTDIV must be greater than or equal to 16.

How to derive USARTDIV from USART_BRR register values

Example 1

To obtain 9600 bauds with usart_ker_ck_pres= 8 MHz:

- In case of oversampling by 16:
  USARTDIV = 8 000 000/9600
  BRR[3:0] = USARTDIV = 0d833 = 0x0341
- In case of oversampling by 8:
  USARTDIV = 2 * 8 000 000/9600
  USARTDIV = 1666,66 (0d1667 = 0x683)
  BRR[3:0] = 0x3 >>1 = 0x1
  BRR[3:0] = 0x681

Example 2

To obtain 921.6 kbauds with usart_ker_ck_pres = 48 MHz:

- In case of oversampling by 16:
  USARTDIV = 48 000 000/921 600
  BRR[3:0] = USARTDIV = 52 = 0x34
- In case of oversampling by 8:
  USARTDIV = 2 * 48 000 000/921 600
  USARTDIV = 104 (0d104 = 0x68)
  BRR[3:0] = USARTDIV[3:0] >> 1 = 0x8 >> 1 = 0x4
  BRR[3:0] = 0x64

61.5.9 Tolerance of the USART receiver to clock deviation

The USART asynchronous receiver operates correctly only if the total clock system deviation is less than the tolerance of the USART receiver.

The causes which contribute to the total deviation are:

- DTRA: deviation due to the transmitter error (which also includes the deviation of the transmitter's local oscillator)
- DQUANT: error due to the baud rate quantization of the receiver
- DREC: deviation of the receiver local oscillator
- DTCL: deviation due to the transmission line (generally due to the transceivers which can introduce an asymmetry between the low-to-high transition timing and the high-to-low transition timing)

$$DTRA + DQUANT + DREC + DTCL + DWU < USART\ receiver\ tolerance$$

where

DWU is the error due to sampling point deviation when the wake-up from low-power mode is used.

when M[1:0] = 01:

$$DWU = \frac{t_{WUUSART}}{11 \times Tbit}$$

when M[1:0] = 00:

$$DWU = \frac{t_{WUUSART}}{10 \times Tbit}$$

when M[1:0] = 10:

$$DWU = \frac{t_{WUUSART}}{9 \times Tbit}$$

$t_{WUUSART}$ is the time between the detection of the start bit falling edge and the instant when the clock (requested by the peripheral) is ready and reaching the peripheral, and the regulator is ready.

The USART receiver can receive data correctly at up to the maximum tolerated deviation specified in *Table 672*, *Table 673*, depending on the following settings:

- 9-, 10- or 11-bit character length defined by the M bits in the USART_CR1 register
- Oversampling by 8 or 16 defined by the OVER8 bit in the USART_CR1 register
- Bits BRR[3:0] of USART_BRR register are equal to or different from 0000.
- Use of 1 bit or 3 bits to sample the data, depending on the value of the ONEBIT bit in the USART_CR3 register.

Table 672. Tolerance of the USART receiver when BRR [3:0] = 0000

M bits	OVER8 bit = 0		OVER8 bit = 1	
	ONEBIT = 0	ONEBIT = 1	ONEBIT = 0	ONEBIT = 1
00	3.75%	4.375%	2.50%	3.75%
01	3.41%	3.97%	2.27%	3.41%
10	4.16%	4.86%	2.77%	4.16%

Table 673. Tolerance of the USART receiver when BRR[3:0] is different from 0000

M bits	OVER8 bit = 0		OVER8 bit = 1	
	ONEBIT = 0	ONEBIT = 1	ONEBIT = 0	ONEBIT = 1
00	3.33%	3.88%	2%	3%
01	3.03%	3.53%	1.82%	2.73%
10	3.7%	4.31%	2.22%	3.33%

Note: The data specified in Table 672 and Table 673 may slightly differ in the special case when the received frames contain some Idle frames of exactly 10-bit times when M bits = 00 (11-bit times when M= 01 or 9- bit times when M = 10).

61.5.10 USART auto baud rate detection

The USART can detect and automatically set the USART_BRR register value based on the reception of one character. Automatic baud rate detection is useful under two circumstances:

- The communication speed of the system is not known in advance.
- The system is using a relatively low accuracy clock source and this mechanism enables the correct baud rate to be obtained without measuring the clock deviation.

The clock source frequency must be compatible with the expected communication speed.

- When oversampling by 16, the baud rate ranges from usart_ker_ck_pres/65535 and usart_ker_ck_pres/16.
- When oversampling by 8, the baud rate ranges from usart_ker_ck_pres/32763 and usart_ker_ck_pres/8.

Before activating the auto baud rate detection, the auto baud rate detection mode must be selected through the ABRMOD[1:0] field in the USART_CR2 register. There are four modes based on different character patterns. In these auto baud rate modes, the baud rate is measured several times during the synchronization data reception and each measurement is compared to the previous one.

These modes are the following:

- **Mode 0**: Any character starting with a bit at 1.

  In this case the USART measures the duration of the start bit (falling edge to rising edge).
- **Mode 1:** Any character starting with a 10xx bit pattern.

  In this case, the USART measures the duration of the Start and of the 1st data bit. The measurement is done falling edge to falling edge, to ensure a better accuracy in the case of slow signal slopes.
- **Mode 2**: A 0x7F character frame (it may be a 0x7F character in LSB first mode or a 0xFE in MSB first mode).

  In this case, the baud rate is updated first at the end of the start bit (BRs), then at the end of bit 6 (based on the measurement done from falling edge to falling edge: BR6). Bit0 to bit6 are sampled at BRs while further bits of the character are sampled at BR6.
- **Mode 3**: A 0x55 character frame.

  In this case, the baud rate is updated first at the end of the start bit (BRs), then at the end of bit0 (based on the measurement done from falling edge to falling edge: BR0), and finally at the end of bit6 (BR6). Bit 0 is sampled at BRs, bit 1 to bit 6 are sampled at BR0, and further bits of the character are sampled at BR6. In parallel, another check is performed for each intermediate RX line transition. An error is generated if the transitions on RX are not sufficiently synchronized with the receiver (the receiver being based on the baud rate calculated on bit 0).

Prior to activating the auto baud rate detection, the USART_BRR register must be initialized by writing a non-zero baud rate value.

The automatic baud rate detection is activated by setting the ABREN bit in the USART_CR2 register. The USART then waits for the first character on the RX line. The auto baud rate operation completion is indicated by the setting of the ABRF flag in the USART_ISR register. If the line is noisy, the correct baud rate detection cannot be guaranteed. In this case the BRR value may be corrupted and the ABRE error flag is set. This also happens if the communication speed is not compatible with the automatic baud rate detection range (bit duration not between 16 and 65536 clock periods (oversampling by 16) and not between 8 and 65536 clock periods (oversampling by 8)).

The auto baud rate detection can be re-launched later by resetting the ABRF flag (by writing a 0).

When FIFO management is disabled and an auto baud rate error occurs, the ABRE flag is set through RXNE and FE bits.

When FIFO management is enabled and an auto baud rate error occurs, the ABRE flag is set through RXFNE and FE bits.

If the FIFO mode is enabled, the auto baud rate detection must be made using the data on the first RXFIFO location. So, prior to launching the auto baud rate detection, make sure that the RXFIFO is empty by checking the RXFNE flag in USART_ISR register.

Note: The BRR value might be corrupted if the USART is disabled (UE = 0) during an auto baud rate operation.

61.5.11 USART multiprocessor communication

It is possible to perform USART multiprocessor communications (with several USARTs connected in a network). For instance one of the USARTs can be the master with its TX output connected to the RX inputs of the other USARTs, while the others are slaves with their respective TX outputs logically ANDed together and connected to the RX input of the master.

In multiprocessor configurations, it is often desirable that only the intended message recipient actively receives the full message contents, thus reducing redundant USART service overhead for all non addressed receivers.

The non-addressed devices can be placed in mute mode by means of the muting function. To use the mute mode feature, the MME bit must be set in the USART_CR1 register.

Note: When FIFO management is enabled and MME is already set, MME bit must not be cleared and then set again quickly (within two usart_ker_ck cycles), otherwise mute mode might remain active.

When the mute mode is enabled:

- none of the reception status bits can be set;
- all the receive interrupts are inhibited;
- the RWU bit in USART_ISR register is set to 1. RWU can be controlled automatically by hardware or by software, through the MMRQ bit in the USART_RQR register, under certain conditions.

The USART can enter or exit from mute mode using one of two methods, depending on the WAKE bit in the USART_CR1 register:

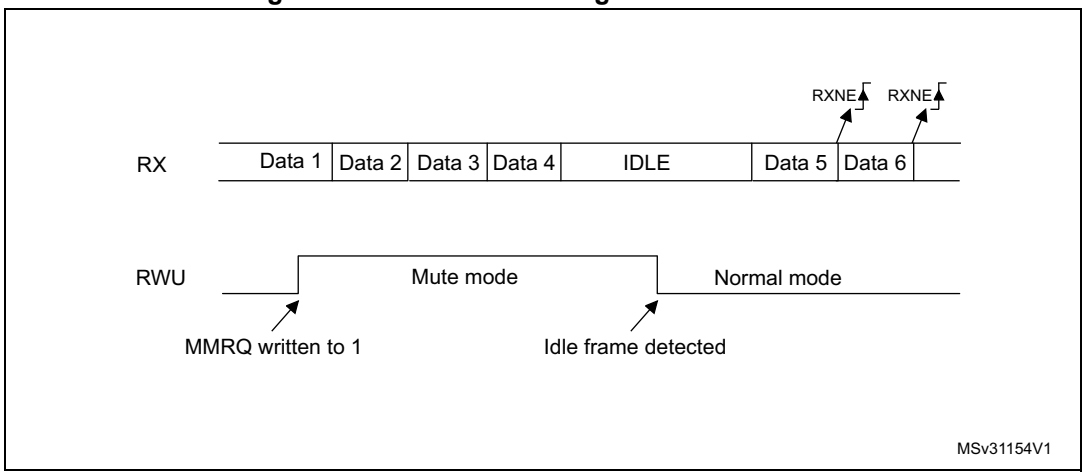
- Idle line detection if the WAKE bit is reset,
- Address mark detection if the WAKE bit is set.

Idle line detection (WAKE = 0)

The USART enters mute mode when the MMRQ bit is written to 1 and the RWU is automatically set.

The USART wakes up when an Idle frame is detected. The RWU bit is then cleared by hardware but the IDLE bit is not set in the USART_ISR register. An example of mute mode behavior using Idle line detection is given in *Figure 831*.

Figure 831. Mute mode using Idle line detection



Note: If the MMRQ is set while the IDLE character has already elapsed, mute mode is not entered (RWU is not set).

If the USART is activated while the line is idle, the idle state is detected after the duration of one IDLE frame (not only after the reception of one character frame).

4-bit/7-bit address mark detection (WAKE = 1)

In this mode, bytes are recognized as addresses if their MSB is a 1, otherwise they are considered as data. In an address byte, the address of the targeted receiver is put in the 4 or 7 LSBs. The choice of 7 or 4 bit address detection is done using the ADDM7 bit. This 4-bit/7-bit word is compared by the receiver with its own address which is programmed in the ADD bits in the USART_CR2 register.

Note: In 7-bit and 9-bit data modes, address detection is done on 6-bit and 8-bit addresses (ADD[5:0] and ADD[7:0]) respectively.

The USART enters mute mode when an address character is received which does not match its programmed address. In this case, the RWU bit is set by hardware. The RXNE flag is not set for this address byte and no interrupt or DMA request is issued when the USART enters mute mode. When FIFO management is enabled, the software must ensure that there is at least one empty location in the RXFIFO before entering mute mode.

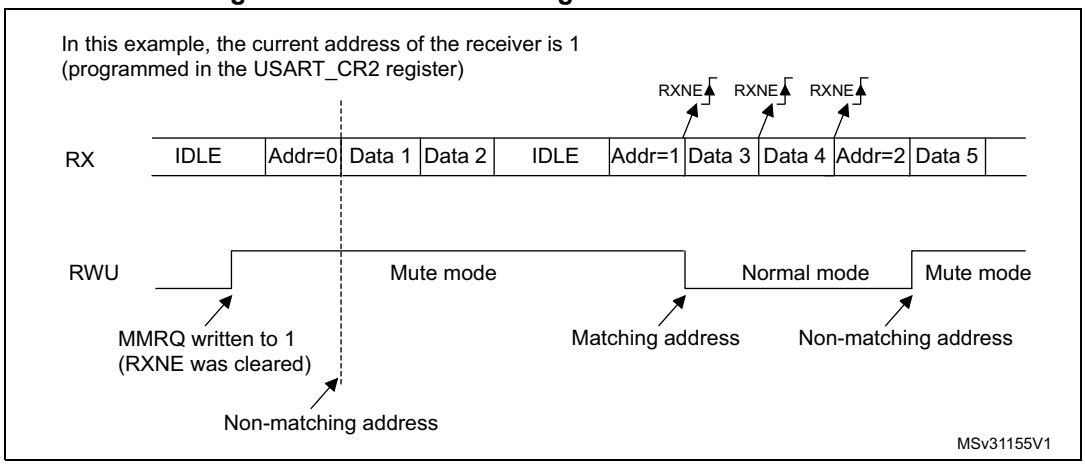
The USART also enters mute mode when the MMRQ bit is written to 1. The RWU bit is also automatically set in this case.

The USART exits from mute mode when an address character is received which matches the programmed address. Then the RWU bit is cleared and subsequent bytes are received normally. The RXNE/RXFNE bit is set for the address character since the RWU bit has been cleared.

Note: When FIFO management is enabled, when MMRQ is set while the receiver is sampling last bit of a data, this data may be received before effectively entering in mute mode

An example of mute mode behavior using address mark detection is given in *Figure 832*.

Figure 832. Mute mode using address mark detection



61.5.12 USART Modbus communication

The USART offers basic support for the implementation of Modbus/RTU and Modbus/ASCII protocols. Modbus/RTU is a half-duplex, block-transfer protocol. The control part of the protocol (address recognition, block integrity control and command interpretation) must be implemented in software.

The USART offers basic support for the end of the block detection, without software overhead or other resources.

Modbus/RTU

In this mode, the end of one block is recognized by a “silence” (idle line) for more than 2 character times. This function is implemented through the programmable timeout function.

The timeout function and interrupt must be activated, through the RTOEN bit in the USART_CR2 register and the RTOIE in the USART_CR1 register. The value corresponding to a timeout of 2 character times (for example 22 x bit time) must be programmed in the RTO register. When the receive line is idle for this duration, after the last stop bit is received, an interrupt is generated, informing the software that the current block reception has not completed.

Modbus/ASCII

In this mode, the end of a block is recognized by a specific (CR/LF) character sequence. The USART manages this mechanism using the character match function.

By programming the LF ASCII code in the ADD[7:0] field and by activating the character match interrupt (CMIE = 1), the software is informed when a LF has been received and can check the CR/LF in the DMA buffer.

61.5.13 USART parity control

Parity control (generation of parity bit in transmission and parity checking in reception) can be enabled by setting the PCE bit in the USART_CR1 register. Depending on the frame length defined by the M bits, the possible USART frame formats are as listed in *Table 674*.

Table 674. USART frame formats

M bits	PCE bit	USART frame(1)
00	0	| SB | 8 bit data | STB |
00	1	| SB | 7-bit data | PB | STB |
01	0	| SB | 9-bit data | STB |
01	1	| SB | 8-bit data PB | STB |
10	0	| SB | 7bit data | STB |
10	1	| SB | 6-bit data | PB | STB |

1. Legends: SB: start bit, STB: stop bit, PB: parity bit. In the data register, the PB is always taking the MSB position (8th or 7th, depending on the M bit value).

Even parity

The parity bit is calculated to obtain an even number of “1s” inside the frame of the 6, 7 or 8 LSB bits (depending on M bit values) and the parity bit.

As an example, if data = 00110101, and 4 bits are set, then the parity bit is equal to 0 if even parity is selected (PS bit in USART_CR1 = 0).

Odd parity

The parity bit is calculated to obtain an odd number of “1s” inside the frame made of the 6, 7 or 8 LSB bits (depending on M bit values) and the parity bit.

As an example, if data = 00110101 and 4 bits set, then the parity bit is equal to 1 if odd parity is selected (PS bit in USART_CR1 = 1).

Parity checking in reception

If the parity check fails, the PE flag is set in the USART_ISR register and an interrupt is generated if PEIE is set in the USART_CR1 register. The PE flag is cleared by software writing 1 to the PECF in the USART_ICR register.

Parity generation in transmission

If the PCE bit is set in USART_CR1, then the MSB bit of the data written in the data register is transmitted but is changed by the parity bit (even number of “1s” if even parity is selected (PS = 0) or an odd number of “1s” if odd parity is selected (PS = 1)).

61.5.14 USART LIN (local interconnection network) mode

This section is relevant only when LIN mode is supported. Refer to *Section 61.4: USART implementation*.

The LIN mode is selected by setting the LINEN bit in the USART_CR2 register. In LIN mode, the following bits must be kept cleared:

- STOP[1:0] and CLKEN in the USART_CR2 register,
- SCEN, HDSEL and IREN in the USART_CR3 register.

LIN transmission

The procedure described in *Section 61.5.5* has to be applied for LIN master transmission. It must be the same as for normal USART transmission with the following differences:

- Clear the M bit to configure 8-bit word length.
- Set the LINEN bit to enter LIN mode. In this case, setting the SBKRQ bit sends 13 zero bits as a break character. Then 2 bits of value ‘1 are sent to enable the next start detection.

LIN reception

When LIN mode is enabled, the break detection circuit is activated. The detection is totally independent from the normal USART receiver. A break can be detected whenever it occurs, during Idle state or during a frame.

When the receiver is enabled (RE = 1 in USART_CR1), the circuit looks at the RX input for a start signal. The method for detecting start bits is the same when searching break characters or data. After a start bit has been detected, the circuit samples the next bits exactly like for the data (on the 8th, 9th and 10th samples). If 10 (when the LBDL = 0 in USART_CR2) or 11 (when LBDL = 1 in USART_CR2) consecutive bits are detected as 0, and are followed by a delimiter character, the LBDF flag is set in USART_ISR. If the LBDIE bit = 1, an interrupt is generated. Before validating the break, the delimiter is checked for as it signifies that the RX line has returned to a high level.

If a 1 is sampled before the 10 or 11 have occurred, the break detection circuit cancels the current detection and searches for a start bit again.

If the LIN mode is disabled (LINEN = 0), the receiver continues working as normal USART, without taking into account the break detection.

If the LIN mode is enabled (LINEN = 1), as soon as a framing error occurs (that is, stop bit detected at 0, which is the case for any break frame), the receiver stops until the break detection circuit receives either a ‘1, if the break word was not complete, or a delimiter character if a break has been detected.

The behavior of the break detector state machine and the break flag is shown in *Figure 833*.

Examples of break frames are given in *Figure 834*.

Figure 833. Break detection in LIN mode (11-bit break length - LBDL bit is set)

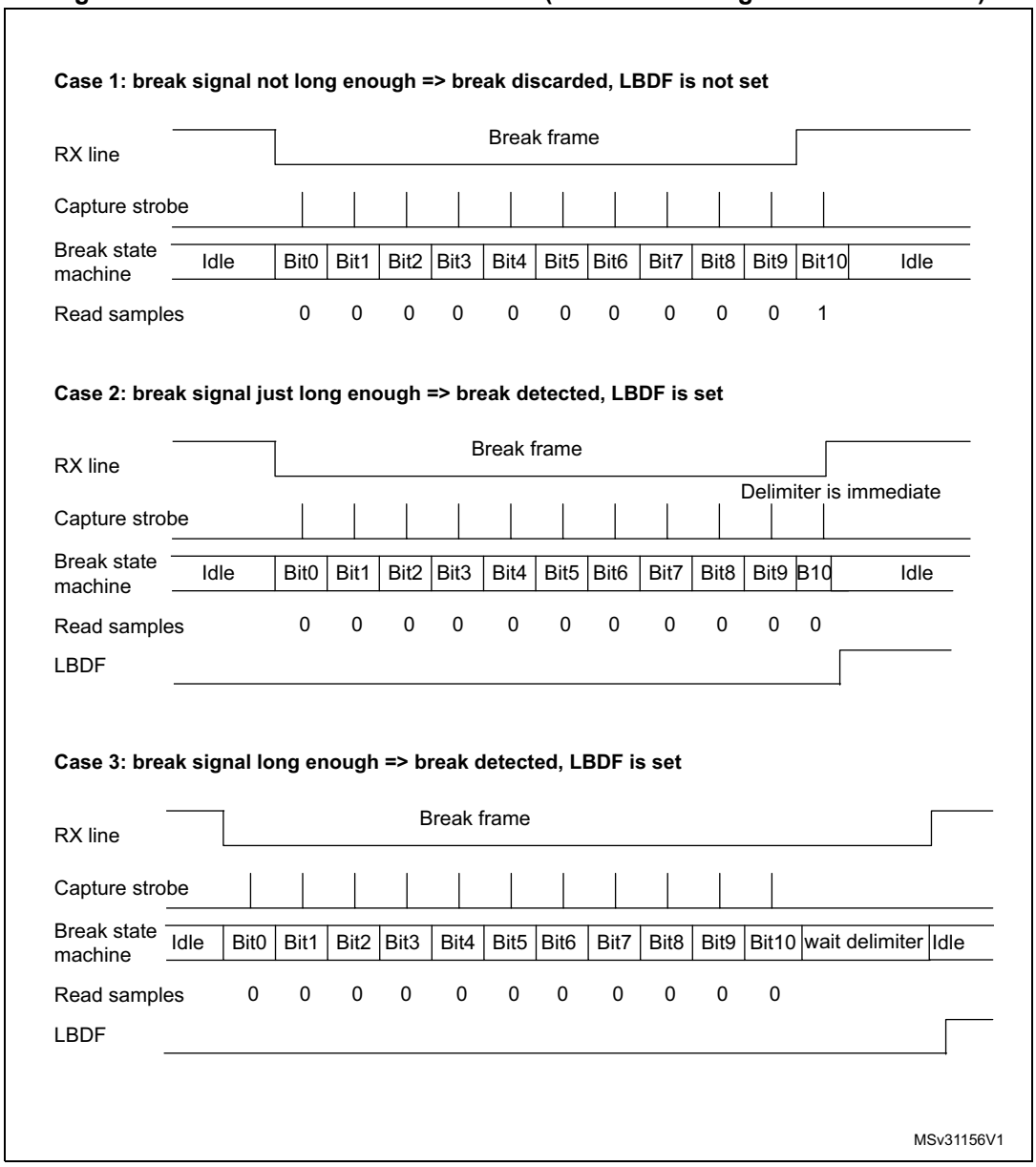
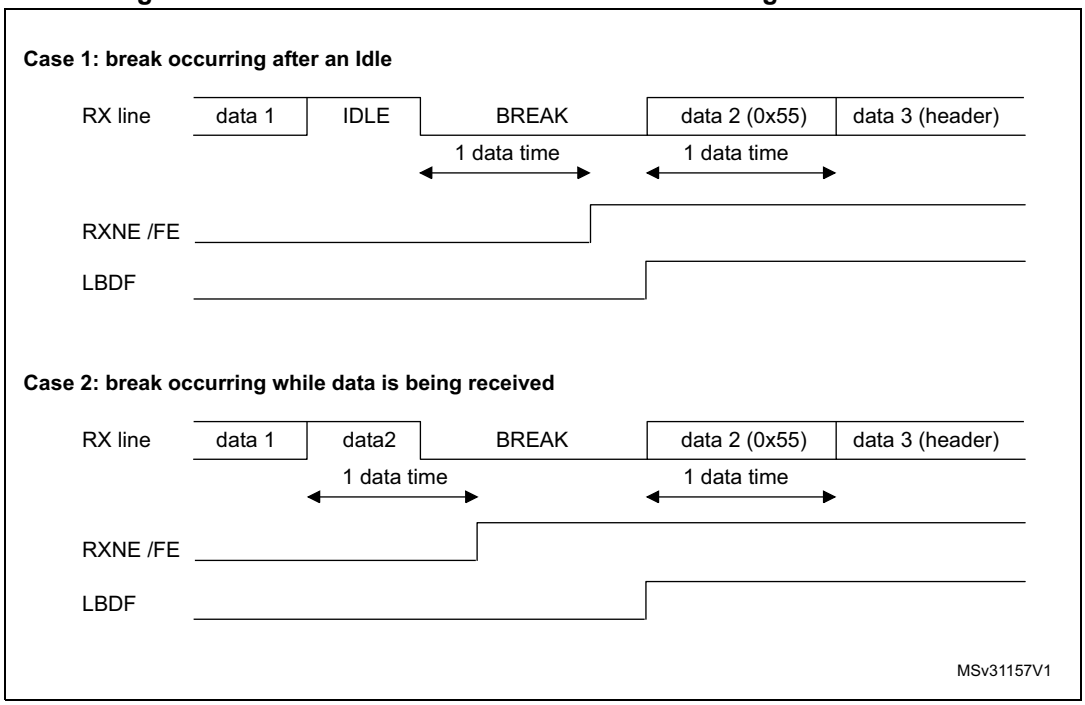


Figure 834. Break detection in LIN mode vs. Framing error detection



61.5.15 USART synchronous mode

Master mode

The synchronous master mode is selected by programming the CLKEN bit in the USART_CR2 register to 1. In synchronous mode, the following bits must be kept cleared:

- LINEN bit in the USART_CR2 register,
- SCEN, HDSEL and IREN bits in the USART_CR3 register.

In this mode, the USART can be used to control bidirectional synchronous serial communications in master mode. The CK pin is the output of the USART transmitter clock. No clock pulses are sent to the CK pin during start bit and stop bit. Depending on the state of the LBCL bit in the USART_CR2 register, clock pulses are, or are not, generated during the last valid data bit (address mark). The CPOL bit in the USART_CR2 register is used to select the clock polarity, and the CPHA bit in the USART_CR2 register is used to select the phase of the external clock (see *Figure 835*, *Figure 836* and *Figure 837*).

During the Idle state, preamble and send break, the external CK clock is not activated.

In synchronous master mode, the USART transmitter operates exactly like in asynchronous mode. However, since CK is synchronized with TX (according to CPOL and CPHA), the data on TX is synchronous.

In synchronous master mode, the USART receiver operates in a different way compared to asynchronous mode. If RE is set to 1, the data are sampled on CK (rising or falling edge, depending on CPOL and CPHA), without any oversampling. A given setup and a hold time must be respected (which depends on the baud rate: 1/16 bit time).

Note: In master mode, the CK pin operates in conjunction with the TX pin. Thus, the clock is provided only if the transmitter is enabled (TE = 1) and data are being transmitted (USART_TDR data register written). This means that it is not possible to receive synchronous data without transmitting data.

Figure 835. USART example of synchronous master transmission

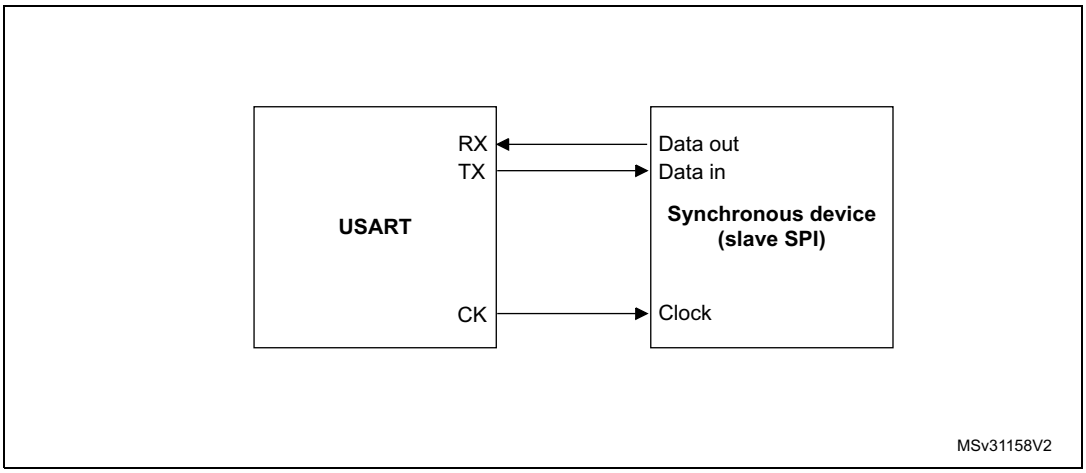


Figure 836. USART data clock timing diagram in synchronous master mode (M bits = 00)

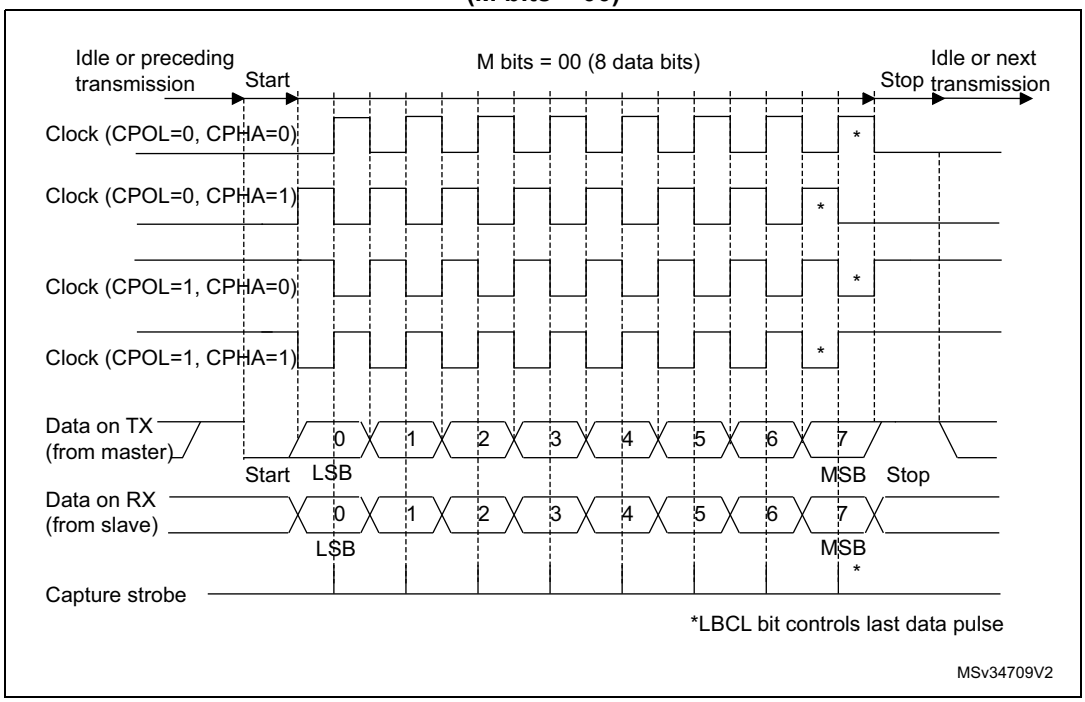
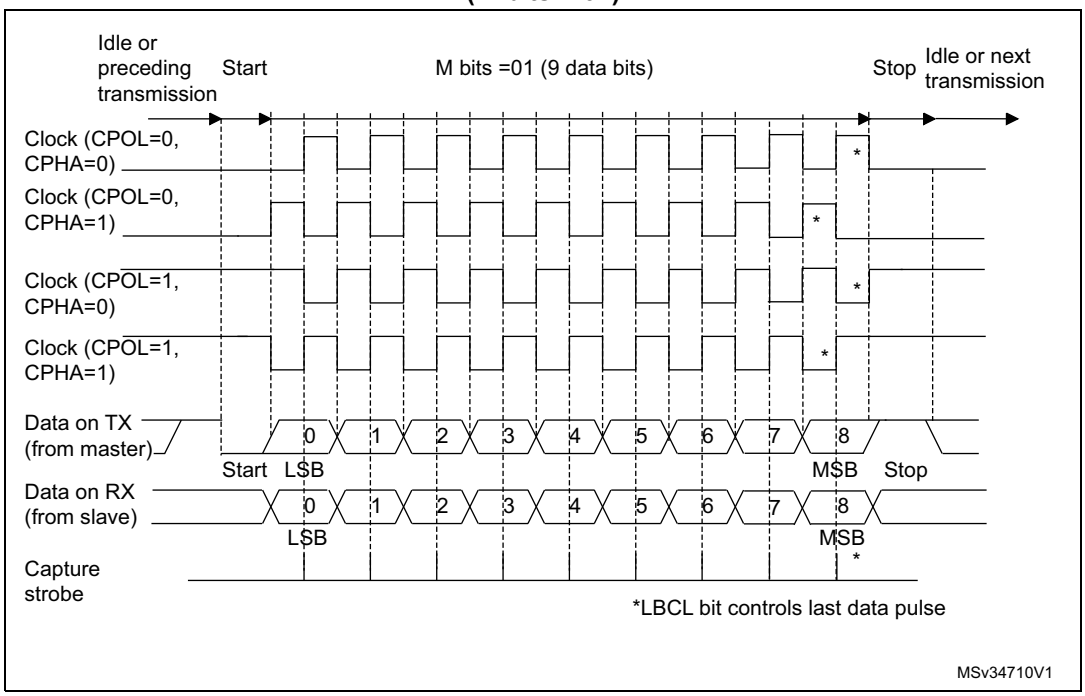


Figure 837. USART data clock timing diagram in synchronous master mode (M bits = 01)



Slave mode

The synchronous slave mode is selected by programming the SLVEN bit in the USART_CR2 register to 1. In synchronous slave mode, the following bits must be kept cleared:

- LINEN and CLKEN bits in the USART_CR2 register,
- SCEN, HDSEL and IREN bits in the USART_CR3 register.

In this mode, the USART can be used to control bidirectional synchronous serial communications in slave mode. The CK pin is the input of the USART in slave mode.

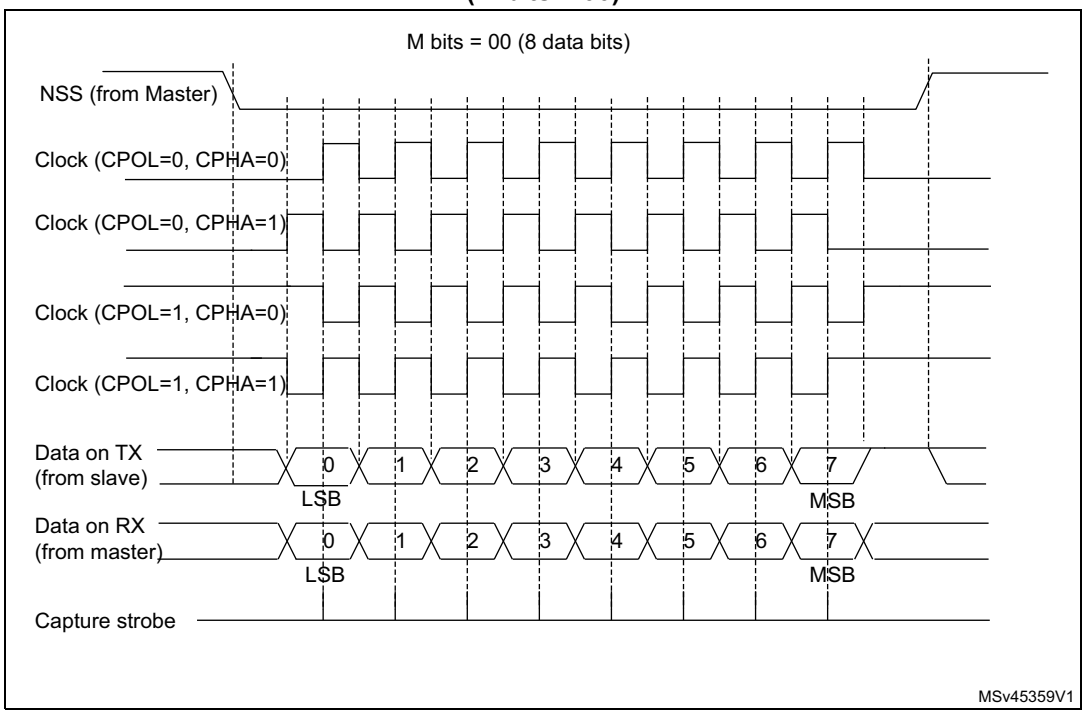
*Note: When the peripheral is used in SPI slave mode, the frequency of peripheral clock source (*usart_ker_ck_pres*) must be greater than 3 times the CK input frequency.*

The CPOL bit and the CPHA bit in the USART_CR2 register are used to select the clock polarity and the phase of the external clock, respectively (see *Figure 838*).

An underrun error flag is available in slave transmission mode. This flag is set when the first clock pulse for data transmission appears while the software has not yet loaded any value to USART_TDR.

The slave supports the hardware and software NSS management.

Figure 838. USART data clock timing diagram in synchronous slave mode (M bits = 00)



Slave Select (NSS) pin management

The hardware or software slave select management can be set through the DIS_NSS bit in the USART_CR2 register:

- Software NSS management (DIS_NSS = 1)

  SPI slave is always selected and NSS input pin is ignored.

  The external NSS pin remains free for other application uses.
- Hardware NSS management (DIS_NSS = 0)

  The SPI slave selection depends on NSS input pin. The slave is selected when NSS is low and deselected when NSS is high.

Note: The LBCL (used only on SPI master mode), CPOL and CPHA bits have to be selected when the USART is disabled (UE = 0) to ensure that the clock pulses function correctly.

In SPI slave mode, the USART must be enabled before starting the master communications (or between frames while the clock is stable). Otherwise, if the USART slave is enabled while the master is in the middle of a frame, it becomes desynchronized with the master. The data register of the slave needs to be ready before the first edge of the communication clock or before the end of the ongoing communication, otherwise the SPI slave transmits zeros.

SPI slave underrun error

When an underrun error occurs, the UDR flag is set in the USART_ISR register, and the SPI slave goes on sending the last data until the underrrun error flag is cleared by software.

The underrun flag is set at the beginning of the frame. An underrun error interrupt is triggered if EIE bit is set in the USART_CR3 register.

The underrun error flag is cleared by setting bit UDRCF in the USART_ICR register.

In case of underrun error, it is still possible to write to the TDR register. Clearing the underrun error enables sending new data.

If an underrun error occurred and there is no new data written in TDR, then the TC flag is set at the end of the frame.

Note: An underrun error may occur if the moment the data is written to the USART_TDR is too close to the first CK transmission edge. To avoid this underrun error, the USART_TDR must be written 3 usart_ker_ck *cycles before the first CK edge.*

61.5.16 USART single-wire half-duplex communication

Single-wire half-duplex mode is selected by setting the HDSEL bit in the USART_CR3 register. In this mode, the following bits must be kept cleared:

- LINEN and CLKEN bits in the USART_CR2 register,
- SCEN and IREN bits in the USART_CR3 register.

The USART can be configured to follow a single-wire half-duplex protocol where the TX and RX lines are internally connected. The selection between half- and full-duplex communication is made with a control bit HDSEL in USART_CR3.

As soon as HDSEL is written to 1:

- The TX and RX lines are internally connected.
- The RX pin is no longer used.
- The TX pin is always released when no data is transmitted. Thus, it acts as a standard I/O in idle or in reception. It means that the I/O must be configured so that TX is configured as alternate function open-drain with an external pull-up.

Apart from this, the communication protocol is similar to normal USART mode. Any conflict on the line must be managed by software (for instance by using a centralized arbiter). In particular, the transmission is never blocked by hardware and continues as soon as data are written in the data register while the TE bit is set.

61.5.17 USART receiver timeout

The receiver timeout feature is enabled by setting the RTOEN bit in the USART_CR2 control register.

The timeout duration is programmed using the RTO bitfields in the USART_RTOR register.

The receiver timeout counter starts counting:

- from the end of the stop bit if STOP = 00 or STOP = 11
- from the end of the second stop bit if STOP = 10.
- from the beginning of the stop bit if STOP = 01.

When the timeout duration has elapsed, the RTOF flag in the USART_ISR register is set. A timeout is generated if RTOIE bit in USART_CR1 register is set.

61.5.18 USART smartcard mode

This section is relevant only when smartcard mode is supported. Refer to *Section 61.4: USART implementation*.

Smartcard mode is selected by setting the SCEN bit in the USART_CR3 register. In smartcard mode, the following bits must be kept cleared:

- LINEN bit in the USART_CR2 register,
- HDSEL and IREN bits in the USART_CR3 register.

The CLKEN bit can also be set to provide a clock to the smartcard.

The smartcard interface is designed to support asynchronous smartcard protocol as defined in the ISO 7816-3 standard. Both T = 0 (character mode) and T = 1 (block mode) are supported.

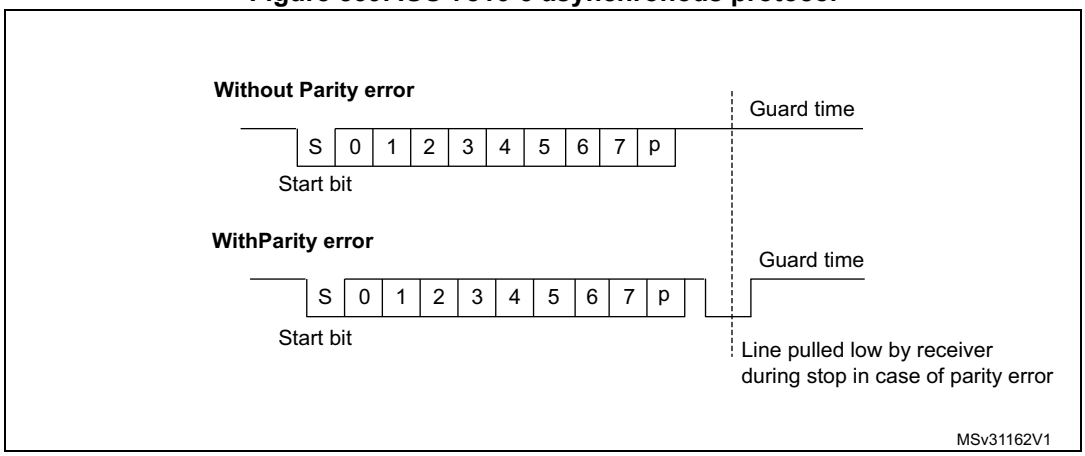
The USART must be configured as:

- 8 bits plus parity: M = 1 and PCE = 1 in the USART_CR1 register
- 1.5 stop bits when transmitting and receiving data: STOP = 11 in the USART_CR2 register. It is also possible to choose 0.5 stop bit for reception.

In T = 0 (character) mode, the parity error is indicated at the end of each character during the guard time period.

Figure 839 shows examples of what can be seen on the data line with and without parity error.

Figure 839. ISO 7816-3 asynchronous protocol



When connected to a smartcard, the TX output of the USART drives a bidirectional line that is also driven by the smartcard. The TX pin must be configured as open drain.

Smartcard mode implements a single wire half duplex communication protocol.

- Transmission of data from the transmit shift register is guaranteed to be delayed by a minimum of 1/2 baud clock. In normal operation a full transmit shift register starts shifting on the next baud clock edge. In smartcard mode this transmission is further delayed by a guaranteed 1/2 baud clock.
- In transmission, if the smartcard detects a parity error, it signals this condition to the USART by driving the line low (NACK). This NACK signal (pulling transmit line low for 1 baud clock) causes a framing error on the transmitter side (configured with 1.5 stop bits). The USART can handle automatic re-sending of data according to the protocol.

The number of retries is programmed in the SCARCNT bitfield. If the USART continues receiving the NACK after the programmed number of retries, it stops transmitting and signals the error as a framing error. The TXE bit (TXFNF bit in case FIFO mode is enabled) may be set using the TXFRQ bit in the USART_RQR register.

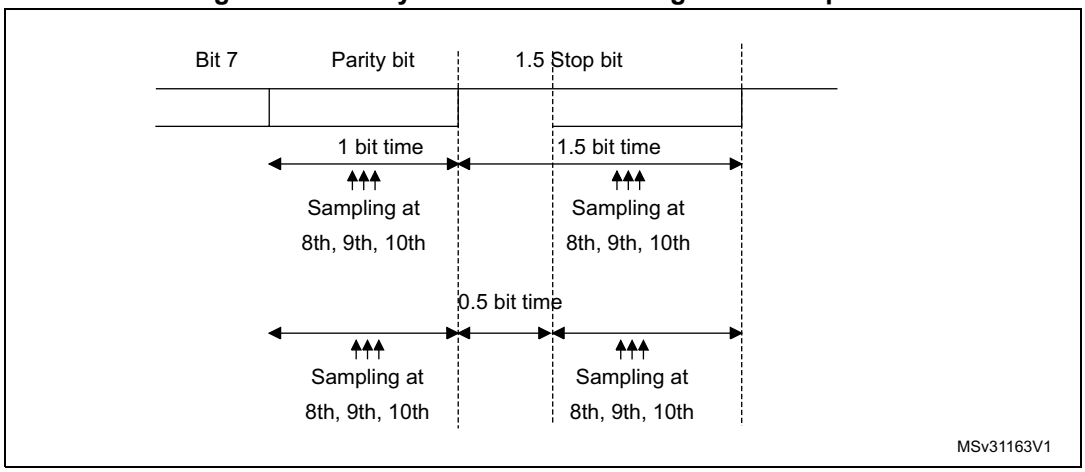
- Smartcard auto-retry in transmission: A delay of 2.5 baud periods is inserted between the NACK detection by the USART and the start bit of the repeated character. The TC bit is set immediately at the end of reception of the last repeated character (no guard time). If the software wants to repeat it again, it must ensure the minimum 2-baud periods required by the standard.
- If a parity error is detected during reception of a frame programmed with a 1.5 stop bit period, the transmit line is pulled low for a baud clock period after the completion of the receive frame. This is to indicate to the smartcard that the data transmitted to the USART has not been correctly received. A parity error is NACKed by the receiver if the NACK control bit is set, otherwise a NACK is not transmitted (to be used in T = 1 mode). If the received character is erroneous, the RXNE (RXFNE in case FIFO mode is enabled)/receive DMA request is not activated. According to the protocol specification, the smartcard must resend the same character. If the received character is still erroneous after the maximum number of retries specified in the SCARCNT bitfield, the USART stops transmitting the NACK and signals the error as a parity error.
- Smartcard auto-retry in reception: the BUSY flag remains set if the USART NACKs the card but the card doesn't repeat the character.
- In transmission, the USART inserts the guard time (as programmed in the guard time register) between two successive characters. As the guard time is measured after the stop bit of the previous character, the GT[7:0] register must be programmed to the desired CGT character guard time, as defined by the 7816-3 specification) minus 12 (the duration of one character).
- The assertion of the TC flag can be delayed by programming the guard time register. In normal operation, TC is asserted when the transmit shift register is empty and no further transmit requests are outstanding. In smartcard mode an empty transmit shift register triggers the guard time counter to count up to the programmed value in the guard time register. TC is forced low during this time. When the guard time counter reaches the programmed value TC is asserted high. The TCBGT flag can be used to detect the end of data transfer without waiting for guard time completion. This flag is set just after the end of frame transmission and if no NACK has been received from the card.
- The de-assertion of TC flag is unaffected by smartcard mode.
- If a framing error is detected on the transmitter end (due to a NACK from the receiver), the NACK is not detected as a start bit by the receive block of the transmitter. According to the ISO protocol, the duration of the received NACK can be 1 or 2 baud clock periods.
- On the receiver side, if a parity error is detected and a NACK is transmitted the receiver does not detect the NACK as a start bit.

Note: Break characters are not significant in smartcard mode. A 0x00 data with a framing error is treated as data and not as a break.

No Idle frame is transmitted when toggling the TE bit. The Idle frame (as defined for the other configurations) is not defined by the ISO protocol.

Figure 840 shows how the NACK signal is sampled by the USART. In this example the USART is transmitting data and is configured with 1.5 stop bits. The receiver part of the USART is enabled in order to check the integrity of the data and the NACK signal.

Figure 840. Parity error detection using the 1.5 stop bits



The USART can provide a clock to the smartcard through the CK output. In smartcard mode, CK is not associated to the communication but is simply derived from the internal peripheral input clock through a 5-bit prescaler. The division ratio is configured in the USART_GTPR register. CK frequency can be programmed from usart_ker_ck_pres/2 to usart_ker_ck_pres/62, where usart_ker_ck_pres is the peripheral input clock divided by a programmed prescaler.

Block mode (T = 1)

In T = 1 (block) mode, the parity error transmission can be deactivated by clearing the NACK bit in the USART_CR3 register.

When requesting a read from the smartcard, in block mode, the software must program the RTOR register to the BWT (block wait time) – 11 value. If no answer is received from the card before the expiration of this period, a timeout interrupt is generated. If the first character is received before the expiration of the period, it is signaled by the RXNE/RXFNE interrupt.

Note: The RXNE/RXFNE interrupt must be enabled even when using the USART in DMA mode to read from the smartcard in block mode. In parallel, the DMA must be enabled only after the first received byte.

After the reception of the first character (RXNE/RXFNE interrupt), the RTO register must be programmed to the CWT (character wait time – 11 value), in order to enable the automatic check of the maximum wait time between two consecutive characters. This time is expressed in baud time units. If the smartcard does not send a new character in less than the CWT period after the end of the previous character, the USART signals it to the software through the RTOF flag and interrupt (when RTOIE bit is set).

Note: As in the smartcard protocol definition, the BWT/CWT values must be defined from the beginning (start bit) of the last character. The RTO register must be programmed to BWT – 11 or CWT – 11, respectively, taking into account the length of the last character itself.

A block length counter is used to count all the characters received by the USART. This counter is reset when the USART is transmitting. The length of the block is communicated by the smartcard in the third byte of the block (prologue field). This value must be programmed to the BLEN field in the USART_RTOR register. When using DMA mode, before the start of the block, this register field must be programmed to the minimum value

(0x0). With this value, an interrupt is generated after the 4th received character. The software must read the LEN field (third byte), its value must be read from the receive buffer.

In interrupt driven receive mode, the length of the block may be checked by software or by programming the BLEN value. However, before the start of the block, the maximum value of BLEN (0xFF) may be programmed. The real value is programmed after the reception of the third character.

If the block is using the LRC longitudinal redundancy check (1 epilogue byte), the BLEN=LEN. If the block is using the CRC mechanism (2 epilog bytes), BLEN=LEN+1 must be programmed. The total block length (including prologue, epilogue and information fields) equals BLEN+4. The end of the block is signaled to the software through the EOBF flag and interrupt (when EOBIE bit is set).

In case of an error in the block length, the end of the block is signaled by the RTO interrupt (Character Wait Time overflow).

Note: The error checking code (LRC/CRC) must be computed/verified by software.

Direct and inverse convention

The smartcard protocol defines two conventions: direct and inverse.

The direct convention is defined as: LSB first, logical bit value of 1 corresponds to a H state of the line and parity is even. In order to use this convention, the following control bits must be programmed: MSBFIRST = 0, DATAINV = 0 (default values).

The inverse convention is defined as: MSB first, logical bit value 1 corresponds to an L state on the signal line and parity is even. In order to use this convention, the following control bits must be programmed: MSBFIRST = 1, DATAINV =1.

Note: When logical data values are inverted (0 = H, 1 = L), the parity bit is also inverted in the same way.

In order to recognize the card convention, the card sends the initial character, TS, as the first character of the ATR (Answer To Reset) frame. The two possible patterns for the TS are: LHHL LLL LLH and LHHL HHH LLH.

- (H) LHHL LLL LLH sets up the inverse convention: state L encodes value 1 and moment 2 conveys the most significant bit (MSB first). When decoded by inverse convention, the conveyed byte is equal to '3F'.
- (H) LHHL HHH LLH sets up the direct convention: state H encodes value 1 and moment 2 conveys the least significant bit (LSB first). When decoded by direct convention, the conveyed byte is equal to '3B'.

Character parity is correct when there is an even number of bits set to 1 in the nine moments 2 to 10.

As the USART does not know which convention is used by the card, it needs to be able to recognize either pattern and act accordingly. The pattern recognition is not done in hardware, but through a software sequence. Moreover, supposing that the USART is configured in direct convention (default) and the card answers with the inverse convention, TS = LHHL LLL LLH ≥ the USART received character is equal to 03 and the parity is odd.

Therefore, two methods are available for TS pattern recognition:

Method 1

The USART is programmed in standard smartcard mode/direct convention. In this case, the TS pattern reception generates a parity error interrupt and error signal to the card.

- The parity error interrupt informs the software that the card did not answer correctly in direct convention. Software then reprograms the USART for inverse convention
- In response to the error signal, the card retries the same TS character, and it is correctly received this time, by the reprogrammed USART

Alternatively, in answer to the parity error interrupt, the software may decide to reprogram the USART and to also generate a new reset command to the card, then wait again for the TS.

Method 2

The USART is programmed in 9-bit/no-parity mode, no bit inversion. In this mode it receives any of the two TS patterns as:

(H) LHHL LLL LLH = 0x103: inverse convention to be chosen

(H) LHHL HHH LLH = 0x13B: direct convention to be chosen

The software checks the received character against these two patterns and, if any of them match, then programs the USART accordingly for the next character reception.

If none of the two is recognized, a card reset may be generated in order to restart the negotiation.

61.5.19 USART IrDA SIR ENDEC block

This section is relevant only when IrDA mode is supported. Refer to *Section 61.4: USART implementation*.

IrDA mode is selected by setting the IREN bit in the USART_CR3 register. In IrDA mode, the following bits must be kept cleared:

- LINEN, STOP and CLKEN bits in the USART_CR2 register,
- SCEN and HDSEL bits in the USART_CR3 register.

The IrDA SIR physical layer specifies the use of a return-to-zero, inverted (RZI) modulation scheme that represents logic 0 as an infrared light pulse (see *Figure 841*).

The encoding and decoding of data in IrDA mode is handled by hardware blocks.

Even if IrDA is a half-duplex protocol, it requires two pins for transmission and reception (USART_TX and USART_RX).

The SIR transmit encoder modulates the non return-to-zero (NRZ) transmit bit stream output from USART. The output pulse stream is transmitted to an external output driver and infrared LED. USART supports only bit rates up to 115.2 kbauds for the SIR ENDEC. In normal mode the transmitted pulse width is specified as 3/16 of a bit period.

The SIR receive decoder demodulates the return-to-zero bit stream from the infrared detector and outputs the received NRZ serial bit stream to the USART. The decoder input is normally high (marking state) in the Idle state. The transmit encoder output has the opposite polarity to the decoder input. A start bit is detected when the decoder input is low.

- IrDA is a half duplex communication protocol. If the Transmitter is busy (when the USART is sending data to the IrDA encoder), any data on the IrDA receive line is

ignored by the IrDA decoder and if the Receiver is busy (when the USART is receiving decoded data from the USART), data on the TX from the USART to IrDA is not encoded. While receiving data, transmission must be avoided as the data to be transmitted may be corrupted.

- A 0 is transmitted as a high pulse and a 1 is transmitted as a 0. The width of the pulse is specified as 3/16th of the selected bit period in normal mode (see *Figure 842*).
- The SIR decoder converts the IrDA compliant receive signal into a bit stream for USART.
- The SIR receive logic interprets a high state as a logic one and low pulses as logic zeros.
- The transmit encoder output has the opposite polarity to the decoder input. The SIR output is in low state when Idle.
- The IrDA specification requires the acceptance of pulses greater than 1.41 µs. The acceptable pulse width is programmable. Glitch detection logic on the receiver end filters out pulses of width less than two periods, where the period equals PSC / usart_ker_ck_pres (PSC being the prescaler value programmed in the PSC[7:0] bitfield of the USART_GTPR register). Pulses of width less than one period are always rejected, but those of width greater than one and less than two periods may be accepted or rejected, those greater than two periods are accepted as a pulse. The IrDA encoder/decoder does not work when PSC = 0.
- The receiver can communicate with a low-power transmitter.
- In IrDA mode, the stop bits in the USART_CR2 register must be configured to 1 stop bit.

IrDA low-power mode

- Transmitter

  In low-power mode, the pulse width is not maintained at 3 / 16 of the bit period. Instead, the width of the pulse is three times the IrDA low-power period. The IrDA low-power frequency minimum value is 1.42 MHz. Generally, this value is 1.8432 MHz (1.42 MHz < IrDA low-power frequency < 2.12 MHz). A low-power mode programmable divisor divides the system clock to achieve this value.
- Receiver

  Receiving in low-power mode is similar to receiving in normal mode. For glitch detection the USART must discard pulses of duration shorter than one IrDA low-power period. A valid low is accepted only if its duration is greater than two IrDA low-power periods.

Note: IrDA low-power period = PSC / usart_ker_ck_pres, where PSC corresponds to the value programmed in the PSC[7:0] bitfield of *the USART_GTPR register.*

A pulse of width less than two and greater than one IrDA low-power period may or may not be rejected.

The receiver set-up time must be managed by software. The IrDA physical layer specification specifies a minimum of 10 ms delay between transmission and reception.

Figure 841. IrDA SIR ENDEC block diagram

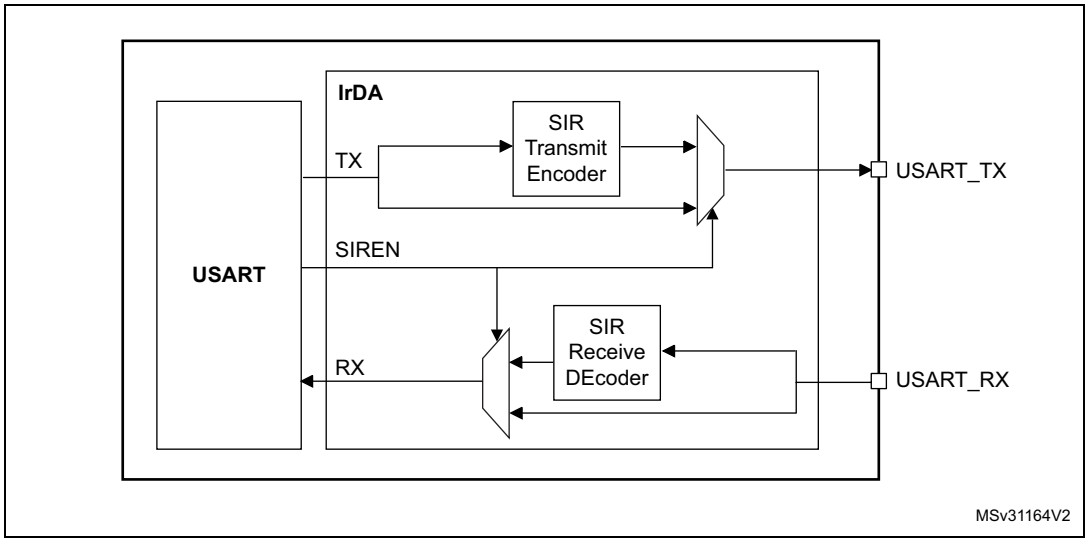
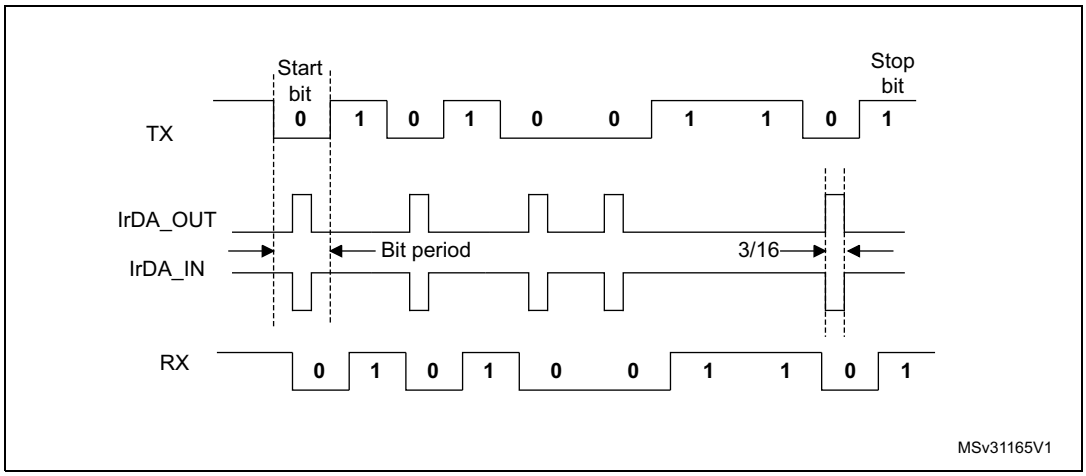


Figure 842. IrDA data modulation (3/16) - normal mode



61.5.20 Continuous communication using USART and DMA

The USART is capable of performing continuous communications using the DMA. The DMA requests for Rx buffer and Tx buffer are generated independently.

Note: Refer to Section 61.4: USART implementation to determine if the DMA mode is supported. If DMA is not supported, use the USART as explained in Section 61.5.7. To perform continuous communications when the FIFO is disabled, clear the TXE/ RXNE flags in the USART_ISR register.

Transmission using DMA

DMA mode can be enabled for transmission by setting the DMAT bit in the USART_CR3 register. Data are loaded from an SRAM area configured using the DMA peripheral (refer to *section direct memory access controller (DMA)*) to the USART_TDR register whenever the TXE flag (TXFNF flag if FIFO mode is enabled) is set. To map a DMA channel for USART transmission, use the following procedure (x denotes the channel number):

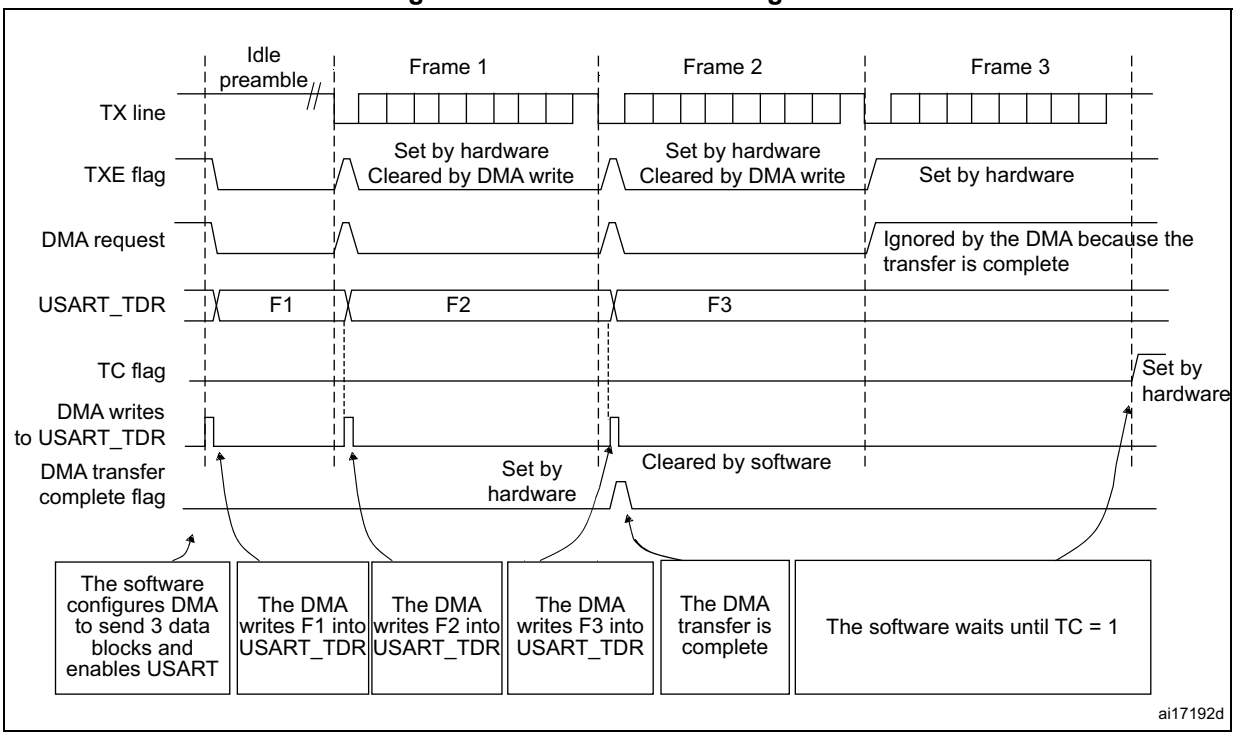
1. Write the USART_TDR register address in the DMA control register to configure it as the destination of the transfer. The data is moved to this address from memory after each TXE (or TXFNF if FIFO mode is enabled) event.
2. Write the memory address in the DMA control register to configure it as the source of the transfer. The data is loaded into the USART_TDR register from this memory area after each TXE (or TXFNF if FIFO mode is enabled) event.
3. Configure the total number of bytes to be transferred to the DMA control register.
4. Configure the channel priority in the DMA register
5. Configure DMA interrupt generation after half/ full transfer as required by the application.
6. Clear the TC flag in the USART_ISR register by setting the TCCF bit in the USART_ICR register.
7. Activate the channel in the DMA register.

When the number of data transfers programmed in the DMA controller is reached, the DMA controller generates an interrupt on the DMA channel interrupt vector.

In transmission mode, once the DMA has written all the data to be transmitted (DMA transfer complete), the TC flag can be monitored to make sure that the USART communication has completed. This is required to avoid corrupting the last transmission before disabling the USART or before the system enters a low-power mode when the peripheral clock is disabled. Software must wait until TC = 1. The TC flag remains cleared during all data transfers and it is set by hardware at the end of transmission of the last frame.

Note: The DMAT bit must not be cleared before the DMA end of transfer.

Figure 843. Transmission using DMA



Note: When FIFO management is enabled, the DMA request is triggered by transmit FIFO not full (that is, TXFNF = 1).

Reception using DMA

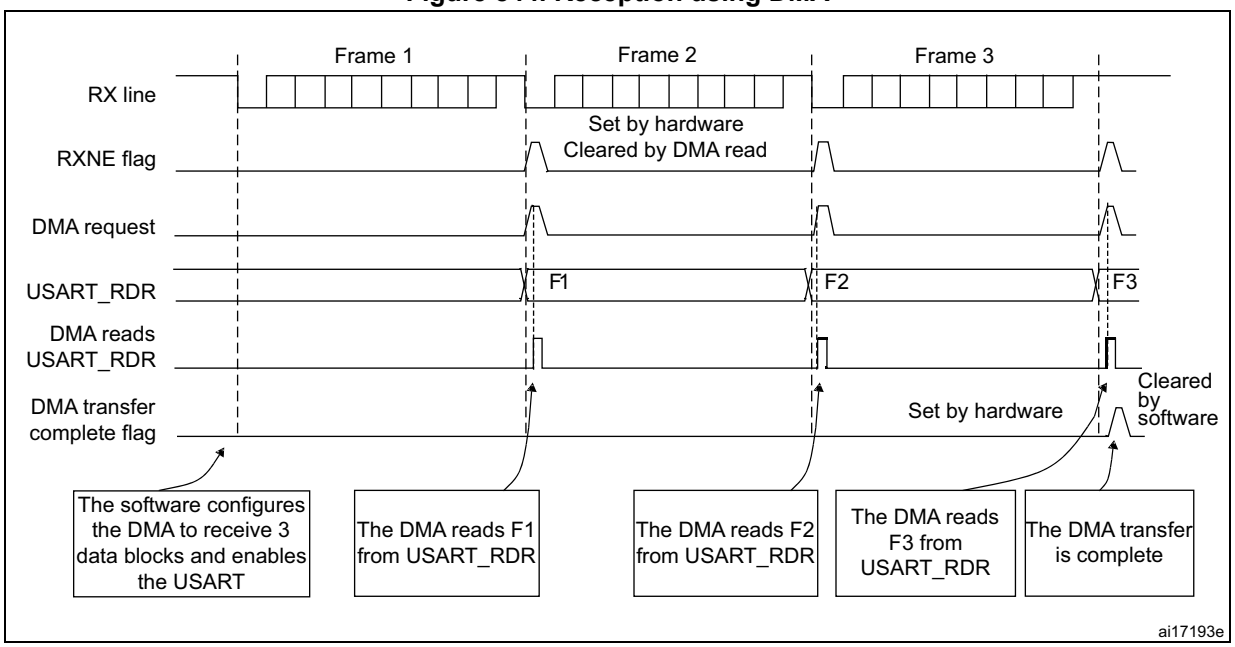
DMA mode can be enabled for reception by setting the DMAR bit in the USART_CR3 register. Data are loaded from the USART_RDR register to an SRAM area configured using the DMA peripheral (refer to *section direct memory access controller (DMA)*) whenever a data byte is received. To map a DMA channel for USART reception, use the following procedure:

1. Write the USART_RDR register address in the DMA control register to configure it as the source of the transfer. The data is moved from this address to the memory after each RXNE (RXFNE in case FIFO mode is enabled) event.
2. Write the memory address in the DMA control register to configure it as the destination of the transfer. The data is loaded from USART_RDR to this memory area after each RXNE (RXFNE in case FIFO mode is enabled) event.
3. Configure the total number of bytes to be transferred to the DMA control register.
4. Configure the channel priority in the DMA control register
5. Configure interrupt generation after half/ full transfer as required by the application.
6. Activate the channel in the DMA control register.

When the number of data transfers programmed in the DMA controller is reached, the DMA controller generates an interrupt on the DMA channel interrupt vector.

Note: The DMAR bit must not be cleared before the DMA end of transfer.

Figure 844. Reception using DMA



Note: When FIFO management is enabled, the DMA request is triggered by receive FIFO not empty (that is, RXFNE = 1).

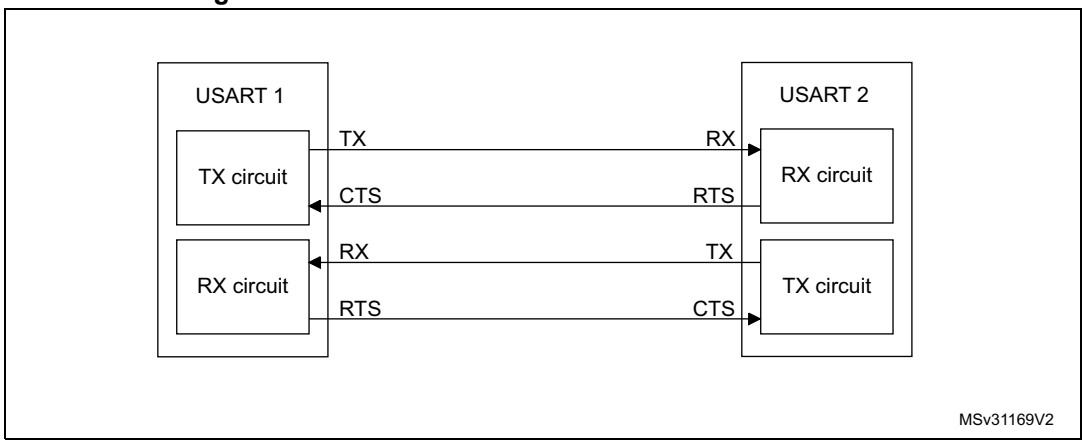
Error flagging and interrupt generation in multibuffer communication

If any error occurs during a transaction in multibuffer communication mode, the error flag is asserted after the current byte. An interrupt is generated if the interrupt enable flag is set. For framing error, overrun error and noise flag, which are asserted with RXNE (RXFNE in case FIFO mode is enabled) in single byte reception, there is a separate error flag interrupt enable bit (EIE bit in the USART_CR3 register), which, if set, enables an interrupt after the current byte if any of these errors occur.

61.5.21 RS232 hardware flow control and RS485 driver enable

It is possible to control the serial data flow between two devices by using the CTS input and the RTS output. The *Figure 845* shows how to connect two devices in this mode:

Figure 845. Hardware flow control between two USARTs

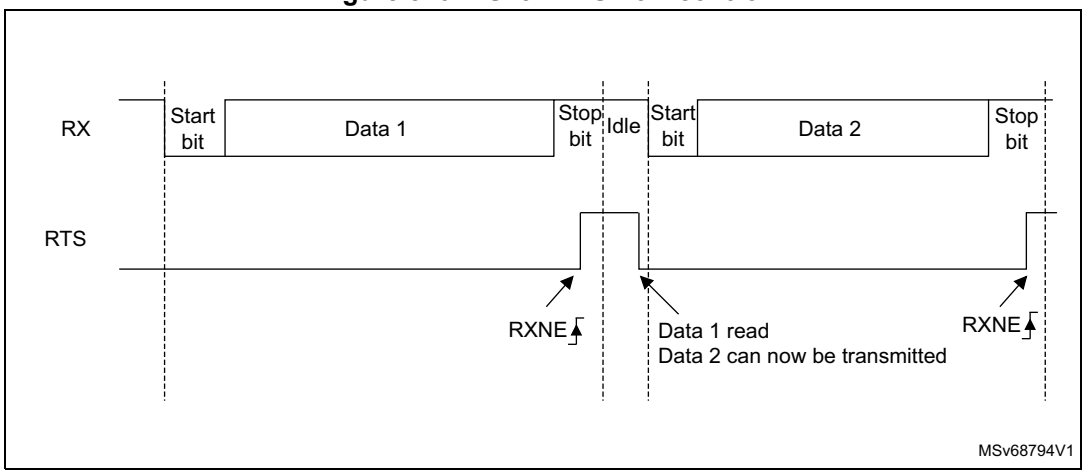


RS232 RTS and CTS flow control can be enabled independently by writing the RTSE and CTSE bits to 1 in the USART_CR3 register.

RS232 RTS flow control

If the RTS flow control is enabled (RTSE = 1), then RTS is deasserted (tied low) as long as the USART receiver is ready to receive a new data. When the receive register is full, RTS is asserted, indicating that the transmission is expected to stop at the end of the current frame. *Figure 846* shows an example of communication with RTS flow control enabled.

Figure 846. RS232 RTS flow control



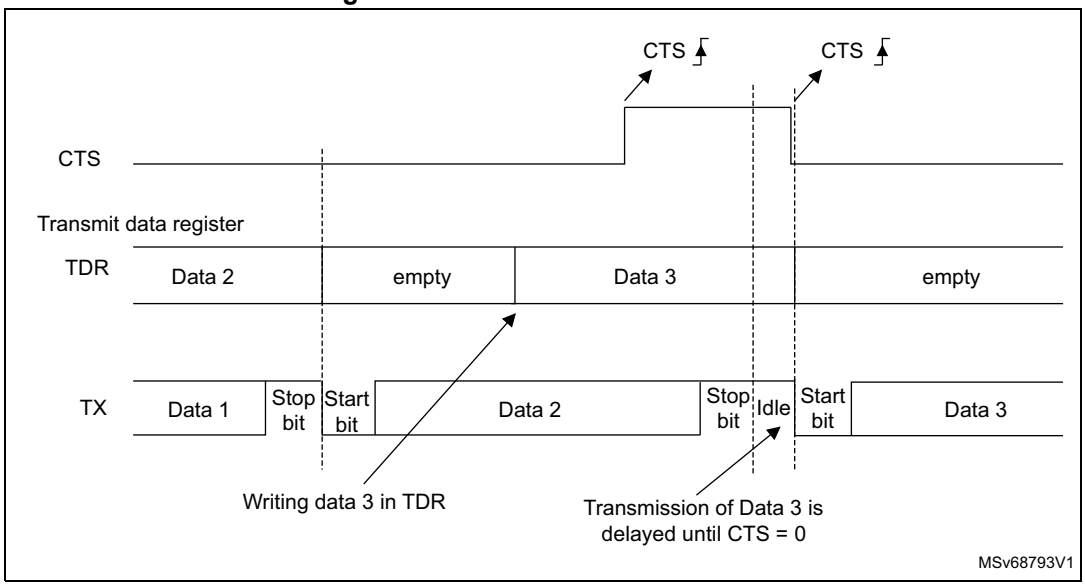
Note: When FIFO mode is enabled, RTS is asserted only when RXFIFO is full.

RS232 CTS flow control

If the CTS flow control is enabled (CTSE = 1), then the transmitter checks the CTS input before transmitting the next frame. If CTS is deasserted (tied low), then the next data is transmitted (assuming that data is to be transmitted, in other words, if TXE/TXFE = 0), else the transmission does not occur. When CTS is asserted during a transmission, the current transmission completes before the transmitter stops.

When CTSE = 1, the CTSIF status bit is automatically set by hardware as soon as the CTS input toggles. It indicates when the receiver becomes ready or not ready for communication. An interrupt is generated if the CTSIE bit in the USART_CR3 register is set. *Figure 847* shows an example of communication with CTS flow control enabled.

Figure 847. RS232 CTS flow control



Note: For correct behavior, CTS must be deasserted at least three USART clock source periods before the end of the current character. In addition, it must be noted that the CTSCF flag may not be set for pulses shorter than 2 x PCLK periods.

RS485 driver enable

The driver enable feature is enabled by setting bit DEM in the USART_CR3 control register. This enables the user to activate the external transceiver control, through the DE (driver enable) signal. The deassertion time is the time between the end of the last stop bit, in a transmitted message, and the de-activation of the DE signal. It is programmed using the DEDT [4:0] bitfields in the USART_CR1 control register. The polarity of the DE signal can be configured using the DEP bit in the USART_CR3 control register.

In USART, the DEAT and DEDT are expressed in sample time units (1/8 or 1/16 bit time, depending on the oversampling rate).

61.5.22 USART low-power management

The USART has advanced low-power mode functions, that enables transferring properly data even when the usart_pclk clock is disabled.

The USART is able to wake up the MCU from low-power mode when the UESM bit is set.

When the usart_pclk is gated, the USART provides a wake-up interrupt (**usart_wkup**) if a specific action requiring the activation of the **usart_pclk** clock is needed:

- If FIFO mode is disabled

  usart_pclk clock has to be activated to empty the USART data register.

  In this case, the usart_wkup interrupt source is RXNE set to 1. The RXNEIE bit must be set before entering low-power mode.
- If FIFO mode is enabled

  usart_pclk clock has to be activated to:
  - To fill the TXFIFO, or
  - To empty the RXFIFO

  In this case, the usart_wkup interrupt source can be:
  - RXFIFO not empty. In this case, the RXFNEIE bit must be set before entering low-power mode.
  - RXFIFO full. In this case, the RXFFIE bit must be set before entering low-power mode, the number of received data corresponds to the RXFIFO size, and the RXFF flag is not set.
  - TXFIFO empty. In this case, the TXFEIE bit must be set before entering low-power mode.

  This enables sending/receiving the data in the TXFIFO/RXFIFO during low-power mode.

  To avoid overrun/underrun errors and transmit/receive data in low-power mode, the usart_wkup interrupt source can be one of the following events:
  - TXFIFO threshold reached. In this case, the TXFTIE bit must be set before entering low-power mode.
  - RXFIFO threshold reached. In this case, the RXFTIE bit must be set before entering low-power mode.

  For example, the application can set the threshold to the maximum RXFIFO size if the wake-up time is less than the time required to receive a single byte across the line.

  Using the RXFIFO full, TXFIFO empty, RXFIFO not empty and RXFIFO/TXFIFO threshold interrupts to wake up the MCU from low-power mode enables doing as many USART transfers as possible during low-power mode with the benefit of optimizing consumption.

Alternatively, a specific **usart_wkup** interrupt can be selected through the WUS bitfields.

When the wake-up event is detected, the WUF flag is set by hardware and a **usart_wkup** interrupt is generated if the WUFIE bit is set.

Note: Before entering low-power mode, make sure that no USART transfers are ongoing. Checking the BUSY flag cannot ensure that low-power mode is never entered when data reception is ongoing.

The WUF flag is set when a wake-up event is detected, independently of whether the MCU is in low-power or active mode.

When entering low-power mode just after having initialized and enabled the receiver, the REACK bit must be checked to make sure the USART is enabled.

When DMA is used for reception, it must be disabled before entering low-power mode and reenabled when exiting from low-power mode.

When the FIFO is enabled, waking up from low-power mode on address match is only possible when mute mode is enabled.

Using mute mode with low-power mode

If the USART is put into mute mode before entering low-power mode:

- Wake-up from mute mode on idle detection must not be used, because idle detection cannot work in low-power mode.
- If the wake-up from mute mode on address match is used, then the low-power mode wake-up source must also be the address match. If the RXNE flag was set when entering the low-power mode, the interface remains in mute mode upon address match and wake up from low-power mode.

Note: When FIFO management is enabled, mute mode can be used with wake-up from low-power mode without any constraints (that is, the two points mentioned above about mute and low-power mode are valid only when FIFO management is disabled).

Wake-up from low-power mode when USART kernel clock (usart_ker_ck) is OFF in low-power mode

If during low-power mode, the usart_ker_ck clock is switched OFF when a falling edge on the USART receive line is detected, the USART interface requests the usart_ker_ck clock to be switched ON thanks to the usart_ker_ck_req signal. usart_ker_ck is then used for the frame reception.

If the wake-up event is verified, the MCU wakes up from low-power mode and data reception goes on normally.

If the wake-up event is not verified, usart_ker_ck is switched OFF again, the MCU is not woken up and remains in low-power mode, and the kernel clock request is released.

The example below shows the case of a wake-up event programmed to “address match detection” and FIFO management disabled.

Figure 848 shows the USART behavior when the wake-up event is verified.

Figure 848. Wake-up event verified (wake-up event = address match, FIFO disabled)

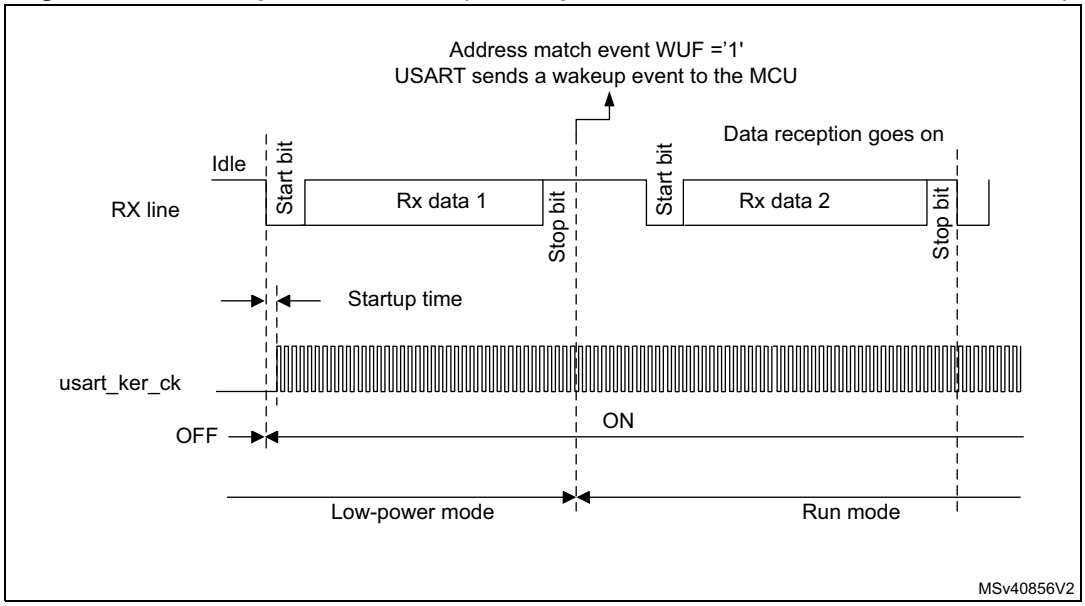
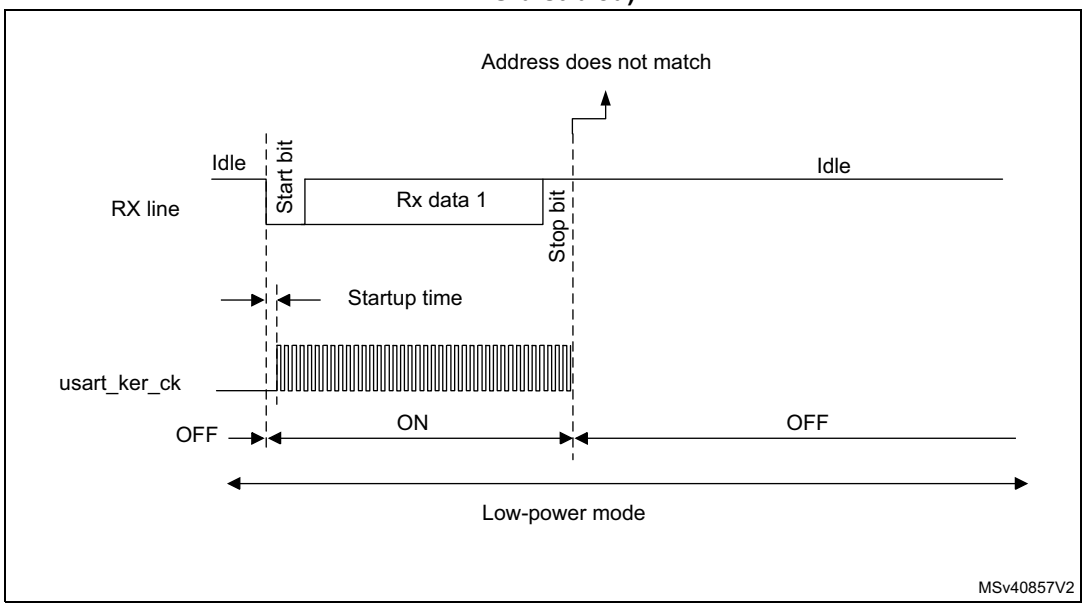


Figure 849 shows the USART behavior when the wake-up event is not verified.

Figure 849. Wake-up event not verified (wake-up event = address match, FIFO disabled)



Note: The figures above are valid when address match or any received frame is used as a wake-up event. If the wake-up event is the start bit detection, the USART sends the wake-up event to the MCU at the end of the start bit.

Determining the maximum USART baud rate that enables to correctly wake up the microcontroller from low-power mode

The maximum baud rate that enables to correctly wake up the microcontroller from low-power mode depends on the wake-up time parameter (refer to the device datasheet) and on the USART receiver tolerance (see *Section 61.5.9: Tolerance of the USART receiver to clock deviation*).

Let us take the example of OVER8 = 0, M bits = 01, ONEBIT = 0 and BRR [3:0] = 0000.

In these conditions, according to *Table 672: Tolerance of the USART receiver when BRR [3:0] = 0000*, the USART receiver tolerance equals 3.41%.

DTRA + DQUANT + DREC + DTCL + DWU < USART receiver tolerance

$D_{WUmax} = t_{WUUSART} / (11 \times T_{bitmin})$

$T_{bitmin} = t_{WUUSART} / (11 \times D_{WUmax})$

where $t_{WUUSART}$ is the wake-up time from low-power mode.

If we consider the ideal case where DTRA, DQUANT, DREC, and DTCL parameters are at 0%, the maximum value of DWU is 3.41%. In fact, we need to consider at least the usart_ker_ck inaccuracy (DREC).

For example, if HSI is used as usart_ker_ck, and the HSI inaccuracy is of 1%, then we obtain:

$t_{WUUSART}$ = 3 µs (values provided only as examples; for correct values, refer to the device datasheet).

D_{WUmax} = USART receiver tolerance – DREC = 3.41% – 1% = 2.41%

T_{bitmin} = 3 µs/ (11 x 2.41%) = 11.32 µs.

As a result, the maximum baud rate enables to wake up correctly from low-power mode is: 1/11.32 µs = 88.36 kbauds.

61.6 USART in low-power modes

Table 675. Effect of low-power modes on the USART

Mode	Description
Sleep	No effect. USART interrupts cause the device to exit Sleep mode.
Stop(1)	The content of the USART registers is kept. The USART is able to wake up the microcontroller from Stop mode when the USART is clocked by an oscillator available in Stop mode.
Standby	The USART peripheral is powered down and must be reinitialized after exiting Standby mode.

1. Refer to *Section 61.4: USART implementation* to know if the wake-up from Stop mode is supported for a given peripheral instance. If an instance is not functional in a given Stop mode, it must be disabled before entering this Stop mode.

61.7 USART interrupts

Refer to *Table 676* for a detailed description of all USART interrupt requests.

Table 676. USART interrupt requests

Interrupt vector	Interrupt event	Event flag	Enable Control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop(1) modes	Exit from Standby mode
USART or UART	Transmit data register empty	TXE	TXEIE	Write TDR	Yes	No	No
	Transmit FIFO not full	TXFNF	TXFNFIE	TXFIFO full		No	
	Transmit FIFO empty	TXFE	TXFEIE	Write TDR or write 1 in TXFRQ		Yes	
	Transmit FIFO threshold reached	TXFT	TXFTIE	Write TDR(2)		Yes	
	CTS interrupt	CTSIF	CTSIE	Write 1 in CTSCF		No	
	Transmission complete	TC	TCIE	Write TDR or write 1 in TCCF		No	
	Transmission complete before guard time	TCBGT	TCBGTIE	Write TDR or write 1 in TCBGT		No	

Table 676. USART interrupt requests (continued)

Interrupt vector	Interrupt event	Event flag	Enable Control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop(1) modes	Exit from Standby mode
USART or UART	Receive data register not empty (data ready to be read)	RXNE	RXNEIE	Read RDR or write 1 in RXFRQ	Yes	Yes	No
	Receive FIFO not empty	RXFNE	RXFNEIE	Read RDR until RXFIFO empty or write 1 in RXFRQ		Yes	
	Receive FIFO full	RXFF(3)	RXFFIE	Read RDR		Yes	
	Receive FIFO threshold reached	RXFT	RXFTIE	Read RDR		Yes	
	Overrun error detected	ORE	RX-NEIE/RX FNEIE	Write 1 in ORECF		No	
	Idle line detected	IDLE	IDLEIE	Write 1 in IDLECF		No	
	Parity error	PE	PEIE	Write 1 in PECF		No	
	LIN break	LBDF	LBDIE	Write 1 in LBDCF		No	
	Noise error in multibuffer communication.	NE	EIE	Write 1 in NFCF		No	
	Overrun error in multibuffer communication.	ORE(4)		Write 1 in ORECF		No	
	Framing error in multibuffer communication.	FE		Write 1 in FECF		No	
	Character match	CMF	CMIE	Write 1 in CMCF		No	
	Receiver timeout	RTOF	RTOFIE	Write 1 in RTOCCF		No	
	End of Block	EOBF	EOBIE	Write 1 in EOBCF		No	
	Wake-up from low-power mode	WUF	WUFIE	Write 1 in WUC		Yes	
	SPI slave underrun error	UDR	EIE	Write 1 in UDRCF		No	

1. The USART can wake up the device from Stop mode only if the peripheral instance supports the wake-up from Stop mode feature. Refer to *Section 61.4: USART implementation* for the list of supported Stop modes.
2. Writing to TDR clears the TXFT flag only if the number of empty locations is less than the value programmed in TXFTCFG[2:0].
3. RXFF flag is asserted if the USART receives n+1 data (n being the RXFIFO size): n data in the RXFIFO and 1 data in USART_RDR. In Stop mode, USART_RDR is not clocked. As a result, this register is not written and once n data are received and written in the RXFIFO, the RXFF interrupt is asserted (RXFF flag is not set).
4. When OVRDIS = 0.

61.8 USART registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The peripheral registers have to be accessed by words (32 bits).

61.8.1 USART control register 1 (USART_CR1)

Address offset: 0x00

Reset value: 0x0000 0000

The same register can be used in FIFO mode enabled (this section) and FIFO mode disabled (next section).

FIFO mode enable, FIFOEN = 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXFFIE	TXFEIE	FIFOEN	M1	EOBIE	RTOIE	DEAT[4:0]					DEDT[4:0]				
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OVER8	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXFNFIE	TCIE	RXFNEIE	IDLEIE	TE	RE	UESM	UE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **RXFFIE**: RXFIFO Full interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated when RXFF = 1 in the USART_ISR register

Bit 30 **TXFEIE**: TXFIFO empty interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated when TXFE = 1 in the USART_ISR register

Bit 29 **FIFOEN**: FIFO mode enable
This bit is set and cleared by software.
0: FIFO mode is disabled.
1: FIFO mode is enabled.
This bitfield can only be written when the USART is disabled (UE = 0).
Note: FIFO mode can be used on standard UART communication, in SPI master/slave mode and in smartcard modes only. It must not be enabled in IrDA and LIN modes.

Bit 28 **M1**: Word length
This bit must be used in conjunction with bit 12 (M0) to determine the word length. It is set or cleared by software.
M[1:0] = 00: 1 start bit, 8 Data bits, n stop bits
M[1:0] = 01: 1 start bit, 9 Data bits, n stop bits
M[1:0] = 10: 1 start bit, 7 Data bits, n stop bits
This bit can only be written when the USART is disabled (UE = 0).
Note: In 7-bits data length mode, the smartcard mode, LIN master mode and auto baud rate (0x7F and 0x55 frames detection) are not supported.

Bit 27 **EOBIE**: End of block interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated when the EOBF flag is set in the USART_ISR register

Note: If the USART does not support smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 26 **RTOIE**: Receiver timeout interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated when the RTOF bit is set in the USART_ISR register.

Note: If the USART does not support the Receiver timeout feature, this bit is reserved and must be kept at reset value. Section 61.4: USART implementation.

Bits 25:21 **DEAT[4:0]**: Driver Enable assertion time

This 5-bit value defines the time between the activation of the DE (Driver Enable) signal and the beginning of the start bit. It is expressed in sample time units (1/8 or 1/16 bit time, depending on the oversampling rate).

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bits 20:16 **DEDT[4:0]**: Driver Enable deassertion time

This 5-bit value defines the time between the end of the last stop bit, in a transmitted message, and the de-activation of the DE (Driver Enable) signal. It is expressed in sample time units (1/8 or 1/16 bit time, depending on the oversampling rate).

If the USART_TDR register is written during the DEDT time, the new data is transmitted only when the DEDT and DEAT times have both elapsed.

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 15 **OVER8**: Oversampling mode

0: Oversampling by 16

1: Oversampling by 8

This bit can only be written when the USART is disabled (UE = 0).

Note: In LIN, IrDA and smartcard modes, this bit must be kept cleared.

Bit 14 **CMIE**: Character match interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated when the CMF bit is set in the USART_ISR register.

Bit 13 **MME**: Mute mode enable

This bit enables the USART mute mode function. When set, the USART can switch between active and mute mode, as defined by the WAKE bit. It is set and cleared by software.

0: Receiver in active mode permanently

1: Receiver can switch between mute mode and active mode.

Bit 12 **M0**: Word length

This bit is used in conjunction with bit 28 (M1) to determine the word length. It is set or cleared by software (refer to bit 28 (M1)description).

This bit can only be written when the USART is disabled (UE = 0).

Bit 11 **WAKE**: Receiver wake-up method
This bit determines the USART wake-up method from mute mode. It is set or cleared by software.
0: Idle line
1: Address mark
This bitfield can only be written when the USART is disabled (UE = 0).

Bit 10 **PCE**: Parity control enable
This bit selects the hardware parity control (generation and detection). When the parity control is enabled, the computed parity is inserted at the MSB position (9th bit if M = 1; 8th bit if M=0) and the parity is checked on the received data. This bit is set and cleared by software. Once it is set, PCE is active after the current byte (in reception and in transmission).
0: Parity control disabled
1: Parity control enabled
This bitfield can only be written when the USART is disabled (UE = 0).

Bit 9 **PS**: Parity selection
This bit selects the odd or even parity when the parity generation/detection is enabled (PCE bit set). It is set and cleared by software. The parity is selected after the current byte.
0: Even parity
1: Odd parity
This bitfield can only be written when the USART is disabled (UE = 0).

Bit 8 **PEIE**: PE interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever PE = 1 in the USART_ISR register

Bit 7 **TXFNFIE**: TXFIFO not full interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever TXFNF = 1 in the USART_ISR register

Bit 6 **TCIE**: Transmission complete interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever TC = 1 in the USART_ISR register

Bit 5 **RXFNEIE**: RXFIFO not empty interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever ORE = 1 or RXFNE = 1 in the USART_ISR register

Bit 4 **IDLEIE**: IDLE interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever IDLE = 1 in the USART_ISR register

Bit 3 **TE**: Transmitter enable

This bit enables the transmitter. It is set and cleared by software.

0: Transmitter is disabled

1: Transmitter is enabled

Note: When the USART acts as a transmitter, a low pulse on the TE bit (0 followed by 1) sends a preamble (idle line) after the current word, except in smartcard mode. In order to generate an idle character, the TE must not be immediately written to 1. To ensure the required duration, the software can poll the TEACK bit in the USART_ISR register.

In smartcard mode, when TE is set, there is a 1 bit-time delay before the transmission starts.

Bit 2 **RE**: Receiver enable

This bit enables the receiver. It is set and cleared by software.

0: Receiver is disabled

1: Receiver is enabled and begins searching for a start bit

Bit 1 **UESM**: USART enable in low-power mode

When this bit is cleared, the USART cannot wake up the MCU from low-power mode.

When this bit is set, the USART can wake up the MCU from low-power mode.

This bit is set and cleared by software.

0: USART not able to wake up the MCU from low-power mode.

1: USART able to wake up the MCU from low-power mode.

Note: It is recommended to set the UESM bit just before entering low-power mode, and clear it when exiting low-power mode.

Bit 0 **UE**: USART enable

When this bit is cleared, the USART prescalers and outputs are stopped immediately, and all current operations are discarded. The USART configuration is kept, but all the USART_ISR status flags are reset. This bit is set and cleared by software.

0: USART prescaler and outputs disabled, low-power mode

1: USART enabled

Note: To enter low-power mode without generating errors on the line, the TE bit must be previously reset and the software must wait for the TC bit in the USART_ISR to be set before resetting the UE bit.

The DMA requests are also reset when UE = 0 so the DMA channel must be disabled before resetting the UE bit.

In smartcard mode, (SCEN = 1), the CK is always available when CLKEN = 1, regardless of the UE bit value.

61.8.2 USART control register 1 [alternate] (USART_CR1)

Address offset: 0x00

Reset value: 0x0000 0000

The same register can be used in FIFO mode enabled (previous section) and FIFO mode disabled (this section).

FIFO mode disabled, FIFOEN = 0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	FIFO EN	M1	EOBIE	RTOIE	DEAT[4:0]					DEDT[4:0]				
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OVER8	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXEIE	TCIE	RXNEIE	IDLEIE	TE	RE	UESM	UE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **FIFOEN**: FIFO mode enable
This bit is set and cleared by software.
0: FIFO mode is disabled.
1: FIFO mode is enabled.
This bitfield can only be written when the USART is disabled (UE = 0).
Note: FIFO mode can be used on standard UART communication, in SPI master/slave mode and in smartcard modes only. It must not be enabled in IrDA and LIN modes.

Bit 28 **M1**: Word length
This bit must be used in conjunction with bit 12 (M0) to determine the word length. It is set or cleared by software.
M[1:0] = 00: 1 start bit, 8 Data bits, n stop bits
M[1:0] = 01: 1 start bit, 9 Data bits, n stop bits
M[1:0] = 10: 1 start bit, 7 Data bits, n stop bits
This bit can only be written when the USART is disabled (UE = 0).
Note: In 7-bits data length mode, the smartcard mode, LIN master mode and auto baud rate (0x7F and 0x55 frames detection) are not supported.

Bit 27 **EOBIE**: End of block interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated when the EOBF flag is set in the USART_ISR register
Note: If the USART does not support smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 26 **RTOIE**: Receiver timeout interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated when the RTOF bit is set in the USART_ISR register.
Note: If the USART does not support the Receiver timeout feature, this bit is reserved and must be kept at reset value. Section 61.4: USART implementation.

Bits 25:21 **DEAT[4:0]**: Driver Enable assertion time

This 5-bit value defines the time between the activation of the DE (Driver Enable) signal and the beginning of the start bit. It is expressed in sample time units (1/8 or 1/16 bit time, depending on the oversampling rate).

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bits 20:16 **DEDT[4:0]**: Driver Enable deassertion time

This 5-bit value defines the time between the end of the last stop bit, in a transmitted message, and the de-activation of the DE (Driver Enable) signal. It is expressed in sample time units (1/8 or 1/16 bit time, depending on the oversampling rate).

If the USART_TDR register is written during the DEDT time, the new data is transmitted only when the DEDT and DEAT times have both elapsed.

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 15 **OVER8**: Oversampling mode

0: Oversampling by 16

1: Oversampling by 8

This bit can only be written when the USART is disabled (UE = 0).

Note: In LIN, IrDA and smartcard modes, this bit must be kept cleared.

Bit 14 **CMIE**: Character match interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated when the CMF bit is set in the USART_ISR register.

Bit 13 **MME**: Mute mode enable

This bit enables the USART mute mode function. When set, the USART can switch between active and mute mode, as defined by the WAKE bit. It is set and cleared by software.

0: Receiver in active mode permanently

1: Receiver can switch between mute mode and active mode.

Bit 12 **M0**: Word length

This bit is used in conjunction with bit 28 (M1) to determine the word length. It is set or cleared by software (refer to bit 28 (M1)description).

This bit can only be written when the USART is disabled (UE = 0).

Bit 11 **WAKE**: Receiver wake-up method

This bit determines the USART wake-up method from mute mode. It is set or cleared by software.

0: Idle line

1: Address mark

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 10 **PCE**: Parity control enable

This bit selects the hardware parity control (generation and detection). When the parity control is enabled, the computed parity is inserted at the MSB position (9th bit if M = 1; 8th bit if M = 0) and the parity is checked on the received data. This bit is set and cleared by software. Once it is set, PCE is active after the current byte (in reception and in transmission).

0: Parity control disabled

1: Parity control enabled

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 9 **PS**: Parity selection

This bit selects the odd or even parity when the parity generation/detection is enabled (PCE bit set). It is set and cleared by software. The parity is selected after the current byte.
0: Even parity
1: Odd parity
This bitfield can only be written when the USART is disabled (UE = 0).

Bit 8 **PEIE**: PE interrupt enable

This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever PE = 1 in the USART_ISR register

Bit 7 **TXEIE**: Transmit data register empty

This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever TXE = 1 in the USART_ISR register

Bit 6 **TCIE**: Transmission complete interrupt enable

This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever TC = 1 in the USART_ISR register

Bit 5 **RXNEIE**: Receive data register not empty interrupt enable

This bit is set and cleared by software.
0: Interrupt is inhibited
1: USART interrupt is generated whenever ORE = 1 or RXNE = 1 in the USART_ISR register

Bit 4 **IDLEIE**: IDLE interrupt enable

This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever IDLE = 1 in the USART_ISR register

Bit 3 **TE**: Transmitter enable

This bit enables the transmitter. It is set and cleared by software.
0: Transmitter is disabled
1: Transmitter is enabled

Note: When the USART acts as a transmitter, a low pulse on the TE bit (0 followed by 1) sends a preamble (idle line) after the current word, except in smartcard mode. In order to generate an idle character, the TE must not be immediately written to 1. To ensure the required duration, the software can poll the TEACK bit in the USART_ISR register.
In smartcard mode, when TE is set, there is a 1 bit-time delay before the transmission starts.

Bit 2 **RE**: Receiver enable

This bit enables the receiver. It is set and cleared by software.
0: Receiver is disabled
1: Receiver is enabled and begins searching for a start bit

Bit 1 **UESM**: USART enable in low-power mode

When this bit is cleared, the USART cannot wake up the MCU from low-power mode.
When this bit is set, the USART can wake up the MCU from low-power mode.
This bit is set and cleared by software.
0: USART not able to wake up the MCU from low-power mode.
1: USART able to wake up the MCU from low-power mode.

Note: It is recommended to set the UESM bit just before entering low-power mode, and clear it when exiting low-power mode.

Bit 0 **UE**: USART enable

When this bit is cleared, the USART prescalers and outputs are stopped immediately, and all current operations are discarded. The USART configuration is kept, but all the USART_ISR status flags are reset. This bit is set and cleared by software.

0: USART prescaler and outputs disabled, low-power mode

1: USART enabled

Note: To enter low-power mode without generating errors on the line, the TE bit must be previously reset and the software must wait for the TC bit in the USART_ISR to be set before resetting the UE bit.

The DMA requests are also reset when UE = 0 so the DMA channel must be disabled before resetting the UE bit.

In smartcard mode, (SCEN = 1), the CK is always available when CLKEN = 1, regardless of the UE bit value.

61.8.3 USART control register 2 (USART_CR2)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADD[7:0]								RTOEN	ABRMOD[1:0]		ABREN	MSBFIRST	DATAINV	TXINV	RXINV
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SWAP	LINEN	STOP[1:0]		CLKEN	CPOL	CPHA	LBCL	Res.	LBDIE	LBDL	ADDM7	DIS_NSS	Res.	Res.	SLVEN
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw			rw

Bits 31:24 **ADD[7:0]**: Address of the USART node

These bits give the address of the USART node in mute mode or a character code to be recognized in low-power or Run mode:

- In mute mode: they are used in multiprocessor communication to wake up from mute mode with 4-bit/7-bit address mark detection. The MSB of the character sent by the transmitter is equal to 1. In 4-bit address mark detection, only ADD[3:0] bits are used.
- In low-power mode: they are used for wake up from low-power mode on character match. When WUS[1:0] is programmed to 0b00 (WUF active on address match), the wake-up from low-power mode is performed when the received character corresponds to the character programmed through ADD[6:0] or ADD[3:0] bitfield (depending on ADDM7 bit), and WUF interrupt is enabled by setting WUFIE bit. The MSB of the character sent by transmitter is equal to 1.
- In Run mode with mute mode inactive (for example, end-of-block detection in ModBus protocol): the whole received character (8 bits) is compared to ADD[7:0] value and CMF flag is set on match. An interrupt is generated if the CMIE bit is set.

These bits can only be written when the USART is disabled (UE = 0).

Bit 23 **RTOEN**: Receiver timeout enable

This bit is set and cleared by software.

0: Receiver timeout feature disabled.

1: Receiver timeout feature enabled.

When this feature is enabled, the RTOF flag in the USART_ISR register is set if the RX line is idle (no reception) for the duration programmed in the RTOR (receiver timeout register).

Note: If the USART does not support the Receiver timeout feature, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bits 22:21 **ABRMOD[1:0]**: Auto baud rate mode

These bits are set and cleared by software.

00: Measurement of the start bit is used to detect the baud rate.

01: Falling edge to falling edge measurement (the received frame must start with a single bit = 1 -> Frame = Start10xxxxxx)

10: 0x7F frame detection.

11: 0x55 frame detection

This bitfield can only be written when ABREN = 0 or the USART is disabled (UE = 0).

Note: If DATAINV = 1 and/or MSBFIRST = 1 the patterns must be the same on the line, for example 0xAA for MSBFIRST)

If the USART does not support the auto baud rate feature, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 20 **ABREN**: Auto baud rate enable

This bit is set and cleared by software.

0: Auto baud rate detection is disabled.

1: Auto baud rate detection is enabled.

Note: If the USART does not support the auto baud rate feature, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 19 **MSBFIRST**: Most significant bit first

This bit is set and cleared by software.

0: data is transmitted/received with data bit 0 first, following the start bit.

1: data is transmitted/received with the MSB (bit 7/8) first, following the start bit.

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 18 **DATAINV:** Binary data inversion

This bit is set and cleared by software.

0: Logical data from the data register are send/received in positive/direct logic. (1 = H, 0 = L)

1: Logical data from the data register are send/received in negative/inverse logic. (1 = L, 0 = H).

The parity bit is also inverted.

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 17 **TXINV:** TX pin active level inversion

This bit is set and cleared by software.

0: TX pin signal works using the standard logic levels (V_{DD} = 1 / idle, Gnd = 0 / mark)

1: TX pin signal values are inverted. ((V_{DD} = 0 / mark, Gnd = 1 / idle).

This enables the use of an external inverter on the TX line.

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 16 **RXINV:** RX pin active level inversion

This bit is set and cleared by software.

0: RX pin signal works using the standard logic levels (V_{DD} = 1 / idle, Gnd = 0 / mark)

1: RX pin signal values are inverted. ((V_{DD} = 0 / mark, Gnd = 1 / idle).

This enables the use of an external inverter on the RX line.

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 15 **SWAP:** Swap TX/RX pins

This bit is set and cleared by software.

0: TX/RX pins are used as defined in standard pinout

1: The TX and RX pins functions are swapped. This enables to work in the case of a cross-wired connection to another UART.

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 14 **LINEN**: LIN mode enable

This bit is set and cleared by software.

0: LIN mode disabled

1: LIN mode enabled

The LIN mode enables the capability to send LIN synchronous breaks (13 low bits) using the SBKRQ bit in the USART_CR1 register, and to detect LIN Sync breaks.

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the USART does not support LIN mode, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bits 13:12 **STOP[1:0]**: Stop bits

These bits are used for programming the stop bits.

00: 1 stop bit

01: 0.5 stop bit.

10: 2 stop bits

11: 1.5 stop bits

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 11 **CLKEN**: Clock enable

This bit enables the user to enable the CK pin.

0: CK pin disabled

1: CK pin enabled

Note: If neither synchronous mode nor smartcard mode is supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

In smartcard mode, in order to provide correctly the CK clock to the smartcard, the steps below must be respected:
UE = 0
SCEN = 1
GTPR configuration
CLKEN= 1
UE = 1

Bit 10 **CPOL**: Clock polarity

This bit enables the user to select the polarity of the clock output on the CK pin in synchronous mode. It works in conjunction with the CPHA bit to produce the desired clock/data relationship

0: Steady low value on CK pin outside transmission window

1: Steady high value on CK pin outside transmission window

This bit can only be written when the USART is disabled (UE = 0).

Note: If synchronous mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 9 **CPHA**: Clock phase

This bit is used to select the phase of the clock output on the CK pin in synchronous mode. It works in conjunction with the CPOL bit to produce the desired clock/data relationship (see *Figure 829* and *Figure 830*)

0: The first clock transition is the first data capture edge

1: The second clock transition is the first data capture edge

This bit can only be written when the USART is disabled (UE = 0).

Note: If synchronous mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 8 **LBCL**: Last bit clock pulse

This bit is used to select whether the clock pulse associated with the last data bit transmitted (MSB) has to be output on the CK pin in synchronous mode.

0: The clock pulse of the last data bit is not output to the CK pin

1: The clock pulse of the last data bit is output to the CK pin

Caution: The last bit is the 7th or 8th or 9th data bit transmitted depending on the 7 or 8 or 9 bit format selected by the M bit in the USART_CR1 register.

This bit can only be written when the USART is disabled (UE = 0).

Note: If synchronous mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **LBDIE**: LIN break detection interrupt enable

Break interrupt mask (break detection using break delimiter).

0: Interrupt is inhibited

1: An interrupt is generated whenever LBDF = 1 in the USART_ISR register

Note: If LIN mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 5 **LBDL**: LIN break detection length

This bit is for selection between 11 bit or 10 bit break detection.

0: 10-bit break detection

1: 11-bit break detection

This bit can only be written when the USART is disabled (UE = 0).

Note: If LIN mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 4 **ADDM7**: 7-bit address detection/4-bit address detection

This bit is for selection between 4-bit address detection or 7-bit address detection.

0: 4-bit address detection

1: 7-bit address detection (in 8-bit data mode)

This bit can only be written when the USART is disabled (UE = 0)

Note: In 7-bit and 9-bit data modes, the address detection is done on 6-bit and 8-bit address (ADD[5:0] and ADD[7:0]) respectively.

Bit 3 **DIS_NSS**:

When the DIS_NSS bit is set, the NSS pin input is ignored.

0: SPI slave selection depends on NSS input pin.

1: SPI slave is always selected and NSS input pin is ignored.

This bitfield can only be written when the USART is disabled (UE = 0).

Note: When SPI slave mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bits 2:1 Reserved, must be kept at reset value.

Bit 0 **SLVEN**: Synchronous slave mode enable
When the SLVEN bit is set, the synchronous slave mode is enabled.
0: Slave mode disabled.
1: Slave mode enabled.
This bitfield can only be written when the USART is disabled (UE = 0).
Note: When SPI slave mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Note: The CPOL, CPHA, and LBCL bits must not be written while the transmitter is enabled.

61.8.4 USART control register 3 (USART_CR3)

Address offset: 0x08

Reset value: 0x0000 0000

FIFO mode enabled, FIFOEN = 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXFTCFG[2:0]			RXF TIE	RXFTCFG[2:0]			TCBG TIE	TXFTIE	WUFIE	WUS1	WUS0	SCARCNT[2:0]			Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DEP	DEM	DDRE	OVR DIS	ONE BIT	CTSIE	CTSE	RTSE	DMAT	DMAR	SCEN	NACK	HD SEL	IRLP	IREN	EIE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 **TXFTCFG[2:0]:** TXFIFO threshold configuration
000:TXFIFO reaches 1/8 of its depth
001:TXFIFO reaches 1/4 of its depth
010:TXFIFO reaches 1/2 of its depth
011:TXFIFO reaches 3/4 of its depth
100:TXFIFO reaches 7/8 of its depth
101:TXFIFO becomes empty
Others: Reserved, must not be used
This bitfield can only be written when the USART is disabled (UE = 0).

Bit 28 **RXFTIE**: RXFIFO threshold interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated when Receive FIFO reaches the threshold programmed in RXFTCFG[2:0].

Bits 27:25 **RXFTCFG[2:0]:** Receive FIFO threshold configuration
000:Receive FIFO reaches 1/8 of its depth
001:Receive FIFO reaches 1/4 of its depth
010:Receive FIFO reaches 1/2 of its depth
011:Receive FIFO reaches 3/4 of its depth
100:Receive FIFO reaches 7/8 of its depth
101:Receive FIFO becomes full
Others: Reserved, must not be used
This bitfield can only be written when the USART is disabled (UE = 0).

Bit 24 **TCBGTIE**: Transmission Complete before guard time, interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever TCBGT = 1 in the USART_ISR register
Note: If the USART does not support the smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 23 **TXFTIE**: TXFIFO threshold interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated when TXFIFO reaches the threshold programmed in TXFTCFG[2:0].

Bit 22 **WUFIE**: Wake-up from low-power mode interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever WUF = 1 in the USART_ISR register
Note: WUFIE must be set before entering in low-power mode.
If the USART does not support the wake-up from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bits 21:20 **WUS[1:0]**: Wake-up from low-power mode interrupt flag selection
This bitfield specifies the event which activates the WUF (wake-up from low-power mode flag).
00: WUF active on address match (as defined by ADD[7:0] and ADDM7)
01: Reserved.
10: WUF active on start bit detection
11: WUF active on RXNE/RXFNE.
This bitfield can only be written when the USART is disabled (UE = 0).
Note: If the USART does not support the wake-up from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bits 19:17 **SCARCNT[2:0]**: Smartcard auto-retry count
This bitfield specifies the number of retries for transmission and reception in smartcard mode.
In transmission mode, it specifies the number of automatic retransmission retries, before generating a transmission error (FE bit set).
In reception mode, it specifies the number or erroneous reception trials, before generating a reception error (RXNE/RXFNE and PE bits set).
This bitfield must be programmed only when the USART is disabled (UE = 0).
When the USART is enabled (UE = 1), this bitfield may only be written to 0x0, in order to stop retransmission.
0x0: retransmission disabled - No automatic retransmission in transmission mode.
0x1 to 0x7: number of automatic retransmission attempts (before signaling error)
Note: If smartcard mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **DEP**: Driver enable polarity selection
0: DE signal is active high.
1: DE signal is active low.
This bit can only be written when the USART is disabled (UE = 0).
Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 14 **DEM**: Driver enable mode

This bit enables the user to activate the external transceiver control, through the DE signal.

0: DE function is disabled.

1: DE function is enabled. The DE signal is output on the RTS pin.

This bit can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Section 61.4: USART implementation on page 2753.

Bit 13 **DDRE**: DMA Disable on reception Error

0: DMA is not disabled in case of reception error. The corresponding error flag is set but RXNE is kept 0 preventing from overrun. As a consequence, the DMA request is not asserted, so the erroneous data is not transferred (no DMA request), but next correct received data is transferred. (used for smartcard mode)

1: DMA is disabled following a reception error. The corresponding error flag is set, as well as RXNE. The DMA request is masked until the error flag is cleared. This means that the software must first disable the DMA request (DMAR = 0) or clear RXNE(RXFNE is case FIFO mode is enabled) before clearing the error flag.

This bit can only be written when the USART is disabled (UE = 0).

Note: The reception errors are: parity error, framing error or noise error.

Bit 12 **OVRDIS**: Overrun Disable

This bit is used to disable the receive overrun detection.

0: Overrun Error Flag, ORE, is set when received data is not read before receiving new data.

1: Overrun functionality is disabled. If new data is received while the RXNE flag is still set the ORE flag is not set and the new received data overwrites the previous content of the USART_RDR register. When FIFO mode is enabled, the RXFIFO is bypassed and data are written directly in USART_RDR register. Even when FIFO management is enabled, the RXNE flag is to be used.

This bit can only be written when the USART is disabled (UE = 0).

Note: This control bit enables *checking the communication flow w/o reading the data*

Bit 11 **ONEBIT**: One sample bit method enable

This bit enables the user to select the sample method. When the one sample bit method is selected the noise detection flag (NE) is disabled.

0: Three sample bit method

1: One sample bit method

This bit can only be written when the USART is disabled (UE = 0).

Bit 10 **CTSIE**: CTS interrupt enable

0: Interrupt is inhibited

1: An interrupt is generated whenever CTSIF = 1 in the USART_ISR register

Note: If the hardware flow control feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 9 **CTSE**: CTS enable

0: CTS hardware flow control disabled

1: CTS mode enabled, data is only transmitted when the CTS input is deasserted (tied to 0). If the CTS input is asserted while data is being transmitted, then the transmission completes before stopping. If data is written into the data register while CTS is asserted, the transmission is postponed until CTS is deasserted.

This bit can only be written when the USART is disabled (UE = 0)

Note: If the hardware flow control feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 8 **RTSE**: RTS enable

0: RTS hardware flow control disabled

1: RTS output enabled, data is only requested when there is space in the receive buffer. The transmission of data is expected to cease after the current character has been transmitted. The RTS output is deasserted (pulled to 0) when data can be received.

This bit can only be written when the USART is disabled (UE = 0).

Note: If the hardware flow control feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 7 **DMAT**: DMA enable transmitter

This bit is set/reset by software

1: DMA mode is enabled for transmission

0: DMA mode is disabled for transmission

Bit 6 **DMAR**: DMA enable receiver

This bit is set/reset by software

1: DMA mode is enabled for reception

0: DMA mode is disabled for reception

Bit 5 **SCEN**: Smartcard mode enable

This bit is used for enabling smartcard mode.

0: Smartcard mode disabled

1: Smartcard mode enabled

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the USART does not support smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 4 **NACK**: Smartcard NACK enable

0: NACK transmission in case of parity error is disabled

1: NACK transmission during parity error is enabled

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the USART does not support smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 3 **HDSEL**: Half-duplex selection

Selection of single-wire half-duplex mode

0: Half-duplex mode is not selected

1: Half-duplex mode is selected

This bit can only be written when the USART is disabled (UE = 0).

Bit 2 **IRLP**: IrDA low-power

This bit is used for selecting between normal and low-power IrDA modes

0: Normal mode

1: Low-power mode

This bit can only be written when the USART is disabled (UE = 0).

Note: If IrDA mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 1 **IREN**: IrDA mode enable

This bit is set and cleared by software.

0: IrDA disabled

1: IrDA enabled

This bit can only be written when the USART is disabled (UE = 0).

Note: If IrDA mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 0 **EIE**: Error interrupt enable

Error Interrupt Enable Bit is required to enable interrupt generation in case of a framing error, overrun error noise flag or SPI slave underrun error (FE = 1 or ORE = 1 or NE = 1 or UDR = 1 in the USART_ISR register).

0: Interrupt inhibited

1: interrupt generated when FE = 1 or ORE = 1 or NE = 1 or UDR = 1 (in SPI slave mode) in the USART_ISR register.

61.8.5 USART control register 3 [alternate] (USART_CR3)

Address offset: 0x08

Reset value: 0x0000 0000

FIFO mode disabled, FIFOEN = 0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCBGTIE	Res.	WUFIE	WUS1	WUS0	SCARCNT[2:0]			Res.
							rw		rw	rw	rw	rw	rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DEP	DEM	DDRE	OVRDIS	ONEBIT	CTSIE	CTSE	RTSE	DMAT	DMAR	SCEN	NACK	HDSEL	IRLP	IREN	EIE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **TCBGTIE**: Transmission Complete before guard time, interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated whenever TCBGT = 1 in the USART_ISR register

Note: If the USART does not support the smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 23 Reserved, must be kept at reset value.

Bit 22 **WUFIE**: Wake-up from low-power mode interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated whenever WUF = 1 in the USART_ISR register

Note: WUFIE must be set before entering in low-power mode.

If the USART does not support the wake-up from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bits 21:20 **WUS[1:0]**: Wake-up from low-power mode interrupt flag selection

This bitfield specifies the event which activates the WUF (wake-up from low-power mode flag).

00: WUF active on address match (as defined by ADD[7:0] and ADDM7)

01: Reserved.

10: WUF active on start bit detection

11: WUF active on RXNE/RXFNE.

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the USART does not support the wake-up from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bits 19:17 **SCARCNT[2:0]**: Smartcard auto-retry count

This bitfield specifies the number of retries for transmission and reception in smartcard mode.

In transmission mode, it specifies the number of automatic retransmission retries, before generating a transmission error (FE bit set).

In reception mode, it specifies the number or erroneous reception trials, before generating a reception error (RXNE/RXFNE and PE bits set).

This bitfield must be programmed only when the USART is disabled (UE = 0).

When the USART is enabled (UE = 1), this bitfield may only be written to 0x0, in order to stop retransmission.

0x0: retransmission disabled - No automatic retransmission in transmission mode.

0x1 to 0x7: number of automatic retransmission attempts (before signaling error)

Note: If smartcard mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **DEP**: Driver enable polarity selection

0: DE signal is active high.

1: DE signal is active low.

This bit can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 14 **DEM**: Driver enable mode

This bit enables the user to activate the external transceiver control, through the DE signal.

0: DE function is disabled.

1: DE function is enabled. The DE signal is output on the RTS pin.

This bit can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Section 61.4: USART implementation.

Bit 13 **DDRE**: DMA Disable on reception Error

0: DMA is not disabled in case of reception error. The corresponding error flag is set but RXNE is kept 0 preventing from overrun. As a consequence, the DMA request is not asserted, so the erroneous data is not transferred (no DMA request), but next correct received data is transferred. (used for smartcard mode)

1: DMA is disabled following a reception error. The corresponding error flag is set, as well as RXNE. The DMA request is masked until the error flag is cleared. This means that the software must first disable the DMA request (DMAR = 0) or clear RXNE(RXFNE is case FIFO mode is enabled) before clearing the error flag.

This bit can only be written when the USART is disabled (UE = 0).

Note: The reception errors are: parity error, framing error or noise error.

Bit 12 **OVRDIS**: Overrun Disable

This bit is used to disable the receive overrun detection.

0: Overrun Error Flag, ORE, is set when received data is not read before receiving new data.

1: Overrun functionality is disabled. If new data is received while the RXNE flag is still set the ORE flag is not set and the new received data overwrites the previous content of the USART_RDR register. When FIFO mode is enabled, the RXFIFO is bypassed and data are written directly in USART_RDR register. Even when FIFO management is enabled, the RXNE flag is to be used.

This bit can only be written when the USART is disabled (UE = 0).

Note: This control bit enables *checking the communication flow w/o reading the data*

Bit 11 **ONEBIT**: One sample bit method enable

This bit enables the user to select the sample method. When the one sample bit method is selected the noise detection flag (NE) is disabled.

0: Three sample bit method

1: One sample bit method

This bit can only be written when the USART is disabled (UE = 0).

Bit 10 **CTSIE**: CTS interrupt enable

0: Interrupt is inhibited

1: An interrupt is generated whenever CTSIF = 1 in the USART_ISR register

Note: If the hardware flow control feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 9 **CTSE**: CTS enable

0: CTS hardware flow control disabled

1: CTS mode enabled, data is only transmitted when the CTS input is deasserted (tied to 0). If the CTS input is asserted while data is being transmitted, then the transmission completes before stopping. If data is written into the data register while CTS is asserted, the transmission is postponed until CTS is deasserted.

This bit can only be written when the USART is disabled (UE = 0)

Note: If the hardware flow control feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 8 **RTSE**: RTS enable

0: RTS hardware flow control disabled

1: RTS output enabled, data is only requested when there is space in the receive buffer. The transmission of data is expected to cease after the current character has been transmitted. The RTS output is deasserted (pulled to 0) when data can be received.

This bit can only be written when the USART is disabled (UE = 0).

Note: If the hardware flow control feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 7 **DMAT**: DMA enable transmitter

This bit is set/reset by software

1: DMA mode is enabled for transmission

0: DMA mode is disabled for transmission

Bit 6 **DMAR**: DMA enable receiver

This bit is set/reset by software

1: DMA mode is enabled for reception

0: DMA mode is disabled for reception

Bit 5 **SCEN**: Smartcard mode enable

This bit is used for enabling smartcard mode.

0: Smartcard mode disabled

1: Smartcard mode enabled

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the USART does not support smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 4 **NACK**: Smartcard NACK enable

0: NACK transmission in case of parity error is disabled

1: NACK transmission during parity error is enabled

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the USART does not support smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 3 **HDSEL**: Half-duplex selection

Selection of single-wire half-duplex mode

0: Half-duplex mode is not selected

1: Half-duplex mode is selected

This bit can only be written when the USART is disabled (UE = 0).

Bit 2 **IRLP**: IrDA low-power

This bit is used for selecting between normal and low-power IrDA modes

0: Normal mode

1: Low-power mode

This bit can only be written when the USART is disabled (UE = 0).

Note: If IrDA mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 1 **IREN**: IrDA mode enable

This bit is set and cleared by software.

0: IrDA disabled

1: IrDA enabled

This bit can only be written when the USART is disabled (UE = 0).

Note: If IrDA mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 0 **EIE**: Error interrupt enable

Error Interrupt Enable Bit is required to enable interrupt generation in case of a framing error, overrun error noise flag or SPI slave underrun error (FE = 1 or ORE = 1 or NE = 1or UDR = 1 in the USART_ISR register).

0: Interrupt inhibited

1: interrupt generated when FE = 1 or ORE = 1 or NE = 1 or UDR = 1 (in SPI slave mode) in the USART_ISR register.

61.8.6 USART baud rate register (USART_BRR)

This register can only be written when the USART is disabled (UE = 0). It may be automatically updated by hardware in auto baud rate detection mode.

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BRR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **BRR[15:0]:** USART baud rate

BRR[15:4]

BRR[15:4] correspond to USARTDIV[15:4]

BRR[3:0]

When OVER8 = 0, BRR[3:0] = USARTDIV[3:0].

When OVER8 = 1:

BRR[2:0] = USARTDIV[3:0] shifted 1 bit to the right.

BRR[3] must be kept cleared.

61.8.7 USART guard time and prescaler register (USART_GTPR)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GT[7:0]								PSC[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **GT[7:0]**: Guard time value

This bitfield is used to program the Guard time value in terms of number of baud clock periods.

This is used in smartcard mode. The transmission complete flag is set after this guard time value.

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If smartcard mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bits 7:0 **PSC[7:0]**: Prescaler value

Condition: IrDA low-power and normal IrDA mode

PSC[7:0] = IrDA normal and Low-power baud rate

This bitfield is used for programming the prescaler for dividing the USART source clock to achieve the low-power frequency:

The source clock is divided by the value given in the register (8 significant bits):

00000000: Reserved - do not program this value

00000001: divides the source clock by 1

00000010: divides the source clock by 2

...

Condition: Smartcard mode

PSC[4:0]: Prescaler value

This bitfield is used for programming the prescaler for dividing the USART source clock to provide the smartcard clock.

The value given in the register (5 significant bits) is multiplied by 2 to give the division factor of the source clock frequency:

00000: Reserved - do not program this value

00001: divides the source clock by 2

00010: divides the source clock by 4

00011: divides the source clock by 6

...

This bitfield can only be written when the USART is disabled (UE = 0).

Note: Bits [7:5] must be kept cleared if smartcard mode is used.

This bitfield is reserved and forced by hardware to 0 when the smartcard and IrDA modes are not supported. Refer to Section 61.4: USART implementation.

61.8.8 USART receiver timeout register (USART_RTOR)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BLEN[7:0]								RTO[23:16]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RTO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **BLEN[7:0]**: Block Length

This bitfield gives the block length in smartcard T = 1 reception. Its value equals the number of information characters + the length of the Epilogue Field (1 – LEC / 2 – CRC) – 1.

Examples:

BLEN = 0 -> 0 information characters + LEC

BLEN = 1 -> 0 information characters + CRC

BLEN = 255 -> 254 information characters + CRC (total 256 characters))

In smartcard mode, the block length counter is reset when TXE = 0 (TXFE = 0 in case FIFO mode is enabled).

This bitfield can be used also in other modes. In this case, the block length counter is reset when RE = 0 (receiver disabled) and/or when the EOBCF bit is written to 1.

Note: This value can be programmed after the start of the block reception (using the data from the LEN character in the Prologue Field). It must be programmed only once per received block.

Bits 23:0 **RTO[23:0]**: Receiver timeout value

This bitfield gives the Receiver timeout value in terms of number of bit duration.

In Standard mode, the RTOF flag is set if, after the last received character, no new start bit is detected for more than the RTO value.

In smartcard mode, this value is used to implement the CWT and BWT. See smartcard chapter for more details. In the standard, the CWT/BWT measurement is done starting from the start bit of the last received character.

Note: This value must only be programmed once per received character.

Note: RTOR can be written on-the-fly. If the new value is lower than or equal to the counter, the RTOF flag is set.

This register is reserved and forced by hardware to "0x00000000" when the receiver timeout feature is not supported. Refer to Section 61.4: USART implementation.

61.8.9 USART request register (USART_RQR)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXFRQ	RXFRQ	MMRQ	SBKRQ	ABRRQ
											w	w	w	w	w

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **TXFRQ**: Transmit data flush request

When FIFO mode is disabled, writing 1 to this bit sets the TXE flag. This enables to discard the transmit data. This bit must be used only in smartcard mode, when data have not been sent due to errors (NACK) and the FE flag is active in the USART_ISR register. If the USART does not support smartcard mode, this bit is reserved and must be kept at reset value.

When FIFO is enabled, TXFRQ bit is set to flush the whole FIFO. This sets the TXFE flag (Transmit FIFO empty, bit 23 in the USART_ISR register). Flushing the Transmit FIFO is supported in both UART and smartcard modes.

Note: In FIFO mode, the TXFNF flag is reset during the flush request until TxFIFO is empty in order to ensure that no data are written in the data register.

Bit 3 **RXFRQ**: Receive data flush request

Writing 1 to this bit empties the entire receive FIFO, that is clears the bit RXFNE.

This enables to discard the received data without reading them, and avoid an overrun condition.

Bit 2 **MMRQ**: Mute mode request

Writing 1 to this bit puts the USART in mute mode and resets the RWU flag.

Bit 1 **SBKRQ**: Send break request

Writing 1 to this bit sets the SBKF flag and request to send a BREAK on the line, as soon as the transmit machine is available.

Note: When the application needs to send the break character following all previously inserted data, including the ones not yet transmitted, the software must wait for the TXE flag assertion before setting the SBKRQ bit.

Bit 0 **ABRRQ**: Auto baud rate request

Writing 1 to this bit resets the ABRF and ABRE flags in the USART_ISR and requests an automatic baud rate measurement on the next received data frame.

Note: If the USART does not support the auto baud rate feature, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

61.8.10 USART interrupt and status register (USART_ISR)

Address offset: 0x1C

Reset value: 0x0XX0 00C0

XX = 28 if FIFO/smartcard mode supported

XX = 08 if FIFO supported and smartcard mode not supported

The same register can be used in FIFO mode enabled (this section) and FIFO mode disabled (next section).

FIFO mode enabled, FIFOEN = 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TXFT	RXFT	TCBGT	RXFF	TXFE	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY
				r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ABRF	ABRE	UDR	EOBF	RTOF	CTS	CTSIF	LBDF	TXFNF	TC	RXFNE	IDLE	ORE	NE	FE	PE
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **TXFT**: TXFIFO threshold flag

This bit is set by hardware when the number of empty locations in the TXFIFO is greater than the threshold programmed in the TXFTCFG[2:0] bitfield of USART_CR3 register.
An interrupt is generated if the TXFTIE bit (bit 31) is set in the USART_CR3 register.
0: TXFIFO does not reach the programmed threshold.
1: TXFIFO reached the programmed threshold.

Bit 26 **RXFT**: RXFIFO threshold flag

This bit is set by hardware when the threshold programmed in the RXFTCFG[2:0] bitfield of the USART_CR3 register is reached. This means that there are (RXFTCFG[2:0] – 1) data in the Receive FIFO and one data in the USART_RDR register. An interrupt is generated if the RXFTIE bit = 1 (bit 28) in the USART_CR3 register.
0: Receive FIFO does not reach the programmed threshold.
1: Receive FIFO reached the programmed threshold.

Note: When the RXFTCFG[2:0] threshold is configured to 101, the RXFT flag is set if RXFIFO size data are available, that is, (RXFIFO size – 1) data in the RXFIFO and 1 data in the USART_RDR. Consequently, the (RXFIFO size + 1) th received data does not cause an overrun error. The overrun error occurs after receiving the (RXFIFO size + 2) th data.

Bit 25 **TCBGT:** Transmission complete before guard time flag

This bit is set when the last data written in the USART_TDR has been transmitted correctly out of the shift register.
It is set by hardware in smartcard mode, if the transmission of a frame containing data has completed and if the smartcard did not send back any NACK. An interrupt is generated if TCBGTIE = 1 in the USART_CR3 register.
This bit is cleared by software, by writing 1 to the TCBGTCF in the USART_ICR register or by a write to the USART_TDR register.
0: Transmission has not completed, or transmission has completed unsuccessfully (that is, a NACK is received from the card)
1: Transmission has completed successfully (before Guard time completion and there is no NACK from the smart card).

Note: If the USART does not support the smartcard mode, this bit is reserved and kept at reset value. If the USART supports the smartcard mode and the smartcard mode is enabled, the TCBGT reset value is 1. Refer to Section 61.4: USART implementation.

Bit 24 **RXFF**: RXFIFO Full

This bit is set by hardware when the number of received data corresponds to RXFIFO size + 1 (RXFIFO full + 1 data in the USART_RDR register.
An interrupt is generated if the RXFFIE bit = 1 in the USART_CR1 register.
0: RXFIFO not full.
1: RXFIFO Full.

Bit 23 **TXFE**: TXFIFO Empty

This bit is set by hardware when TXFIFO is Empty. When the TXFIFO contains at least one data, this flag is cleared. The TXFE flag can also be set by writing 1 to the bit TXFRQ (bit 4) in the USART_RQR register.
An interrupt is generated if the TXFEIE bit = 1 (bit 30) in the USART_CR1 register.
0: TXFIFO not empty.
1: TXFIFO empty.

Bit 22 **REACK**: Receive enable acknowledge flag

This bit is set/reset by hardware, when the Receive Enable value is taken into account by the USART.

It can be used to verify that the USART is ready for reception before entering low-power mode.

Note: If the USART does not support the wake-up from Stop feature, this bit is reserved and kept at reset value. Refer to Section 61.4: USART implementation.

Bit 21 **TEACK**: Transmit enable acknowledge flag

This bit is set/reset by hardware, when the Transmit Enable value is taken into account by the USART.

It can be used when an idle frame request is generated by writing TE = 0, followed by TE = 1 in the USART_CR1 register, in order to respect the TE = 0 minimum period.

Bit 20 **WUF**: Wake-up from low-power mode flag

This bit is set by hardware, when a wake-up event is detected. The event is defined by the WUS bitfield. It is cleared by software, writing a 1 to the WUCF in the USART_ICR register.

An interrupt is generated if WUFIE = 1 in the USART_CR3 register.

Note: When UESM is cleared, WUF flag is also cleared.

If the USART does not support the wake-up from Stop feature, this bit is reserved and kept at reset value. Refer to Section 61.4: USART implementation.

Bit 19 **RWU**: Receiver wake-up from mute mode

This bit indicates if the USART is in mute mode. It is cleared/set by hardware when a wake-up/mute sequence is recognized. The mute mode control sequence (address or IDLE) is selected by the WAKE bit in the USART_CR1 register.

When wake-up on idle mode is selected, this bit can only be set by software, writing 1 to the MMRQ bit in the USART_RQR register.

0: Receiver in active mode

1: Receiver in mute mode

Note: If the USART does not support the wake-up from Stop feature, this bit is reserved and kept at reset value. Refer to Section 61.4: USART implementation.

Bit 18 **SBKF**: Send break flag

This bit indicates that a send break character was requested. It is set by software, by writing 1 to the SBKRQ bit in the USART_CR3 register. It is automatically reset by hardware during the stop bit of break transmission.

0: No break character transmitted

1: Break character transmitted

Bit 17 **CMF**: Character match flag

This bit is set by hardware, when a the character defined by ADD[7:0] is received. It is cleared by software, writing 1 to the CMCF in the USART_ICR register.

An interrupt is generated if CMIE = 1in the USART_CR1 register.

0: No Character match detected

1: Character match detected

Bit 16 **BUSY**: Busy flag

This bit is set and reset by hardware. It is active when a communication is ongoing on the RX line (successful start bit detected). It is reset at the end of the reception (successful or not).

0: USART is idle (no reception)

1: Reception ongoing

Bit 15 **ABRF:** Auto baud rate flag

This bit is set by hardware when the automatic baud rate has been set (RXFNE is also set, generating an interrupt if RXFNEIE = 1) or when the auto baud rate operation has completed without success (ABRE = 1) (ABRE, RXFNE and FE are also set in this case)

It is cleared by software, in order to request a new auto baud rate detection, by writing 1 to the ABRRQ in the USART_RQR register.

Note: If the USART does not support the auto baud rate feature, this bit is reserved and kept at reset value.

Bit 14 **ABRE**: Auto baud rate error

This bit is set by hardware if the baud rate measurement failed (baud rate out of range or character comparison failed)

It is cleared by software, by writing 1 to the ABRRQ bit in the USART_RQR register.

Note: If the USART does not support the auto baud rate feature, this bit is reserved and kept at reset value.

Bit 13 **UDR**: SPI slave underrun error flag

In slave transmission mode, this flag is set when the first clock pulse for data transmission appears while the software has not yet loaded any value into USART_TDR. This flag is reset by setting UDRCF bit in the USART_ICR register.

0: No underrun error

1: underrun error

Note: If the USART does not support the SPI slave mode, this bit is reserved and kept at reset value. Refer to Section 61.4: USART implementation.

Bit 12 **EOBF**: End of block flag

This bit is set by hardware when a complete block has been received (for example T = 1 smartcard mode). The detection is done when the number of received bytes (from the start of the block, including the prologue) is equal or greater than BLEN + 4.

An interrupt is generated if EOBIE = 1 in the USART_CR1 register.

It is cleared by software, writing 1 to EOBCF in the USART_ICR register.

0: End of block not reached

1: End of block (number of characters) reached

Note: If smartcard mode is not supported, this bit is reserved and kept at reset value. Refer to Section 61.4: USART implementation.

Bit 11 **RTOF**: Receiver timeout

This bit is set by hardware when the timeout value, programmed in the RTOR register has lapsed, without any communication. It is cleared by software, writing 1 to the RTOCF bit in the USART_ICR register.

An interrupt is generated if RTOIE = 1 in the USART_CR2 register.

In smartcard mode, the timeout corresponds to the CWT or BWT timings.

0: Timeout value not reached

1: Timeout value reached without any data reception

Note: If a time equal to the value programmed in RTOR register separates 2 characters, RTOF is not set. If this time exceeds this value + 2 sample times (2/16 or 2/8, depending on the oversampling method), RTOF flag is set.

The counter counts even if RE = 0 but RTOF is set only when RE = 1. If the timeout has already elapsed when RE is set, then RTOF is set.

If the USART does not support the Receiver timeout feature, this bit is reserved and kept at reset value.

Bit 10 **CTS**: CTS flag

This bit is set/reset by hardware. It is an inverted copy of the status of the CTS input pin.

0: CTS line set

1: CTS line reset

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 9 **CTSIF**: CTS interrupt flag

This bit is set by hardware when the CTS input toggles, if the CTSE bit is set. It is cleared by software, by writing 1 to the CTSCF bit in the USART_ICR register.

An interrupt is generated if CTSIE = 1 in the USART_CR3 register.

0: No change occurred on the CTS status line

1: A change occurred on the CTS status line

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 8 **LBDF**: LIN break detection flag

This bit is set by hardware when the LIN break is detected. It is cleared by software, by writing 1 to the LBDCF in the USART_ICR.

An interrupt is generated if LBDIE = 1 in the USART_CR2 register.

0: LIN Break not detected

1: LIN break detected

Note: If the USART does not support LIN mode, this bit is reserved and kept at reset value. Refer to Section 61.4: USART implementation.

Bit 7 **TXFNF:** TXFIFO not full

TXFNF is set by hardware when TXFIFO is not full meaning that data can be written in the USART_TDR. Every write operation to the USART_TDR places the data in the TXFIFO. This flag remains set until the TXFIFO is full. When the TXFIFO is full, this flag is cleared indicating that data can not be written into the USART_TDR.

An interrupt is generated if the TXFNFIE bit = 1 in the USART_CR1 register.

0: Transmit FIFO is full

1: Transmit FIFO is not full

Note: The TXFNF is kept reset during the flush request until TXFIFO is empty. After sending the flush request (by setting TXFRQ bit), the flag TXFNF must be checked prior to writing in TXFIFO (TXFNF and TXFE is set at the same time).

This bit is used during single buffer transmission.

Bit 6 **TC**: Transmission complete

This bit indicates that the last data written in the USART_TDR has been transmitted out of the shift register.

It is set by hardware when the transmission of a frame containing data has completed, and the TXFE bit is set.

An interrupt is generated if TCIE = 1 in the USART_CR1 register.

The TC bit is cleared by software, by writing 1 to the TCCF of the USART_ICR register, or by a write to the USART_TDR register.

0: Transmission has not completed

1: Transmission has completed

Note: If the TE bit is reset and no transmission is ongoing, the TC bit is immediately set.

Bit 5 **RXFNE**: RXFIFO not empty

RXFNE bit is set by hardware when the RXFIFO is not empty, meaning that data can be read from the USART_RDR register. Every read operation from the USART_RDR frees a location in the RXFIFO.

RXFNE is cleared when the RXFIFO is empty. The RXFNE flag can also be cleared by writing 1 to the RXFRQ in the USART_RQR register.

An interrupt is generated if RXFNEIE = 1 in the USART_CR1 register.

0: Data is not received

1: Received data is ready to be read.

Bit 4 **IDLE**: Idle line detected

This bit is set by hardware when an Idle Line is detected. An interrupt is generated if IDLEIE = 1 in the USART_CR1 register. It is cleared by software, writing 1 to the IDLECF in the USART_ICR register.

0: No Idle line is detected

1: Idle line is detected

Note: The IDLE bit is not set again until the RXFNE bit has been set (that is, a new idle line occurs).

If mute mode is enabled (MME = 1), IDLE is set if the USART is not mute (RWU = 0), whatever the mute mode selected by the WAKE bit. If RWU = 1, IDLE is not set.

Bit 3 **ORE**: Overrun error

This bit is set by hardware when the data currently being received in the shift register is ready to be transferred into the USART_RDR register while RXFF = 1. It is cleared by a software, writing 1 to the ORECF, in the USART_ICR register.

An interrupt is generated if RXFNEIE = 1 in the USART_CR1 register, or EIE = 1 in the USART_CR3 register.

0: No overrun error

1: Overrun error is detected

Note: When this bit is set, the USART_RDR register content is not lost but the shift register is overwritten. An interrupt is generated if the ORE flag is set during multi buffer communication if the EIE bit is set.

This bit is permanently forced to 0 (no overrun detection) when the bit OVRDIS is set in the USART_CR3 register.

Bit 2 **NE**: Noise detection flag

This bit is set by hardware when noise is detected on a received frame. It is cleared by software, writing 1 to the NFCF bit in the USART_ICR register.

0: No noise is detected

1: Noise is detected

Note: This bit does not generate an interrupt as it appears at the same time as the RXFNE bit which itself generates an interrupt. An interrupt is generated when the NE flag is set during multi buffer communication if the EIE bit is set.

When the line is noise-free, the NE flag can be disabled by programming the ONEBIT bit to 1 to increase the USART tolerance to deviations (Refer to Section 61.5.9: Tolerance of the USART receiver to clock deviation).

This error is associated with the character in the USART_RDR.

Bit 1 **FE**: Framing error

This bit is set by hardware when a de-synchronization, excessive noise or a break character is detected. It is cleared by software, writing 1 to the FECF bit in the USART_ICR register.
When transmitting data in smartcard mode, this bit is set when the maximum number of transmit attempts is reached without success (the card NACKs the data frame).
An interrupt is generated if EIE = 1 in the USART_CR3 register.
0: No Framing error is detected
1: Framing error or break character is detected

Note: This error is associated with the character in the USART_RDR.

Bit 0 **PE**: Parity error

This bit is set by hardware when a parity error occurs in reception mode. It is cleared by software, writing 1 to the PECF in the USART_ICR register.
An interrupt is generated if PEIE = 1 in the USART_CR1 register.
0: No parity error
1: Parity error

Note: This error is associated with the character in the USART_RDR.

61.8.11 USART interrupt and status register [alternate] (USART_ISR)

Address offset: 0x1C

Reset value: 0x0XX0 00C0

XX = 28 if FIFO/smartcard mode supported

XX = 08 if FIFO supported and smartcard mode not supported)

The same register can be used in FIFO mode enabled (previous section) and FIFO mode disabled (this section).

FIFO mode disabled, FIFOEN = 0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	TCBGT	Res.	Res.	RE ACK	TE ACK	WUF	RWU	SBKF	CMF	BUSY
						r			r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ABRF	ABRE	UDR	EOBF	RTOF	CTS	CTSIF	LBDF	TXE	TC	RXNE	IDLE	ORE	NE	FE	PE
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **TCBGT:** Transmission complete before guard time flag

This bit is set when the last data written in the USART_TDR has been transmitted correctly out of the shift register.

It is set by hardware in smartcard mode, if the transmission of a frame containing data has completed, and if the smartcard did not send back any NACK. An interrupt is generated if TCBGTIE = 1 in the USART_CR3 register.

This bit is cleared by software, by writing 1 to the TCBGTCF in the USART_ICR register or by a write to the USART_TDR register.

0: Transmission has not completed or transmission has completed unsuccessfully (that is, a NACK is received from the card)

1: Transmission has not completed successfully (before Guard time completion and there is no NACK from the smart card).

Note: If the USART does not support the smartcard mode, this bit is reserved and kept at reset value. If the USART supports the smartcard mode and the smartcard mode is enabled, the TCBGT reset value is 1. Refer to Section 61.4: USART implementation.

Bits 24:23 Reserved, must be kept at reset value.

Bit 22 **REACK**: Receive enable acknowledge flag

This bit is set/reset by hardware, when the Receive Enable value is taken into account by the USART.

It can be used to verify that the USART is ready for reception before entering low-power mode.

Note: If the USART does not support the wake-up from Stop feature, this bit is reserved and kept at reset value. Refer to Section 61.4: USART implementation.

Bit 21 **TEACK**: Transmit enable acknowledge flag

This bit is set/reset by hardware, when the Transmit Enable value is taken into account by the USART.

It can be used when an idle frame request is generated by writing TE = 0, followed by TE = 1 in the USART_CR1 register, in order to respect the TE = 0 minimum period.

Bit 20 **WUF**: Wake-up from low-power mode flag

This bit is set by hardware, when a wake-up event is detected. The event is defined by the WUS bitfield. It is cleared by software, writing a 1 to the WUCF in the USART_ICR register.

An interrupt is generated if WUFIE = 1 in the USART_CR3 register.

Note: When UESM is cleared, WUF flag is also cleared.

If the USART does not support the wake-up from Stop feature, this bit is reserved and kept at reset value. Refer to Section 61.4: USART implementation.

Bit 19 **RWU**: Receiver wake-up from mute mode

This bit indicates if the USART is in mute mode. It is cleared/set by hardware when a wake-up/mute sequence is recognized. The mute mode control sequence (address or IDLE) is selected by the WAKE bit in the USART_CR1 register.

When wake-up on idle mode is selected, this bit can only be set by software, writing 1 to the MMRQ bit in the USART_RQR register.

0: Receiver in active mode

1: Receiver in mute mode

Note: If the USART does not support the wake-up from Stop feature, this bit is reserved and kept at reset value. Refer to Section 61.4: USART implementation.

Bit 18 **SBKF**: Send break flag

This bit indicates that a send break character was requested. It is set by software, by writing 1 to the SBKRQ bit in the USART_CR3 register. It is automatically reset by hardware during the stop bit of break transmission.

0: No break character transmitted

1: Break character transmitted

Bit 17 **CMF**: Character match flag

This bit is set by hardware, when a the character defined by ADD[7:0] is received. It is cleared by software, writing 1 to the CMCF in the USART_ICR register.

An interrupt is generated if CMIE = 1 in the USART_CR1 register.

0: No Character match detected

1: Character match detected

Bit 16 **BUSY**: Busy flag

This bit is set and reset by hardware. It is active when a communication is ongoing on the RX line (successful start bit detected). It is reset at the end of the reception (successful or not).

0: USART is idle (no reception)

1: Reception ongoing

Bit 15 **ABRF:** Auto baud rate flag

This bit is set by hardware when the automatic baud rate has been set (RXNE is also set, generating an interrupt if RXNEIE = 1) or when the auto baud rate operation has completed without success (ABRE = 1) (ABRE, RXNE and FE are also set in this case)

It is cleared by software, in order to request a new auto baud rate detection, by writing 1 to the ABRRQ in the USART_RQR register.

Note: If the USART does not support the auto baud rate feature, this bit is reserved and kept at reset value.

Bit 14 **ABRE**: Auto baud rate error

This bit is set by hardware if the baud rate measurement failed (baud rate out of range or character comparison failed)

It is cleared by software, by writing 1 to the ABRRQ bit in the USART_RQR register.

Note: If the USART does not support the auto baud rate feature, this bit is reserved and kept at reset value.

Bit 13 **UDR**: SPI slave underrun error flag

In slave transmission mode, this flag is set when the first clock pulse for data transmission appears while the software has not yet loaded any value into USART_TDR. This flag is reset by setting UDRCF bit in the USART_ICR register.

0: No underrun error

1: underrun error

Note: If the USART does not support the SPI slave mode, this bit is reserved and kept at reset value. Refer to Section 61.4: USART implementation.

Bit 12 **EOBF**: End of block flag

This bit is set by hardware when a complete block has been received (for example T = 1 smartcard mode). The detection is done when the number of received bytes (from the start of the block, including the prologue) is equal or greater than BLEN + 4.

An interrupt is generated if EOBIE = 1 in the USART_CR1 register.

It is cleared by software, writing 1 to EOBCF in the USART_ICR register.

0: End of block not reached

1: End of block (number of characters) reached

Note: If smartcard mode is not supported, this bit is reserved and kept at reset value. Refer to Section 61.4: USART implementation.

Bit 11 **RTOF**: Receiver timeout

This bit is set by hardware when the timeout value, programmed in the RTOR register has lapsed, without any communication. It is cleared by software, writing 1 to the RTOCF bit in the USART_ICR register.

An interrupt is generated if RTOIE = 1 in the USART_CR2 register.

In smartcard mode, the timeout corresponds to the CWT or BWT timings.

0: Timeout value not reached

1: Timeout value reached without any data reception

Note: If a time equal to the value programmed in RTOR register separates 2 characters, RTOF is not set. If this time exceeds this value + 2 sample times (2/16 or 2/8, depending on the oversampling method), RTOF flag is set.

The counter counts even if RE = 0 but RTOF is set only when RE = 1. If the timeout has already elapsed when RE is set, then RTOF is set.

If the USART does not support the Receiver timeout feature, this bit is reserved and kept at reset value.

Bit 10 **CTS**: CTS flag

This bit is set/reset by hardware. It is an inverted copy of the status of the CTS input pin.

0: CTS line set

1: CTS line reset

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 9 **CTSIF**: CTS interrupt flag

This bit is set by hardware when the CTS input toggles, if the CTSE bit is set. It is cleared by software, by writing 1 to the CTSCF bit in the USART_ICR register.

An interrupt is generated if CTSIE = 1 in the USART_CR3 register.

0: No change occurred on the CTS status line

1: A change occurred on the CTS status line

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 8 **LBDF**: LIN break detection flag

This bit is set by hardware when the LIN break is detected. It is cleared by software, by writing 1 to the LBDCF in the USART_ICR.

An interrupt is generated if LBDIE = 1 in the USART_CR2 register.

0: LIN Break not detected

1: LIN break detected

Note: If the USART does not support LIN mode, this bit is reserved and kept at reset value. Refer to Section 61.4: USART implementation.

Bit 7 **TXE:** Transmit data register empty

TXE is set by hardware when the content of the USART_TDR register has been transferred into the shift register. It is cleared by writing to the USART_TDR register. The TXE flag can also be set by writing 1 to the TXFRQ in the USART_RQR register, in order to discard the data (only in smartcard T = 0 mode, in case of transmission failure).

An interrupt is generated if the TXEIE bit = 1 in the USART_CR1 register.

0: Data register full

1: Data register empty

Bit 6 **TC**: Transmission complete

This bit indicates that the last data written in the USART_TDR has been transmitted out of the shift register. The TC flag is set when the transmission of a frame containing data has completed and when TXE is set.

An interrupt is generated if TCIE = 1 in the USART_CR1 register.

TC bit is cleared by software by writing 1 to the TCCF in the USART_ICR register or by writing to the USART_TDR register.

Bit 5 **RXNE**: Read data register not empty

RXNE bit is set by hardware when the content of the USART_RDR shift register has been transferred to the USART_RDR register. It is cleared by reading from the USART_RDR register. The RXNE flag can also be cleared by writing 1 to the RXFRQ in the USART_RQR register.

An interrupt is generated if RXNEIE = 1 in the USART_CR1 register.

0: Data is not received

1: Received data is ready to be read.

Bit 4 **IDLE**: Idle line detected

This bit is set by hardware when an Idle Line is detected. An interrupt is generated if IDLEIE = 1 in the USART_CR1 register. It is cleared by software, writing 1 to the IDLECF in the USART_ICR register.

0: No Idle line is detected

1: Idle line is detected

Note: The IDLE bit is not set again until the RXNE bit has been set (that is, a new idle line occurs).

If mute mode is enabled (MME = 1), IDLE is set if the USART is not mute (RWU = 0), whatever the mute mode selected by the WAKE bit. If RWU = 1, IDLE is not set.

Bit 3 **ORE**: Overrun error

This bit is set by hardware when the data currently being received in the shift register is ready to be transferred into the USART_RDR register while RXNE = 1. It is cleared by a software, writing 1 to the ORECF, in the USART_ICR register.

An interrupt is generated if RXNEIE = 1 in the USART_CR1 register, or EIE = 1 in the USART_CR3 register.

1: Overrun error is detected

Note: When this bit is set, the USART_RDR register content is not lost but the shift register is overwritten. An interrupt is generated if the ORE flag is set during multi buffer communication if the EIE bit is set.

This bit is permanently forced to 0 (no overrun detection) when the bit OVRDIS is set in the USART_CR3 register.

Bit 2 **NE**: Noise detection flag

This bit is set by hardware when noise is detected on a received frame. It is cleared by software, writing 1 to the NFCF bit in the USART_ICR register.

0: No noise is detected

1: Noise is detected

Note: This bit does not generate an interrupt as it appears at the same time as the RXNE bit which itself generates an interrupt. An interrupt is generated when the NE flag is set during multi buffer communication if the EIE bit is set.

When the line is noise-free, the NE flag can be disabled by programming the ONEBIT bit to 1 to increase the USART tolerance to deviations (Refer to Section 61.5.9: Tolerance of the USART receiver to clock deviation).

This error is associated with the character in the USART_RDR.

Bit 1 **FE**: Framing error

This bit is set by hardware when a de-synchronization, excessive noise or a break character is detected. It is cleared by software, writing 1 to the FECF bit in the USART_ICR register.

When transmitting data in smartcard mode, this bit is set when the maximum number of transmit attempts is reached without success (the card NACKs the data frame).

An interrupt is generated if EIE = 1 in the USART_CR3 register.

0: No Framing error is detected

1: Framing error or break character is detected

Note: This error is associated with the character in the USART_RDR.

Bit 0 **PE**: Parity error

This bit is set by hardware when a parity error occurs in reception mode. It is cleared by software, writing 1 to the PECF in the USART_ICR register.

An interrupt is generated if PEIE = 1 in the USART_CR1 register.

0: No parity error

1: Parity error

Note: This error is associated with the character in the USART_RDR.

61.8.12 USART interrupt flag clear register (USART_ICR)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUCF	Res.	Res.	CMCF	Res.
											w			w	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	UDRCF	EOBCF	RTOCF	Res.	CTSCF	LBDCF	TCBGTCF	TCCF	TXFECF	IDLECF	ORECF	NECF	FECF	PECF
		w	w	w		w	w	w	w	w	w	w	w	w	w

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **WUCF**: Wake-up from low-power mode clear flag

Writing 1 to this bit clears the WUF flag in the USART_ISR register.

Note: If the USART does not support the wake-up from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bits 19:18 Reserved, must be kept at reset value.

Bit 17 **CMCF**: Character match clear flag

Writing 1 to this bit clears the CMF flag in the USART_ISR register.

Bits 16:14 Reserved, must be kept at reset value.

Bit 13 **UDRCF**:SPI slave underrun clear flag

Writing 1 to this bit clears the UDRF flag in the USART_ISR register.

Note: If the USART does not support SPI slave mode, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation

Bit 12 **EOBCF**: End of block clear flag

Writing 1 to this bit clears the EOBF flag in the USART_ISR register.

Note: If the USART does not support smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 11 **RTOCF**: Receiver timeout clear flag
Writing 1 to this bit clears the RTOF flag in the USART_ISR register.
Note: If the USART does not support the Receiver timeout feature, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 10 Reserved, must be kept at reset value.

Bit 9 **CTSCF**: CTS clear flag
Writing 1 to this bit clears the CTSIF flag in the USART_ISR register.
Note: If the hardware flow control feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 8 **LBDCF**: LIN break detection clear flag
Writing 1 to this bit clears the LBDF flag in the USART_ISR register.
Note: If LIN mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

Bit 7 **TCBGTCF**: Transmission complete before Guard time clear flag
Writing 1 to this bit clears the TCBGT flag in the USART_ISR register.

Bit 6 **TCCF**: Transmission complete clear flag
Writing 1 to this bit clears the TC flag in the USART_ISR register.

Bit 5 **TXFECF**: TXFIFO empty clear flag
Writing 1 to this bit clears the TXFE flag in the USART_ISR register.

Bit 4 **IDLECF**: Idle line detected clear flag
Writing 1 to this bit clears the IDLE flag in the USART_ISR register.

Bit 3 **ORECF**: Overrun error clear flag
Writing 1 to this bit clears the ORE flag in the USART_ISR register.

Bit 2 **NECF**: Noise detected clear flag
Writing 1 to this bit clears the NE flag in the USART_ISR register.

Bit 1 **FECF**: Framing error clear flag
Writing 1 to this bit clears the FE flag in the USART_ISR register.

Bit 0 **PECF**: Parity error clear flag
Writing 1 to this bit clears the PE flag in the USART_ISR register.

61.8.13 USART receive data register (USART_RDR)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDR[8:0]								
							r	r	r	r	r	r	r	r	r

Bits 31:9 Reserved, must be kept at reset value.

Bits 8:0 **RDR[8:0]**: Receive data value

Contains the received data character.

The RDR register provides the parallel interface between the input shift register and the internal bus (see *Section 61.5.1: USART block diagram*).

When receiving with the parity enabled, the value read in the MSB bit is the received parity bit.

61.8.14 USART transmit data register (USART_TDR)

Address offset: 0x28

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDR[8:0]								
							rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bits 8:0 **TDR[8:0]**: Transmit data value

Contains the data character to be transmitted.

The USART_TDR register provides the parallel interface between the internal bus and the output shift register (see *Section 61.5.1: USART block diagram*).

When transmitting with the parity enabled (PCE bit set to 1 in the USART_CR1 register), the value written in the MSB (bit 7 or bit 8 depending on the data length) has no effect because it is replaced by the parity.

Note: This register must be written only when TXE/TXFNF = 1.

61.8.15 USART prescaler register (USART_PRESC)

This register can only be written when the USART is disabled (UE = 0).

Address offset: 0x2C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **PRESCALER[3:0]**: Clock prescaler

The USART input clock can be divided by a prescaler factor:

0000: input clock not divided
0001: input clock divided by 2
0010: input clock divided by 4
0011: input clock divided by 6
0100: input clock divided by 8
0101: input clock divided by 10
0110: input clock divided by 12
0111: input clock divided by 16
1000: input clock divided by 32
1001: input clock divided by 64
1010: input clock divided by 128
1011: input clock divided by 256
Others: Reserved, must not be used

Note: When PRESCALER is programmed with a value different of the allowed ones, programmed prescaler value is equal to 1011 that is, input clock divided by 256.

If the prescaler is not supported, this bitfield is reserved and must be kept at reset value. Refer to Section 61.4: USART implementation.

61.8.16 USART register map

Table 677. USART register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	USART_CR1 FIFO mode enabled	RXFFIE	TXFEIE	FIFOEN	M1	EOBIE	RTOIE	DEAT[4:0]					DEDT[4:0]					OVER8	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXFNFIE	TCIE	RXFNEIE	IDLEIE	TE	RE	UESM	UE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00	USART_CR1 FIFO mode disabled	Res.	Res.	FIFOEN	M1	EOBIE	RTOIE	DEAT[4:0]					DEDT[4:0]					OVER8	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXEIE	TCIE	RXNEIE	IDLEIE	TE	RE	UESM	UE
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	USART_CR2	ADD[7:0]								RTOEN	ABRMOD[1:0]		ABREN	MSBFIRST	DATAINV	TXINV	RXINV	SWAP	LINEN	STOP [1:0]		CLKEN	CPOL	CPHA	LBCL	Res.	LBDIE	LBDL	ADDM7	DIS_NSS	Res.	Res.	SLVEN
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0			0
0x08	USART_CR3 FIFO mode enabled	TXFTCFG[2:0]			RXFTIE	RXFTCFG2:0]			TCBGTIE	TXFTIE	WUFIE	WUS 1	WUS 0	SCAR CNT2:0]			Res.	DEP	DEM	DDRE	OVRDIS	ONEBIT	CTSIE	CTSE	RTSE	DMAT	DMAR	SCEN	NACK	HDSEL	IRLP	IREN	EIE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	USART_CR3 FIFO mode disabled	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCBGTIE	Res.	WUFIE	WUS 1	WUS 0	SCAR CNT2:0]			Res.	DEP	DEM	DDRE	OVRDIS	ONEBIT	CTSIE	CTSE	RTSE	DMAT	DMAR	SCEN	NACK	HDSEL	IRLP	IREN	EIE
	Reset value								0		0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 677. USART register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0C	USART_BRR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BRR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	USART_ GTPR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GT[7:0]								PSC[7:0]							
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	USART_ RTOR	BLEN[7:0]								RTO[23:0]																							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	USART_RQR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXFRQ	RXFRQ	MMRQ	SBKRQ	ABRRQ
	Reset value																												0	0	0	0	0
0x1C	USART_ISR FIFO mode enabled	Res.	Res.	Res.	Res.	TXFT	RXFT	TCBGT	RXFF	TXFE	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY	ABRF	ABRE	UDR	EOBF	RTOF	CTS	CTSIF	LBDF	TXFNF	TC	RXFNE	IDLE	ORE	NE	FE	PE
	Reset value					0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
0x1C	USART_ISR FIFO mode disabled	Res.	Res.	Res.	Res.	Res.	Res.	TCBGT	Res.	Res.	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY	ABRF	ABRE	UDR	EOBF	RTOF	CTS	CTSIF	LBDF	TXE	TC	RXNE	IDLE	ORE	NE	FE	PE
	Reset value							0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
0x20	USART_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUCF	Res.	Res.	CMCF	Res.	Res.	Res.	UDRCF	EOBCF	RTOCF	Res.	CTSCF	LBDCF	TCBGTCF	TCCF	TXFECF	IDLECF	ORECF	NECF	FECF	PECF
	Reset value												0			0				0	0	0		0	0	0	0	0	0	0	0	0	0
0x24	USART_RDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDR[8:0]								
	Reset value																								0	0	0	0	0	0	0	0	0
0x28	USART_TDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDR[8:0]								
	Reset value																								0	0	0	0	0	0	0	0	0
0x2C	USART_ PRESC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[3:0]			
	Reset value																													0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

62 Low-power universal asynchronous receiver transmitter (LPUART)

62.1 LPUART introduction

The LPUART is an UART, which enables bidirectional UART communications with a limited power consumption. Only a 32.768 kHz LSE clock is required to enable UART communications up to 9600 bauds. Higher baud rates can be reached when the LPUART is clocked by clock sources different from the LSE clock.

Even when the microcontroller is in low-power mode, the LPUART can wait for an incoming UART frame while having an extremely low energy consumption. The LPUART includes all necessary hardware support to make asynchronous serial communications possible with minimum power consumption.

It supports half-duplex single-wire communications and modem operations (CTS/RTS).

It also supports multiprocessor communications.

DMA (direct memory access) can be used for data transmission/reception.

62.2 LPUART main features

- Full-duplex asynchronous communications
- NRZ standard format (mark/space)
- Programmable baud rate
- From 300 bauds to 9600 bauds using a 32.768 kHz clock source.
- Higher baud rates can be achieved by using a higher frequency clock source
- Two internal FIFOs to transmit and receive data

  Each FIFO can be enabled/disabled by software and come with status flags for FIFOs states.
- Dual clock domain with dedicated kernel clock for peripherals independent from PCLK.
- Programmable data word length (7 or 8 or 9 bits)
- Programmable data order with MSB-first or LSB-first shifting
- Configurable stop bits (1 or 2 stop bits)
- Single-wire half-duplex communications
- Continuous communications using DMA
- Received/transmitted bytes are buffered in reserved SRAM using centralized DMA.
- Separate enable bits for transmitter and receiver
- Separate signal polarity control for transmission and reception
- Swappable Tx/Rx pin configuration
- Hardware flow control for modem and RS485 transceiver
- Transfer detection flags:
  - Receive buffer full
  - Transmit buffer empty
  - Busy and end of transmission flags

- Parity control:
  - Transmits parity bit
  - Checks parity of received data byte
- Four error detection flags:
  - Overrun error
  - Noise detection
  - Frame error
  - Parity error
- Interrupt sources with flags
- Multiprocessor communications: wake-up from mute mode by idle line detection or address mark detection
- Wake-up from Stop mode

62.3 LPUART implementation

The tables below describe the LPUART implementation. USARTs and UARTs are included for comparison.

Table 678. Instance implementation on STM32H5E4/5F4 and STM32H5E5/5F5

Instance	STM32H5Ex/H5Fx
USART1	Full
USART2	Full
USART3	Full
USART6	Full
USART10	Full
USART11	Full
UART4	Basic
UART5	Basic
UART7	Basic
UART8	Basic
UART12	Basic
LPUART1	Low-power

Table 679. USART/LPUART features

Modes/features(1)	Full feature set	Basic feature set	Low-power feature set
Hardware flow control for modem	X	X	X
Continuous communication using DMA	X	X	X
Multiprocessor communication	X	X	X
Synchronous mode (master/slave)	X	-	-

Table 679. USART/LPUART features (continued)

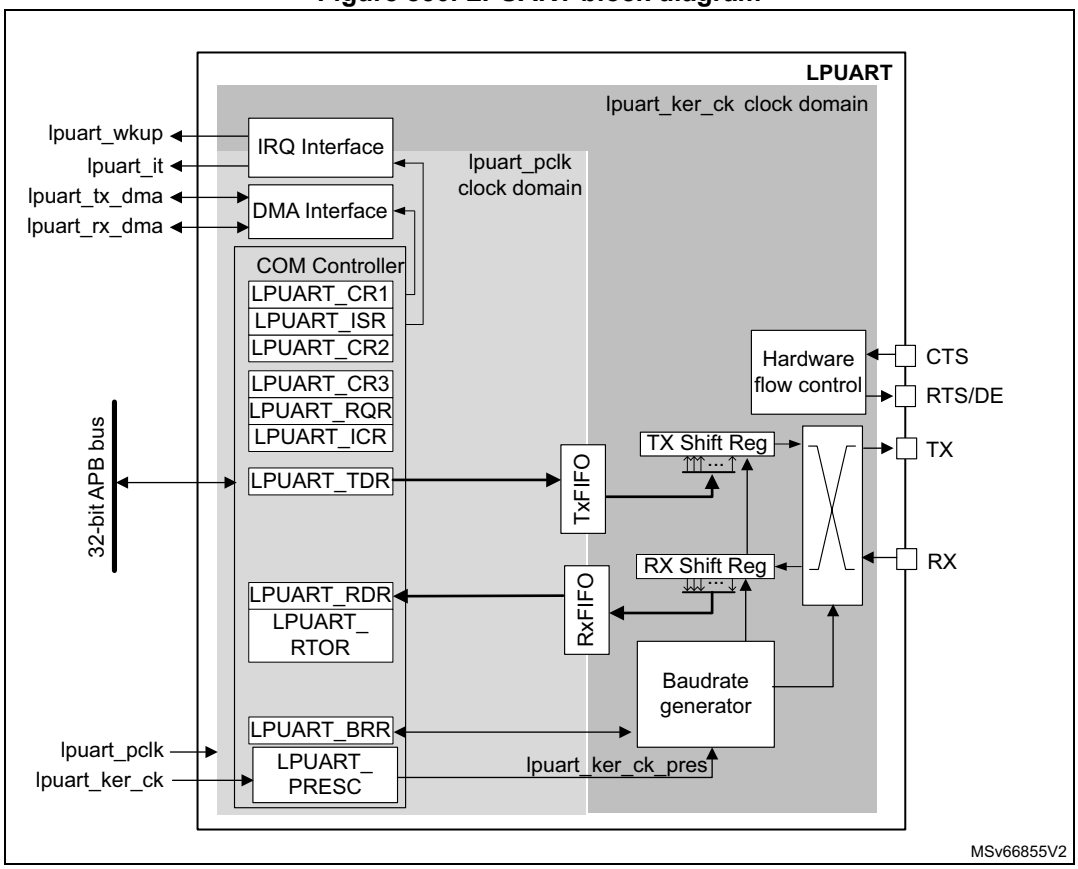
Modes/features[1]	Full feature set	Basic feature set	Low-power feature set
Smartcard mode	X	-	-
Single-wire half-duplex communication	X	X	X
IrDA SIR ENDEC block	X	X	-
LIN mode	X	X	-
Dual clock domain	X	X	X
Receiver timeout interrupt	X	X	-
Modbus communication	X	X	-
Auto baud rate detection	X	X	-
Driver enable	X	X	X
USART data length	7, 8 and 9 bits		
Tx/Rx FIFO	X	X	X
Tx/Rx FIFO size (bytes)	8		
Wake-up from low-power mode	X[2]	X[2]	X[2]

1. X = supported.
2. Wake-up supported from Stop mode.

62.4 LPUART functional description

62.4.1 LPUART block diagram

Figure 850. LPUART block diagram



62.4.2 LPUART pins and internal signals

Description LPUART input/output pins

- LPUART bidirectional communications

  LPUART bidirectional communications require a minimum of two pins: Receive Data In (RX) and Transmit Data Out (TX):

  – **RX** (Receive Data Input):

    RX is the serial data input.

  – **TX (**Transmit Data Output)

    When the transmitter is disabled, the output pin returns to its I/O port configuration. When the transmitter is enabled and nothing is to be transmitted, the TX pin is at high level. In single-wire mode, this I/O is used to transmit and receive the data.

- RS232 hardware flow control mode

  The RS232 hardware flow control mode requires the following pins:

  – **CTS (**Clear To Send)

    When driven high, this signal blocks the data transmission at the end of the current transfer.

  – **RTS** (Request to send)

    When it is low, this signal indicates that the LPUART is ready to receive data.

- RS485 hardware flow control mode

  The **DE** (Driver Enable) pin is required in RS485 hardware control mode. This signal activates the transmission mode of the external transceiver.

Refer to *Table 680* and *Table 681* for the list of LPUART input/output pins and internal signals.

Table 680. LPUART input/output pins

Pin name	Signal type	Description
LPUART_RX	Input	Serial data receive input.
LPUART_TX	Output	Transmit data output.
LPUART_CTS	Input	Clear to send
LPUART_RTS	Output	Request to send
LPUART_DE(1)	Output	Driver enable

1. LPUART_DE and LPUART_RTS share the same pin.

Description LPUART input/output signals

Table 681. LPUART internal input/output signals

Signal name	Signal type	Description
lpuart_pclk	Input	APB clock
lpuart_ker_ck	Input	LPUART kernel clock
lpuart_wkup	Output	LPUART provides a wake-up interrupt

Table 681. LPUART internal input/output signals (continued)

Signal name	Signal type	Description
lpuart_it	Output	LPUART global interrupt
lpuart_tx_dma	Input/output	LPUART transmit DMA request
lpuart_rx_dma	Input/output	LPUART receive DMA request

62.4.3 LPUART clocks

The simplified block diagram given in *Section 62.4.1: LPUART block diagram* shows two fully independent clock domains:

- The **lpuart_pclk** clock domain

  The **lpuart_pclk** clock signal feeds the peripheral bus interface. It must be active when accesses to the LPUART registers are required.
- The **lpuart_ker_ck** kernel clock domain

  The **lpuart_ker_ck** is the LPUART clock source. It is independent of the **lpuart_pclk** and delivered by the RCC. So, the LPUART registers can be written/read even when the **lpuart_ker_ck** is stopped.

  When the dual clock domain feature is not supported, the **lpuart_ker_ck i**s the same as the lpuart_pclk clock.

There is no constraint between **lpuart_pclk** and **lpuart_ker_ck**: **lpuart_ker_ck** can be faster or slower than **lpuart_pclk**, with no more limitation than the ability for the software to manage the communication fast enough.

62.4.4 LPUART character description

The word length can be set to 7 or 8 or 9 bits, by programming the M bits (M0: bit 12 and M1: bit 28) in the LPUART_CR1 register (see *Figure 824*).

- 7-bit character length: M[1:0] = 10
- 8-bit character length: M[1:0] = 00
- 9-bit character length: M[1:0] = 01

By default, the signal (TX or RX) is in low state during the start bit. It is in high state during the stop bit.

These values can be inverted, separately for each signal, through polarity configuration control.

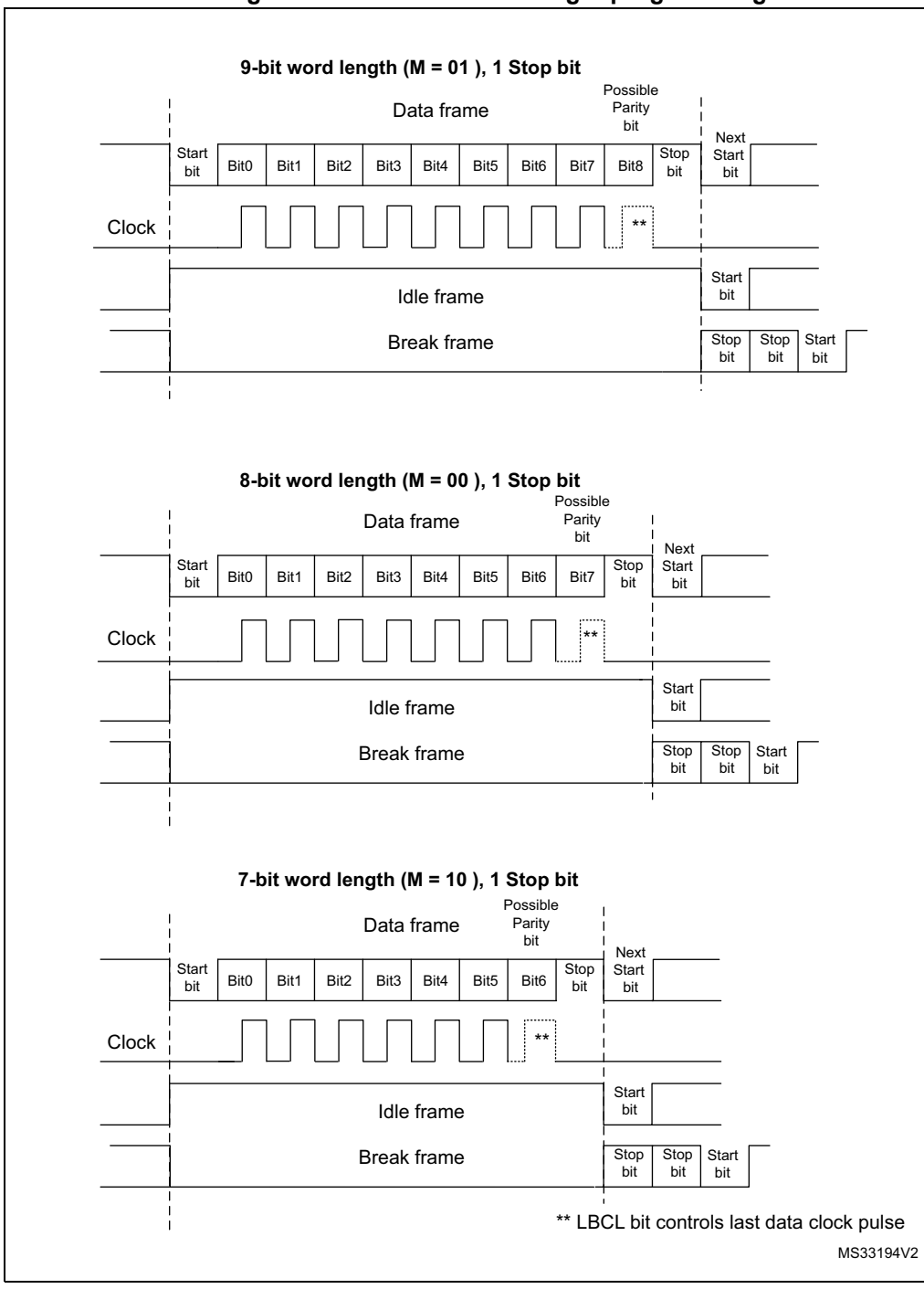
An ***idle character*** is interpreted as an entire frame of “1”s (the number of “1”s includes the number of stop bits).

A ***break character*** is interpreted on receiving “0”s for a frame period. At the end of the break frame, the transmitter inserts 2 stop bits.

Transmission and reception are driven by a common baud rate generator. The transmission and reception clocks are generated when the enable bit is set for the transmitter and receiver, respectively.

The details of each block is given below.

Figure 851. LPUART word length programming



62.4.5 LPUART FIFOs and thresholds

The LPUART can operate in FIFO mode.

The LPUART comes with a transmit FIFO (TXFIFO) and a Receive FIFO (RXFIFO). The FIFO mode is enabled by setting FIFOEN bit (bit 29) in the LPUART_CR1 register.

Since 9 bits the maximum data word length is 9 bits, the TXFIFO is 9-bit wide. However, the RXFIFO default width is 12 bits. This is due to the fact that the receiver does not only store the data in the FIFO, but also the error flags associated to each character (Parity error, Noise error and Framing error flags).

Note: The received data is stored in the RXFIFO together with the corresponding flags. However, only the data are read when reading the RDR.

The status flags are available in the LPUART_ISR register.

It is possible to define the TXFIFO and RXFIFO levels at which the Tx and RX interrupts are triggered. These thresholds are programmed through the RXFTCFG[2:0] and TXFTCFG[2:0] bitfields of the LPUART_CR3 control register.

In this case:

- The Rx interrupt is generated when the number of received data in the RXFIFO reaches the threshold programmed in the RXFTCFG[2:0] bitfield.

  In this case, the RXFT flag is set in the LPUART_ISR register. This means that RXFTCFG[2:0] data have been received: 1 data in LPUART_RDR and (RXFTCFG[2:0] – 1) data in the RXFIFO. As an example, when the RXFTCFG[2:0] is programmed to 101, the RXFT flag is set when a number of data corresponding to the FIFO size has been received: FIFO size – 1 data in the RXFIFO and 1 data in the LPUART_RDR. As a result, the next received data does not set the overrun flag.
- The Tx interrupt is generated when the number of empty locations in the TXFIFO is greater than the threshold programmed in the TXFTCFG[2:0] bitfield of the LSART_CR3 register.

62.4.6 LPUART transmitter

The transmitter can send data words of either 7 or 8 or 9 bits, depending on the M bit status. The transmit enable bit (TE) must be set in order to activate the transmitter function. The data in the transmit shift register is output on the TX pin.

Character transmission

During an LPUART transmission, data shifts out least significant bit first (default configuration) on the TX pin. In this mode, the LPUART_TDR register consists of a buffer (TDR) between the internal bus and the transmit shift register (see *Section 62.4.1: LPUART block diagram*).

When FIFO mode is enabled, the data written to the LPUART_TDR register are queued in the TXFIFO.

Every character is preceded by a start bit bit, which corresponds to a low logic level for one bit period. The character is terminated by a configurable number of stop bits.

The number of stop bits can be 1 or 2.

Note: The TE bit must be set before writing the data to be transmitted to the LPUART_TDR.

The TE bit must not be reset during data transmission. Resetting the TE bit during the transmission corrupts the data on the TX pin as the baud rate counters is frozen. The current data being transmitted are lost.

An idle frame is sent after the TE bit is enabled.

Configurable stop bits

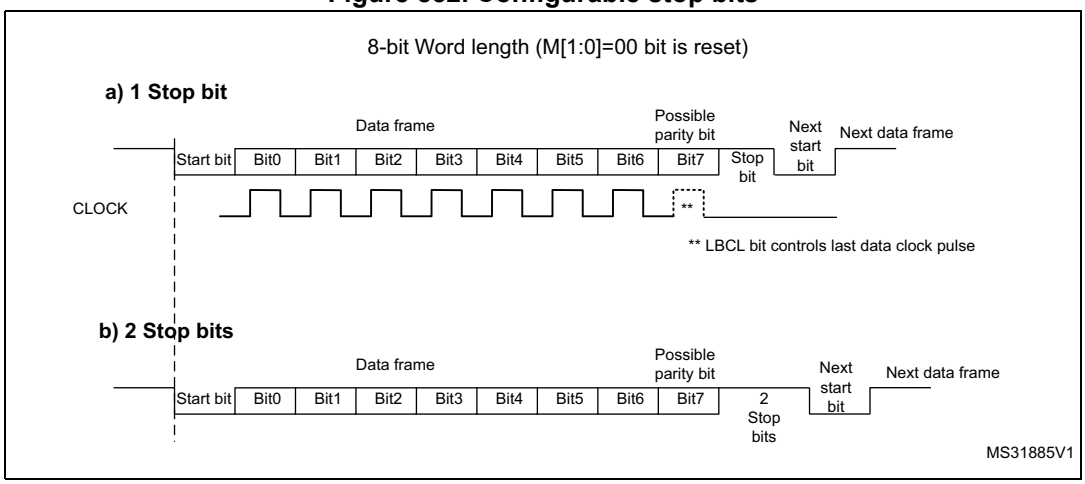
The number of stop bits to be transmitted with every character can be programmed in LPUART_CR2 (bits 13, 12).

- ***1 stop bit***: This is the default value of the number of stop bits.
- ***2 stop bits***: This is supported by normal LPUART, single-wire, and modem modes.

An idle frame transmission includes the stop bits.

A break transmission is 10 low bits (when M[1:0] = 00) or 11 low bits (when M[1:0] = 01) or 9 low bits (when M[1:0] = 10) followed by 2 stop bits. It is not possible to transmit long breaks (break of length greater than 9/10/11 low bits).

Figure 852. Configurable stop bits



Character transmission procedure

To transmit a character, follow the sequence below:

1. Program the M bits in LPUART_CR1 to define the word length.
2. Select the desired baud rate using the LPUART_BRR register.
3. Program the number of stop bits in LPUART_CR2.
4. Enable the LPUART by writing the UE bit in LPUART_CR1 register to 1.
5. Select DMA enable (DMAT) in LPUART_CR3 if multibuffer communication is to take place. Configure the DMA register as explained in *Section 62.4.13: Continuous communication using DMA and LPUART*.
6. Set the TE bit in LPUART_CR1 to send an idle frame as first transmission.

7. Write the data to send in the LPUART_TDR register. Repeat this operation for each data to be transmitted in case of single buffer.
   – When FIFO mode is disabled, writing a data in the LPUART_TDR clears the TXE flag.
   – When FIFO mode is enabled, writing a data in the LPUART_TDR adds one data to the TXFIFO. Write operations to the LPUART_TDR are performed when the TXFNF flag is set. This flag remains set until the TXFIFO is full.
8. When the last data is written to the LPUART_TDR register, wait until TC = 1. This indicates that the transmission of the last frame has been completed.
   – When FIFO mode is disabled, this indicates that the transmission of the last frame has been completed.
   – When FIFO mode is enabled, this indicates that both TXFIFO and shift register are empty.

   This check is required to avoid corrupting the last transmission when the LPUART is disabled or enters Halt mode.

Single byte communication

- When FIFO mode disabled:

  Writing to the transmit data register always clears the TXE bit. The TXE flag is set by hardware to indicate that:
  – the data have been moved from the LPUART_TDR register to the shift register and data transmission has started;
  – the LPUART_TDR register is empty;
  – the next data can be written to the LPUART_TDR register without overwriting the previous data.

  The TXE flag generates an interrupt if the TXEIE bit is set.

  When a transmission is ongoing, a write instruction to the LPUART_TDR register stores the data in the TDR register, which is copied to the shift register at the end of the current transmission.

  When no transmission is ongoing, a write instruction to the LPUART_TDR register places the data in the shift register, the data transmission starts, and the TXE bit is set.
- When FIFO mode is enabled, the TXFNF (TXFIFO not full) flag is set by hardware to indicate that:
  – The TXFIFO is not full;
  – The LPUART_TDR register is empty;
  – The next data can be written to the LPUART_TDR register without overwriting the previous data. When a transmission is ongoing, a write operation to the

LPUART_TDR register stores the data in the TXFIFO. Data are copied from the TXFIFO to the shift register at the end of the current transmission.

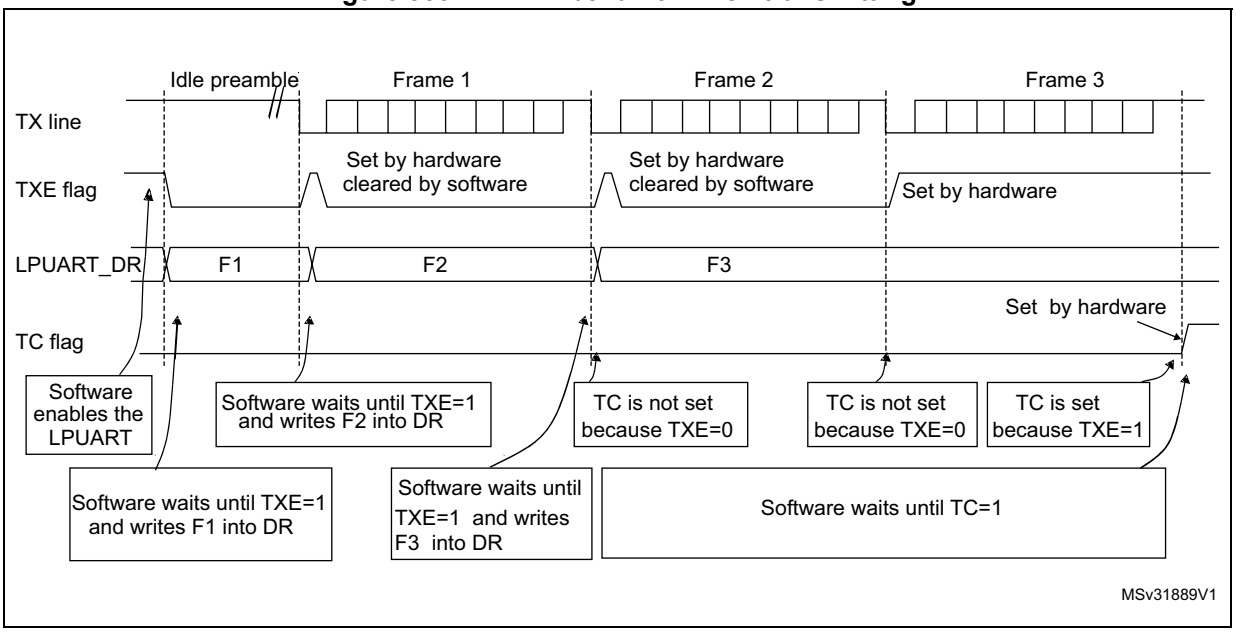
When the TXFIFO is not full, the TXFNF flag stays at 1 even after a write in LPUART_TDR. It is cleared when the TXFIFO is full. This flag generates an interrupt if the TXFNEIE bit is set.

Alternatively, interrupts can be generated and data can be written to the TXFIFO when the TXFIFO threshold is reached. In this case, the CPU can write a block of data defined by the programmed threshold.

If a frame is transmitted (after the stop bit) and the TXE flag (TXFE in case of FIFO mode) is set, the TC bit goes high. An interrupt is generated if the TCIE bit is set in the LPUART_CR1 register.

After writing the last data in the LPUART_TDR register, it is mandatory to wait for TC = 1 before disabling the LPUART or causing the microcontroller to enter the low-power mode (see *Figure 853: TC/TXE behavior when transmitting*).

Figure 853. TC/TXE behavior when transmitting



Note: When FIFO management is enabled, the TXFNF flag is used for data transmission.

Break characters

Setting the SBKRQ bit transmits a break character. The break frame length depends on the M bits (see *Figure 851*).

If a 1 is written to the SBKRQ bit, a break character is sent on the TX line after completing the current character transmission. The SBKF bit is set by the write operation and it is reset by hardware when the break character is complete (during the stop bits after the break character). The LPUART inserts a logic 1 signal (STOP) for the duration of 2 bits at the end of the break frame to guarantee the recognition of the start bit of the next frame.

When the SBKRQ bit is set, the break character is sent at the end of the current transmission.

When FIFO mode is enabled, sending the break character has priority on sending data even if the TXFIFO is full.

Idle characters

Setting the TE bit drives the LPUART to send an idle frame before the first data frame.

62.4.7 LPUART receiver

The LPUART can receive data words of either 7 or 8 or 9 bits depending on the M bits in the LPUART_CR1 register.

Start bit detection

In the LPUART, the start bit is detected when a falling edge occurs on the Rx line, followed by a sample taken in the middle of the start bit to confirm that it is still 0. If the start sample is at 1, then the noise error flag (NE) is set, then the start bit is discarded and the receiver waits for a new start bit. Else, the receiver continues to sample all incoming bits normally.

Character reception

During an LPUART reception, data are shifted with the least significant bit first (default configuration) through the RX pin. In this mode, the LPUART_RDR register consists of a buffer (RDR) between the internal bus and the received shift register.

Character reception procedure

To receive a character, follow the sequence below:

1. Program the M bits in LPUART_CR1 to define the word length.
2. Select the desired baud rate using the baud rate register LPUART_BRR
3. Program the number of stop bits in LPUART_CR2.
4. Enable the LPUART by writing the UE bit in LPUART_CR1 register to 1.
5. Select DMA enable (DMAR) in LPUART_CR3 if multibuffer communication is to take place. Configure the DMA register as explained in *Section 62.4.13: Continuous communication using DMA and LPUART*.
6. Set the RE bit LPUART_CR1. This enables the receiver, which begins searching for a start bit.

When a character is received

- When FIFO mode is disabled, the RXNE bit is set. It indicates that the content of the shift register is transferred to the RDR. In other words, data has been received and can be read (as well as its associated error flags).
- When FIFO mode is enabled, the RXFNE bit is set indicating that the RXFIFO is not empty. Reading the LPUART_RDR returns the oldest data entered in the RXFIFO.

When a data is received, it is stored in the RXFIFO, together with the corresponding error bits.

- An interrupt is generated if the RXNEIE (RXFNEIE in case of FIFO mode) bit is set.
- The error flags can be set if a frame error, noise, or an overrun error has been detected during reception.
- In multibuffer communication mode:
  - When FIFO mode is disabled, the RXNE flag is set after every byte received and is cleared by the DMA read of the receive data register.
  - When FIFO mode is enabled, the RXFNE flag is set when the RXFIFO is not empty. After every DMA request, a data is retrieved from the RXFIFO. DMA request is triggered by RXFIFO is not empty, that is, there is a data in the RXFIFO to be read.
- In single-buffer mode:
  - When FIFO mode is disabled, clearing the RXNE flag is done by performing a software read from the LPUART_RDR register. The RXNE flag can also be cleared by writing 1 to the RXFRQ in the LPUART_RQR register. The RXNE bit must be cleared before the end of the reception of the next character to avoid an overrun error.
  - When FIFO mode is enabled, the RXFNE flag is set when the RXFIFO is not empty. After every read operation from the LPUART_RDR register, a data is retrieved from the RXFIFO. When the RXFIFO is empty, the RXFNE flag is cleared. The RXFNE flag can also be cleared by writing 1 to the RXFRQ bit in the LPUART_RQR register. When the RXFIFO is full, the first entry in the RXFIFO must be read before the end of the reception of the next character to avoid an overrun error. The RXFNE flag generates an interrupt if the RXFNEIE bit is set. Alternatively, interrupts can be generated and data can be read from RXFIFO when the RXFIFO threshold is reached. In this case, the CPU can read a block of data defined by the programmed threshold.

Break character

When a break character is received, the LPUART handles it as a framing error.

Idle character

When an idle frame is detected, it is handled in the same way as a data character reception except that an interrupt is generated if the IDLEIE bit is set.

Overrun error

- FIFO mode disabled

  An overrun error occurs when a character is received when RXNE has not been reset.

  Data cannot be transferred from the shift register to the RDR register until the RXNE bit is cleared. The RXNE flag is set after every byte received.

  An overrun error occurs if the RXNE flag is set when the next data is received or the previous DMA request has not been serviced. When an overrun error occurs:

  – The ORE bit is set;
  – The RDR content is not lost. The previous data is available when a read to LPUART_RDR is performed.
  – The shift register is overwritten. After that, any data received during overrun is lost.
  – An interrupt is generated if either the RXNEIE bit or EIE bit is set.

- FIFO mode enabled

  An overrun error occurs when the shift register is ready to be transferred when the receive FIFO is full.

  Data cannot be transferred from the shift register to the LPUART_RDR register until there is one free location in the RXFIFO. The RXFNE flag is set when the RXFIFO is not empty.

  An overrun error occurs if the RXFIFO is full and the shift register is ready to be transferred. When an overrun error occurs:

  – The ORE bit is set;
  – The first entry in the RXFIFO is not lost. It is available when a read to LPUART_RDR is performed.
  – The shift register is overwritten. After that, any data received during overrun is lost.
  – An interrupt is generated if either the RXFNEIE bit or EIE bit is set.

The ORE bit is reset by setting the ORECF bit in the ICR register.

Note: The ORE bit, when set, indicates that at least 1 data has been lost. T

When the FIFO mode is disabled, there are two possibilities

- *If RXNE = 1, then the last valid data is stored in the receive register (RDR) and can be read,*
- *If RXNE = 0, then the last valid data has already been read and there is nothing left to be read in the RDR. This case can occur when the last valid data is read in the RDR at the same time as the new (and lost) data is received.*

Selecting the clock source

The choice of the clock source is done through the clock control system (see *Section Reset and clock controller (RCC)*). The clock source must be selected through the UE bit, before enabling the LPUART.

The clock source must be selected according to two criteria:

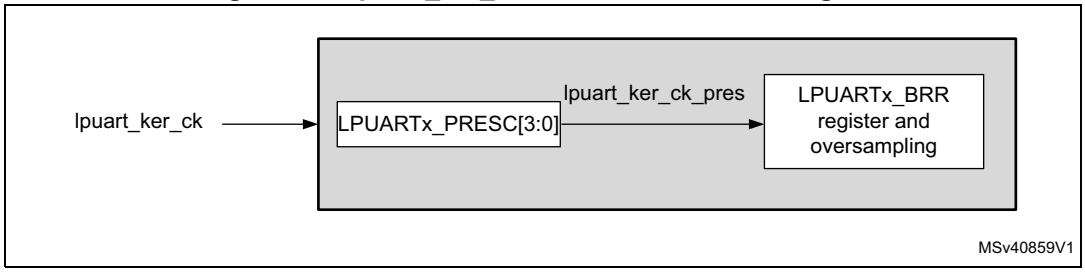
- Possible use of the LPUART in low-power mode
- Communication speed.

The clock source frequency is lpuart_ker_ck.

When the dual clock domain and the wake-up from low-power mode features are supported, the lpuart_ker_ck clock source can be configured in the RCC (see *Section Reset and clock controller (RCC)*). Otherwise, the lpuart_ker_ck is the same as lpuart_pclk.

The lpuart_ker_ck can be divided by a programmable factor in the LPUART_PRESC register.

Figure 854. lpuart_ker_ck clock divider block diagram



Some lpuart_ker_ck sources enable the LPUART to receive data while the MCU is in low-power mode. Depending on the received data and wake-up mode selection, the LPUART wakes up the MCU, when needed, in order to transfer the received data by software reading the LPUART_RDR register or by DMA.

For the other clock sources, the system must be active to enable LPUART communications.

The communication speed range (specially the maximum communication speed) is also determined by the clock source.

The receiver samples each incoming bit as close as possible to the middle of the bit-period. Only a single sample is taken of each of the incoming bits.

Note: There is no noise detection for data.

Framing error

A framing error is detected when the stop bit is not recognized on reception at the expected time, following either a desynchronization or excessive noise.

When the framing error is detected:

- The FE bit is set by hardware.
- The invalid data is transferred from the Shift register to the LPUART_RDR register.
- No interrupt is generated in case of single byte communication. However, this bit rises at the same time as the RXNE bit which itself generates an interrupt. In case of multibuffer communication, an interrupt is issued if the EIE bit is set in the LPUART_CR3 register.

The FE bit is reset by writing 1 to the FECF in the LPUART_ICR register.

Configurable stop bits during reception

The number of stop bits to be received can be configured through the control bits of LPUART_CR2: it can be either 1 or 2 in normal mode.

- **1 stop bit**: sampling for 1 stop bit is done on the 8th, 9th, and 10th samples.
- **2 stop bits**: sampling for the 2 stop bits is done in the middle of the second stop bit. The RXNE and FE flags are set just after this sample, that is, during the second stop bit. The first stop bit is not checked for framing error.

62.4.8 LPUART baud rate generation

The baud rate for the receiver and transmitter (Rx and Tx) are both set to the value programmed in the LPUART_BRR register.

$$\text{Tx/Rx baud} = \frac{256 \times \text{lpuart_ker_ck_pres}}{\text{LPUARTDIV}}$$

LPUARTDIV is defined in the LPUART_BRR register.

Note: The baud counters are updated to the new value in the baud registers after a write operation to LPUART_BRR. Hence, the baud rate register value must not be changed during communication.

It is forbidden to write values lower than 0x300 in the LPUART_BRR register.

lpuart_ker_ck_pres must range from 3 x baud rate to 4096 x baud rate.

The maximum baud rate that can be reached when the LPUART clock source is the LSE, is 9600 bauds. Higher baud rates can be reached when the LPUART is clocked by clock sources different from the LSE clock.

Table 682. Error calculation for programmed baud rates at lpuart_ker_ck_pres= 32.768 kHz

Baud rate		lpuart_ker_ck_pres= 32.768 kHz		
S.No	**Desired**	**Actual**	**Value programmed in the baud rate register**	**% Error = (Calculated – Desired) B.rate / Desired B.rate**
1	0.3 kbaud	300 baud	0x6D3A	0
2	0.6 kbaud	600 baud	0x369D	0
3	1200 bauds	1200.087 bauds	0x1B4E	0.007
4	2400 bauds	2400.17 bauds	0xDA7	0.007
5	4800 bauds	4801.72 bauds	0x6D3	0.035
6	9600 kbauds	9608.94 bauds	0x369	0.093

62.4.9 Tolerance of the LPUART receiver to clock deviation

The asynchronous receiver of the LPUART works correctly only if the total clock system deviation is less than the tolerance of the LPUART receiver. The causes that contribute to the total deviation are:

- DTRA: deviation due to the transmitter error (which also includes the deviation of the transmitter's local oscillator)
- DQUANT: error due to the baud rate quantization of the receiver
- DREC: deviation of the receiver local oscillator
- DTCL: deviation due to the transmission line (generally due to the transceivers, which can introduce an asymmetry between the low-to-high transition timing and the high-to-low transition timing)

$$DTRA + DQUANT + DREC + DTCL + DWU < \text{LPUART receiver tolerance}$$

where

DWU is the error due to sampling point deviation when the wake-up from low-power mode is used.

when M[1:0] = 01:

$$DWU = \frac{t_{WULPUART}}{11 \times Tbit}$$

when M[1:0] = 00:

$$DWU = \frac{t_{WULPUART}}{10 \times Tbit}$$

when M[1:0] = 10:

$$DWU = \frac{t_{WULPUART}}{9 \times Tbit}$$

$t_{WULPUART}$ is the time between the detection of the start bit falling edge and the instant when the clock (requested by the peripheral) is ready and reaching the peripheral, and the regulator is ready.

The LPUART receiver can receive data correctly at up to the maximum tolerated deviation specified in *Table 683*:

- Number of stop bits defined through STOP[1:0] bits in the LPUART_CR2 register
- LPUART_BRR register value.

Table 683. Tolerance of the LPUART receiver

M bits	768 < BRR < 1024	1024 < BRR < 2048	2048 < BRR < 4096	4096 ≤ BRR
8 bits (M = 00), 1 stop bit	1.82%	2.56%	3.90%	4.42%
9 bits (M = 01), 1 stop bit	1.69%	2.33%	2.53%	4.14%
7 bits (M = 10), 1 stop bit	2.08%	2.86%	4.35%	4.42%
8 bits (M = 00), 2 stop bits	2.08%	2.86%	4.35%	4.42%
9 bits (M = 01), 2 stop bits	1.82%	2.56%	3.90%	4.42%
7 bits (M = 10), 2 stop bits	2.34%	3.23%	4.92%	4.42%

Note: The data specified in Table 683 may slightly differ in the special case when the received frames contain some idle frames of exactly 10-bit times when M bits = 00 (11-bit times when M = 01 or 9- bit times when M = 10).

62.4.10 LPUART multiprocessor communication

It is possible to perform LPUART multiprocessor communications (with several LPUARTs connected in a network). For instance one of the LPUARTs can be the master, with its TX output connected to the RX inputs of the other LPUARTs. The others are slaves, with their respective TX outputs are logically ANDed together and connected to the RX input of the master.

In multiprocessor configurations it is often desirable that only the intended message recipient actively receives the full message contents, thus reducing redundant LPUART service overhead for all nonaddressed receivers.

The nonaddressed devices can be placed in mute mode by means of the muting function. To use the mute mode feature, the MME bit must be set in the LPUART_CR1 register.

Note: When FIFO management is enabled and MME is already set, MME bit must not be cleared and then set again quickly (within two lpuart_ker_ck *cycles), otherwise mute mode might remain active.*

When the mute mode is enabled:

- none of the reception status bits can be set;
- all the receive interrupts are inhibited;
- the RWU bit in the LPUART_ISR register is set to 1. RWU can be controlled automatically by hardware or by software, through the MMRQ bit in the LPUART_RQR register, under certain conditions.

The LPUART can enter or exit from mute mode using one of two methods, depending on the WAKE bit in the LPUART_CR1 register:

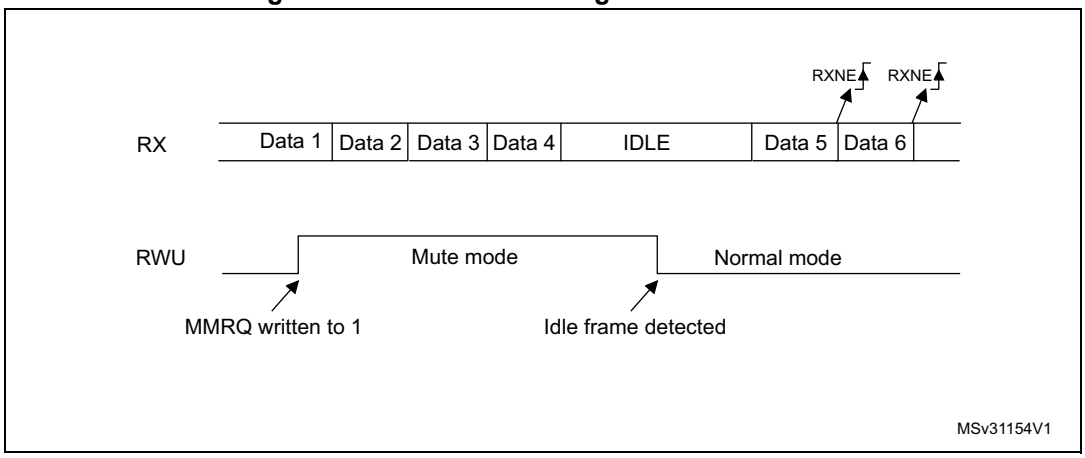
- Idle Line detection if the WAKE bit is reset,
- Address mark detection if the WAKE bit is set.

Idle line detection (WAKE = 0)

The LPUART enters mute mode when the MMRQ bit is written to 1 and the RWU is automatically set.

The LPUART wakes up when an Idle frame is detected. The RWU bit is then cleared by hardware but the IDLE bit is not set in the LPUART_ISR register. An example of mute mode behavior using Idle line detection is given in *Figure 855*.

Figure 855. Mute mode using Idle line detection



Note: If the MMRQ is set while the IDLE character has already elapsed, mute mode is not entered (RWU is not set).

If the LPUART is activated while the line is IDLE, the idle state is detected after the duration of one IDLE frame (not only after the reception of one character frame).

4-bit/7-bit address mark detection (WAKE = 1)

In this mode, bytes are recognized as addresses if their MSB is a 1 otherwise they are considered as data. In an address byte, the address of the targeted receiver is put in the 4 or 7 LSBs. The choice of 7- or 4-bit address detection is done using the ADDM7 bit. This 4-bit/7-bit word is compared by the receiver with its own address, which is programmed in the ADD bits in the LPUART_CR2 register.

Note: In 7-bit and 9-bit data modes, address detection is done on 6-bit and 8-bit addresses (ADD[5:0] and ADD[7:0]) respectively.

The LPUART enters mute mode when an address character is received which does not match its programmed address. In this case, the RWU bit is set by hardware. The RXNE flag is not set for this address byte and no interrupt or DMA request is issued when the LPUART enters mute mode.

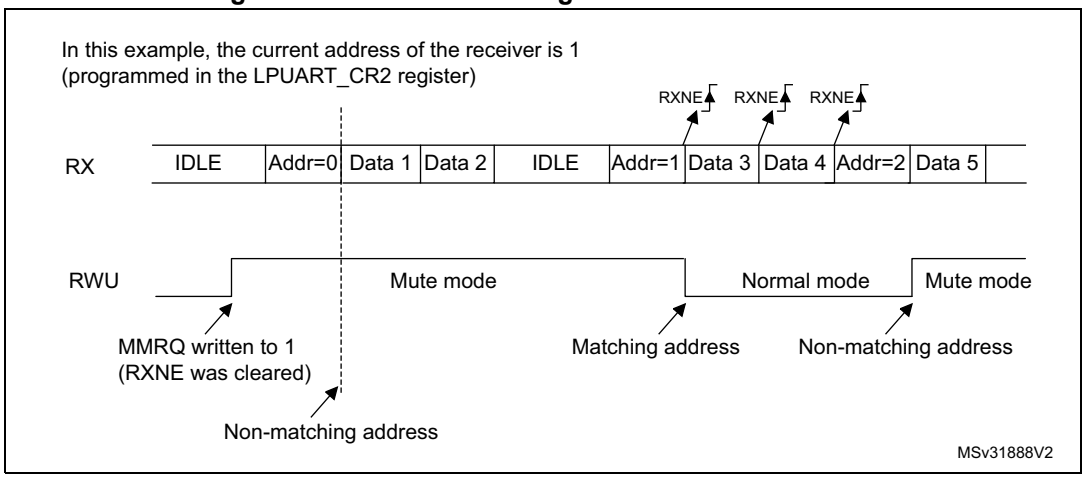
The LPUART also enters mute mode when the MMRQ bit is written to 1. The RWU bit is also automatically set in this case.

The LPUART exits from mute mode when an address character is received which matches the programmed address. Then the RWU bit is cleared and subsequent bytes are received normally. The RXNE/RXFNE bit is set for the address character since the RWU bit has been cleared.

Note: When FIFO management is enabled, when MMRQ bit is set while the receiver is sampling the last bit of a data, this data may be received before effectively entering in mute mode.

An example of mute mode behavior using address mark detection is given in *Figure 856*.

Figure 856. Mute mode using address mark detection



62.4.11 LPUART parity control

Parity control (generation of parity bit in transmission and parity checking in reception) can be enabled by setting the PCE bit in the LPUART_CR1 register. Depending on the frame length defined by the M bits, the possible LPUART frame formats are as listed in *Table 684*.

Table 684: LPUART frame formats

M bits	PCE bit	LPUART frame(1)
00	0	| SB | 8 bit data | STB |
00	1	| SB | 7-bit data | PB | STB |
01	0	| SB | 9-bit data | STB |
01	1	| SB | 8-bit data PB | STB |
10	0	| SB | 7bit data | STB |
10	1	| SB | 6-bit data | PB | STB |

1. Legends: SB: start bit, STB: stop bit, PB: parity bit.
2. In the data register, the PB is always taking the MSB position (8th or 7th, depending on the M bit value).

Even parity

The parity bit is calculated to obtain an even number of “1s” inside the frame, which is made of the 6, 7 or 8 LSB bits (depending on M bit values) and the parity bit.

As an example, if data = 00110101, and 4 bits are set, then the parity bit is equal to 0 if even parity is selected (PS bit in LPUART_CR1 = 0).

Odd parity

The parity bit is calculated to obtain an odd number of “1s” inside the frame made of the 6, 7 or 8 LSB bits (depending on M bit values) and the parity bit.

As an example, if data = 00110101 and 4 bits set, then the parity bit is equal to 1 if odd parity is selected (PS bit in LPUART_CR1 = 1).

Parity checking in reception

If the parity check fails, the PE flag is set in the LPUART_ISR register and an interrupt is generated if PEIE is set in the LPUART_CR1 register. The PE flag is cleared by software writing 1 to the PECF in the LPUART_ICR register.

Parity generation in transmission

If the PCE bit is set in LPUART_CR1, then the MSB bit of the data written in the data register is transmitted but is changed by the parity bit (even number of “1s” if even parity is selected (PS = 0) or an odd number of “1s” if odd parity is selected (PS = 1)).

62.4.12 LPUART single-wire half-duplex communication

Single-wire half-duplex mode is selected by setting the HDSEL bit in the LPUART_CR3 register.

The LPUART can be configured to follow a single-wire half-duplex protocol where the TX and RX lines are internally connected. The selection between half- and full-duplex communication is made with a control bit HDSEL in LPUART_CR3.

As soon as HDSEL is written to 1:

- The TX and RX lines are internally connected.
- The RX pin is no longer used
- The TX pin is always released when no data is transmitted. Thus, it acts as a standard I/O in idle or in reception. It means that the I/O must be configured so that TX is configured as alternate function open-drain with an external pull-up.

Apart from this, the communication protocol is similar to normal LPUART mode. Any conflict on the line must be managed by software (for instance by using a centralized arbiter). In particular, the transmission is never blocked by hardware and continues as soon as data is written in the data register while the TE bit is set.

Note: In LPUART communications, in the case of 1-stop bit configuration, the RXNE flag is set in the middle of the stop bit.

62.4.13 Continuous communication using DMA and LPUART

The LPUART is capable of performing continuous communication using the DMA. The DMA requests for Rx buffer and Tx buffer are generated independently.

Note: Refer to Section 62.3: LPUART implementation to determine if the DMA mode is supported. If DMA is not supported, use the LPUSRT as explained in Section 62.4.7. To perform continuous communication. When FIFO is disabled, clear the TXE/ RXNE flags in the LPUART_ISR register.

Transmission using DMA

DMA mode can be enabled for transmission by setting the DMAT bit in the LPUART_CR3 register. Data are loaded from an SRAM area configured using the DMA peripheral (refer to Section *direct memory access controller*) to the LPUART_TDR register whenever the TXE flag (TXFNF flag if FIFO mode is enabled) is set. To map a DMA channel for LPUART transmission, use the following procedure (x denotes the channel number):

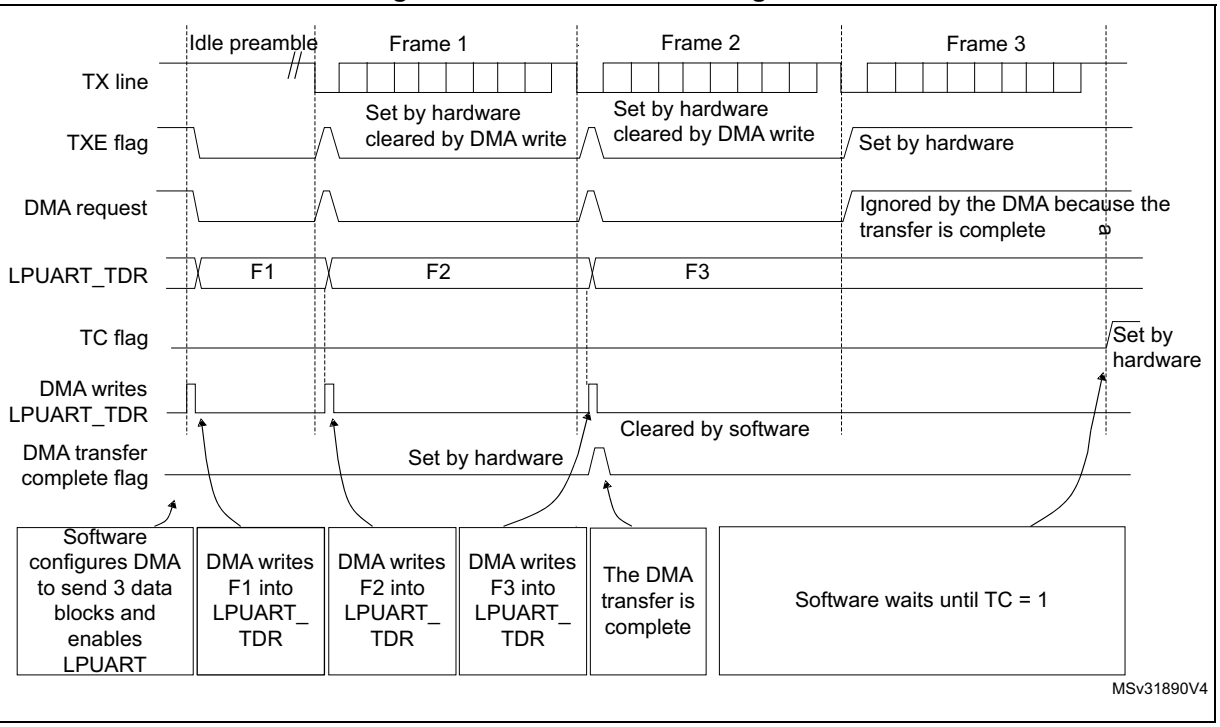
1. Write the LPUART_TDR register address in the DMA control register to configure it as the destination of the transfer. The data is moved to this address from memory after each TXE (or TXFNF if FIFO mode is enabled) event.
2. Write the memory address in the DMA control register to configure it as the source of the transfer. The data is loaded into the LPUART_TDR register from this memory area after each TXE (or TXFNF if FIFO mode is enabled) event.
3. Configure the total number of bytes to be transferred to the DMA control register.
4. Configure the channel priority in the DMA register
5. Configure DMA interrupt generation after half/ full transfer as required by the application.
6. Clear the TC flag in the LPUART_ISR register by setting the TCCF bit in the LPUART_ICR register.
7. Activate the channel in the DMA register.

When the number of data transfers programmed in the DMA controller is reached, the DMA controller generates an interrupt on the DMA channel interrupt vector.

In transmission mode, once the DMA has written all the data to be transmitted (DMA transfer complete), the TC flag can be monitored to make sure that the LPUART communication has completed. This is required to avoid corrupting the last transmission before disabling the LPUART or entering low-power mode. Software must wait until TC = 1. The TC flag remains cleared during all data transfers and it is set by hardware at the end of transmission of the last frame.

Note: The DMAT bit must not be cleared before the DMA end of transfer.

Figure 857. Transmission using DMA



Note: When FIFO management is enabled, the DMA request is triggered by transmit FIFO not full (that is, TXFNF = 1).

Reception using DMA

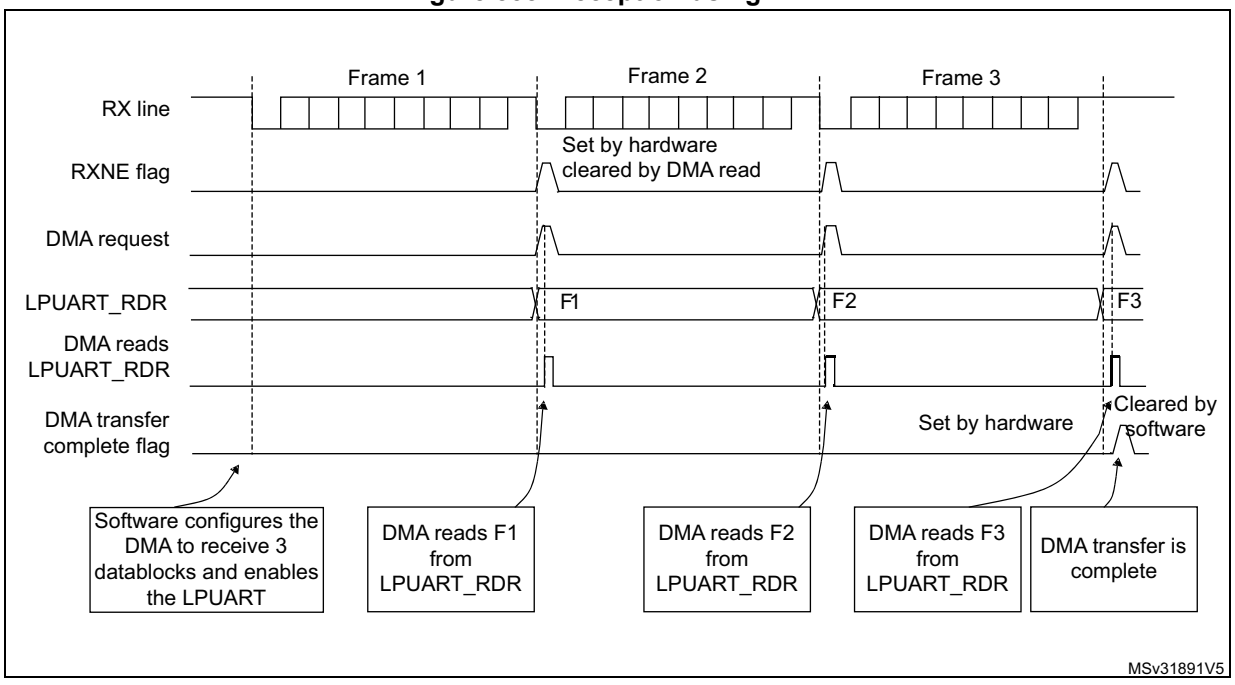
DMA mode can be enabled for reception by setting the DMAR bit in the LPUART_CR3 register. Data are loaded from the LPUART_RDR register to a SRAM area configured using the DMA peripheral (refer to section *direct memory access controller (DMA)*) whenever a data byte is received. To map a DMA channel for LPUART reception, use the following procedure:

1. Write the LPUART_RDR register address in the DMA control register to configure it as the source of the transfer. The data is moved from this address to the memory after each RXNE (RXFNE in case FIFO mode is enabled) event.
2. Write the memory address in the DMA control register to configure it as the destination of the transfer. The data is loaded from LPUART_RDR to this memory area after each RXNE (RXFNE in case FIFO mode is enabled) event.
3. Configure the total number of bytes to be transferred to the DMA control register.
4. Configure the channel priority in the DMA control register
5. Configure interrupt generation after half/ full transfer as required by the application.
6. Activate the channel in the DMA control register.

When the number of data transfers programmed in the DMA controller is reached, the DMA controller generates an interrupt on the DMA channel interrupt vector.

Note: The DMAR bit must not be cleared before the DMA end of transfer.

Figure 858. Reception using DMA



Note: When FIFO management is enabled, the DMA request is triggered by receive FIFO not empty (that is, RXFNE = 1).

Error flagging and interrupt generation in multibuffer communication

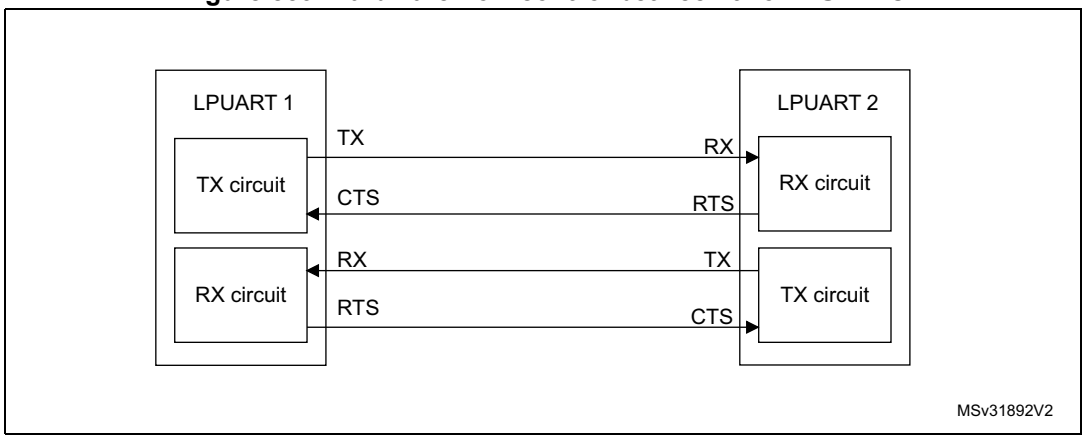
If any error occurs during a transaction In multibuffer communication mode, the error flag is asserted after the current byte. An interrupt is generated if the interrupt enable flag is set.

For framing error, overrun error and noise flag, which are asserted with RXNE (RXFNE in case FIFO mode is enabled) in single byte reception, there is a separate error flag interrupt enable bit (EIE bit in the LPUART_CR3 register), which, if set, enables an interrupt after the current byte if any of these errors occur.

62.4.14 RS232 hardware flow control and RS485 driver enable

It is possible to control the serial data flow between two devices by using the CTS input and the RTS output. *Figure 859* shows how to connect two devices in this mode.

Figure 859. Hardware flow control between two LPUARTs

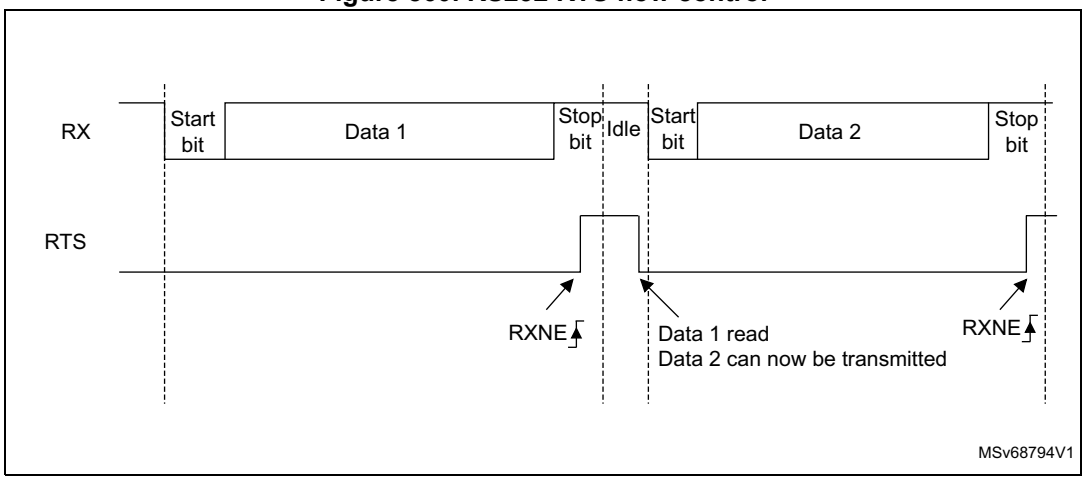


RS232 RTS and CTS flow control can be enabled independently by writing the RTSE and CTSE bits respectively to 1 (in the LPUART_CR3 register).

RS232 RTS flow control

If the RTS flow control is enabled (RTSE = 1), then RTS is deasserted (tied low) as long as the LPUART receiver is ready to receive a new data. When the receive register is full, RTS is asserted, indicating that the transmission is expected to stop at the end of the current frame. *Figure 860* shows an example of communication with RTS flow control enabled.

Figure 860. RS232 RTS flow control



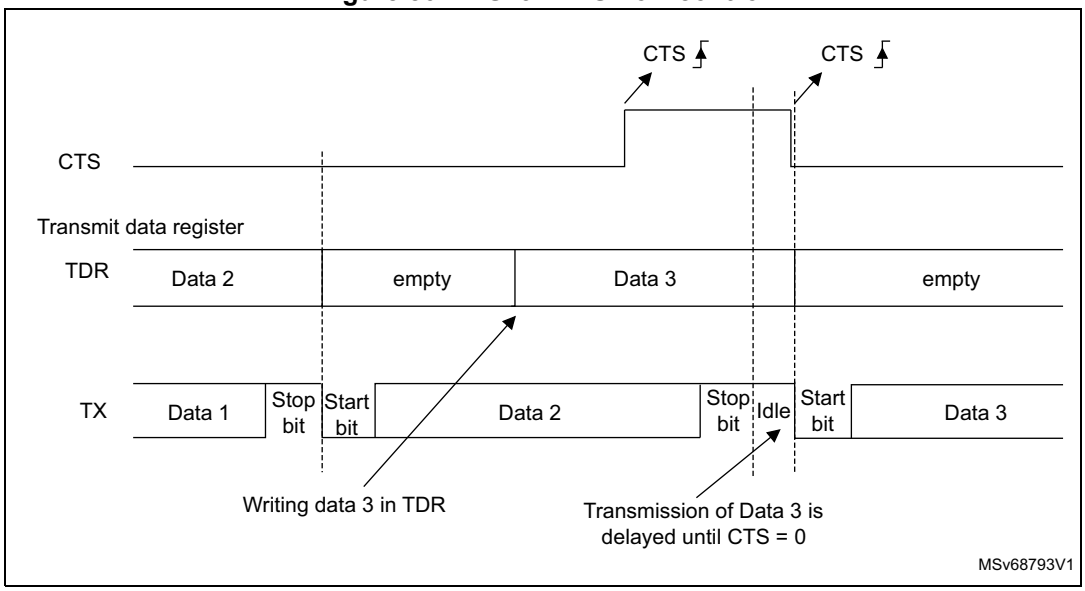
Note: When FIFO mode is enabled, RTS is asserted only when RXFIFO is full.

RS232 CTS flow control

If the CTS flow control is enabled (CTSE = 1), then the transmitter checks the CTS input before transmitting the next frame. If CTS is deasserted (tied low), then the next data is transmitted (assuming that data is to be transmitted, in other words, if TXE/TXFE = 0), else the transmission does not occur. When CTS is asserted during a transmission, the current transmission completes before the transmitter stops.

When CTSE = 1, the CTSIF status bit is automatically set by hardware as soon as the CTS input toggles. It indicates when the receiver becomes ready or not ready for communication. An interrupt is generated if the CTSIE bit in the LPUART_CR3 register is set. *Figure 861* shows an example of communication with CTS flow control enabled.

Figure 861. RS232 CTS flow control



Note: For correct behavior, CTS must be deasserted at least 3 LPUART clock source periods before the end of the current character. In addition it must be noted that the CTSCF flag may not be set for pulses shorter than 2 x PCLK periods.

RS485 driver enable

The driver enable feature is enabled by setting bit DEM in the LPUART_CR3 control register. This enables activating the external transceiver control, through the DE (Driver Enable) signal. The assertion time is the time between the activation of the DE signal and the beginning of the start bit. It is programmed using the DEAT [4:0] bitfields in the LPUART_CR1 control register. The deassertion time is the time between the end of the last stop bit, in a transmitted message, and the deactivation of the DE signal. It is programmed using the DEDT [4:0] bitfields in the LPUART_CR1 control register. The polarity of the DE signal can be configured using the DEP bit in the LPUART_CR3 control register.

The LPUART DEAT and DEDT are expressed in LPUART clock source ($f_{lpuart_ker_ck_pres}$) cycles:

- The driver enable assertion time equals
  - (1 + (DEAT x P)) x lpuart_ker_ck_pres, if P # 0
  - (1 + DEAT) x lpuart_ker_ck_pres, if P = 0
- The driver enable deassertion time equals
  - (1 + (DEDT x P)) x lpuart_ker_ck_pres, if P # 0
  - (1 + DEDT) x lpuart_ker_ck_pres, if P = 0

where P = BRR[20:11]

62.4.15 LPUART low-power management

The LPUART has advanced low-power mode functions that enable it to transfer properly data even when the lpuart_pclk clock is disabled.
The LPUART is able to wake up the MCU from low-power mode when the UESM bit is set.
When the lpuart_pclk is gated, the LPUART provides a wake-up interrupt (**lpuart_wkup**) if a specific action requiring the activation of the **lpuart_pclk** clock is needed:

- If FIFO mode is disabled

  luart_pclk clock has to be activated to empty the LPUART data register.

  In this case, the lpuart_wkup interrupt source is the RXNE set to 1. The RXNEIE bit must be set before entering low-power mode.

- If FIFO mode is enabled

  luart_pclk clock has to be activated
  - To fill the TXFIFO, or
  - To empty the RXFIFO

  In this case, the lpuart_wkup interrupt source can be:
  - RXFIFO not empty. In this case, the RXFNEIE bit must be set before entering low-power mode.
  - RXFIFO full. In this case, the RXFFIE bit must be set before entering low-power mode, the number of received data corresponds to the RXFIFO size, and the RXFF flag is not set.
  - TXFIFO empty. In this case, the TXFEIE bit must be set before entering low-power mode.

  This enables sending/receiving the data in the TXFIFO/RXFIFO during low-power mode.

  To avoid overrun/underrun errors and transmit/receive data in low-power mode, the lpuart_wkup interrupt source can be one of the following events:
  - TXFIFO threshold reached. In this case, the TXFTIE bit must be set before entering low-power mode.
  - RXFIFO threshold reached. In this case, the RXFTIE bit must be set before entering low-power mode.

  For example, the application can set the threshold to the maximum RXFIFO size if the wake-up time is less than the time to receive a single byte across the line.

  Using the RXFIFO full, TXFIFO empty, RXFIFO not empty and RXFIFO/TXFIFO threshold interrupts to wake up the MCU from low-power mode enables doing as many

LPUART transfers as possible during low-power mode with the benefit of optimizing consumption.

Alternatively, a specific **lpuart_wkup** interrupt may be selected through the WUS bitfields.

When the wake-up event is detected, the WUF flag is set by hardware and the **lpuart_wkup** interrupt is generated if the WUFIE bit is set.

Note: Before entering low-power mode, make sure that no LPUART transfer is ongoing. Checking the BUSY flag cannot ensure that low-power mode is never entered when data reception is ongoing.

The WUF flag is set when a wake-up event is detected, independently of whether the MCU is in low-power or in an active mode.

When entering low-power mode just after having initialized and enabled the receiver, the REACK bit must be checked to ensure that the LPUART is actually enabled.

When DMA is used for reception, it must be disabled before entering low-power mode and reenabled upon exit from low-power mode.

When FIFO is enabled, the wake-up from low-power mode on address match is only possible when mute mode is enabled.

Using mute mode with low-power mode

If the LPUART is put into mute mode before entering low-power mode:

- Wake-up from mute mode on idle detection must not be used, because idle detection cannot work in low-power mode.
- If the wake-up from mute mode on address match is used, then the low-power mode wake-up source from must also be the address match. If the RXNE flag was set when entering the low-power mode, the interface remains in mute mode upon address match and wake up from low-power mode.

Note: When FIFO management is enabled, mute mode is used with wake-up from low-power mode without any constraints (that is, the two points mentioned above about mute and low-power mode are valid only when FIFO management is disabled).

Wake-up from low-power mode when LPUART kernel clock lpuart_ker_ck is OFF in low-power mode

If during low-power mode, the lpuart_ker_ck clock is switched OFF, when a falling edge on the LPUART receive line is detected, the LPUART interface requests the lpuart_ker_ck clock to be switched ON thanks to the lpuart_ker_ck_req signal. The lpuart_ker_ck is then used for the frame reception.

If the wake-up event is verified, the MCU wakes up from low-power mode and data reception goes on normally.

If the wake-up event is not verified, the lpuart_ker_ck is switched OFF again, the MCU is not woken up and stays in low-power mode and the kernel clock request is released.

The example below shows the case of a wake-up event programmed to “address match detection” and FIFO management disabled.

Figure 862 shows the behavior when the wake-up event is verified.

Figure 862. Wake-up event verified (wake-up event = address match, FIFO disabled)

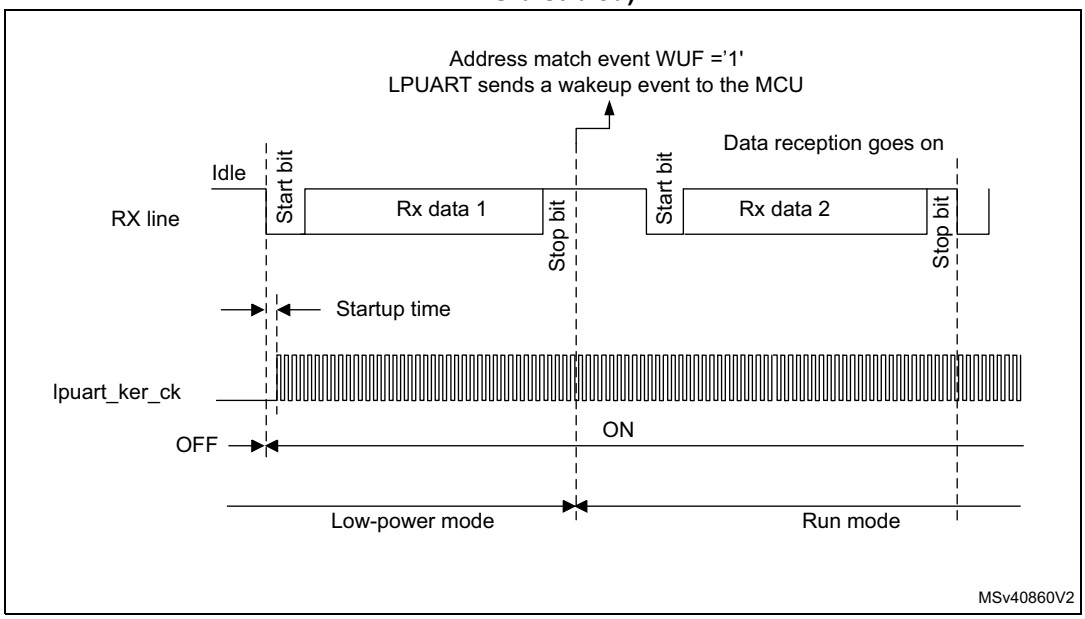
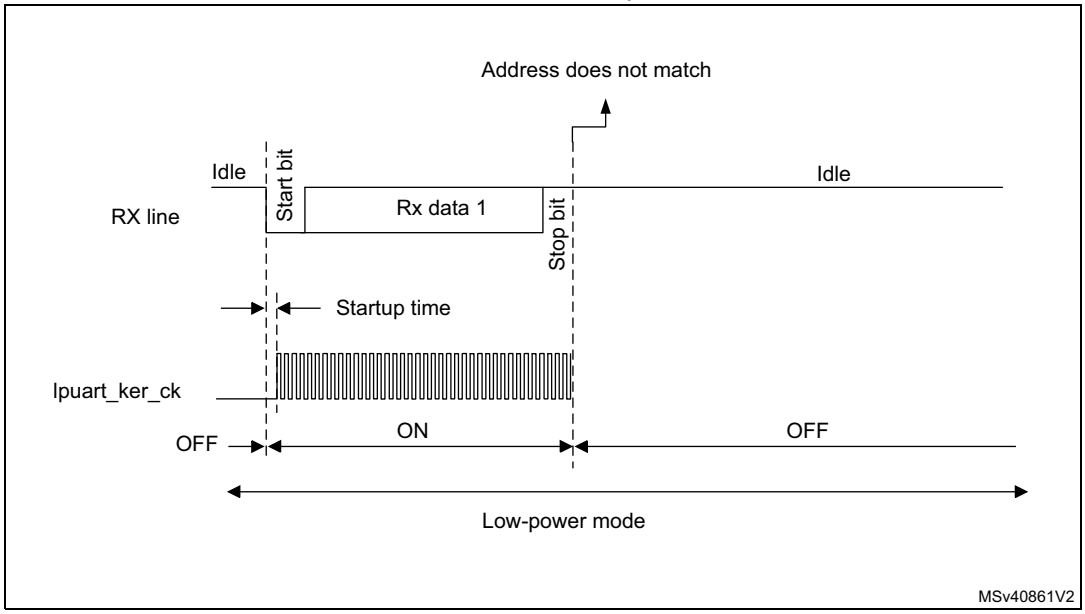


Figure 863 shows the behavior when the wake-up event is not verified.

Figure 863. Wake-up event not verified (wake-up event = address match, FIFO disabled)



Note: The above figures are valid when address match or any received frame is used as wake-up event. In the case the wake-up event is the start bit detection, the LPUART sends the wake-up event to the MCU at the end of the start bit.

Determining the maximum LPUART baud rate that enables to correctly wake up the MCU from low-power mode

The maximum baud rate that enables to correctly wake up the MCU from low-power mode depends on the wake-up time parameter (refer to the device datasheet) and on the LPUART receiver tolerance (see *Section 62.4.9: Tolerance of the LPUART receiver to clock deviation*).

Let us take the example of OVER8 = 0, M bits = 01, ONEBIT = 0 and BRR [3:0] = 0000.

In these conditions, according to *Table 683: Tolerance of the LPUART receiver*, the LPUART receiver tolerance equals 3.41%.

DTRA + DQUANT + DREC + DTCL + DWU < LPUART receiver tolerance

$D_{WUmax} = t_{WULPUART} / (11 \times T_{bit\ Min})$

$T_{bit\ Min} = t_{WULPUART} / (11 \times D_{WUmax})$

where $t_{WULPUART}$ is the wake-up time from low-power mode.

If we consider the ideal case where DTRA, DQUANT, DREC, and DTCL parameters are at 0%, the maximum value of DWU is 3.41%. In reality, we need to consider at least the lpuart_ker_ck inaccuracy.

For example, if HSI is used as lpuart_ker_ck, and the HSI inaccuracy is of 1%, then we obtain:

$t_{WULPUART}$ = 3 µs (values provided only as examples; for correct values, refer to the device datasheet).

D_{WUmax} = 3.41% – 1% = 2.41%

$T_{bit\ min}$ = 3 µs/ (11 x 2.41%) = 11.32 µs.

As a result, the maximum baud rate that enables to wake up correctly from low-power mode is: 1/11.32 µs = 88.36 kbauds.

62.5 LPUART in low-power modes

Table 685. Effect of low-power modes on the LPUART

Mode	Description
Sleep	No effect. LPUART interrupts cause the device to exit Sleep mode.
Stop(1)	The content of the LPUART registers is kept. The LPUART is able to wake up the microcontroller from Stop mode when the LPUART is clocked by an oscillator available in Stop mode.
Standby	The LPUART peripheral is powered down and must be reinitialized after exiting Standby mode.

1. Refer to *Section 62.3: LPUART implementation* to know if the wake-up from Stop mode is supported for a given peripheral instance. If an instance is not functional in a given Stop mode, it must be disabled before entering this Stop mode.

62.6 LPUART interrupts

Refer to *Table 686* for a detailed description of all LPUART interrupt requests.

Table 686. LPUART interrupt requests

Interrupt vector	Interrupt event	Event flag	Enable Control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop(1) modes	Exit from Standby mode
LPUART	Transmit data register empty	TXE	TXEIE	Write TDR	Yes	No	No
	Transmit FIFO Not Full	TXFNF	TXFNFIE	TXFIFO full		No	
	Transmit FIFO Empty	TXFE	TXFEIE	Write TDR or write 1 in TXFRQ		Yes	
	Transmit FIFO threshold reached	TXFT	TXFTIE	Write TDR		Yes	
	CTS interrupt	CTSIF	CTSIE	Write 1 in CTSCF		No	
	Transmission Complete	TC	TCIE	Write TDR or write 1 in TCCF		No	
	Receive data register not empty (data ready to be read)	RXNE	RXNEIE	Read RDR or write 1 in RXFRQ	Yes	Yes	
	Receive FIFO Not Empty	RXFNE	RXFNEIE	Read RDR until RXFIFO empty or write 1 in RXFRQ		Yes	
	Receive FIFO Full	RXFF(2)	RXFFIE	Read RDR		Yes	
	Receive FIFO threshold reached	RXFT	RXFTIE	Read RDR		Yes	
	Overrun error detected	ORE	RX-NEIE/RX FNEIE	Write 1 in ORECF		No	
	Idle line detected	IDLE	IDLEIE	Write 1 in IDLECF		No	
	Parity error	PE	PEIE	Write 1 in PECF		No	
	Noise error in multibuffer communication.	NE	EIE	Write 1 in NFCF		No	
	Overrun error in multibuffer communication.	ORE(3)		Write 1 in ORECF		No	
	Framing Error in multibuffer communication.	FE		Write 1 in FECF		No	
	Character match	CMF	CMIE	Write 1 in CMCF		No	
	Wake-up from low-power mode	WUF	WUFIE	Write 1 in WUC		Yes	

1. The LPUART can wake up the device from Stop mode only if the peripheral instance supports the wake-up from Stop mode feature. Refer to *Section 62.3: LPUART implementation* for the list of supported Stop modes.
2. RXFF flag is asserted if the LPUART receives n+1 data (n being the RXFIFO size): n data in the RXFIFO and 1 data in LPUART_RDR. In Stop mode, LPUART_RDR is not clocked. As a result, this register is not written and once n data are received and written in the RXFIFO, the RXFF interrupt is asserted (RXFF flag is not set).
3. When OVRDIS = 0.

62.7 LPUART registers

Refer to *Section 1.2: List of abbreviations for registers* for a list of abbreviations used in register descriptions.

The peripheral registers have to be accessed by words (32 bits).

62.7.1 LPUART control register 1 (LPUART_CR1)

Address offset: 0x00

Reset value: 0x0000 0000

The same register can be used in FIFO mode enabled (this section) and FIFO mode disabled (next section).

FIFO mode enabled, FIFOEN = 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXFFIE	TXFEIE	FIFOEN	M1	Res.	Res.	DEAT[4:0]					DEDT[4:0]				
rw	rw	rw	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXFNFIE	TCIE	RXFNEIE	IDLEIE	TE	RE	UESM	UE
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **RXFFIE:**RXFIFO Full interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: An LPUART interrupt is generated when RXFF = 1 in the LPUART_ISR register

Bit 30 **TXFEIE:**TXFIFO empty interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: An LPUART interrupt is generated when TXFE = 1 in the LPUART_ISR register

Bit 29 **FIFOEN:**FIFO mode enable
This bit is set and cleared by software.
0: FIFO mode is disabled.
1: FIFO mode is enabled.

Bit 28 **M1**: Word length

This bit must be used in conjunction with bit 12 (M0) to determine the word length. It is set or cleared by software.

M[1:0] = 00: 1 Start bit, 8 Data bits, n stop bits

M[1:0] = 01: 1 Start bit, 9 Data bits, n stop bits

M[1:0] = ‘10: 1 Start bit, 7 Data bits, n stop bits

This bit can only be written when the LPUART is disabled (UE = 0).

Note: In 7-bit data length mode, the smartcard mode, LIN master mode and auto baud rate (0x7F and 0x55 frames detection) are not supported.

Bits 27:26 Reserved, must be kept at reset value.

Bits 25:21 **DEAT[4:0]**: Driver Enable assertion time

This 5-bit value defines the time between the activation of the DE (Driver Enable) signal and the beginning of the start bit. It is expressed in lpuart_ker_ck clock cycles. For more details, refer *Section 61.5.21: RS232 hardware flow control and RS485 driver enable*.

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bits 20:16 **DEDT[4:0]**: Driver Enable deassertion time

This 5-bit value defines the time between the end of the last stop bit, in a transmitted message, and the de-activation of the DE (Driver Enable) signal.It is expressed in lpuart_ker_ck clock cycles. For more details, refer *Section 62.4.14: RS232 hardware flow control and RS485 driver enable*.

If the LPUART_TDR register is written during the DEDT time, the new data is transmitted only when the DEDT and DEAT times have both elapsed.

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 15 Reserved, must be kept at reset value.

Bit 14 **CMIE**: Character match interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: A LPUART interrupt is generated when the CMF bit is set in the LPUART_ISR register.

Bit 13 **MME**: Mute mode enable

This bit activates the mute mode function of the LPUART. When set, the LPUART can switch between the active and mute modes, as defined by the WAKE bit. It is set and cleared by software.

0: Receiver in active mode permanently

1: Receiver can switch between mute mode and active mode.

Bit 12 **M0**: Word length

This bit is used in conjunction with bit 28 (M1) to determine the word length. It is set or cleared by software (refer to bit 28 (M1) description).

This bit can only be written when the LPUART is disabled (UE = 0).

Bit 11 **WAKE**: Receiver wake-up method

This bit determines the LPUART wake-up method from mute mode. It is set or cleared by software.

0: Idle line

1: Address mark

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 10 **PCE**: Parity control enable

This bit selects the hardware parity control (generation and detection). When the parity control is enabled, the computed parity is inserted at the MSB position (9th bit if M = 1; 8th bit if M = 0) and parity is checked on the received data. This bit is set and cleared by software. Once it is set, PCE is active after the current byte (in reception and in transmission).

0: Parity control disabled

1: Parity control enabled

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 9 **PS**: Parity selection

This bit selects the odd or even parity when the parity generation/detection is enabled (PCE bit set). It is set and cleared by software. The parity is selected after the current byte.

0: Even parity

1: Odd parity

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 8 **PEIE**: PE interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: An LPUART interrupt is generated whenever PE = 1 in the LPUART_ISR register

Bit 7 **TXFNFIE**: TXFIFO not full interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: A LPUART interrupt is generated whenever TXFNF = 1 in the LPUART_ISR register

Bit 6 **TCIE**: Transmission complete interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: An LPUART interrupt is generated whenever TC = 1 in the LPUART_ISR register

Bit 5 **RXFNEIE**: RXFIFO not empty interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: A LPUART interrupt is generated whenever ORE = 1 or RXFNE = 1 in the LPUART_ISR register

Bit 4 **IDLEIE**: IDLE interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: An LPUART interrupt is generated whenever IDLE = 1 in the LPUART_ISR register

Bit 3 **TE**: Transmitter enable

This bit enables the transmitter. It is set and cleared by software.

0: Transmitter is disabled

1: Transmitter is enabled

Note: When the LPUART acts as a transmitter, a low pulse on the TE bit (0 followed by 1) sends a preamble (idle line) after the current word, except in smartcard mode. In order to generate an idle character, the TE must not be immediately written to 1. To ensure the required duration, the software can poll the TEACK bit in the LPUART_ISR register.

In smartcard mode, when TE is set, there is a 1 bit-time delay before the transmission starts.

Bit 2 **RE**: Receiver enable

This bit enables the receiver. It is set and cleared by software.

0: Receiver is disabled

1: Receiver is enabled and begins searching for a start bit

Bit 1 **UESM**: LPUART enable in low-power mode

When this bit is cleared, the LPUART cannot wake up the MCU from low-power mode.

When this bit is set, the LPUART can wake up the MCU from low-power mode.

This bit is set and cleared by software.

0: LPUART not able to wake up the MCU from low-power mode.

1: LPUART able to wake up the MCU from low-power mode.

Note: It is recommended to set the UESM bit just before entering low-power mode, and clear it when exiting low-power mode.

Bit 0 **UE**: LPUART enable

When this bit is cleared, the LPUART prescalers and outputs are stopped immediately, and current operations are discarded. The configuration of the LPUART is kept, but all the status flags, in the LPUART_ISR are reset. This bit is set and cleared by software.

0: LPUART prescaler and outputs disabled, low-power mode

1: LPUART enabled

Note: To enter low-power mode without generating errors on the line, the TE bit must be reset before and the software must wait for the TC bit in the LPUART_ISR to be set before resetting the UE bit.

The DMA requests are also reset when UE = 0 so the DMA channel must be disabled before resetting the UE bit.

62.7.2 LPUART control register 1 [alternate] (LPUART_CR1)

Address offset: 0x00

Reset value: 0x0000 0000

The same register can be used in FIFO mode enabled (previous section) and FIFO mode disabled (this section).

FIFO mode disabled, FIFOEN = 0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	FIFO EN	M1	Res.	Res.	DEAT[4:0]					DEDT[4:0]				
		rw	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXEIE	TCIE	RXNEIE	IDLEIE	TE	RE	UESM	UE
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **FIFOEN:**FIFO mode enable

This bit is set and cleared by software.

0: FIFO mode is disabled.

1: FIFO mode is enabled.

Bit 28 **M1**: Word length

This bit must be used in conjunction with bit 12 (M0) to determine the word length. It is set or cleared by software.

M[1:0] = 00: 1 Start bit, 8 Data bits, n stop bits

M[1:0] = 01: 1 Start bit, 9 Data bits, n stop bits

M[1:0] = ‘10: 1 Start bit, 7 Data bits, n stop bits

This bit can only be written when the LPUART is disabled (UE = 0).

Note: In 7-bit data length mode, the smartcard mode, LIN master mode and auto baud rate (0x7F and 0x55 frames detection) are not supported.

Bits 27:26 Reserved, must be kept at reset value.

Bits 25:21 **DEAT[4:0]**: Driver Enable assertion time

This 5-bit value defines the time between the activation of the DE (Driver Enable) signal and the beginning of the start bit. It is expressed in lpuart_ker_ck clock cycles. For more details, refer *Section 61.5.21: RS232 hardware flow control and RS485 driver enable*.

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bits 20:16 **DEDT[4:0]**: Driver Enable deassertion time

This 5-bit value defines the time between the end of the last stop bit, in a transmitted message, and the de-activation of the DE (Driver Enable) signal.It is expressed in lpuart_ker_ck clock cycles. For more details, refer *Section 62.4.14: RS232 hardware flow control and RS485 driver enable*.

If the LPUART_TDR register is written during the DEDT time, the new data is transmitted only when the DEDT and DEAT times have both elapsed.

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 15 Reserved, must be kept at reset value.

Bit 14 **CMIE**: Character match interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: A LPUART interrupt is generated when the CMF bit is set in the LPUART_ISR register.

Bit 13 **MME**: Mute mode enable

This bit activates the mute mode function of the LPUART. When set, the LPUART can switch between the active and mute modes, as defined by the WAKE bit. It is set and cleared by software.

0: Receiver in active mode permanently

1: Receiver can switch between mute mode and active mode.

Bit 12 **M0**: Word length

This bit is used in conjunction with bit 28 (M1) to determine the word length. It is set or cleared by software (refer to bit 28 (M1) description).

This bit can only be written when the LPUART is disabled (UE = 0).

Bit 11 **WAKE**: Receiver wake-up method

This bit determines the LPUART wake-up method from mute mode. It is set or cleared by software.

0: Idle line

1: Address mark

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 10 **PCE**: Parity control enable

This bit selects the hardware parity control (generation and detection). When the parity control is enabled, the computed parity is inserted at the MSB position (9th bit if M = 1; 8th bit if M = 0) and parity is checked on the received data. This bit is set and cleared by software. Once it is set, PCE is active after the current byte (in reception and in transmission).

0: Parity control disabled

1: Parity control enabled

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 9 **PS**: Parity selection

This bit selects the odd or even parity when the parity generation/detection is enabled (PCE bit set). It is set and cleared by software. The parity is selected after the current byte.

0: Even parity

1: Odd parity

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 8 **PEIE**: PE interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: An LPUART interrupt is generated whenever PE = 1 in the LPUART_ISR register

Bit 7 **TXEIE**: Transmit data register empty

This bit is set and cleared by software.

0: Interrupt is inhibited

1: A LPUART interrupt is generated whenever TXE = 1 in the LPUART_ISR register

Bit 6 **TCIE**: Transmission complete interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: An LPUART interrupt is generated whenever TC = 1 in the LPUART_ISR register

Bit 5 **RXNEIE**: Receive data register not empty interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: A LPUART interrupt is generated whenever ORE = 1 or RXNE = 1 in the LPUART_ISR register

Bit 4 **IDLEIE**: IDLE interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: An LPUART interrupt is generated whenever IDLE = 1 in the LPUART_ISR register

Bit 3 **TE**: Transmitter enable

This bit enables the transmitter. It is set and cleared by software.

0: Transmitter is disabled

1: Transmitter is enabled

Note: When the LPUART acts as a transmitted, a low pulse on the TE bit (0 followed by 1) sends a preamble (idle line) after the current word, except in smartcard mode. In order to generate an idle character, the TE must not be immediately written to '1. To ensure the required duration, the software can poll the TEACK bit in the LPUART_ISR register.

In smartcard mode, when TE is set, there is a 1 bit-time delay before the transmission starts.

Bit 2 **RE**: Receiver enable

This bit enables the receiver. It is set and cleared by software.

0: Receiver is disabled

1: Receiver is enabled and begins searching for a start bit

Bit 1 **UESM**: LPUART enable in low-power mode

When this bit is cleared, the LPUART cannot wake up the MCU from low-power mode.

When this bit is set, the LPUART can wake up the MCU from low-power mode.

This bit is set and cleared by software.

0: LPUART not able to wake up the MCU from low-power mode.

1: LPUART able to wake up the MCU from low-power mode.

Note: It is recommended to set the UESM bit just before entering low-power mode, and clear it when exiting low-power mode.

Bit 0 **UE**: LPUART enable

When this bit is cleared, the LPUART prescalers and outputs are stopped immediately, and current operations are discarded. The configuration of the LPUART is kept, but all the status flags, in the LPUART_ISR are reset. This bit is set and cleared by software.

0: LPUART prescaler and outputs disabled, low-power mode

1: LPUART enabled

Note: To enter low-power mode without generating errors on the line, the TE bit must be reset before and the software must wait for the TC bit in the LPUART_ISR to be set before resetting the UE bit.

The DMA requests are also reset when UE = 0 so the DMA channel must be disabled before resetting the UE bit.

62.7.3 LPUART control register 2 (LPUART_CR2)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADD[7:0]								Res.	Res.	Res.	Res.	MSBFIRST	DATAINV	TXINV	RXINV
rw	rw	rw	rw	rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SWAP	Res.	STOP[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDM7	Res.	Res.	Res.	Res.
rw		rw	rw								rw				

Bits 31:24 **ADD[7:0]**: Address of the LPUART node

These bits give the address of the LPUART node in mute mode or a character code to be recognized in low-power or Run mode:

- In mute mode: they are used in multiprocessor communication to wake up from mute mode with 4-bit/7-bit address mark detection. The MSB of the character sent by the transmitter is equal to 1. In 4-bit address mark detection, only ADD[3:0] bits are used.
- In low-power mode: they are used for wake up from low-power mode on character match. When WUS[1:0] is programmed to 0b00 (WUF active on address match), the wake-up from low-power mode is performed when the received character corresponds to the character programmed through ADD[6:0] or ADD[3:0] bitfield (depending on ADDM7 bit), and WUF interrupt is enabled by setting WUFIE bit. The MSB of the character sent by transmitter is equal to 1.
- In Run mode with mute mode inactive (for example, end-of-block detection in ModBus protocol): the whole received character (8 bits) is compared to ADD[7:0] value and CMF flag is set on match. An interrupt is generated if the CMIE bit is set.

These bits can only be written when the reception is disabled (RE = 0) or when the LPUART is disabled (UE = 0).

Bits 23:20 Reserved, must be kept at reset value.

Bit 19 **MSBFIRST**: Most significant bit first

This bit is set and cleared by software.
0: data is transmitted/received with data bit 0 first, following the start bit.
1: data is transmitted/received with the MSB (bit 7/8) first, following the start bit.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 18 **DATAINV:** Binary data inversion

This bit is set and cleared by software.
0: Logical data from the data register are send/received in positive/direct logic. (1=H, 0=L)
1: Logical data from the data register are send/received in negative/inverse logic. (1=L, 0=H). The parity bit is also inverted.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 17 **TXINV:** TX pin active level inversion

This bit is set and cleared by software.
0: TX pin signal works using the standard logic levels (V_{DD} = 1 / idle, Gnd = 0 / mark)
1: TX pin signal values are inverted. ((V_{DD} = 0 / mark, Gnd = 1 / idle).
This enables the use of an external inverter on the TX line.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 16 **RXINV:** RX pin active level inversion

This bit is set and cleared by software.
0: RX pin signal works using the standard logic levels (V_{DD} = 1 / idle, Gnd = 0/mark)
1: RX pin signal values are inverted. ((V_{DD} = 0/mark, Gnd = 1 / idle).
This enables the use of an external inverter on the RX line.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 15 **SWAP:** Swap TX/RX pins

This bit is set and cleared by software.
0: TX/RX pins are used as defined in standard pinout
1: The TX and RX pins functions are swapped. This enables to work in the case of a cross-wired connection to another UART.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 14 Reserved, must be kept at reset value.

Bits 13:12 **STOP[1:0]**: Stop bits
These bits are used for programming the stop bits.
00: 1 stop bit
01: Reserved.
10: 2 stop bits
11: Reserved
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bits 11:5 Reserved, must be kept at reset value.

Bit 4 **ADDM7**:7-bit Address Detection/4-bit Address Detection
This bit is for selection between 4-bit address detection or 7-bit address detection.
0: 4-bit address detection
1: 7-bit address detection (in 8-bit data mode)
This bit can only be written when the LPUART is disabled (UE = 0)
Note: In 7-bit and 9-bit data modes, the address detection is done on 6-bit and 8-bit address (ADD[5:0] and ADD[7:0]) respectively.

Bits 3:0 Reserved, must be kept at reset value.

62.7.4 LPUART control register 3 (LPUART_CR3)

Address offset: 0x08

Reset value: 0x0000 0000

FIFO mode enabled, FIFOEN = 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXFTCFG[2:0]			RXFTIE	RXFTCFG[2:0]			Res.	TXFTIE	WUFIE	WUS1	WUS0	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DEP	DEM	DDRE	OVRDIS	Res.	CTSIE	CTSE	RTSE	DMAT	DMAR	Res.	Res.	HDSEL	Res.	Res.	EIE
rw	rw	rw	rw		rw	rw	rw	rw	rw			rw			rw

Bits 31:29 **TXFTCFG[2:0]:** TXFIFO threshold configuration
000:TXFIFO reaches 1/8 of its depth.
001:TXFIFO reaches 1/4 of its depth.
110:TXFIFO reaches 1/2 of its depth.
011:TXFIFO reaches 3/4 of its depth.
100:TXFIFO reaches 7/8 of its depth.
101:TXFIFO becomes empty.
Others: Reserved, must not be used.
This bit can only be written when the LPUART is disabled (UE = 0).

Bit 28 **RXFTIE**: RXFIFO threshold interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: An LPUART interrupt is generated when Receive FIFO reaches the threshold programmed in RXFTCFG[2:0].

Bits 27:25 **RXFTCFG[2:0]:** Receive FIFO threshold configuration
000:Receive FIFO reaches 1/8 of its depth.
001:Receive FIFO reaches 1/4 of its depth.
110:Receive FIFO reaches 1/2 of its depth.
011:Receive FIFO reaches 3/4 of its depth.
100:Receive FIFO reaches 7/8 of its depth.
101:Receive FIFO becomes full.
Others: Reserved, must not be used.
This bit can only be written when the LPUART is disabled (UE = 0).

Bit 24 Reserved, must be kept at reset value.

Bit 23 **TXFTIE**: TXFIFO threshold interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: A LPUART interrupt is generated when TXFIFO reaches the threshold programmed in TXFTCFG[2:0].

Bit 22 **WUFIE**: Wake-up from low-power mode interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: LPUART interrupt generated whenever WUF = 1 in the LPUART_ISR register

Note: WUFIE must be set before entering in low-power mode.
If the LPUART *does not support the wake-up from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 62.3: LPUART implementation.*

Bits 21:20 **WUS[1:0]**: Wake-up from low-power mode interrupt flag selection
This bitfield specifies the event which activates the WUF (wake-up from low-power mode flag).
00: WUF active on address match (as defined by ADD[7:0] and ADDM7)
01: Reserved.
10: WUF active on start bit detection
11: WUF active on RXNE/RXFNE.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Note: If the LPUART *does not support the wake-up from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 62.3: LPUART implementation.*

Bits 19:16 Reserved, must be kept at reset value.

Bit 15 **DEP**: Driver enable polarity selection
0: DE signal is active high.
1: DE signal is active low.
This bit can only be written when the LPUART is disabled (UE = 0).

Bit 14 **DEM**: Driver enable mode
This bit enables the user to activate the external transceiver control, through the DE signal.
0: DE function is disabled.
1: DE function is enabled. The DE signal is output on the RTS pin.
This bit can only be written when the LPUART is disabled (UE = 0).

Bit 13 **DDRE**: DMA Disable on reception Error

0: DMA is not disabled in case of reception error. The corresponding error flag is set but RXNE is kept 0 preventing from overrun. As a consequence, the DMA request is not asserted, so the erroneous data is not transferred (no DMA request), but next correct received data is transferred.

1: DMA is disabled following a reception error. The corresponding error flag is set, as well as RXNE. The DMA request is masked until the error flag is cleared. This means that the software must first disable the DMA request (DMAR = 0) or clear RXNE before clearing the error flag.

This bit can only be written when the LPUART is disabled (UE = 0).

Note: The reception errors are: parity error, framing error or noise error.

Bit 12 **OVRDIS**: Overrun Disable

This bit is used to disable the receive overrun detection.

0: Overrun Error Flag, ORE is set when received data is not read before receiving new data.

1: Overrun functionality is disabled. If new data is received while the RXNE flag is still set the ORE flag is not set and the new received data overwrites the previous content of the LPUART_RDR register.

This bit can only be written when the LPUART is disabled (UE = 0).

Note: This control bit enables *checking the communication flow w/o reading the data.*

Bit 11 Reserved, must be kept at reset value.

Bit 10 **CTSIE**: CTS interrupt enable

0: Interrupt is inhibited

1: An interrupt is generated whenever CTSIF = 1 in the LPUART_ISR register

Bit 9 **CTSE**: CTS enable

0: CTS hardware flow control disabled

1: CTS mode enabled, data is only transmitted when the CTS input is deasserted (tied to 0). If the CTS input is asserted while data is being transmitted, then the transmission completes before stopping. If data is written into the data register while CTS is asserted, the transmission is postponed until CTS is deasserted.

This bit can only be written when the LPUART is disabled (UE = 0)

Bit 8 **RTSE**: RTS enable

0: RTS hardware flow control disabled

1: RTS output enabled, data is only requested when there is space in the receive buffer. The transmission of data is expected to cease after the current character has been transmitted. The RTS output is deasserted (pulled to 0) when data can be received.

This bit can only be written when the LPUART is disabled (UE = 0).

Bit 7 **DMAT**: DMA enable transmitter

This bit is set/reset by software

1: DMA mode is enabled for transmission

0: DMA mode is disabled for transmission

Bit 6 **DMAR**: DMA enable receiver

This bit is set/reset by software

1: DMA mode is enabled for reception

0: DMA mode is disabled for reception

Bits 5:4 Reserved, must be kept at reset value.

Bit 3 **HDSEL**: Half-duplex selection
Selection of single-wire half-duplex mode
0: Half-duplex mode is not selected
1: Half-duplex mode is selected
This bit can only be written when the LPUART is disabled (UE = 0).

Bits 2:1 Reserved, must be kept at reset value.

Bit 0 **EIE**: Error interrupt enable
Error Interrupt Enable Bit is required to enable interrupt generation in case of a framing error, overrun error or noise flag (FE = 1 or ORE = 1 or NE = 1 in the LPUART_ISR register).
0: Interrupt is inhibited
1: An interrupt is generated when FE = 1 or ORE = 1 or NE = 1 in the LPUART_ISR register.

62.7.5 LPUART control register 3 [alternate] (LPUART_CR3)

Address offset: 0x08

Reset value: 0x0000 0000

FIFO mode disabled, FIFOEN = 0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUFIE	WUS1	WUS0	Res.	Res.	Res.	Res.
									rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DEP	DEM	DDRE	OVRDIS	Res.	CTSIE	CTSE	RTSE	DMAT	DMAR	Res.	Res.	HDSEL	Res.	Res.	EIE
rw	rw	rw	rw		rw	rw	rw	rw	rw			rw			rw

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **WUFIE**: Wake-up from low-power mode interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: LPUART interrupt generated whenever WUF = 1 in the LPUART_ISR register

Note: WUFIE must be set before entering in low-power mode.
If the LPUART *does not support the wake-up from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 62.3: LPUART implementation.*

Bits 21:20 **WUS[1:0]**: Wake-up from low-power mode interrupt flag selection
This bitfield specifies the event which activates the WUF (wake-up from low-power mode flag).
00: WUF active on address match (as defined by ADD[7:0] and ADDM7)
01: Reserved.
10: WUF active on start bit detection
11: WUF active on RXNE/RXFNE.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Note: If the LPUART *does not support the wake-up from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 62.3: LPUART implementation.*

Bits 19:16 Reserved, must be kept at reset value.

Bit 15 **DEP**: Driver enable polarity selection
0: DE signal is active high.
1: DE signal is active low.
This bit can only be written when the LPUART is disabled (UE = 0).

Bit 14 **DEM**: Driver enable mode
This bit enables the user to activate the external transceiver control, through the DE signal.
0: DE function is disabled.
1: DE function is enabled. The DE signal is output on the RTS pin.
This bit can only be written when the LPUART is disabled (UE = 0).

Bit 13 **DDRE**: DMA Disable on reception Error
0: DMA is not disabled in case of reception error. The corresponding error flag is set but RXNE is kept 0 preventing from overrun. As a consequence, the DMA request is not asserted, so the erroneous data is not transferred (no DMA request), but next correct received data is transferred.
1: DMA is disabled following a reception error. The corresponding error flag is set, as well as RXNE. The DMA request is masked until the error flag is cleared. This means that the software must first disable the DMA request (DMAR = 0) or clear RXNE before clearing the error flag.
This bit can only be written when the LPUART is disabled (UE = 0).
Note: The reception errors are: parity error, framing error or noise error.

Bit 12 **OVRDIS**: Overrun Disable
This bit is used to disable the receive overrun detection.
0: Overrun Error Flag, ORE is set when received data is not read before receiving new data.
1: Overrun functionality is disabled. If new data is received while the RXNE flag is still set the ORE flag is not set and the new received data overwrites the previous content of the LPUART_RDR register.
This bit can only be written when the LPUART is disabled (UE = 0).
Note: This control bit enables *checking the communication flow w/o reading the data.*

Bit 11 Reserved, must be kept at reset value.

Bit 10 **CTSIE**: CTS interrupt enable
0: Interrupt is inhibited
1: An interrupt is generated whenever CTSIF = 1 in the LPUART_ISR register

Bit 9 **CTSE**: CTS enable
0: CTS hardware flow control disabled
1: CTS mode enabled, data is only transmitted when the CTS input is deasserted (tied to 0). If the CTS input is asserted while data is being transmitted, then the transmission completes before stopping. If data is written into the data register while CTS is asserted, the transmission is postponed until CTS is deasserted.
This bit can only be written when the LPUART is disabled (UE = 0)

Bit 8 **RTSE**: RTS enable
0: RTS hardware flow control disabled
1: RTS output enabled, data is only requested when there is space in the receive buffer. The transmission of data is expected to cease after the current character has been transmitted. The RTS output is deasserted (pulled to 0) when data can be received.
This bit can only be written when the LPUART is disabled (UE = 0).

Bit 7 **DMAT**: DMA enable transmitter
This bit is set/reset by software
1: DMA mode is enabled for transmission
0: DMA mode is disabled for transmission

Bit 6 **DMAR**: DMA enable receiver
This bit is set/reset by software
1: DMA mode is enabled for reception
0: DMA mode is disabled for reception

Bits 5:4 Reserved, must be kept at reset value.

Bit 3 **HDSEL**: Half-duplex selection
Selection of single-wire half-duplex mode
0: Half-duplex mode is not selected
1: Half-duplex mode is selected
This bit can only be written when the LPUART is disabled (UE = 0).

Bits 2:1 Reserved, must be kept at reset value.

Bit 0 **EIE**: Error interrupt enable
Error Interrupt Enable Bit is required to enable interrupt generation in case of a framing error, overrun error or noise flag (FE = 1 or ORE = 1 or NE = 1 in the LPUART_ISR register).
0: Interrupt is inhibited
1: An interrupt is generated when FE = 1 or ORE = 1 or NE = 1 in the LPUART_ISR register.

62.7.6 LPUART baud rate register (LPUART_BRR)

This register can only be written when the LPUART is disabled (UE = 0). It may be automatically updated by hardware in auto baud rate detection mode.

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BRR[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BRR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **BRR[19:0]:** LPUART baud rate division (LPUARTDIV)

Note: It is forbidden to write values lower than 0x300 in the LPUART_BRR register.

Provided that LPUART_BRR must be ≥ 0x300 and LPUART_BRR is 20 bits, a care must be taken when generating high baud rates using high lpuart_ker_ck_pres values. lpuart_ker_ck_pres must be in the range [3 x baud rate..4096 x baud rate].

62.7.7 LPUART request register (LPUART_RQR)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXFRQ	RXFRQ	MMRQ	SBKRQ	Res.
											w	w	w	w	

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **TXFRQ**: Transmit data flush request

This bit is used when FIFO mode is enabled. TXFRQ bit is set to flush the whole FIFO. This sets the flag TXFE (TXFIFO empty, bit 23 in the LPUART_ISR register).

Note: In FIFO mode, the TXFNF flag is reset during the flush request until TxFIFO is empty in order to ensure that no data are written in the data register.

Bit 3 **RXFRQ**: Receive data flush request

Writing 1 to this bit clears the RXNE flag.

This enables discarding the received data without reading it, and avoid an overrun condition.

Bit 2 **MMRQ**: Mute mode request

Writing 1 to this bit puts the LPUART in Mute mode and resets the RWU flag.

Bit 1 **SBKRQ**: Send break request

Writing 1 to this bit sets the SBKF flag and request to send a BREAK on the line, as soon as the transmit machine is available.

Note: If the application needs to send the break character following all previously inserted data, including the ones not yet transmitted, the software must wait for the TXE flag assertion before setting the SBKRQ bit.

Bit 0 Reserved, must be kept at reset value.

62.7.8 LPUART interrupt and status register (LPUART_ISR)

Address offset: 0x1C

Reset value: 0x0080 00C0

The same register can be used in FIFO mode enabled (this section) and FIFO mode disabled (next section).

FIFO mode enabled, FIFOEN = 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TXFT	RXFT	Res.	RXFF	TXFE	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY
				r	r		r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	CTS	CTSIF	Res.	TXFNF	TC	RXFNE	IDLE	ORE	NE	FE	PE
					r	r		r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **TXFT**: TXFIFO threshold flag

This bit is set by hardware when the number of empty locations in the TXFIFO is greater than the threshold programmed in the TXFTCFG[2:0] bitfield of LPUART_CR3 register.An interrupt is generated if the TXFTIE bit = 1 (bit 31) in the LPUART_CR3 register.

0: TXFIFO does not reach the programmed threshold.

1: TXFIFO reached the programmed threshold.

Bit 26 **RXFT**: RXFIFO threshold flag

This bit is set by hardware when the RXFIFO reaches the threshold programmed in the RXFTCFG[2:0] bitfield of the LPUART_CR3 register, that is, the Receive FIFO contains RXFTCFG[2:0] data. An interrupt is generated if the RXFTIE bit = 1 (bit 28) in the LPUART_CR3 register.

0: Receive FIFO does not reach the programmed threshold.

1: Receive FIFO reached the programmed threshold.

Note: When the RXFTCFG[2:0] threshold is configured to 101, the RXFT flag is set if RXFIFO size data are available, that is, (RXFIFO size – 1) data in the RXFIFO and 1 data in the LPUART_RDR. Consequently, the (RXFIFO size + 1) th received data does not cause an overrun error. The overrun error occurs after receiving the (RXFIFO size + 2) th data.

Bit 25 Reserved, must be kept at reset value.

Bit 24 **RXFF**: RXFIFO Full

This bit is set by hardware when the number of received data corresponds to RXFIFO size + 1 (RXFIFO full + 1 data in the LPUART_RDR register.

An interrupt is generated if the RXFFIE bit = 1 in the LPUART_CR1 register.

0: RXFIFO is not Full.

1: RXFIFO is Full.

Bit 23 **TXFE**: TXFIFO Empty

This bit is set by hardware when TXFIFO is Empty. When the TXFIFO contains at least one data, this flag is cleared. The TXFE flag can also be set by writing 1 to the bit TXFRQ (bit 4) in the LPUART_RQR register.

An interrupt is generated if the TXFEIE bit = 1 (bit 30) in the LPUART_CR1 register.

0: TXFIFO is not empty.

1: TXFIFO is empty.

Bit 22 **REACK**: Receive enable acknowledge flag

This bit is set/reset by hardware, when the Receive Enable value is taken into account by the LPUART.

It can be used to verify that the LPUART is ready for reception before entering low-power mode.

Note: If the LPUART does not support the wake-up from Stop feature, this bit is reserved and kept at reset value.

Bit 21 **TEACK**: Transmit enable acknowledge flag

This bit is set/reset by hardware, when the Transmit Enable value is taken into account by the LPUART.

It can be used when an idle frame request is generated by writing TE = 0, followed by TE = 1 in the LPUART_CR1 register, in order to respect the TE = 0 minimum period.

Bit 20 **WUF**: Wake-up from low-power mode flag

This bit is set by hardware, when a wake-up event is detected. The event is defined by the WUS bitfield. It is cleared by software, writing a 1 to the WUCF in the LPUART_ICR register.
An interrupt is generated if WUFIE = 1 in the LPUART_CR3 register.

Note: When UESM is cleared, WUF flag is also cleared.

If the LPUART *does not support the wake-up from Stop feature, this bit is reserved and kept at reset value. Refer to Section 62.3: LPUART implementation.*

Bit 19 **RWU**: Receiver wake-up from mute mode

This bit indicates if the LPUART is in mute mode. It is cleared/set by hardware when a wake-up/mute sequence is recognized. The mute mode control sequence (address or IDLE) is selected by the WAKE bit in the LPUART_CR1 register.
When wake-up on IDLE mode is selected, this bit can only be set by software, writing 1 to the MMRQ bit in the LPUART_RQR register.
0: Receiver in active mode
1: Receiver in mute mode

Note: If the LPUART does not support the wake-up from Stop feature, this bit is reserved and kept at reset value.

Bit 18 **SBKF**: Send break flag

This bit indicates that a send break character was requested. It is set by software, by writing 1 to the SBKRQ bit in the LPUART_CR3 register. It is automatically reset by hardware during the stop bit of break transmission.
0: No break character transmitted
1: Break character transmitted

Bit 17 **CMF**: Character match flag

This bit is set by hardware, when a the character defined by ADD[7:0] is received. It is cleared by software, writing 1 to the CMCF in the LPUART_ICR register.
An interrupt is generated if CMIE = 1in the LPUART_CR1 register.
0: No Character match detected
1: Character match detected

Bit 16 **BUSY**: Busy flag

This bit is set and reset by hardware. It is active when a communication is ongoing on the RX line (successful start bit detected). It is reset at the end of the reception (successful or not).
0: LPUART is idle (no reception)
1: reception ongoing

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **CTS**: CTS flag

This bit is set/reset by hardware. It is an inverted copy of the status of the CTS input pin.
0: CTS line set
1: CTS line reset

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 9 **CTSIF**: CTS interrupt flag

This bit is set by hardware when the CTS input toggles, if the CTSE bit is set. It is cleared by software, by writing 1 to the CTSCF bit in the LPUART_ICR register.

An interrupt is generated if CTSIE = 1 in the LPUART_CR3 register.

0: No change occurred on the CTS status line

1: A change occurred on the CTS status line

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 8 Reserved, must be kept at reset value.

Bit 7 **TXFNF:** TXFIFO not full

TXFNF is set by hardware when TXFIFO is not full, and so data can be written in the LPUART_TDR. Every write in the LPUART_TDR places the data in the TXFIFO. This flag remains set until the TXFIFO is full. When the TXFIFO is full, this flag is cleared indicating that data can not be written into the LPUART_TDR.

The TXFNF is kept reset during the flush request until TXFIFO is empty. After sending the flush request (by setting TXFRQ bit), the flag TXFNF must be checked prior to writing in TXFIFO (TXFNF and TXFE are set at the same time).

An interrupt is generated if the TXFNFIE bit = 1 in the LPUART_CR1 register.

0: Data register is full/Transmit FIFO is full.

1: Data register/Transmit FIFO is not full.

Note: This bit is used during single buffer transmission.

Bit 6 **TC**: Transmission complete

This bit indicates that the last data written in the LPUART_TDR has been transmitted out of the shift register.

It is set by hardware when the transmission of a frame containing data has completed and the TXFE bit is set.

An interrupt is generated if TCIE = 1 in the LPUART_CR1 register.

The TC bit is cleared by software, by writing 1 to the TCCF of the LPUART_ICR register, or by a write to the LPUART_TDR register.

0: Transmission has not completed

1: Transmission has completed

Note: If the TE bit is reset and no transmission is ongoing, the TC bit is immediately set.

Bit 5 **RXFNE**: RXFIFO not empty

RXFNE bit is set by hardware when the RXFIFO is not empty, and so data can be read from the LPUART_RDR register. Every read of the LPUART_RDR frees a location in the RXFIFO. It is cleared when the RXFIFO is empty.

The RXFNE flag can also be cleared by writing 1 to the RXFRQ in the LPUART_RQR register.

An interrupt is generated if RXFNEIE = 1 in the LPUART_CR1 register.

0: Data is not received

1: Received data is ready to be read.

Bit 4 **IDLE**: Idle line detected

This bit is set by hardware when an Idle line is detected. An interrupt is generated if IDLEIE = 1 in the LPUART_CR1 register. It is cleared by software, writing 1 to the IDLECF in the LPUART_ICR register.

0: No Idle line is detected

1: Idle line is detected

Note: The IDLE bit is not set again until the RXFNE bit has been set (that is, a new idle line occurs).

If mute mode is enabled (MME = 1), IDLE is set if the LPUART is not mute (RWU = 0), whatever the mute mode selected by the WAKE bit. If RWU = 1, IDLE is not set.

Bit 3 **ORE**: Overrun error

This bit is set by hardware when the data currently being received in the shift register is ready to be transferred into the LPUART_RDR register while RXFF = 1. It is cleared by a software, writing 1 to the ORECF, in the LPUART_ICR register.

An interrupt is generated if RXFNEIE = 1 in the LPUART_CR1 register, or EIE = 1 in the LPUART_CR3 register.

1: Overrun error is detected

Note: When this bit is set, the LPUART_RDR register content is not lost but the shift register is overwritten. An interrupt is generated if the ORE flag is set during multi buffer communication if the EIE bit is set.

This bit is permanently forced to 0 (no overrun detection) when the bit OVRDIS is set in the LPUART_CR3 register.

Bit 2 **NE:** Start bit noise detection flag

This bit is set by hardware when noise is detected on the start bit of a received frame. It is cleared by software, writing 1 to the NFCF bit in the LPUART_ICR register.

0: No noise is detected

1: Noise is detected

Note: This bit does not generate an interrupt as it appears at the same time as the RXFNE bit which itself generates an interrupt. An interrupt is generated when the NE flag is set during multi buffer communication if the EIE bit is set.

This error is associated with the character in the LPUART_RDR.

Bit 1 **FE**: Framing error

This bit is set by hardware when a de-synchronization, excessive noise or a break character is detected. It is cleared by software, writing 1 to the FECF bit in the LPUART_ICR register.

When transmitting data in smartcard mode, this bit is set when the maximum number of transmit attempts is reached without success (the card NACKs the data frame).

An interrupt is generated if EIE = 1 in the LPUART_CR3 register.

0: No Framing error is detected

1: Framing error or break character is detected

Note: This error is associated with the character in the LPUART_RDR.

Bit 0 **PE**: Parity error

This bit is set by hardware when a parity error occurs in reception mode. It is cleared by software, writing 1 to the PECF in the LPUART_ICR register.

An interrupt is generated if PEIE = 1 in the LPUART_CR1 register.

0: No parity error

1: Parity error

Note: This error is associated with the character in the LPUART_RDR.

62.7.9 LPUART interrupt and status register [alternate] (LPUART_ISR)

Address offset: 0x1C

Reset value: 0x0000 00C0

The same register can be used in FIFO mode enabled (previous section) and FIFO mode disabled (this section).

FIFO mode disabled, FIFOEN = 0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY
									r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	CTS	CTSIF	Res.	TXE	TC	RXNE	IDLE	ORE	NE	FE	PE
					r	r		r	r	r	r	r	r	r	r

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **REACK**: Receive enable acknowledge flag

This bit is set/reset by hardware, when the Receive Enable value is taken into account by the LPUART.

It can be used to verify that the LPUART is ready for reception before entering low-power mode.

Note: If the LPUART does not support the wake-up from Stop feature, this bit is reserved and kept at reset value.

Bit 21 **TEACK**: Transmit enable acknowledge flag

This bit is set/reset by hardware, when the Transmit Enable value is taken into account by the LPUART.

It can be used when an idle frame request is generated by writing TE = 0, followed by TE = 1 in the LPUART_CR1 register, in order to respect the TE = 0 minimum period.

Bit 20 **WUF**: Wake-up from low-power mode flag

This bit is set by hardware, when a wake-up event is detected. The event is defined by the WUS bitfield. It is cleared by software, writing a 1 to the WUCF in the LPUART_ICR register.

An interrupt is generated if WUFIE = 1 in the LPUART_CR3 register.

Note: When UESM is cleared, WUF flag is also cleared.

If the LPUART *does not support the wake-up from Stop feature, this bit is reserved and kept at reset value. Refer to Section 62.3: LPUART implementation.*

Bit 19 **RWU**: Receiver wake-up from mute mode

This bit indicates if the LPUART is in mute mode. It is cleared/set by hardware when a wake-up/mute sequence is recognized. The mute mode control sequence (address or IDLE) is selected by the WAKE bit in the LPUART_CR1 register.

When wake-up on IDLE mode is selected, this bit can only be set by software, writing 1 to the MMRQ bit in the LPUART_RQR register.

0: Receiver in active mode

1: Receiver in mute mode

Note: If the LPUART does not support the wake-up from Stop feature, this bit is reserved and kept at reset value.

Bit 18 **SBKF**: Send break flag

This bit indicates that a send break character was requested. It is set by software, by writing 1 to the SBKRQ bit in the LPUART_CR3 register. It is automatically reset by hardware during the stop bit of break transmission.

0: No break character transmitted

1: Break character transmitted

Bit 17 **CMF**: Character match flag

This bit is set by hardware, when a the character defined by ADD[7:0] is received. It is cleared by software, writing 1 to the CMCF in the LPUART_ICR register.

An interrupt is generated if CMIE = 1in the LPUART_CR1 register.

0: No Character match detected

1: Character match detected

Bit 16 **BUSY**: Busy flag

This bit is set and reset by hardware. It is active when a communication is ongoing on the RX line (successful start bit detected). It is reset at the end of the reception (successful or not).

0: LPUART is idle (no reception)

1: Reception ongoing

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **CTS**: CTS flag

This bit is set/reset by hardware. It is an inverted copy of the status of the CTS input pin.

0: CTS line set

1: CTS line reset

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 9 **CTSIF**: CTS interrupt flag

This bit is set by hardware when the CTS input toggles, if the CTSE bit is set. It is cleared by software, by writing 1 to the CTSCF bit in the LPUART_ICR register.

An interrupt is generated if CTSIE = 1 in the LPUART_CR3 register.

0: No change occurred on the CTS status line

1: A change occurred on the CTS status line

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 8 Reserved, must be kept at reset value.

Bit 7 **TXE:** Transmit data register empty

TXE is set by hardware when the content of the LPUART_TDR register has been transferred into the shift register. It is cleared by a write to the LPUART_TDR register.

An interrupt is generated if the TXEIE bit = 1 in the LPUART_CR1 register.

0: Data register full

1: Data register empty

Note: This bit is used during single buffer transmission.

Bit 6 **TC**: Transmission complete

This bit indicates that the last data written in the LPUART_TDR has been transmitted out of the shift register. The TC flag is set when the transmission of a frame containing data has completed and when TXE is set.

An interrupt is generated if TCIE = 1 in the LPUART_CR1 register.

TC bit is cleared by software by writing 1 to the TCCF in the LPUART_ICR register or by writing to the LPUART_TDR register.

Bit 5 **RXNE**: Read data register not empty

RXNE bit is set by hardware when the content of the LPUART_RDR shift register has been transferred to the LPUART_RDR register. It is cleared by a read to the LPUART_RDR register. The

RXNE flag can also be cleared by writing 1 to the RXFRQ in the LPUART_RQR register.

The RXFNE flag can also be cleared by writing 1 to the RXFRQ in the LPUART_RQR register.

An interrupt is generated if RXNEIE = 1 in the LPUART_CR1 register.

0: Data is not received

1: Received data is ready to be read.

Bit 4 **IDLE**: Idle line detected

This bit is set by hardware when an Idle Line is detected. An interrupt is generated if IDLEIE = 1 in the LPUART_CR1 register. It is cleared by software, writing 1 to the IDLECF in the LPUART_ICR register.

0: No Idle line is detected

1: Idle line is detected

Note: The IDLE bit is not set again until the RXNE bit has been set (that is, a new idle line occurs).

If mute mode is enabled (MME = 1), IDLE is set if the LPUART is not mute (RWU = 0), whatever the mute mode selected by the WAKE bit. If RWU = 1, IDLE is not set.

Bit 3 **ORE**: Overrun error

This bit is set by hardware when the data currently being received in the shift register is ready to be transferred into the LPUART_RDR register while RXNE = 1 (RXFF = 1 in case FIFO mode is enabled). It is cleared by a software, writing 1 to the ORECF, in the LPUART_ICR register.

An interrupt is generated if RXNEIE = 1 in the LPUART_CR1 register, or EIE = 1 in the LPUART_CR3 register.

1: Overrun error is detected

Note: When this bit is set, the LPUART_RDR register content is not lost but the shift register is overwritten. An interrupt is generated if the ORE flag is set during multi buffer communication if the EIE bit is set.

This bit is permanently forced to 0 (no overrun detection) when the bit OVRDIS is set in the LPUART_CR3 register.

Bit 2 **NE:** Start bit noise detection flag

This bit is set by hardware when noise is detected on the start bit of a received frame. It is cleared by software, writing 1 to the NFCF bit in the LPUART_ICR register.

0: No noise is detected

1: Noise is detected

Note: This bit does not generate an interrupt as it appears at the same time as the RXNE/RXFNE bit which itself generates an interrupt. An interrupt is generated when the NE flag is set during multi buffer communication if the EIE bit is set.

In FIFO mode, this error is associated with the character in the LPUART_RDR.

Bit 1 **FE**: Framing error

This bit is set by hardware when a de-synchronization, excessive noise or a break character is detected. It is cleared by software, writing 1 to the FECF bit in the LPUART_ICR register.
When transmitting data in smartcard mode, this bit is set when the maximum number of transmit attempts is reached without success (the card NACKs the data frame).
An interrupt is generated if EIE = 1 in the LPUART_CR3 register.
0: No Framing error is detected
1: Framing error or break character is detected

Note: In FIFO mode, this error is associated with the character in the LPUART_RDR.

Bit 0 **PE**: Parity error

This bit is set by hardware when a parity error occurs in reception mode. It is cleared by software, writing 1 to the PECF in the LPUART_ICR register.
An interrupt is generated if PEIE = 1 in the LPUART_CR1 register.
0: No parity error
1: Parity error

Note: In FIFO mode, this error is associated with the character in the LPUART_RDR.

62.7.10 LPUART interrupt flag clear register (LPUART_ICR)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUCF	Res.	Res.	CMCF	Res.
											w			w	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CTSCF	Res.	Res.	TCCF	Res.	IDLECF	ORECF	NECF	FECF	PECF
						w			w		w	w	w	w	w

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **WUCF**: Wake-up from low-power mode clear flag

Writing 1 to this bit clears the WUF flag in the LPUART_ISR register.

Note: If the LPUART *does not support the wake-up from Stop feature, this bit is reserved and must be kept at reset value.* Refer to *Section 62.3: LPUART implementation.*

Bits 19:18 Reserved, must be kept at reset value.

Bit 17 **CMCF**: Character match clear flag

Writing 1 to this bit clears the CMF flag in the LPUART_ISR register.

Bits 16:10 Reserved, must be kept at reset value.

Bit 9 **CTSCF**: CTS clear flag

Writing 1 to this bit clears the CTSIF flag in the LPUART_ISR register.

Bit 8 Reserved, must be kept at reset value.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **TCCF**: Transmission complete clear flag

Writing 1 to this bit clears the TC flag in the LPUART_ISR register.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **IDLECF**: Idle line detected clear flag
Writing 1 to this bit clears the IDLE flag in the LPUART_ISR register.

Bit 3 **ORECF**: Overrun error clear flag
Writing 1 to this bit clears the ORE flag in the LPUART_ISR register.

Bit 2 **NECF**: Noise detected clear flag
Writing 1 to this bit clears the NE flag in the LPUART_ISR register.

Bit 1 **FECF**: Framing error clear flag
Writing 1 to this bit clears the FE flag in the LPUART_ISR register.

Bit 0 **PECF**: Parity error clear flag
Writing 1 to this bit clears the PE flag in the LPUART_ISR register.

62.7.11 LPUART receive data register (LPUART_RDR)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDR[8:0]								
							r	r	r	r	r	r	r	r	r

Bits 31:9 Reserved, must be kept at reset value.

Bits 8:0 **RDR[8:0]**: Receive data value
Contains the received data character.
The RDR register provides the parallel interface between the input shift register and the internal bus (see *Section 62.4.1: LPUART block diagram*).
When receiving with the parity enabled, the value read in the MSB bit is the received parity bit.

62.7.12 LPUART transmit data register (LPUART_TDR)

Address offset: 0x28

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDR[8:0]								
							rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bits 8:0 **TDR[8:0]**: Transmit data value

Contains the data character to be transmitted.

The TDR register provides the parallel interface between the internal bus and the output shift register (see *Section 62.4.1: LPUART block diagram*).

When transmitting with the parity enabled (PCE bit set to 1 in the LPUART_CR1 register), the value written in the MSB (bit 7 or bit 8 depending on the data length) has no effect because it is replaced by the parity.

Note: This register must be written only when TXE/TXFNF = 1.

62.7.13 LPUART prescaler register (LPUART_PRESC)

This register can only be written when the LPUART is disabled (UE = 0).

Address offset: 0x2C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **PRESCALER[3:0]**: Clock prescaler

The LPUART input clock can be divided by a prescaler:

0000: input clock not divided
0001: input clock divided by 2
0010: input clock divided by 4
0011: input clock divided by 6
0100: input clock divided by 8
0101: input clock divided by 10
0110: input clock divided by 12
0111: input clock divided by 16
1000: input clock divided by 32
1001: input clock divided by 64
1010: input clock divided by 128
1011: input clock divided by 256
Others: Reserved, must not be used.

Note: When PRESCALER is programmed with a value different of the allowed ones, programmed prescaler value is equal to 1011, that is, input clock divided by 256.

If the prescaler is not supported, this bitfield is reserved and must be kept at reset value. Refer to Section 62.3: LPUART implementation.

62.7.14 LPUART register map

Table 687. LPUART register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	LPUART_CR1FIFO mode enabled	RXFFIE	TXFEIE	FIFOEN	M1	Res.	Res.	DEAT[4:0]						DEDT[4:0]				Res.	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXFNFIE	TCIE	RXFNEIE	IDLEIE	TE	RE	UESM	UE
	Reset value	0	0	0	0			0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00	LPUART_CR1FIFO mode disabled	Res.	Res.	FIFOEN	M1	Res.	Res.	DEAT[4:0]						DEDT[4:0]				Res.	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXEIE	TCIE	RXNEIE	IDLEIE	TE	RE	UESM	UE
	Reset value			0	0			0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	LPUART_CR2	ADD[7:0]								Res.	Res.	Res.	Res.	MSBFIRST	DATAINV	TXINV	RXINV	SWAP	Res.	STOP [1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDM7	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0					0	0	0	0	0		0	0								0				
0x08	LPUART_CR3 FIFO mode enabled	TXFTCFG[2:0]			RXFTIE	RXFTCFG[2:0]			Res.	TXFTIE	WUFIE	WUS 1	WUS 0	Res.	Res.	Res.	Res.	DEP	DEM	DDRE	OVRDIS	Res.	CTSIE	CTSE	RTSE	DMAT	DMAR	Res.	Res.	HDSEL	Res.	Res.	Res.	EIE
	Reset value	0	0	0	0	0	0	0		0	0	0	0					0	0	0	0		0	0	0	0	0			0			0
0x08	LPUART_CR3 FIFO mode disabled	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUFIE	WUS 1	WUS 0	Res.	Res.	Res.	Res.	DEP	DEM	DDRE	OVRDIS	Res.	CTSIE	CTSE	RTSE	DMAT	DMAR	Res.	Res.	HDSEL	Res.	Res.	Res.	EIE
	Reset value										0	0	0					0	0	0	0		0	0	0	0	0			0				0
0x0C	LPUART_BRR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BRR[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10-0x14	Reserved																																
0x18	LPUART_RQR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXFRQ	RXFRQ	MMRQ	SBKRQ	Res.
	Reset value																												0	0	0	0	
0x1C	LPUART_ISRFIFO mode enabled	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXFF	TXFF	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY	Res.	Res.	Res.	Res.	Res.	CTS	CTSIF	Res.	TXFNF	TC	RXFNE	IDLE	ORE	NE	FE	PE
	Reset value								0	1	0	0	0	0	0	0	0						0	0		1	0	0	0	0	0	0	0
0x1C	LPUART_ISRFIFO mode disabled	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY	Res.	Res.	Res.	Res.	Res.	CTS	CTSIF	Res.	TXE	TC	RXNE	IDLE	ORE	NE	FE	PE
	Reset value										0	0	0	0	0	0	0						0	0		1	0	0	0	0	0	0	0
0x20	LPUART_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUCF	Res.	Res.	CMCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CTSCF	Res.	Res.	TCCF	Res.	IDLECF	ORECF	NECF	FECF	PECF
	Reset value												0			0								0			0		0	0	0	0	0
0x24	LPUART_RDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res	RDR[8:0]								
	Reset value																								0	0	0	0	0	0	0	0	0

Table 687. LPUART register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x28	LPUART_TDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDR[8:0]								
	Reset value																								0	0	0	0	0	0	0	0	0
0x2C	LPUART_ PRESC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[3:0]			
	Reset value																													0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

63 Serial peripheral interface (SPI)

63.1 SPI introduction

The serial peripheral interface (SPI) can be used to communicate with external devices while using the specific synchronous protocol. The SPI protocol supports half-duplex, full-duplex, and simplex synchronous, serial communication with external devices. The interface can be configured as master or slave and can operate in multislave or multimaster configurations. The device configured as master provides a communication clock (SCK) to the slave device. The slave select (NSS) and ready (RDY) signals can be applied optionally just to set up communication with a concrete slave and to ensure it handles the data flow properly. The Motorola data format is used by default, but some other specific modes are supported as well.

63.2 SPI main features

- Full-duplex synchronous transfers on three lines
- Half-duplex synchronous transfer on two lines (with bidirectional data line)
- Simplex synchronous transfers on two lines (with unidirectional data line)
- From 4-bit up to 32-bit data size selection
- Multimaster or multislave mode capability
- Dual clock domain, the peripheral kernel clock is independent from the APB bus clock
- Baud rate prescaler up to kernel frequency/2 or bypass from RCC in master mode
- Protection of configuration and setting
- Slave select hardware or software management for both master and slave
- Adjustable minimum delays between data and between NSS and data flow
- Configurable NSS signal polarity and timing, MISO x MOSI swap capability
- Programmable clock polarity and phase with optional sampling delay when reading master data
- Programmable data order with MSB-first or LSB-first shifting
- Programmable number of data within a transfer to control NSS and CRC
- Dedicated transmission and reception flags with interrupt capability
- SPI Motorola and TI format support
- Hardware CRC can verify the integrity of the communication at the end of a transfer by:
  - Adding CRC value in Tx mode
  - Automatic CRC error checking for Rx mode

- Error detection with interrupt capability in case of data overrun, CRC error, data underrun, the mode fault, and frame error, depending on the operating mode
- Two 8-bit width embedded Rx and Tx FIFOs (FIFO size depends on instances)
- Configurable FIFO thresholds (to handle the data packets)
- Capability to handle data streams by system DMA controller
- Configurable behavior at slave underrun condition (support of cascaded circular buffers)
- Optional status pin RDY signalizing that the slave device is ready to handle the data flow

63.3 SPI implementation

The table below describes the SPI implementation.

Table 688. SPI features

SPI feature	SPI1, SPI2, SPI3 (full-featured instances)	SPI4, SPI5, SPI6 (full-featured instances)
Data and CRC size	Configurable from 4 to 32 bits	Configurable from 4 to 16 bits
CRC computation	CRC polynomial length configurable from 5 to 33 bits	CRC polynomial length configurable from 5 to 17 bits
FIFO size	16x8 bits	8x8 bits
FIFO threshold	1 - 16 data	1 - 16 data
Number of data control (TSIZE)	Up to 65535	Up to 65535
I2S feature	Yes	No
Autonomous in Stop modes with wake-up capability	No	No
Autonomous in LP-Stop and Standby modes with wake-up capability	No	No

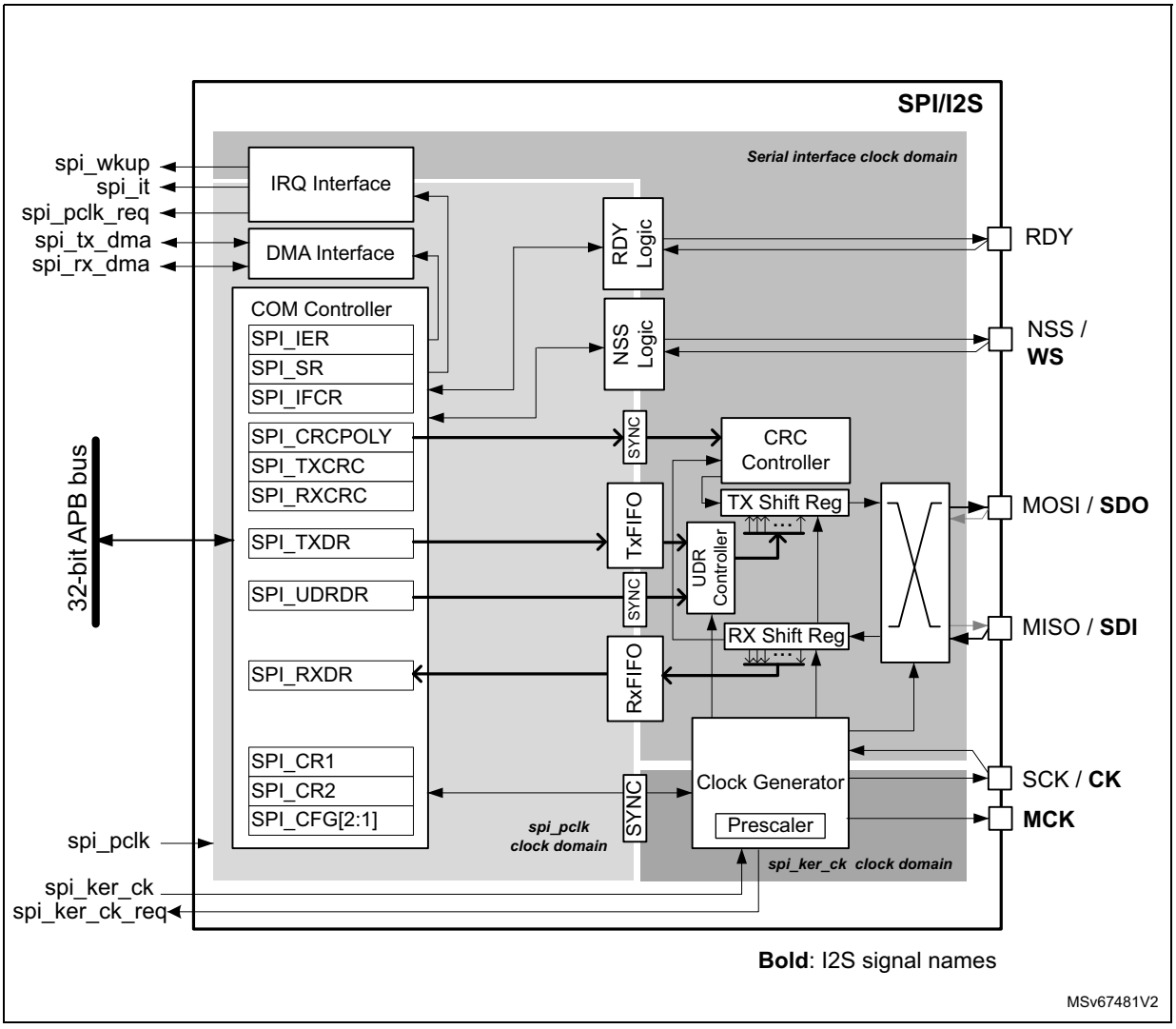
Note: For detailed information about instance capabilities to exit from Stop and Standby modes, refer to Table 692: SPI wake-up and interrupt requests.

63.4 SPI functional description

63.4.1 SPI block diagram

The SPI enables synchronous, serial communications between the MCU and external devices. The application software can manage the communication by polling the status flag or using a dedicated SPI interrupt. The main SPI elements and their interactions are shown in *Figure 864*.

Figure 864. SPI/I2S block diagram



The simplified scheme of *Figure 864* shows three fully independent clock domains:

- The **spi_pclk** clock domain
- The **spi_ker_ck** kernel clock domain
- The serial interface clock domain

All the control and status signals between these domains are strictly synchronized. There is no specific constraint concerning the frequency ratio between these clock signals. The user

has to consider a ratio compatible with the data flow speed to avoid data underrun or overrun events.

The **spi_pclk** clock signal feeds the peripheral bus interface. It must be active when accesses to the SPI registers are required.

The SPI working in slave mode handles a data flow using the serial interface clock derived from the external SCK signal provided by the external master SPI device. That is why the SPI slave is able to receive and send data even when the **spi_pclk** and **spi_ker_ck** clock signals are inactive. As a consequence, a specific slave logic working within the serial interface clock domain needs some additional traffic to be set up correctly (for example when underrun or overrun is evaluated, see *Section 63.5.2* for details). This cannot be done when the bus becomes idle. In some specific cases, the slave even requires the clock generator working (see *Section 63.5.1*).

When the SPI works as a master, the RCC must provide the **spi_ker_ck** kernel clock to the peripheral during communication to feed the serial interface clock via the clock generator where it can be divided by prescaler or bypassed. The signal is then provided to the slaves via the SCK pin and internally to the serial interface domain of the master.

63.4.2 SPI pins and internal signals

Up to five I/O pins are dedicated to SPI communication with external devices.

- **MISO:** master in / slave out data. In the general case, this pin is used to transmit data in slave mode and receive data in master mode.
- **MOSI:** master out / slave in data. In the general case, this pin is used to transmit data in master mode and receive data in slave mode.
- **SCK:** serial clock output pin for SPI masters and input pin for SPI slaves.
- **NSS:** slave select pin. Depending on the SPI and NSS settings, this pin can be used to either:
  - Select an individual slave device for communication
  - Synchronize the data frame, or
  - Detect a conflict between multiple masters

  See *Section 63.4.7* for details.
- **RDY:** optional status pin signaling slave FIFO occupancies and so the slave availability to continue the transfer without any risk of data flow corruption. It can be checked by the master to control the temporal suspension of the ongoing communication.

All these pins (except RDY) are shared in the I2S mode. This mode features an additional I2S specific MCK signal. For more details about I2S signals, see *Section 63.9.2*.

The SPI bus enables the communication between one master device and one or more slave devices. The bus consists of at least two wires: one for the clock signal and the other for synchronous data transfer. Other signals are optional and can be added depending on the data exchange between SPI nodes and their communication control management.

Refer to *Table 689* and *Table 690* for the list of SPI input / output pins and internal signals.

Table 689. SPI/I2S input/output pins(1)

Pin name	I/O type	Description
MISO/SDI(2)	Input/output	Master data input / slave data output
MOSI/SDO(2)	Input/output	Master data output / slave data input
SCK/CK	Input/output	Master clock output / slave clock input
NSS/WS	Input/output	Master output / slave selection input
RDY	Input/output	SPI master input / slave FIFOs status occupancy output
MCK	Output	I2S master frequency output

1. Refer to the section *Section 63.9.2: Pin sharing with SPI function* for details.
2. Functionality of MOSI/SDO and MISO/SDI pins can be swapped. Their directions may vary in SPI bidirectional half-duplex mode.

Description of SPI input/output signals

Table 690. SPI internal input/output signals

Signal name	Signal type	Description
spi_pclk	Input	SPI clock signal feeds the peripheral bus interface
spi_ker_ck	Input	SPI kernel clock
spi_ker_ck_req	Output	SPI kernel clock request
spi_pclk_req	Output	SPI clock request
spi_wkup	Output	SPI provides a wake-up interrupt
spi_it	Output	SPI global interrupt
spi_tx_dma	Input/output	SPI transmit DMA request
spi_rx_dma	Input/output	SPI receive DMA request

63.4.3 SPI communication general aspects

The SPI allows the MCU to communicate using different configurations, depending on the device targeted and the application requirements. These configurations use two or three wires (with software slave select management) or three or four wires (with hardware slave select management). The communication is always initiated and controlled by the master. The master provides a clock signal on the SCK line and selects or synchronizes slaves for communication by NSS line when it is managed by hardware.

The data between the master and the slave flow synchronously on the MOSI and/or MISO lines.

63.4.4 Communications between one master and one slave

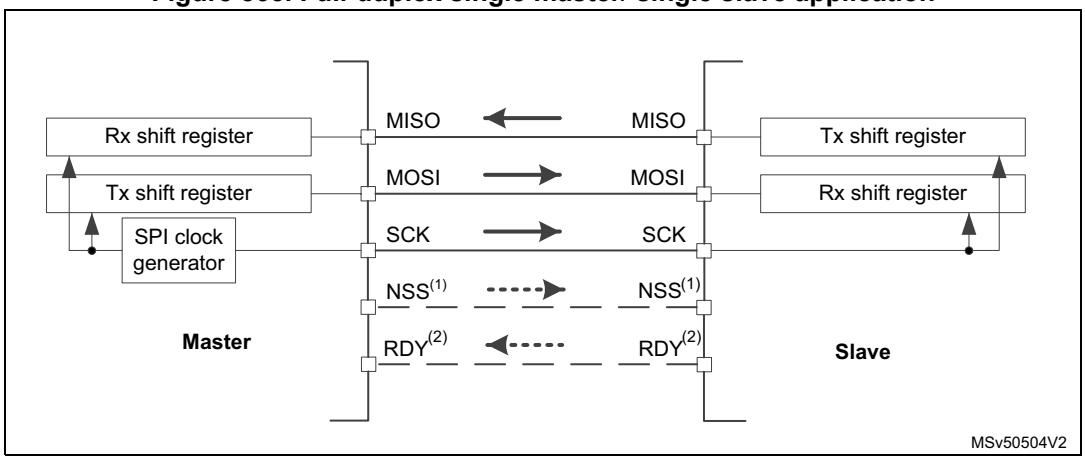
The communication flow can use one of three possible modes: the full-duplex (three wires) mode, half-duplex (two wires) mode, or the simplex (two wires) mode. The NSS signal is optional in single master-slave configuration and is often not connected between the two communication nodes. Nevertheless, the NSS signal can be helpful in this configuration to synchronize the data flow and it is used by default for some specific SPI modes (for example the TI mode).

The next optional RDY signal can help to ensure the correct management of all the transferred data at slave side.

Full-duplex communication

By default, the SPI is configured for full-duplex communication (bits COMM[1:0] = 00 in the SPI_CFG2 register). In this configuration, the shift registers of the master and slave are linked using two unidirectional lines between the MOSI and the MISO pins. During the SPI communication, the data are shifted synchronously on the SCK clock edges provided by the master. The master transmits the data to be sent to the slave via the MOSI line and receives data from the slave via the MISO line simultaneously. When the data frame transfer is complete (all the bits are shifted) the information between the master and slave is exchanged.

Figure 865. Full-duplex single master/ single slave application

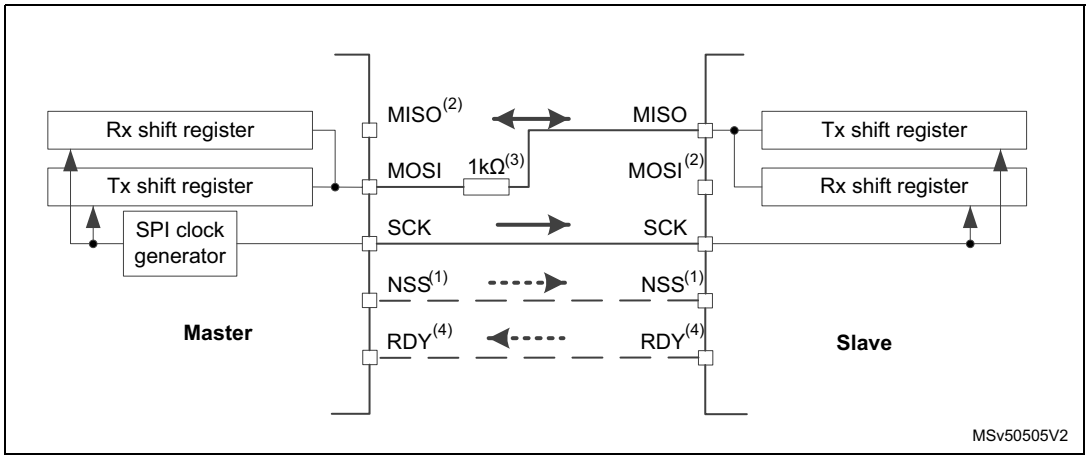


1. The NSS pin interconnection is optional. The slave can be configured to be permanently selected to operate in a single master-slave pair (see *Section 63.4.7*).
2. The RDY signal provided by the slave can be read by the master optionally.

Half-duplex communication

The SPI can communicate in half-duplex mode by setting COMM[1:0] = 11 in the SPI_CFG2 register. In this configuration, one single cross-connection line is used to link the shift registers of the master and slave together. During this communication, the data are synchronously shifted between the shift registers on the SCK clock edge in the transfer direction selected reciprocally by both master and slave with the HDDIR bit in their SPI_CR1 registers. Note that the SPI must be disabled when changing the direction of the communication. In this configuration, the MISO pin at master and the MOSI pin at slave are free for other application uses and act as GPIOs.

Figure 866. Half-duplex single master/ single slave application



1. The NSS pin interconnection is optional. The slave can be configured to be permanently selected to operate in a single master-slave pair (see *Section 63.4.7*).
2. In this configuration, the MISO pin at master and MOSI pin at slave can be used as GPIOs
3. A critical situation can happen when the communication direction is not changed synchronously between two nodes working in bidirectional mode. The new transmitter accesses the common data line while the former transmitter still keeps an opposite value on the line (the value depends on the SPI configuration and communicated data). The nodes can conflict temporarily with opposite output levels on the line until the former transmitter changes its data direction setting. It is suggested to insert a serial resistance between MISO and MOSI pins in this mode to protect the conflicting outputs and limit the current flow between them.
4. The RDY signal provided by the slave can be read by the master optionally.

Simplex communications

The SPI can communicate in simplex mode by setting the SPI in transmit-only or in receive-only using the COMM[1:0] field in the SPI_CFG2 register. In this configuration, only one line is used for the transfer between the shift registers of the master and slave. The remaining MISO or MOSI pin pair is not used for communication and can be used as standard GPIOs.

- **Transmit-only mode: COMM[1:0] = 01**

  The master in transmit-only mode generates the clock as long as there are data available in the TxFIFO and the master transfer is ongoing.

  The slave in transmit-only mode sends data as long as it receives a clock on the SCK pin and the NSS pin (or software managed internal signal) is active (see *Section 63.4.7*).

- **Receive-only mode: COMM[1:0] = 10**

  In master mode, the MOSI output is disabled and can be used as a GPIO. The clock signal is generated continuously as long as the SPI is enabled and the CSTART bit in the SPI_CR1 register is set. The clock is stopped either by software explicitly requesting this by setting the CSUSP bit in the SPI_CR1 register or automatically when the RxFIFO is full, when the MASRX bit in the SPI_CR1 is set.

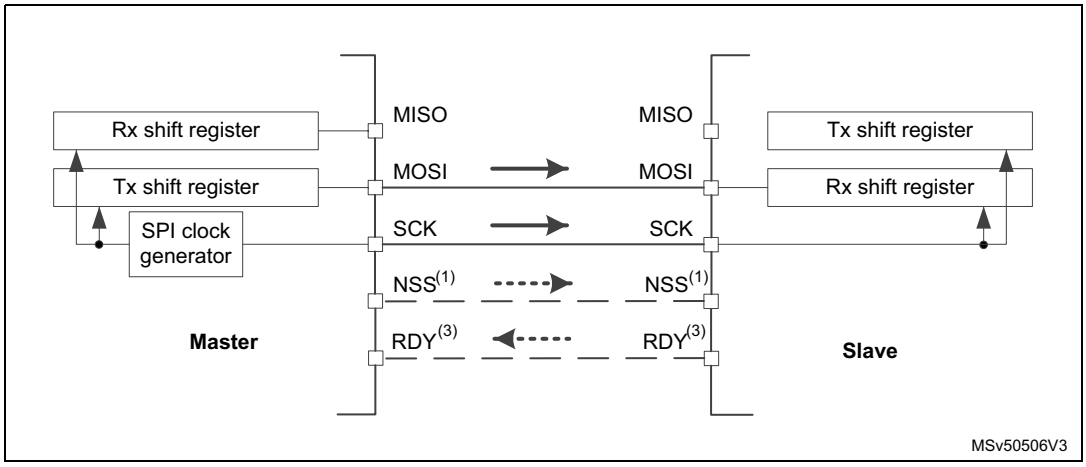
  In slave configuration, the MISO output is disabled and the pin can be used as a GPIO. The slave continues to receive data from the MOSI pin while its slave select signal is active (see *Section 63.4.7*).

Note: In whatever master and slave modes, the data pin dedicated for transmission can be replaced by the data pin dedicated for reception and vice versa by changing the IOSWP bit value in the SPI_CFG2 register (this bit can only be modified when the SPI is disabled).

Any simplex communication can be replaced by a variant of the half-duplex communication with a constant setting of the transfer direction (bidirectional mode is enabled, while the

HDDIR bit is never changed) or by full-duplex control when unused data line and corresponding data flow is ignored.

Figure 867. Simplex single master / single slave application (master in transmit-only / slave in receive-only mode)



1. The NSS pin interconnection is optional. The slave can be configured to be permanently selected to operate in a single master-slave pair (see *Section 63.4.7*).
2. In this configuration, both the MISO pins can be used as GPIOs.
3. The RDY signal provided by the slave can be read by the master optionally.

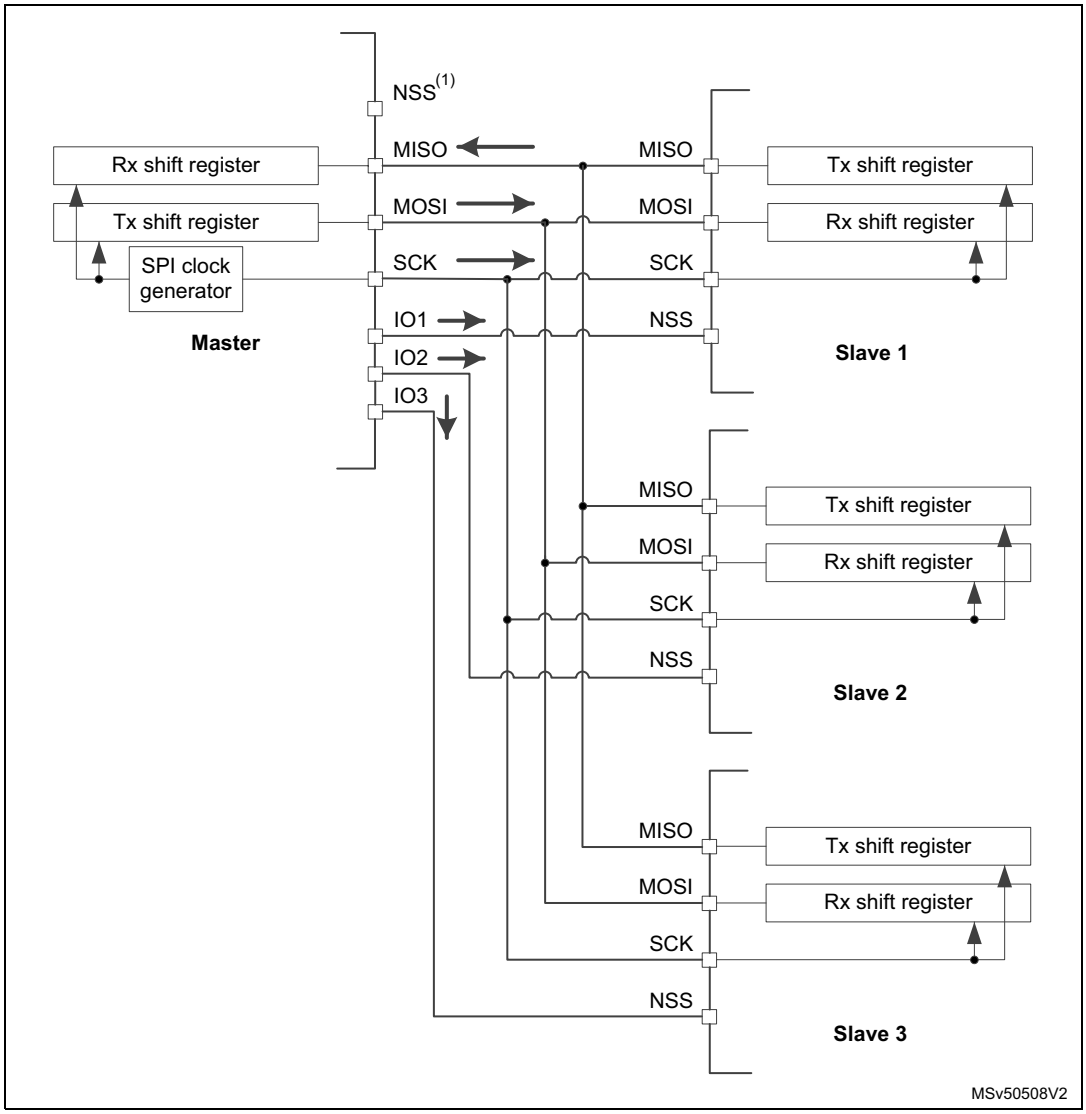
63.4.5 Standard multislave communication

In a configuration with two or more independent slaves, the master uses a star topology with dedicated GPIO pins to manage the chip select lines for each slave separately (see *Figure 868.*).

The master must select one of the slaves individually by pulling low the GPIO connected to the slave NSS input (only one slave can control data on a common MISO line at a given time).

When this is done, a communication between the master and the selected slave is established. In addition to the simplicity, the advantage of this topology is that a specific SPI configuration can be applied for each slave as all the communication sessions are performed separately just within a single master-slave pair. Optionally, when there is no need to read any information from slaves, the master can transmit the same information to the multiple slaves.

Figure 868. Master and three independent slaves connected in star topology



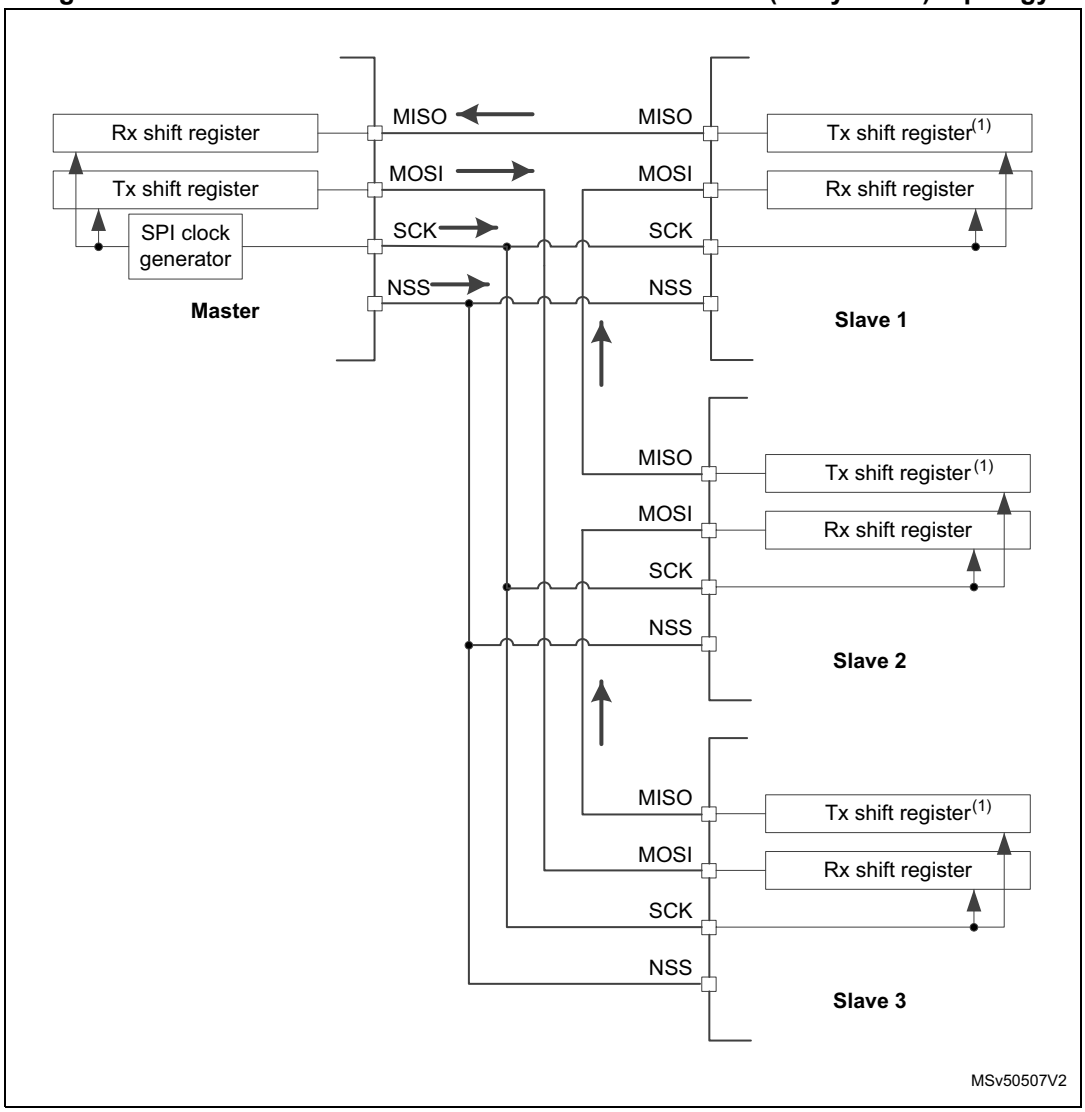
1. The master single NSS pin hardware output functionality cannot support this topology (to be replaced by a set of GPIOs under software control). The NSS pin is free for other application uses (such as GPIO or other alternate functions). Refer to *Section 63.4.7* for details.
2. If the application cannot ensure that no more than a single NSS active signal is provided by the master at a given time, it is better to configure the MISO pins in an open-drain configuration with an external pull-up on the MISO line to prevent conflicts between the interconnected outputs of the slaves. Else, a push-pull configuration can be applied without an extra resistor (see I/O alternate function input/output (GPIO) section).
3. The RDY signals can be read by the master from the slaves optionally.

The master can handle the SPI communication with all the slaves at the same time when a circular topology is applied (see *Figure 869*). All the slaves behave like simple shift registers applied in serial chain under control of common slave select (NSS) and clock (SCK) signals. All the information is shifted simultaneously around the circle while returning back to the master. Sessions have fixed the length where the number of data frames transferred by the master is equal to the number of slaves.

Then when a first data frame is transferred in the chain, the master just sends the information dedicated for the last slave node in the chain, via the first slave node input, while the first information received by the master comes from the last node output at this time.

Correspondingly, the last transferred data finishing the session is dedicated for the first slave node while its first outgoing data just reaches the master input, after its circling around the chain passing through all the other slaves during the session.
The data format configuration and clock setting must be the same for all the nodes in the chain in this topology. As the receive and transmit shift registers are separated internally, a trick with intentional underrun must be applied to the TxFIFO slaves when the information is transferred between the receiver and the transmitter by hardware.
In this case, the transmission underrun feature is configured in a mode repeating the last received data frame (UDRCFG=1). A session can start optionally with a single data pattern written into the TxFIFO by each slave (usually slave status information is applied) before the session starts. In this case, the underrun happens in fact after this first data frame is transferred. To be able to clear the internal underrun condition immediately and restart the session by the TxFIFO content again, the user must disable and enable the SPI between the sessions and must fill the TxFIFO by a new single data pattern (to overcome the propagating delay of the clearing raised in case the underrun is cleared in a standard way by the UDRC bit).

Figure 869. Master and three slaves connected in circular (daisy chain) topology



1. The underrun feature is used by the slaves in this configuration when the slaves are able to transmit data received previously into the Rx shift register once their TxFIFOs become empty.
2. The RDY signals can be read by the master optionally, either separately or configured as open drain outputs (while RDIOP = 0) and connected with a pull-up resistor as a common chain ready status overdriven by the slowest device.

63.4.6 Multimaster communication

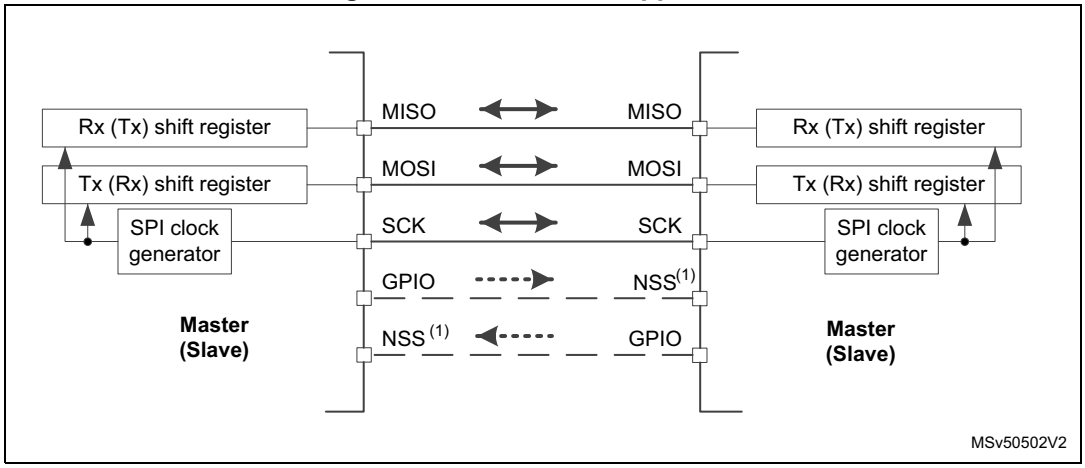
Unless the SPI bus is not designed primarily for a multimaster capability, the user can use a built-in feature that detects a potential conflict between two nodes trying to master the bus at the same time. For this detection, the NSS pin is configured in hardware input mode. The connection of more than two SPI nodes working in this mode is impossible, as only one node can apply its output on a common data line at a given time.

When the nodes are not active, both stay in slave mode by default. Once a node wants to overtake control on the bus, it switches itself into master mode and applies active level on the slave select input of the other node via the dedicated GPIO pin. After the session is

complete, the active slave select signal is released and the node mastering the bus temporarily returns back to passive slave mode waiting for the next session to start.

If both nodes raise their mastering request at the same time, a bus conflict event appears (see mode fault MODF event). The user can apply some simple arbitration process (for example postpone the next attempt by different predefined timeouts applied to both nodes).

Figure 870. Multimaster application



1. The NSS pin is configured at hardware input mode at both nodes. Its active level enables the MISO line output control since the passive node is configured as a slave.
2. The RDY signal is not used in this communication.

63.4.7 Slave select (NSS pin) management

In slave mode, the NSS works as a standard ‘chip select’ input and lets the slave communicate with the master. In master mode, the NSS can be used either as an output or an input. As an input it can prevent a multimaster bus collision, and as an output it can drive a slave select signal of a single slave. The NSS signal can be managed internally (software management of the NSS input) or externally when both the NSS input and output are associated with the NSS pin (hardware slave select management). The user can configure which level of this input/output external signal (present on the NSS pin) is considered as active by the SSIOP bit setting. NSS level is considered as active if it is equal to SSIOP.

The hardware or software slave select management can be set using the SSM bit in the SPI_CFG2 register:

- **Software slave select management (SSM = 1)**: in this configuration, slave select information is driven internally by the SSI bit value in the SPI_CR1 register. The external NSS pin is free for other application uses (such as GPIO or other alternate functions).
- **Hardware slave select management (SSM = 0)**: in this case, there are two possible configurations. The configuration used depends on the NSS output configuration (SSOE bit in the SPI_CFG2 register).
  - **NSS output enable (SSOE = 1)**: this configuration is only used when the MCU is set as master. The NSS pin is managed by the hardware. The functionality is tied to CSTART and EOT control. As a consequence, the master must apply the proper TSIZE > 0 setting to control the NSS output correctly. Even if SPI AF is not applied at the NSS pin (it can be used as a standard GPIO then), keep anyway SSOE = 1 to ensure the default NSS input level and prevent any mode fault

evaluation at the input of the master NSS internal logic applicable at a multimaster topology exclusively.

a) When SSOM = 0 and SP = 000, the NSS signal is driven to the active level as soon as the master transfer starts (CSTART = 1) and it is kept active until its EOT flag is set or the transmission is suspended.

b) When SP = 001, a pulse is generated as defined by the TI mode.

c) When SSOM = 1, SP = 000 and MIDI > 1 the NSS is pulsed inactive between data frames, and kept inactive for a number of SPI clock periods defined by the MIDI value decremented by one (from 1 to 14).

d) NSS input is forced to nonactive state internally at master to prevent any mode fault.

– **NSS output disable (SSM = 0, SSOE = 0)**:

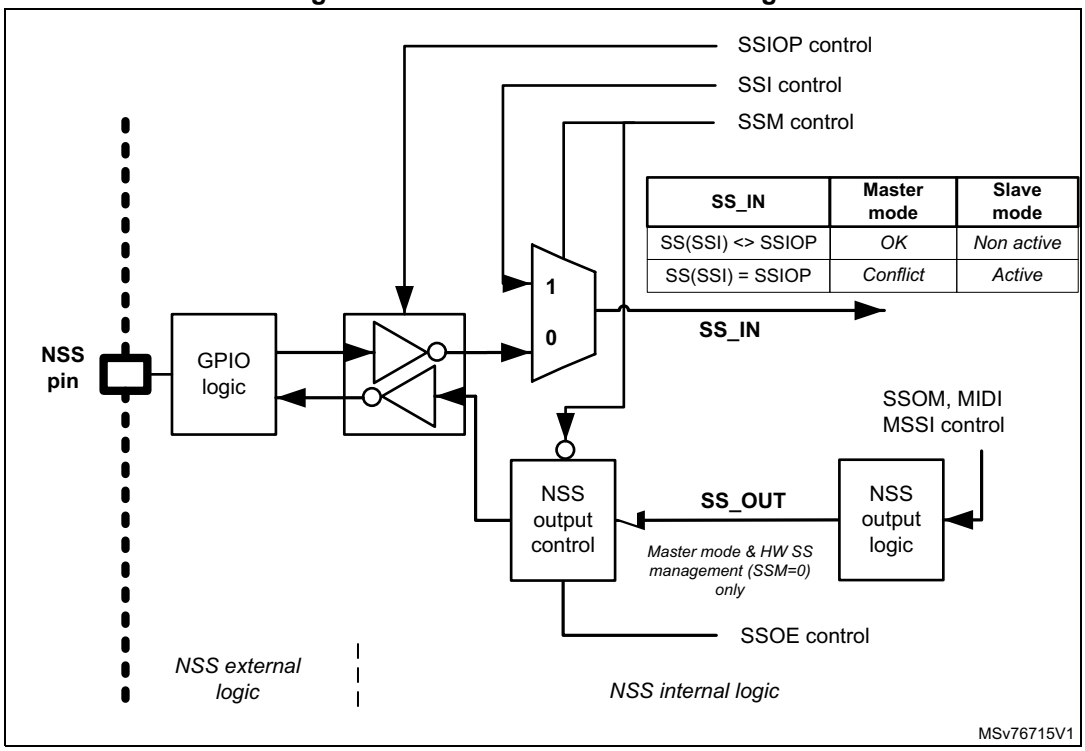
a) If the microcontroller is acting as the master on the bus, this configuration allows multimaster capability. If the NSS pin is pulled into an active level in this mode, the SPI enters master mode fault state and the SPI device is automatically reconfigured in slave mode (MASTER = 0).

b) In slave mode, the NSS pin works as a standard ‘chip select’ input and the slave is selected while the NSS line is at its active level.

Note: The purpose of automatic switching into slave mode when a mode fault occurs is to avoid the possible conflicts on data and clock lines. As the SPE is automatically reset in this condition, both Rx and Tx FIFOs are flushed and current data is lost.

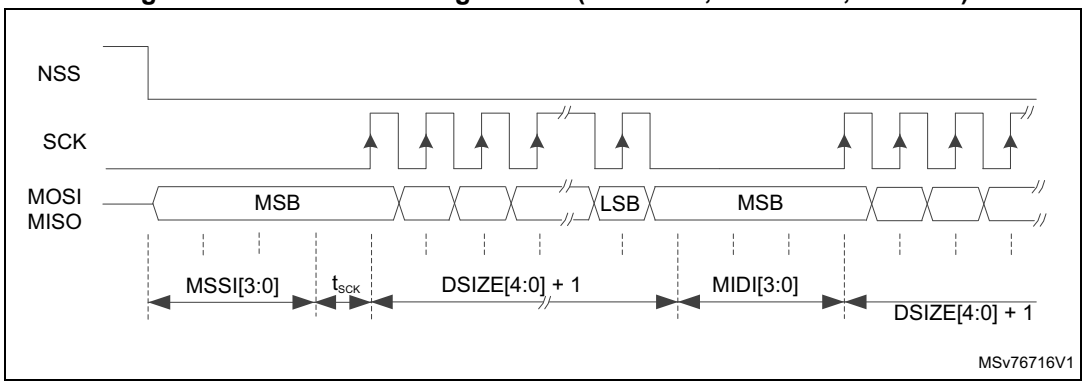
When the SPI slave is enabled in the hardware slave select management mode, all the transfers are ignored even in case of the NSS is found at active level. They are ignored until the slave detects a start of the NSS signal (transition from nonactive to active level) just synchronizing the slave with the master. This is because the hardware management mode cannot be used when the external NSS pin is fixed. There is no such protection in the slave select software management. Then the SSI bit must be changed when there is no traffic on the bus and the SCK signal is in idle state level between transfers exclusively in this case.

Figure 871. Scheme of NSS control logic



When the hardware output NSS control is applied (SSM = 0, SSOE = 1), by configuration of the MIDI[3:0] and MSSI[3:0] bitfields, the user can control the timing of the NSS signal between data frames and can insert an extra delay at the beginning of every transfer (to separate the NSS and clock starts). This can be useful when the slave needs to slow down the flow to obtain sufficient room for correct data handling (see *Figure 872*).

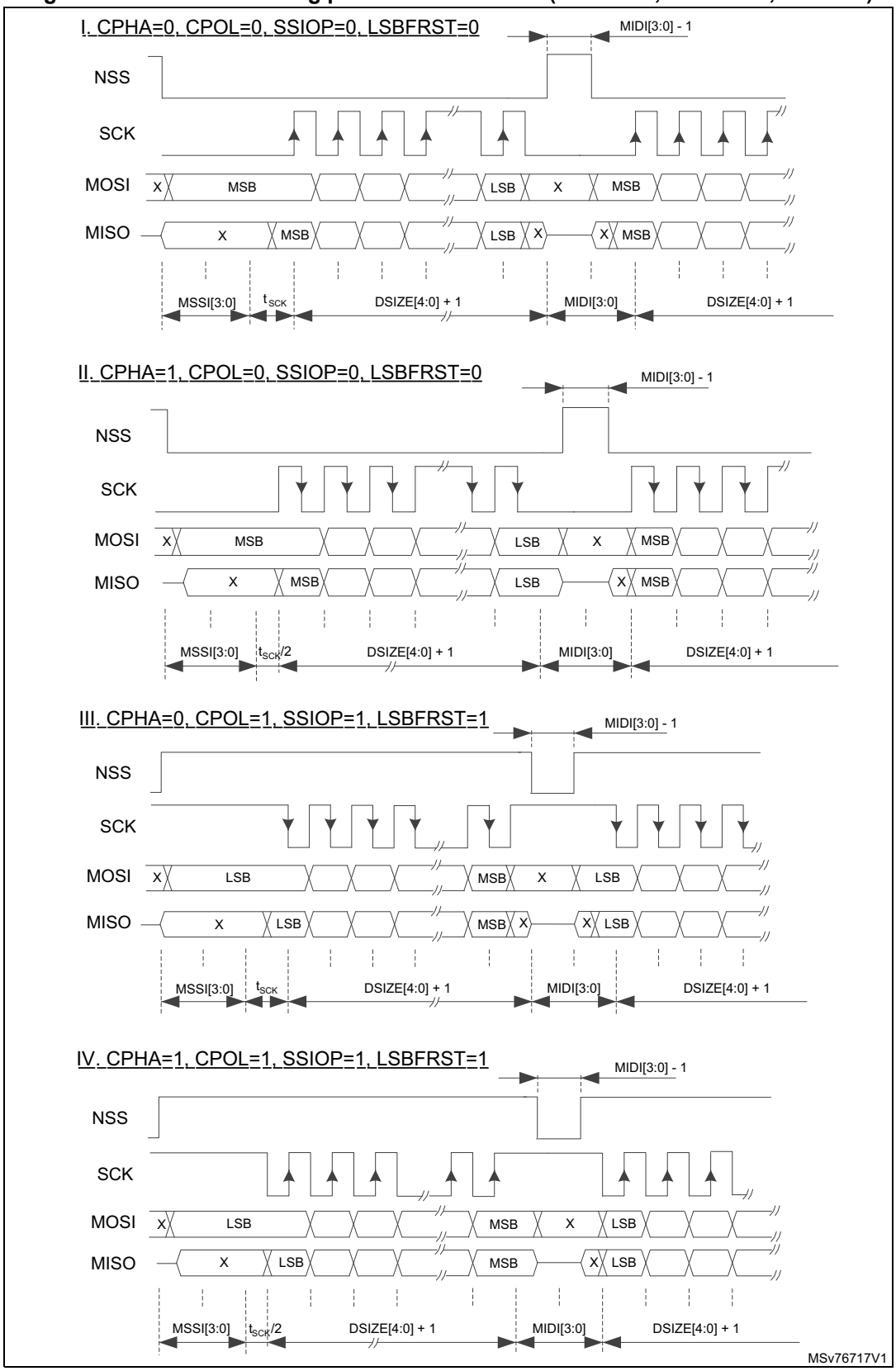
Figure 872. Data flow timing control (SSOE = 1, SSOM = 0, SSM = 0)



1. MSSI[3:0] = 0011, MIDI[3:0] = 0011 (SCK flow is continuous when MIDI[3:0] = 0).
2. CPHA = 0, CPOL = 0, SSIOP = 0, LSBFRST = 0.

Additionally, setting the SSOM bit invokes a specific mode, which interleaves pulses between data frames if there is a sufficient space to provide them (MIDI[3:0] must be set greater than one SPI period). Some configuration examples are shown in *Figure 873*.

Figure 873. NSS interleaving pulses between data (SSOE = 1, SSOM = 1, SSM = 0)



1. MSSI[3:0] = 0010, MIDI[3:0] = 0010.
2. NSS interleaves between data when MIDI[3:0] > 1 wide of the interleaving pulse is always one SCK period less than the gap provided between the frames (defined by the MIDI parameter). If MIDI is set, the frames are separated by a single SCK period but no interleaving pulse appears on NSS.

63.4.8 Ready pin (RDY) management

The status of the slave capability to handle data can be checked on the RDY pin. By default, a low level indicates that the slave is not ready for transfer. The reason can be that the slave TxFIFO is empty, RxFIFO full or the SPI is disabled. An active level of the signal can be selected by the RDIOP bit. If the master continues or starts to communicate with the slave when it indicates a not ready status, it is highly probable that the transfer fails.

The logic to control the RDY output is rather complex, tied closely with the TSIZE and DSIZE settings. The RDY reaction is more pessimistic and sensitive to TxFIFO becoming nearly empty and/or RxFIFO nearly full during a frame transfer. This pessimistic logic is suppressed at the end of a transfer only when RDY stays active, despite TxFIFO becomes fully empty and/or RxFIFO becomes fully occupied. The target is to prevent any data corruption and inform the master in time that it is necessary to suspend the transfer temporarily until the next transferred data can be processed safely again. When the RDY signal input is enabled at master side, the master suspends the communication once the slave indicates not ready status. This prevents the master to complete the transfer of an ongoing frame, which just empties the slave TxFIFO or full fills its RxFIFO until a next data is written and/or read there (despite the frame still can be completed without any constraint). It can make a problem if the TSIZE = 0 configuration is applied at slave because slave then never evaluates the end of the transfer (which suppresses the not ready status just when the last data is sent). Then the user has to release the RxFIFO and/or write additional (even dummy) data to TxFIFO by software at slave side to release the not RDY signal, unblock ST master and so enable it to continue at the communication suspended at middle of a frame occasionally.

When RDY is not used by the master, it must be disabled (RDIOM = 0). Then an internal logic of the master simulates the slave status always ready. In this case, the RDIOP bit setting has no meaning.

Due to synchronization between clock domains and evaluation of the RDY logic on both master and slave sides, the RDY pin feature is not reliable and cannot be used when the size of data frames is configured shorter than 8 bits.

63.4.9 Communication formats

During SPI communication, receive and transmit operations are performed simultaneously. The serial clock (SCK) synchronizes the shifting and sampling of the information on the data lines. The communication format depends on the clock phase, the clock polarity, and the data frame format. To be able to communicate together, the master and slave devices must follow the same communication format and be synchronized correctly.

Clock phase and polarity controls

Four possible timing relationships can be chosen by software, using the CPOL and CPHA bits in the SPI_CFG2 register. The CPOL (clock polarity) bit controls the idle state value of the clock when no data is being transferred. This bit affects both master and slave modes. If CPOL is reset, the SCK pin has a low-level idle state. If CPOL is set, the SCK pin has a high-level idle state.

If the CPHA bit is set, the second edge on the SCK pin captures the first data bit transferred (falling edge if the CPOL bit is reset, rising edge if the CPOL bit is set). Data are latched on each occurrence of this clock transition type. If the CPHA bit is reset, the first edge on the SCK pin captures the first data bit transferred (falling edge if the CPOL bit is set, rising edge if the CPOL bit is reset). Data are latched on each occurrence of this clock transition type.

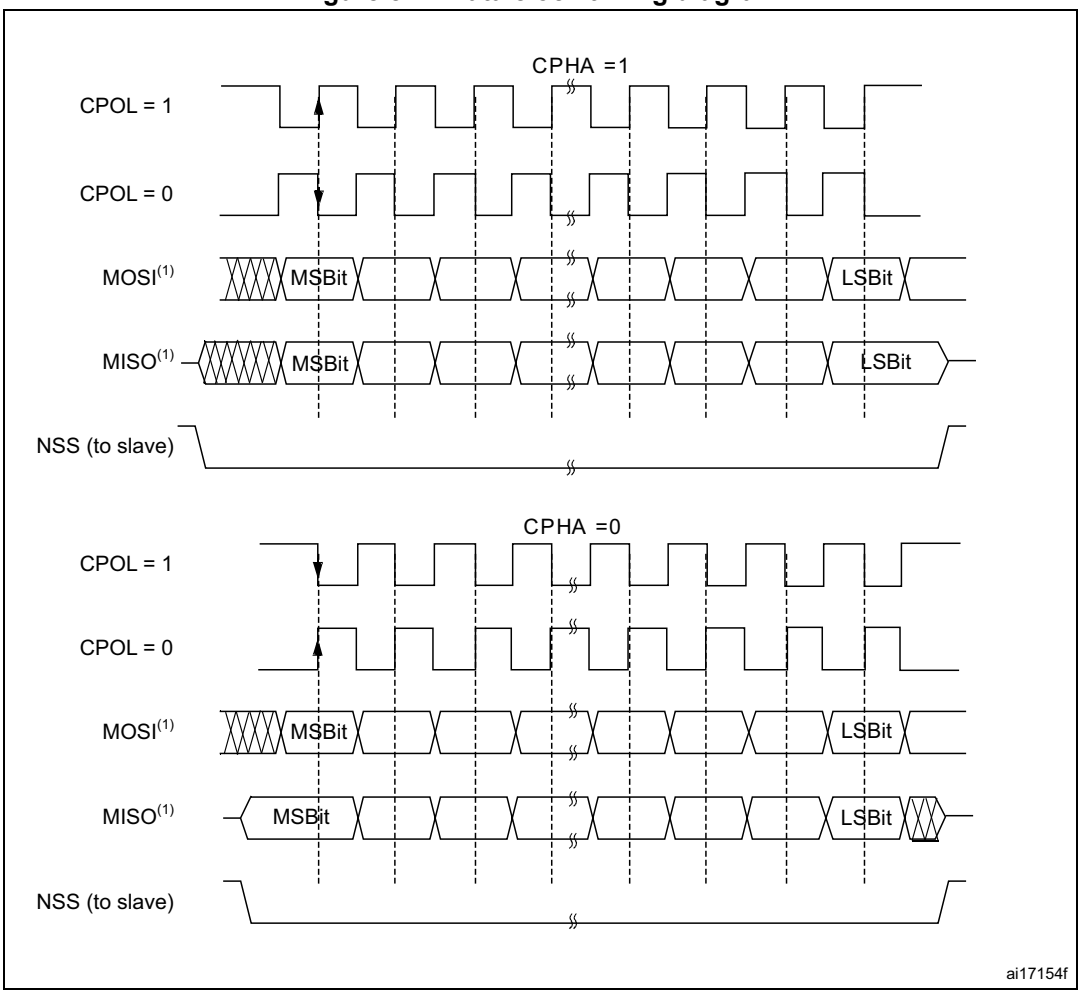
The combination of the CPOL (clock polarity) and CPHA (clock phase) bits selects the data capture clock edges (dotted lines in *Figure 874*).

Figure 874 shows an SPI full-duplex transfer with the four combinations of the CPHA and CPOL bits.

Note: Prior to changing the CPOL/CPHA bits the SPI must be disabled by resetting the SPE bit.

The idle state of SCK must correspond to the polarity selected in the SPI_CFG2 register (by pulling the SCK pin up if CPOL = 1 or pulling it down if CPOL = 0).

Figure 874. Data clock timing diagram



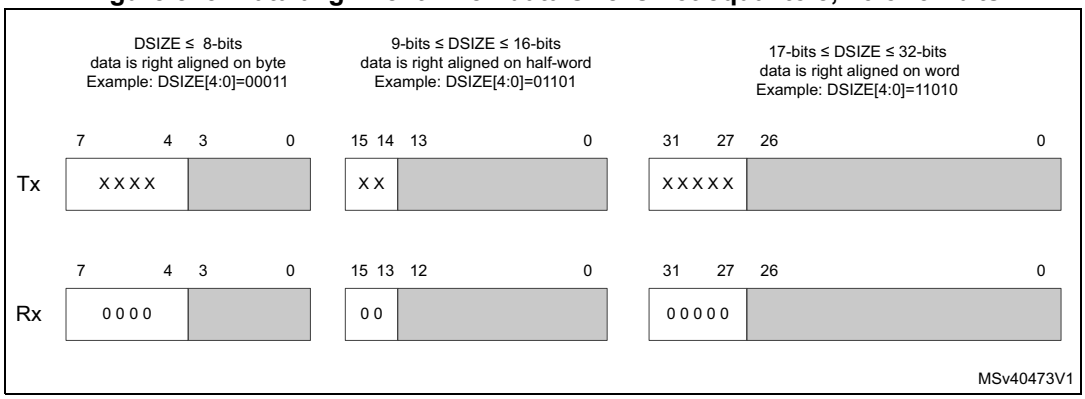
1. The order of data bits depends on the LSBFRST bit setting.
2. The input data sampling can be postponed by a half SCK cycle on the master MISO input (refer to the description of the DRDS bit of the SPI_CFG1 register).

Data frame format

The SPI shift register can be set up to shift out MSB-first or LSB-first, depending on the value of the LSBFRST bit of the SPI_CFG2 register.

The data frame size is configured through the DSIZE bitfield of the SPI_CFG1 register to a range that depends on the SPI instance (see *Section 63.3: SPI implementation*). The setting applies to both transmission and reception. The data bits in the SPI_TXDR/SPI_RXDR registers are right-aligned with 8, 16, or 32 bits, depending on the data size (see *Figure 875*). These registers can consequently be accessed by bytes, half-words, or words. FIFO accesses smaller than a single data are forbidden. When the FIFO occupancy flag is raised, a FIFO access greater than the FIFO threshold can lead to spurious data being read or written data being lost. When the access to/from the SPI_TXDR/SPI_RXDR registers is a multiple of the configured data size, data packing is applied automatically, while the lowest significant bits/bytes are communicated first. For more details, see *Section 63.4.12: SPI data transmission and reception procedures*.

Figure 875. Data alignment when data size is not equal to 8, 16 or 32 bits



63.4.10 Configuring the SPI

The configuration procedure is almost the same for the master and the slave. For specific mode setups, follow the dedicated chapters. When a standard communication must be initialized, perform these steps:

1. Write the proper GPIO registers: configure GPIO alternate functions at MOSI, MISO, SCK, NSS, and RDY pins if applied.
2. Write into the SPI_CFG1 and SPI_CFG2 registers and set up the proper values of all ‘not reserved’ bits and bitfields, prior to enabling the SPI, with the following exceptions:
   a) The SSOM, MASRX, SSOE, RDIOM, MBR[2:0], BPASS, MIDI[3:0], MSSI[3:0] bits are taken into account in master mode only, the MSSI[3:0] bits take effect when the SSOE bit is set, the RDIOP bit takes no effect when the RDIOM bit is not set in master mode. When the slave is configured in TI mode, the MBR[2:0] setting is also considered.
   b) UDRCFG is taken into account in slave mode only.
   c) CRCSIZE[4:0] bitfield must be configured if CRCEN is set.
   d) CPOL, CPHA, LSBFRST, SSOM, SSOE, SSIOP, SSM, RDIOP, RDIOM, MSSI, and MIDI are not required in TI mode.

e) Once the AFCNTR bit is set in the SPI_CFG2 register, all the SPI outputs start to be propagated onto the associated GPIO pins regardless of the peripheral enable. So, any later configuration changes of the SPI_CFG1 and SPI_CFG2 registers can affect the level of signals on these pins.

3. Write to the SPI_CR2 register to select the length of the transfer, if it is not known TSIZE must be programmed to zero.
4. Write to the SPI_CRCPOLY and into the TCRCINI, RCRCINI, and CRC33_17 bits of the SPI_CR1 register to configure the CRC polynomial and CRC calculation if needed.
5. Configure DMA streams dedicated for the SPI Tx and Rx in DMA registers if the DMA streams are used (see *Section 63.4.14: Communication using DMA (direct memory addressing)*).
6. Configure SSI, HDDIR, and MASRX in the SPI_CR1 register if required.
7. Program the IOLOCK bit in the SPI_CR1 register if the configuration protection is required (for safety).

63.4.11 Enabling the SPI

It is recommended to configure and enable the SPI slave before the master sends the clock. But there is no impact if the configuration and enabling procedure is done while traffic is ongoing on the bus, assuming that the NSS signal is managed by hardware at slave or kept inactive by the slave software when the software management of the NSS signal is applied (see *Section 63.4.7*). To prevent any risk of any data underrun, all the data to be sent have to be written to the slave transmitter data register before the master starts its clocking. The SCK signal must be settled to the idle state level corresponding to the selected polarity, before the SPI slave is selected by NSS, else the following transfer may be desynchronized.

When the SPI slave is enabled at the hardware slave select management mode, all the transfers are ignored even in case of the NSS is found at active level. They are ignored until the slave detects a start of the NSS signal (its transition from nonactive to active level) just synchronizing the slave with the master. That is why the hardware management mode cannot be used when the external NSS pin is fixed. There is no such protection at the slave select software management. In this case, the SSI bit must be changed when there is no traffic on the bus and the SCK signal is at idle state level between transfers exclusively in this case.

The master in full duplex (or in any transmit-only mode) starts to communicate when the SPI is enabled, the CSTART bit is set, and the TxFIFO is not empty, or with the next write to TxFIFO.

In any master receive-only mode, the master starts to communicate and the clock starts running after the SPI is enabled and the CSTART bit is set.

For handling DMA, see *Section 63.4.14*.

63.4.12 SPI data transmission and reception procedures

The SPI can transfer data at a very high communication speed. Even though the data is FIFO buffered, handling a continuous data flow by servicing data frames individually leads to an enormous CPU or DMA load, in particular when the data size is small. This potentially leads to a significant limitation of the overall system performance, as well as communication errors such as data overrun or underrun that may be raised when the system latencies in servicing requests become comparable to single data frame transfer time.

The SPI offers advanced hardware control features to prevent these issues from occurring:

- Decreasing the number of events requiring service by collecting the data frames into larger **data packets**

  The number of data frames per packet (FIFO threshold) can be configured. The complete data packet generates a FIFO occupancy event, which is then handled within a single, compact, service.
- Decreasing the number of CPU execution cycles required for the service, by applying the appropriate **data access**:
  - The widest access to the SPI data registers must be applied. This allows cumulative data to be handled by a single register read or write operation (data packing).
  - The number of read/write accesses necessary to complete the data packet must be aligned with the data frame size and the FIFO threshold.
- **Concurrent read and write services** to handle full-duplex data flow based on common FIFO occupancy events.
- Embedded **hardware data counters** to define the exact number of data involved in transfers.

Note: Using these features is optional. Nothing prevents the application from handling the data flow frame by frame.

The following sections give more details and describe specific cases for using these advanced hardware control features to handle data transfers.

Data packet control

The data frame size (number of bits in the frame) is defined through the DSIZE bitfield of the SPI_CFG1 register. The number of data frames per packet can be configured by selecting the FIFO threshold through the FTHLV bitfield of the SPI_CFG1 register. If the threshold value is set to zero, each completed data frame raises the FIFO occupancy event. The data packet occupancy must not exceed half of the FIFO size, which depends on the SPI instance of the product. The FIFO capacity (multiple of 8 bits) is consumed according to the following rules, depending on the data frame size:

- Data frames from 4 to 8 bits occupy one byte of the FIFO.
- Data frames from 9 to 16 bits occupy two bytes of the FIFO.
- Data frames from 17 to 24 bits occupy three bytes of the FIFO.
- Data frames from 25 to 32 bits occupy four bytes of the FIFO.

For example, if the FIFO capacity is 16 bytes, it accommodates up to five 24-bit frames. In this case, the data packet configuration must not exceed two data frames.

The SPI features two separate FIFOs to handle the reception and transmission data flow, the RxFIFO, and the TxFIFO. Their content can be handled by monitoring the occupancy

flags RXP, TXP, and DXP of the SPI_SR register according to the SPI mode (duplex or simplex):

- If RXP is set, at least one complete data packet can be read from the RxFIFO.
- If TXP is set, at least one complete data packet can be written to the TxFIFO.
- If DXP is set, at least one complete data packet can be read from the RxFIFO and written to the TxFIFO at full-duplex mode.

These flags can be polled by software, or they can trigger an interrupt and/or a DMA request (if enabled through the RXPIE, TXPIE, and DXPIE bits of the SPI_EIR register or the RXDMAEN and TXDMAEN bits of the SPI_CFG1 register).

Once an occupancy flag is set, the software or the DMA must read and/or write a complete data packet before checking the flag again to verify if the next packet can be handled. This cycle can be repeated until the corresponding flag is read at zero.
Both RxFIFO and TxFIFO contents are flushed and cannot be accessed when the SPI is disabled (SPE cleared in the SPI_CR1 register).

Data packing versus data register access control

The content of the RxFIFO and TxFIFO can be accessed by reading/writing from/to the SPI data registers SPI_RXDR and SPI_TXDR, respectively. A read access from the SPI_RXDR register returns the oldest values stored in the RxFIFO that have not been read yet. A write access to the SPI_TXDR register stores the data written at the end of the send queue in the TxFIFO.

These data registers can be accessed by 8-, 16-, or 32-bit read and write CPU instructions, forced by the register address casting applied by the software. Data packing is performed automatically by hardware if the data access applied by the software is a multiple of the data size. It allows handling more than one data in parallel in a single data register access. Then the SPI operates using the lowest significant byte or half-word first. FIFO data accesses of less than the configured data size are forbidden. To avoid spurious data being read or written data being lost, a complete data packet (configured through the FIFO threshold) must be serviced when the corresponding FIFO occupancy flag is set. If the data pattern is not byte-, half-word, or word-aligned, only the valid data bits are stored right-aligned to the FIFO and transferred on the bus. Unused bits are discarded on the transmitter side and padded with zeros on the receiver side.

For example, if the data frame size fits into one byte, the data packing is used automatically when a 16-bit or 32-bit read/write access is performed by software from/to the SPI_RXDR/SPI_TXDR register. In this case, two respectively four data are handled by a single 16-bit respectively 32-bit access. Additionally, if such data frames are grouped into packets of four via the FIFO threshold setting, the packet to be serviced is signalized by raising the corresponding FIFO occupancy flag (TXP, RXP, or DXP). If the instance FIFO threshold is sufficient, a packet containing eight 8-bit data frames can be handled by two consecutive 32-bit accesses upon the same single threshold event. The most efficient data handling is achieved when the data packet size (defined by DSIZE and FTHLV bitfields) is aligned with the read/write access from/to the data registers.

Concurrent read and write services

In full-duplex mode, both TxFIFO and RxFIFO packet occupancies can be monitored through a common FIFO flag (DXP). When the DXP flag is set, the application performs the specified number of writes to SPI_TXDR to upload the content of one entire data packet for transmission, followed by the same number of reads from SPI_RXDR to download the

content of one received data packet. Once one data packet is uploaded and one packet is downloaded, the application software or the DMA checks again the DXP flag and repeats the data packet read and write operation sequence until DXP is read as zero.

The drawback of services based on DXP exclusively is that servicing the TxFIFO is delayed on purpose due to the SPI nature since the TXP events precedes the RXP ones. To allow continuous SCK clock flow on the master side and prevent underrun on the slave side, it is recommended to prefill a few data ahead to the TxFIFO at the transfer start, and wait until the transfer is complete to read the last received data.

Hardware data counter

If a hardware data counter is used (TSIZE bitfield of the SPI_CR2 register set to a nonzero value), the application software does not need to calculate the remaining number of data to be handled. The end of transfer automatically controls the CRC, as well as the hardware slave select management, when used. The user application does not need to ensure that the overall number of data is a multiple of the packet size. If the last data packet is incomplete, it is serviced in the same way as any full packet. The unused part of this last packet is not handled by the peripheral. Only the valid data are written into the TxFIFO and/or read from the RxFIFO, and the redundant writes and reads are discarded. When the hardware counter reaches zero, the EOT flag is raised, and the RXP flag is not set for the last data packet. If the last packet is not aligned with the packet size, the TXP and EOT occupancy events are not related to the configured packet size but to the number of remaining data calculated by hardware.

If TSIZE is kept at zero (for example due to an unpredictable number of data), only the number of transferred data corresponding to the FIFO thresholds is supported. If some data are not aligned with the configured packet size, they may remain pending and available in the RxFIFO. In this case, the FTHLV level is not reached and the RXP flag is not set. Then the number of remaining received data frames in the RxFIFO is indicated by the RXWNE and RXPLVL bitfields of the SPI_SR register. Nevertheless, the application software can still read the complete data packet from the RxFIFO and the redundant data are read as zero. To prevent such an unaligned data reception, the user must configure the FIFO threshold to a single data (FTHLV = 0). In this case, each data frame is serviced by its own RXP occupancy event.

Data transfer handling

Data are transferred using MOSI and MISO lines, depending on the SPI communication mode and associated configuration. The mode is configured through the COMM[1:0] bitfield of the SPI_CFG2 register. The HDDIR bit of the SPI_CR1 register controls the data flow direction in half-duplex mode. The communication flow is handled by the master via the NSS and SCK signals. The slave selected for the communication is fully subordinated to the master communication activity, no matter if it handles the data flow on time or not. The slave can only temporarily suspend the master communication by using the RDY signal. The active levels of RDY and NSS signals can be changed, or MISO and MOSI functionality swapped (via the RDIOP, SSIOP and IOSWP bits of the SPI_CFG2 register).

The SPI master transmitter can operate in full-duplex, simplex, or half-duplex mode. In full-duplex mode, data are received synchronously. The master starts the data transfer once the CSTART bit of the SPI_CR1 register is set, provided the SPI is enabled and the TxFIFO

content is not empty. The master then provides the serial clock signal continuously on the SCK pin until:

- The total number of required data programmed in TSIZE is transferred, or
- The transfer is suspended.

An automatic temporary suspension of the master transmission occurs when:

- The slave does not assert the RDY signal, if it is used, or
- The TxFIFO becomes empty, or
- In full-duplex mode, the RxFIFO becomes full while the automatic suspension is enabled (MASRX set in the SPI_CR1 register).

When an automatic suspension occurs, the master stops providing the clock, and the transfer proceeds depending on the cause of the suspension, when:

- The slave asserts RDY.
- The master software or the DMA writes additional data to TxFIFO.
- In full-duplex mode, the master software or the DMA releases the RxFIFO to enable it to accommodate new data.

The SPI master can receive data only when it operates in simplex receiver or half-duplex receiver mode. In these modes, the master starts the data transfer when the SPI is enabled, and the transfer is released by setting the CSTART bit. The serial clock signal is then provided continuously on the SCK pin by the master until:

- The total number of required data programmed in TSIZE is received, or
- The transfer is suspended by the master.

An automatic temporary suspension of the reception occurs when:

- The slave does not assert the RDY signal, if it is used, or
- The RxFIFO becomes full while the automatic suspension is enabled (MASRX bit set in the SPI_CR1 register).

When an automatic suspension occurs, the master stops providing the clock and the transfer proceeds depending on the cause of the suspension, when:

- The slave asserts RDY.
- The master software or the DMA releases the RxFIFO to enable it in order to accommodate new data.

A preferable way to terminate a transfer is to program the TSIZE bitfield to generate an EOT event. Hardware NSS signal or CRC handshake can then be controlled. To restart the internal state machine properly, it is recommended to disable the SPI and enable it again when the transfer is complete, even if the SPI configuration is not changed.

A transfer can be suspended at any time by setting the CSUSP bit of the SPI_CR1 register, which clears the CSTART bit. This software suspension control ensures the completion of any ongoing data frame. To restart the internal state machine properly, the SPI must be disabled and enabled again before the next transfer starts.

Oppositely, a temporary automatic suspension controlled by hardware typically results in a frozen and incomplete data frame transfer. This depends on baud rate setting, but usually, due to internal synchronization delays, the SCK signal stops when a few bits from the next data frame are already transferred on the bus. Once the suspension is released, the data frame transmission completes by transferring the remaining bits. That is why this automatic suspension is not quite reliable when the data frame size is less than eight bits. When shorter data frames are used, to prevent any data loss and assure proper RDY and/or

MASRX operation, the user can interleave and so extend the transfer time by inserting additional dummy clock cycles so that the period for a single data frame is higher or equal to eight SCK duration. This is done by setting the MIDI[3:0] bitfield of the SPI_CFG2 register.

Caution: If the SPE bit is cleared in master mode while the transfer is ongoing without any suspension, the clock is stopped even if the current frame transmission is not complete, and the content of the FIFOs is flushed and lost.

63.4.13 Disabling the SPI

To disable the SPI, it is mandatory to follow the disable procedures described in this paragraph.

In the master mode, it is important to do this before the system enters a low-power mode when the peripheral clock is stopped, otherwise, ongoing transfers may be corrupted.

In slave mode, the SPI communication can continue when the **spi_pclk** and **spi_ker_ck** clocks are stopped, without interruption, until any end of communication or data service request condition is reached. The **spi_pclk** can generally be stopped by setting the system into Stop mode. Refer to the RCC section for further information.

The master in full-duplex or transmit-only mode can finish any transfers when it stops providing data for transmission. In this case, the clock stops after the last data transfer. TXC flag can be polled (or interrupt enabled with EOTIE = 1) in order to wait for the last data frame to be sent.

When the master is in any receive-only mode, to stop the peripheral, the SPI communication must first be suspended, by setting the CSUSP bit.

The data received but not read remain stored in RxFIFO when the SPI is suspended.

After such a software suspension, SPI must always be disabled to restart the internal state machine properly.

When SPI is disabled, RxFIFO is flushed. To prevent losing unread data, the user must ensure that RxFIFO is empty when disabling the SPI, by reading all remaining data (as indicated by the RXP, RXWNE, and RXPLVL fields in the SPI_SR register).

The standard disable procedure is based on polling EOT and/or TXC status to check if a transmission session is (fully) completed. This check can be done in specific cases, too, when it is necessary to identify the end of ongoing transfers, for example:

- When the master handles the NSS signal by a GPIO not related to SPI (for example at case of multislave star topology) and it has to provide a proper end-of-NSS pulse for the slave, or
- When transfers from DMA or FIFO are completed while the last data frame or CRC frame transfer is still ongoing in the peripheral bus.

When TSIZE > 0, EOT and TXC signals are equal so polling of EOT is reliable at whatever SPI communication mode to check the end of the bus activity. When TSIZE = 0, the user has to check TXC, SUSP, or FIFO occupancy flags according to the applied SPI mode and the way of the data flow termination.

The correct disable procedure in master mode, except when receive-only mode is used, is:

1. Wait until TXC = 1 and/or EOT = 1 (no more data to transmit and last data frame sent). When CRC is used, it is sent automatically after the last data in the block is processed.

TXC/EOT is set when the CRC frame is complete in this case. When a transmission is suspended the software has to wait until the CSTART bit is cleared.

2. Read all RxFIFO data (until RXWNE = 0 and RXPLVL = 00).
3. Disable the SPI (SPE = 0).

The correct disable procedure for master receive-only modes is:

1. Wait on EOT or break the receive flow by suspending SPI (CSUSP = 1).
2. Wait until SUSP = 1 (the last data frame is processed) if the receive flow is suspended.
3. Read all RxFIFO data (until RXWNE = 0 and RXPLVL = 00).
4. Disable the SPI (SPE = 0).

In slave mode, any ongoing data are lost when disabling the SPI.

Controlling the I/Os

As soon as the SPI is disabled, the associated and enabled AF outputs can still be driven by the device depending on the AFCNTR bit of the SPI_CFG2 register. When active output control is applied (AFCNTR = 1) and SPI has just been disabled (SPE = 0), the enabled outputs associated with SPI control signals (like NSS and SCK at master and RDY at slave) can immediately toggle to inactive level (according to SSIOP and CPOL settings at master and RDIOP at slave respectively). Instead, the data line output (MOSI at master and MISO at slave) can immediately change its level depending on the actual TxFIFO content, with the effect of potentially making invalid and no more guaranteed the value of the latest transferred bit on the bus. If necessary, the user has to take care about proper data hold time at the data line and avoid any eventual fast SPI disable just after the last data transfer is complete.

Note: Despite stability of the latest bit is guaranteed by design during the sampling edge of the clock, some devices can require even extension of this data bit stability interval during the sampling. It can be done, for example by inserting a small software delay between EOT event occurrence and SPI disable action.

63.4.14 Communication using DMA (direct memory addressing)

To operate at its maximum speed and to facilitate the data register read/write process required to avoid overrun, the SPI features a DMA capability, which implements a simple request/acknowledge protocol.

A DMA access is requested when the TXDMAEN or RXDMAEN enable bits of the SPI_CFG1 register are set. Separate requests must be issued to the Tx and Rx buffers to fulfill the service of the defined packet.

- In transmission, a series of DMA requests is triggered each time TXP is set. The DMA then performs a series of writes to the SPI_TXDR register.
- In reception, a series of DMA requests is triggered each time RXP is set. The DMA then performs a series of reads from the SPI_RXDR register. When EOT is set at the end of the transfer and the last data packet is incomplete, then DMA request is activated automatically according to RXWNE and RXPLVL[1:0] setting to read the rest of data.

If the SPI is programmed in receive-only mode, UDR is never set.

If the SPI is programmed in a transmit mode, TXP and UDR can be eventually set at slave side, because transmit data may not be available. In this case, some data are sent on the TX line according with the UDR management selection.

When the SPI is used at a simplex mode, the user must enable the adequate DMA channel only while keeping the complementary unused channel disabled.

If the SPI is programmed in transmit-only mode, RXP and OVR are never set.

If the SPI is programmed in full-duplex mode, RXP and OVR are eventually set, because received data are not read.

In transmission mode, when the DMA or the user has written all the data to be transmitted (the TXTF flag is set in the SPI_SR register), the EOT (or TXC at case TSIZE = 0) flag can be monitored to ensure that the SPI communication is complete. This is required to avoid corrupting the last transmission before disabling the SPI or before disabling the **spi_pclk** in master mode. The software must first wait until EOT = 1 and/or TXC = 1.

When starting communication using DMA, to prevent DMA channel management raising error events, these steps must be followed in order:

1. Enable the DMA Rx buffer in the RXDMAEN bit of the SPI_CFG1 register, if DMA Rx is used.
2. Enable DMA requests for Tx and Rx in DMA registers, if the DMA is used.
3. Enable the DMA Tx buffer in the TXDMAEN bit of the SPI_CFG1 register, if DMA Tx is used.
4. Enable the SPI by setting the SPE bit.

To close communication, it is mandatory to follow these steps in order:

1. Disable DMA requests for Tx and Rx in the DMA registers, if the DMA issued.
2. Disable the SPI by following the SPI disable procedure.
3. Disable DMA Tx and Rx buffers by clearing the TXDMAEN and RXDMAEN bits of the SPI_CFG1 register, if DMA Tx and/or DMA Rx are used.

Data packing with DMA

If the transfers are managed by DMA (TXDMAEN and RXDMAEN set in the SPI_CFG1 register) the packing mode is enabled/disabled automatically depending on the PSIZE value configured for SPI TX and the SPI RX DMA channel.

The packing mode is enabled if the DMA channel PSIZE value is a multiple of the data size. Then the DMA automatically manages the sequences of write and read operations to/from the SPI data registers, based on FIFO occupancy flags, and depending on the FIFO threshold and data size configurations.

The DMA completes the transfer automatically according to the TSIZE field setting, whatever the data packing mode used, and even if the number of data to transfer is not a multiple of the DMA data size (16 bits or 32 bits) while the frame size is smaller.

Alternatively, the last data frames can be written by software, in the single/unpacked mode.

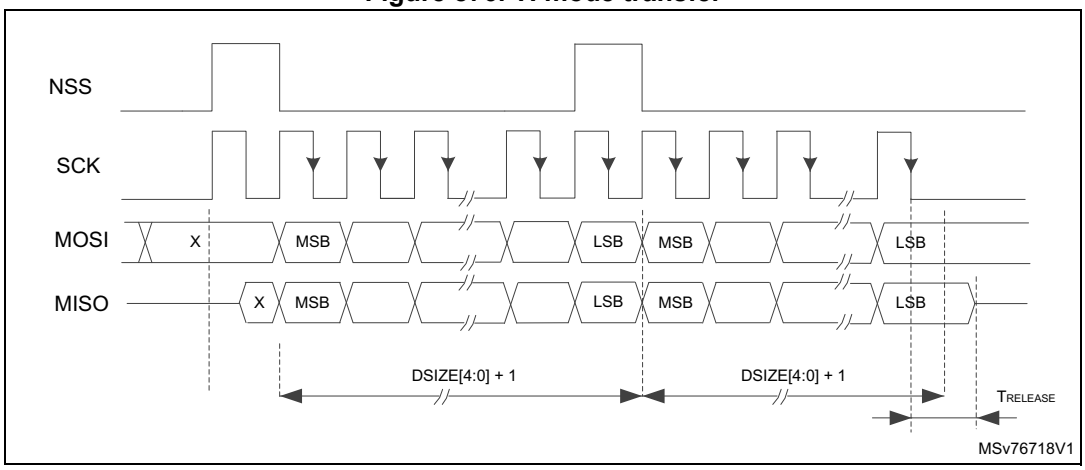
Configuring any DMA data access to less than the configured data size is forbidden. One complete data frame must be always accessed at minimum.

63.5 SPI specific modes and control

63.5.1 TI mode

With a specific SP[2:0] bitfield setting of the SPI_CFG2 register, the SPI can be configured compliant with the TI protocol. The SCK and NSS signals polarity, phase and flow, as well as the bit order are fixed, so the setting of CPOL, CPHA, LSBFRST, SSOM, SSOE, SSIOP, SSM, RDIOP, RDIOM, MSSI, and MIDI is not required when the SPI is in TI mode configuration. The NSS signal synchronizes the protocol by pulses over the LSB data bit as it is shown in *Figure 876*.

Figure 876. TI mode transfer



In slave mode, the clock generator is used to define the time when the slave output at MISO pin becomes high-Z when the current transfer finishes. The master baud rate setting (MBR[2:0] of SPI_CFG1) is applied and any baud rate can be used to determine this moment with optimal flexibility. The delay for the MISO signal to become high-Z (TRELEASE) depends on internal resynchronization, too, which takes the next additional 2-4 periods of the clock signal feeding the generator. It is given by the following formula:

$$\frac{Tbaud}{2} + 2 \times Tspi_ker_ck \leq Trelease \leq \frac{Tbaud}{2} + 4 \times Tspi_ker_ck$$

If the slave detects a misplaced NSS pulse during a data transfer the TIFRE flag is set.

63.5.2 SPI error flags

An SPI interrupt is generated if one of the following error flags is set and the interrupt is enabled by setting the corresponding interrupt enable bit.

Overrun flag (OVR)

An overrun condition occurs when data are received by a master or slave and the RxFIFO has not enough space to store these received data. This can happen if the software or the DMA did not have enough time to read the previously received data (stored in the RxFIFO).

When an overrun condition occurs, the OVR flag is set and the newly received value does not overwrite the previous one in the RxFIFO. The newly received value is discarded and all

data transmitted subsequently are lost. The OVR flag triggers an interrupt if the OVRIE bit is set. Clearing the OVR bit is done by setting the OVRC bit of the SPI_IFCR register. Clearing the RxFIFO content by performing software reads before the OVR bit is cleared reduces the risk of any immediate repetition of its next overrun. It is suggested to release the RxFIFO space as much as possible, this means to read out all the available data packets based on RXP flag indication.

In master mode, the user can prevent the RxFIFO overrun by automatic communication suspend (MASRX bit).

Underrun flag (UDR)

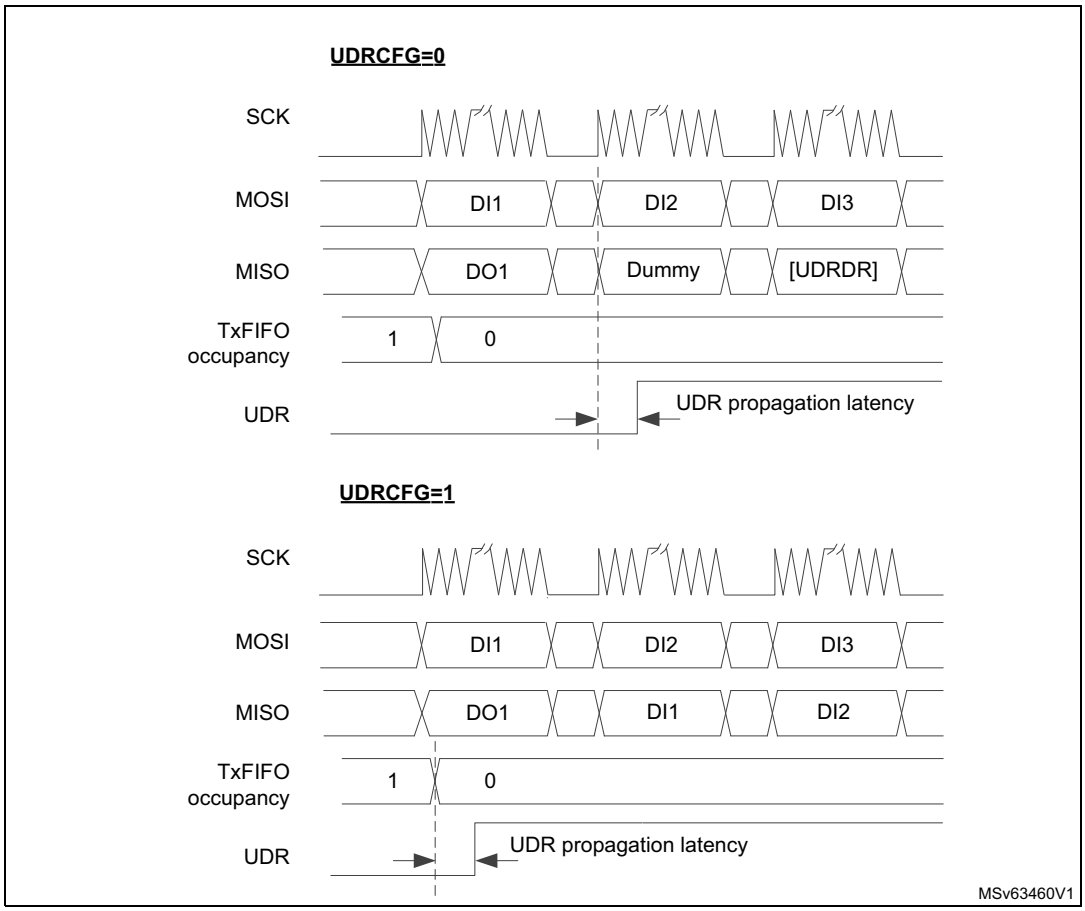
In a slave-transmitting mode, the underrun condition is captured internally by hardware if no data is available for transmission in the slave TxFIFO commonly. The UDR flag setting is then propagated into the status register by hardware (see note below). UDR triggers an interrupt if the UDRIE bit is set.

Underrun detection logic and system behavior depend on the UDRCFG bit. When an underrun is detected by the slave, it can provide out either a constant pattern stored by the user at the UDRDR register or the data received previously from the master. When the first configuration (UDRCFG = 0) is applied, the underrun condition is evaluated whenever the master starts to communicate a new data frame while TxFIFO is empty. Then single additional dummy (accidental) data is always inserted between the last valid data and the constant pattern defined at the UDRDR register (see *Figure 877*). The second configuration (UDRCFG=1) can be used in circular topography structures (see *Figure 869*). Assuming that TxFIFO is not empty when the master starts the communication, the underrun condition is evaluated just once the FIFO becomes empty during the next data flow. Valid data from TxFIFO is then upended by the last received data immediately.

The standard transmission is reenabled once the software clears the UDR flag and this clearing is propagated into SPI logic by hardware. Writing some data to the TxFIFO before the UVR bit is cleared reduces the risk of any immediate repetition of its next underrun.

The data transferred by the slave is unpredictable especially when the transfer starts or continues while TxFIFO is empty and the underrun condition is either not yet captured or just cleared. Typically, this is the case when SPI is just enabled or when a transfer with a defined size just starts. First bits can be corrupted in this case, as well, when the slave software writes the first data into the empty TxFIFO too close prior to starting the data transfer (propagation of the data into TxFIFO takes a few APB clock cycles).

Figure 877. Optional configurations of the slave behavior when an underrun condition is detected



Note: The hardware propagation of an UDR event needs additional traffic on the bus. It always takes a few extra SPI clock cycles after the event happens (both underrun captured by hardware and cleared by software). If clearing of the UDR flag by software is applied close to the end of the data frame transfer or when the SCK line is at idle in between the frames, the next extra underrun pattern is sent initially by the slave before the valid data from TxFIFO becomes transferred again. The user can prevent this by SPI disable/enable action between sessions to restart the underrun logic and so initiate the next session by the valid data.

Mode fault (MODF)

Mode fault occurs when the master device has its internal NSS signal (NSS pin in slave select hardware mode, or SSI bit in slave select software mode) pulled low. This automatically affects the SPI interface in the following ways:

- The MODF bit is set and the SPI interrupt is triggered if the MODFIE bit is set.
- The SPE bit is forced to zero until the MODF bit is set. This disables the SPI and blocks all the peripheral outputs except the MODF interrupt request if enabled.
- The MASTER bit is cleared, thus forcing the device into slave mode.

MODF is cleared by writing 1 to the MODFC bit of the SPI_IFCR register.

To avoid any multiple slave conflicts in a system comprising several MCUs, the NSS pin must be pulled to its nonactive level before reenabling the SPI, by setting the SPE bit.

As a security, the hardware does not allow the SPE bit to be set while the MODF bit is set. In a slave device, the MODF bit cannot be set except as the result of a previous multimaster conflict.

A correct software procedure when a master overtakes the bus in multimaster systems must be the following one:

1. Switch into master mode while SSOE = 0 (potential conflict can appear when another master occupies the bus. In this case, MODF is raised, which prevents any next node switching into master mode).
2. Put GPIO pin dedicated for another master slave select control into active level.
3. Perform a data transfer.
4. Put GPIO pin dedicated for another master slave select control into nonactive level.
5. Switch back to slave mode.

CRC error (CRCE)

This flag is used to verify the validity of the value received when the CRCEN bit of the SPI_CFG1 register is set. The CRCE flag of the SPI_SR register is set if the value received in the shift register does not match the receiver SPI_RXCRC value, after the last data is received (as defined by TSIZE). The CRCE flag triggers an interrupt if the CRCEIE bit is set. Clearing the bit CRCE is done by a writing 1 to the CRCEC bit of the SPI_IFCR register.

TI mode frame format error (TIFRE)

A TI mode frame format error is detected when an NSS pulse occurs during an ongoing communication when the SPI is operating in slave mode and configured to conform to the TI mode protocol. When this error occurs, the TIFRE flag is set in the SPI_SR register. The SPI is not disabled when an error occurs, the NSS pulse is ignored, and the SPI waits for the next NSS pulse before starting a new transfer. The data may be corrupted since the error detection may result in the loss of a few data frames.

The TIFRE flag is cleared by writing 1 to the TIFREC bit of the SPI_IFCR register. If the TIFREIE bit is set, an interrupt is generated on the NSS error detection. As data consistency is no longer guaranteed, communication must be reinitiated by software between master and slave.

63.5.3 CRC computation

Two separate CRC calculators are implemented to check the reliability of transmitted and received data. The CRC polynomial configuration depends on the instance. Refer to *Section 63.3: SPI implementation* for more information.

The length of the polynomial is defined by the most significant bit of the value stored in the SPI_CRCPOLY register. It must be greater than the data frame size (in bits) defined in the DSIZE[4:0] bitfield of the SPI_CFG1 register. To obtain a full-size polynomial, the polynomial length must exceed the maximum data size of the peripheral instance, and the CRC33_17 bit of the SPI_CR1 register must be set to select the most significant bit of the polynomial string.

For example, to select the standard CRC16-CCITT (XMODEM) polynomial x^16 + x^12 + x^5 + 1:

- For a 32-bit instance: write 0x11021 to the SPI_CRCPOLY register and clear the CRC33_17 bit.
- For a 16-bit instance: to obtain the full size, write 0x1021, and set the CRC33_17 bit.

The CRCSIZE field of the SPI_CFG1 register then defines how many most significant bits from the CRC calculation registers are transferred and compared as CRC frame. It is defined independently from the data frame length, but it must be either equal or an integer multiple of the data frame size. Its size cannot exceed the maximum data size of the instance.

To fully benefit from the CRC calculation capability, the polynomial length setting must correspond to the CRC frame size, else the bits unused at the calculation are transferred and expected all zero at the end of the CRC frame if its size is set greater than the polynomial length.

CRC principle

The CRC calculation is enabled by setting the CRCEN bit of the SPI_CFG1 register before the SPI is enabled (SPE = 1). The CRC value is then calculated using the CRC polynomial defined by the CRCPOLY register and CRC33_17 bit. When SPI is enabled, the CRC polynomial can be changed but only in the case when there is no traffic on the bus.

The CRC computation is done, bit by bit, on the sampling clock edge defined by the CPHA and CPOL bits of the SPI_CR1 register. The calculated CRC value is checked automatically at the end of the data block defined by the SPI_CR2 register exclusively.

When a mismatch is detected between the CRC calculated internally on the received data and the CRC received from the transmitter, a CRCE flag is set to indicate a data corruption error. The right procedure for handling the CRC depends on the SPI configuration and the chosen transfer management.

CRC transfer management

Communication starts and continues normally until the last data frame has been sent or received in the SPI_DR register.

The length of the transfer must be defined by TSIZE. When the desired number of data is transferred, the TXCRC is transmitted and the data received on the line are compared to the RXCRC value.

Whatever the CRCSIZE configuration, TSIZE cannot be set to 0xFFFF for a full-featured instance, and to 0x3FF for a limited-featured instance, if CRC is enabled.

In transmission, the CRC computation is frozen during the CRC transfer and the TXCRC is transmitted, in a frame of length equal to the CRCSIZE field value.

In reception, the RXCRC is also frozen when the desired number of data is transferred. Information to be compared with the RXCRC register content is then received in a frame of length equal to the CRCSIZE value.

Once the CRC frame is complete, an automatic check is performed comparing the received CRC value and the value calculated in the SPI_RXCRC register. The software has to check the CRCE flag of the SPI_SR register to determine if the data transfers were corrupted or not. Software clears the CRCE flag by writing 1 to the CRCEC.

The user takes no care about any flushing redundant CRC information, it is done automatically.

Resetting the SPI_TXCRC and SPI_RXCRC values

The SPI_TXCRC and SPI_RXCRC values are initialized automatically when new data is sampled after a CRC phase. This allows the use of DMA circular mode to transfer data without any interruption (several data blocks covered by intermediate CRC checking phases). Initialization patterns for receiver and transmitter can be configured either to zero or to all ones in dependency on setting bits TCRCINI and RCRCINI of the SPI_CR1 register.

The CRC values are reset when the SPI is disabled.

63.6 SPI in low-power modes

Table 691. Effect of low-power modes on the SPI

Mode	Description
Sleep	No effect. SPI interrupts cause the device to exit Sleep mode.
Stop(1)	The content of the SPI registers is kept.
Standby	The SPI instance is not functional in this mode. It is powered down, and must be reinitialized after exiting Standby mode.

1. Refer to *Section 63.3: SPI implementation* for information about wake-up from Stop mode support per instance as well as Standby mode availability. If an instance is not functional in a Stop mode, it must be disabled before entering this Stop mode.

63.7 SPI interrupts

Table 692 gives an overview of the SPI events capable of generating interrupts if enabled. Some of them feature wake-up from low-power mode capability, additionally. Most of them can be enabled and disabled independently while using specific interrupt enable control bits. The flags associated with the events are cleared by specific methods. Refer to the description of SPI registers for more details about the event flags. When SPI is disabled, all the pending interrupt requests are blocked to prevent their propagation into the interrupt services, except the MODF interrupt request.

Table 692. SPI wake-up and interrupt requests

Interrupt vector	Interrupt event	Event flag	Enable Control bit	Event clear method	Exit from Stop and Standby modes capability[1][2]
SPI	TxFIFO ready to be loaded (space available for one data packet - FIFO threshold)	TXP	TXPIE	TXP cleared by hardware when TxFIFO contains less than FTHLV empty locations	Yes
	Data received in RxFIFO (one data packet available - FIFO threshold)	RXP	RXPIE	RXP cleared by hardware when RxFIFO contains less than FTHLV samples	Yes
	Both TXP and RXP active	DXP	DXPIE	When TXP or RXP are cleared	Yes
	Transmission Transfer Filled	TXTF	TXTFIE	Writing TXTFC to 1	No
	Underrun	UDR	UDRIE	Writing UDRC to 1	Yes
	Overrun	OVR	OVRIE	Writing OVRC to 1	Yes
	CRC Error	CRCE	CRCEIE	Writing CRCEC to 1	Yes
	TI Frame Format Error	TIFRE	TIFREIE	Writing TIFREC to 1	No
	Mode Fault	MODF	MODFIE	Writing MODFC to 1	No
	End Of Transfer (full transfer sequence completed - based on TSIZE value)	EOT	EOTIE	Writing EOTC to 1	Yes
	Master mode suspended	SUSP		Writing SUSPC to 1	Yes
	TxFIFO transmission complete (TxFIFO empty)	TXC[3]		TXC cleared by hardware when a transmission activity starts on the bus	No

1. All the interrupt events can wake up the system from Sleep mode at each instance. For detailed information about instances capabilities to exit from concrete Stop and Standby mode refer to the *Functionalities depending on the working mode* table.
2. Refer to *Section 63.3: SPI implementation* for information about Standby mode availability.
3. The TXC flag behavior depends on the TSIZE setting. When TSIZE>0, the flag fully follows the EOT one including its clearing by EOTC.

63.8 I2S main features

- Full duplex communication
- Simplex communication (only transmitter or receiver)
- Master or slave operations
- 8-bit programmable linear prescaler
- Data length can be 16, 24 or 32 bits[a]
- Channel length can be 16 or 32 in master, any value in slave
- Programmable clock polarity
- Error flags signaling for improved reliability: Underrun, overrun, and frame errors
- Embedded Rx and TxFIFOs
- Supported I^2S protocols:
  - I^2S Philips standard
  - MSB-justified standard (left-justified)
  - LSB-justified standard (right-justified)
  - PCM standard (with short and long frame synchronization)
- Data ordering programmable (LSb or MSb first)
- DMA capability for transmission and reception
- Master clock can be output to drive an external audio component:
  - F_{MCK} = 256 x F_{WS} for all I2S modes
  - F_{MCK} = 128 x F_{WS} for all PCM modes

Note: F_{MCK} is the master clock frequency and F_{WS} is the audio sampling frequency.

63.9 I2S functional description

63.9.1 I2S general description

The block diagram shown on *Figure 864* also applies for I2S mode.

The SPI/I2S block can work in I2S/PCM mode, when the bit I2SMOD is set. A dedicated register (SPI_I2SCFGR) is available for configuring the dedicated I2S parameters, which include the clock generator, and the serial link interface.

The I2S/PCM function uses the clock generator to produce the communication clock when the SPI/I2S is set in master mode. This clock generator is also the source of the master clock output (MCK).

Resources such as RxFIFO, TxFIFO, DMA, and parts of interrupt signaling are shared with the SPI function. The low-power mode function is also available in I2S mode (refer to *Section 63.6: SPI in low-power modes* and *Section 63.10: I2S interrupts*).

a. Not always available, refer to *Section 63.3: SPI implementation* in order to check if 24 and 32-bit data widths are supported.

63.9.2 Pin sharing with SPI function

The I2S shares four common pins with the SPI:

- SDO: serial data output (mapped on the MOSI pin) to transmit the audio samples in master, and receive the audio sample in slave mode. Refer to *Section : Serial data line swapping on page 2942*.
- SDI: serial data input (mapped on the MISO pin) to receive the audio samples in master, and transmit the audio sample in slave mode. Refer to *Section : Serial data line swapping on page 2942*.
- WS: word select (mapped on the NSS pin). This is the frame synchronization. It is configured as output in master mode, and as input in slave mode.
- CK: serial clock (mapped on the SCK pin). This is the serial bit clock. It is configured as output in master mode, and as input in slave mode.

An additional pin can be used when a master clock output is needed for some external audio devices:

- MCK: master clock (mapped separately) is used when the I2S is configured in master mode.

63.9.3 Bitfields usable in I2S/PCM mode

When the I2S/PCM mode is selected (I2SMOD = '1'), some bitfields are no longer relevant, and must be forced to a specific value to guarantee the behavior of the I2S/PCM function. *Table 693* shows the list of bits and fields available in the I2S/PCM mode, and indicates which must be forced to a specific value.

Table 693. Bitfields usable in PCM/I2S mode

Register name	Bitfields usable in PCM/I2S Mode	Constraints on other bitfields
SPI/I2S control register 1 (SPI_CR1)	IOLOCK, CSUSP, CSTART, SPE	Other fields set to their reset values
SPI/I2S control register 2 (SPI_CR2)	-	Set to reset value
SPI/I2S configuration register 1 (SPI_CFG1)	TXDMAEN, RXDMAEN, FTHLV	Other fields set to their reset values
SPI/I2S configuration register 2 (SPI_CFG2)	AFCNTR, LSBFRST, IOSWP	Other fields set to their reset values
SPI/I2S interrupt enable register (SPI_IER)	TIFREIE, OVRIE, UDRIE, TXPIE, RXPIE	
SPI/I2S status register (SPI_SR)	SUSP, TIFRE, OVR, UDR, TXP, RXP	Other flags not relevant
SPI/I2S interrupt/status flags clear register (SPI_IFCR)	SUSPC, TIFREC, OVRC, UDRC	Other fields set to their reset values
SPI/I2S receive data register (SPI_RXDR)	The complete register	-

Table 693. Bitfields usable in PCM/I2S mode (continued)

Register name	Bitfields usable in PCM/I2S Mode	Constraints on other bitfields
SPI/I2S polynomial register (SPI_CRCPOLY)	-	Set to reset value
SPI/I2S transmitter CRC register (SPI_TXCRC)	-	
SPI/I2S receiver CRC register (SPI_RXCRC)	-	
SPI/I2S underrun data register (SPI_UDRDR)	-	
SPI/I2S configuration register (SPI_I2SCFGR)	The complete register	-

63.9.4 Slave and master modes

The SPI/I2S block supports master and slave modes for both I2S and PCM protocols. In master mode, both CK, WS and MCK signals are set to output.

In slave mode, both CK and WS signals are set to input. The signal MCK cannot be used in slave mode.

To improve the robustness of the SPI/I2S block in slave mode, the peripheral resynchronizes each reception and transmission on WS signal. This means that:

- In I2S Philips standard, the shift-in or shift-out of each data is triggered one bit clock after each transition of WS.
- In I2S MSB-justified standard, the shift-in or shift-out of each data is triggered as soon as a transition of WS is detected.
- In PCM short standard, the shift-in or shift-out of each data is triggered one bit clock after the active edge of WS.
- In PCM long standard, the shift-in or shift-out of each data is triggered as soon as the active edge of WS is detected

Note: This resynchronization mechanism is not available for the I2S LSB-justified standard.

Note as well that there is no need to provide a kernel clock when the SPI/I2S is configured in slave mode.

63.9.5 Supported audio protocols

The I2S/PCM interface supports four audio standards, configurable using the I2SSTD[1:0] and PCMSYNC bits of the SPI_I2SCFGR register.

In the I2S protocol, the audio data are time-multiplexed on two channels: the left channel and the right channel. The WS signal is used to indicate which channel must be considered as the left, and which one is the right.

In I2S master mode, four frame formats are supported:

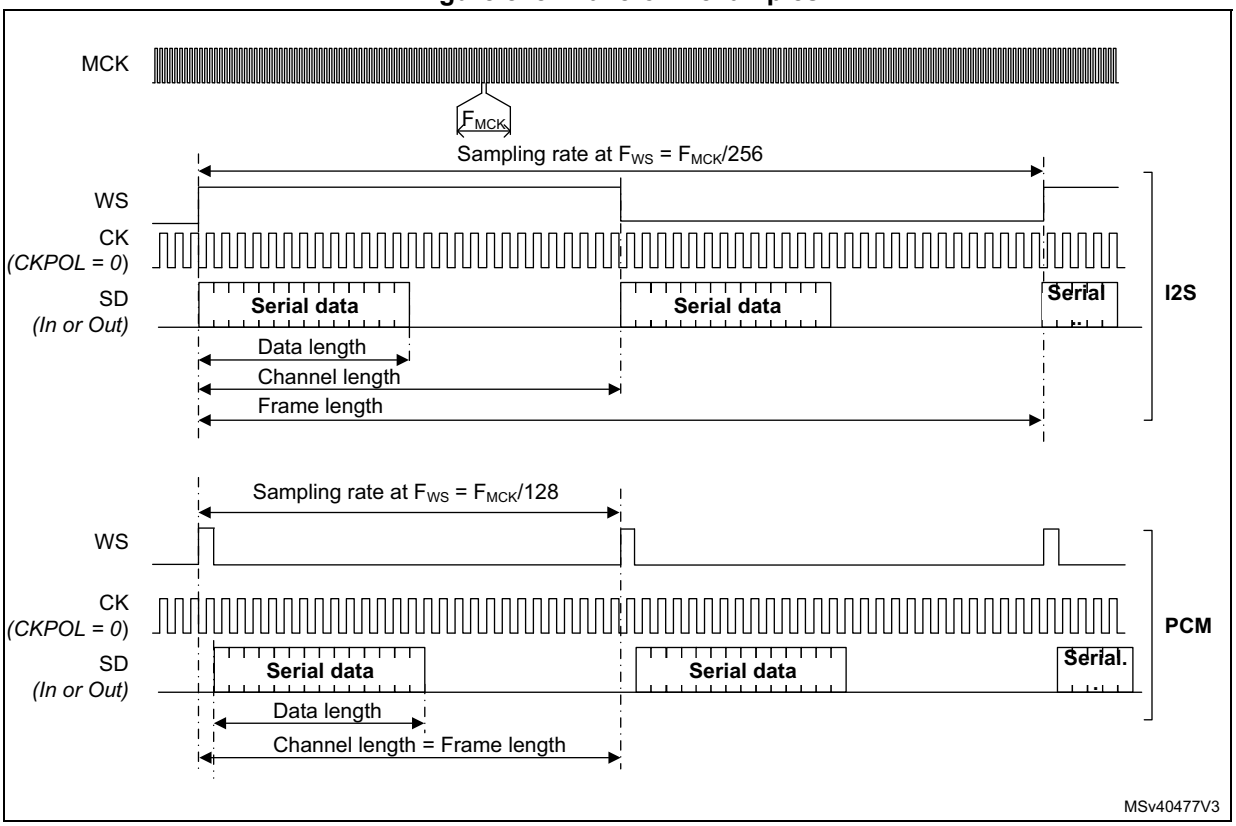
- 16-bit data packed in a 16-bit channel
- 16-bit data packed in a 32-bit channel
- 24-bit data packed in a 32-bit channel[(a)]
- 32-bit data packed in a 32-bit channel[(a)]

In PCM master mode, three frame formats are supported:

- 16-bit data packed in a 16-bit channel
- 16-bit data packed in a 32-bit channel
- 24-bit data packed in a 32-bit channel[(a)]

The figure hereafter shows the main definition used in this section: data length, channel length and frame length.

Figure 878. Waveform examples



For simplicity sake, in the next figures, SDI represents the serial data input and SDO the serial data output. Refer to *Section : Serial data line swapping* for details about the direction control of serial data lines.

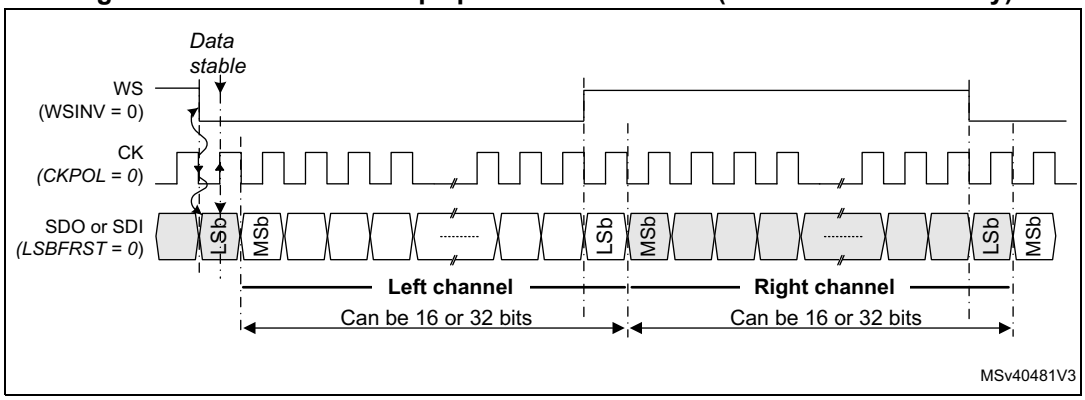
I²S Philips standard

The I2S Philips standard is selected by setting I2SSTD to 0b00. This standard is supported in master and slave mode.

In this standard, the WS signal toggles one CK clock cycle before the first bit (MSb in I2S Philips standard) is available. A falling edge transition of WS indicates that the next data transferred is the left channel, and a rising edge transition indicates that the next data transferred is the right channel.

a. Not always available, refer to *Section 63.3: SPI implementation* to check if 24 and 32-bit data widths are supported.

Figure 879. Master I2S Philips protocol waveforms (16/32-bit full accuracy)



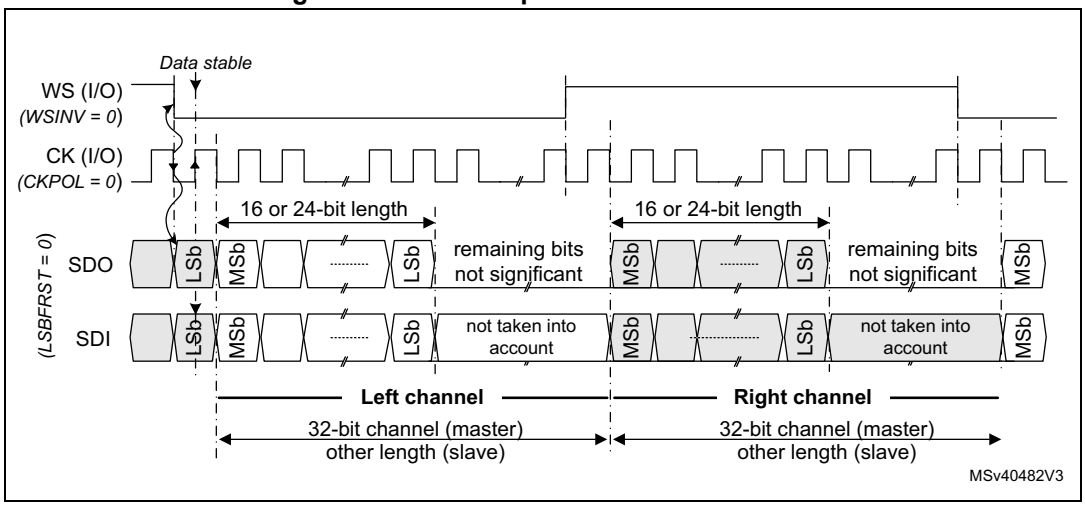
1. Data width of 24 and 32 bits are not always supported (DATLEN = 01 or 10). Refer to *Section 63.3: SPI implementation* for the supported data sizes.

CKPOL is cleared to match the I2S Philips protocol. See *Selection of the CK sampling edge* for information concerning the handling of the WS signal.

Figure 879 shows an example of waveform generated by the SPI/I2S in the case where the channel length is equal to the data length. More precisely, this is true when CHLEN = 0 and DATLEN = 0b00 or when CHLEN = 1 and DATLEN = 0b10.

See *Control of the WS inversion* for information concerning the handling of the WS signal.

Figure 880. I2S Philips standard waveforms



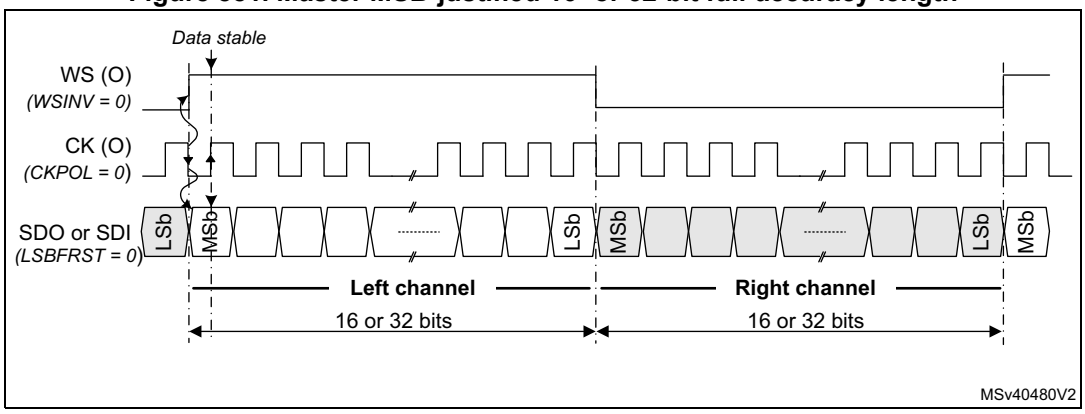
1. Data width of 24 and 32 bits are not always supported (DATLEN = 01 or 10). Refer to *Section 63.3: SPI implementation* for the supported data sizes.

In the case where the channel length is bigger than the data length, the remaining bits are not significant when the SPI/I2S is configured in transmit mode. This is applicable for both master and slave mode.

MSB-justified standard

For this standard, the WS signal toggles when the first data bit is provided. The data transferred represents the left channel if WS is high and the right channel if WS is low.

Figure 881. Master MSB-justified 16- or 32-bit full-accuracy length

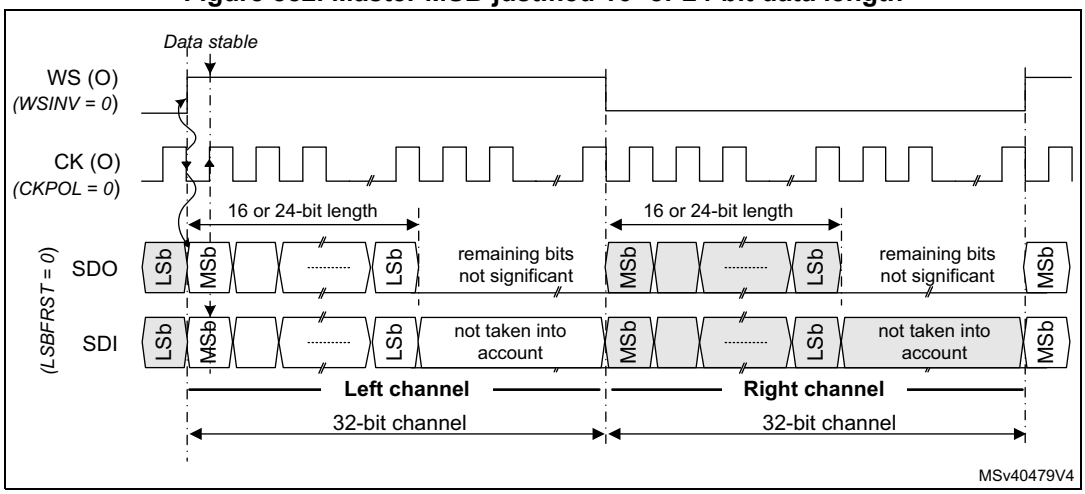


1. Data width of 24 and 32 bits are not always supported (DATLEN = 01 or 10). Refer to *Section 63.3: SPI implementation* to check the supported data size.

CKPOL is cleared to match the I2S MSB-justified protocol. See *Selection of the CK sampling edge* for information concerning the handling of the WS signal.

See *Control of the WS inversion* for information concerning the handling of the WS signal.

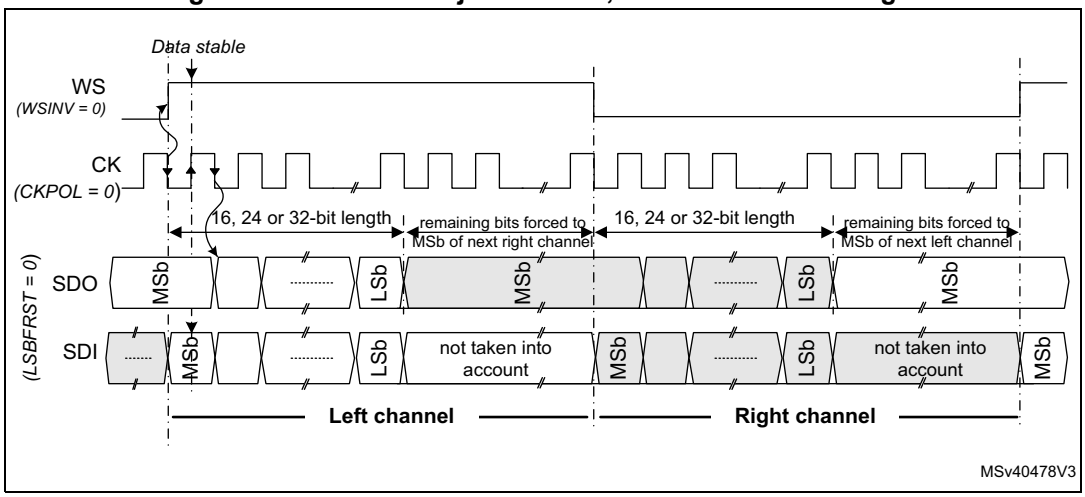
Figure 882. Master MSB-justified 16- or 24-bit data length



1. Data width of 24 and 32 bits are not always supported (DATLEN = 01 or 10). Refer to *Section 63.3: SPI implementation* to check the supported data size.

In the case where the channel length is bigger than the data length, the remaining bits are not significant when the SPI/I2S is configured in master transmit mode. In slave transmit mode, the remaining bits are forced to the value of the first bit of the next data to be generated to avoid timing issues (see *Figure 883*).

Figure 883. Slave MSB-justified 16-, 24- or 32-bit data length



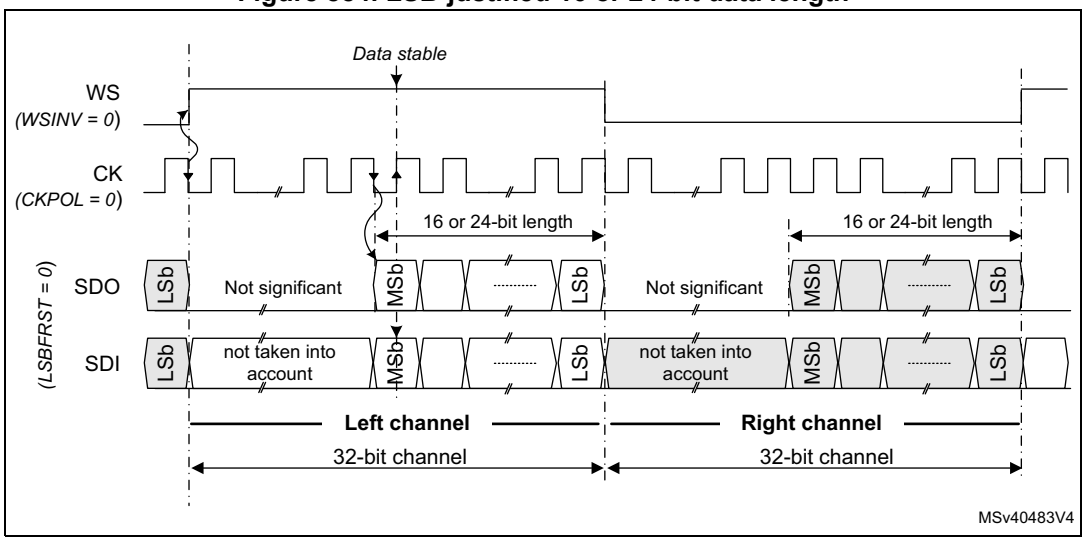
1. Data width of 24 and 32 bits are not always supported (DATLEN = 01 or 10). Refer to *Section 63.3: SPI implementation* to check the supported data size.

LSB-justified standard

This standard is similar to the MSB-justified standard in master mode (no difference for the 16- and 32-bit full-accuracy frame formats). The LSB-justified 16- or 32-bit full-accuracy format gives similar waveforms to MSB-justified mode (see *Figure 881*) because the channel and data have the same length.

Note: In the LSB-justified format, only 16- and 32-bit channel lengths are supported in master and slave mode. This is because it is not possible to transfer properly the data if the channel length is not known by the transmitter and receiver side.

Figure 884. LSB-justified 16 or 24-bit data length



1. Data width of 24 and 32 bits are not always supported (DATLEN = 01 or 10). Refer to *Section 63.3: SPI implementation* to check the supported data size.

CKPOL is cleared in order to match the I2S LSB-justified protocol. See *Selection of the CK sampling edge* for information concerning the handling of the WS signal.

See *Control of the WS inversion* for information concerning the handling of the WS signal.

PCM standard

For the PCM standard, there is no need to use channel-side information. The two PCM modes (short and long frame) are available and can be selected using the PCMSYNC bit of SPI_I2SCFGR register.

In PCM long frame:

- The assertion time of the WS signal is fixed to 13 cycles of CK in master mode,
- The first data bit is received or transmitted as soon as the WS signal is asserted.

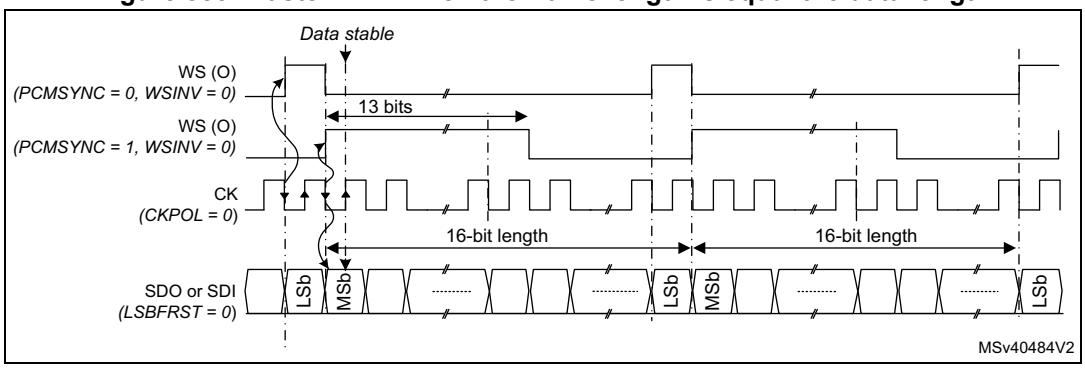
In PCM short frame:

- The assertion time of the WS signal is fixed to one cycle of CK in master mode,
- The first data bit is received or transmitted one cycle of CK after the WS assertion.

For both PCM modes:

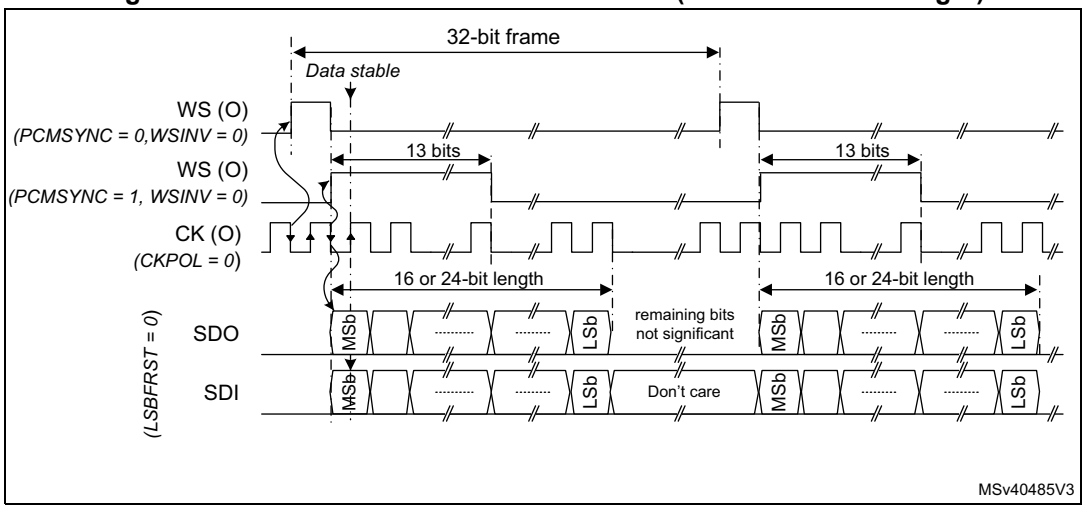
- The first data bit is MSb or LSb depending on the LSBFIRST bit value.
- The CK sampling edge can be selected thanks to CKPOL bit.
- The WS signal can be inverted thanks to the WSINV bit. See *Control of the WS inversion* for information concerning the handling of WS signal.

Figure 885. Master PCM when the frame length is equal the data length



A data size of 16 or 24 bits can be used when the channel length is set to 32 bits.

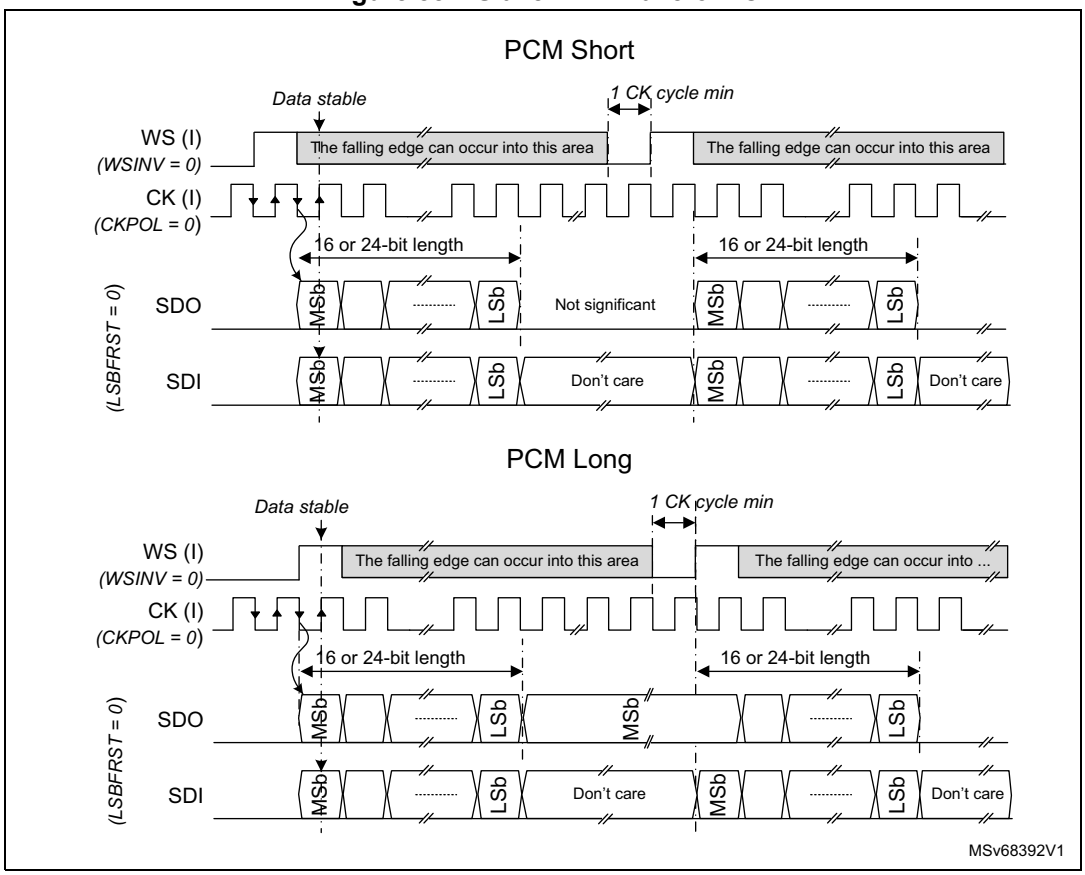
Figure 886. Master PCM standard waveforms (16 or 24-bit data length)



1. Data width of 24 and 32 bits are not always supported (DATLEN = 01 or 10). Refer to *Section 63.3: SPI implementation* to check the supported data size.

If the PCM protocol is used in slave mode, frame lengths can be different from 16 or 32 bits. As shown in *Figure 887*, in slave mode various pulse widths of WS can be accepted as the start of frame is detected by a rising edge of WS. The only constraint is that the WS must go back to its inactive state for at least one CK cycle.

Figure 887. Slave PCM waveforms



1. Data width of 24 and 32 bits are not always supported (DATLEN = 01 or 10). Refer to *Section 63.3: SPI implementation* to check the supported data size.

Note: In the case where the channel length is bigger than the data length, in slave PCM long, the transmission of the remaining bits is forced to the value of the first bit of the next data to be generated if the TXFIFO contains the next data to be transmitted.

In slave mode, CHLEN must be always programmed properly (whatever FIXCH value). For example, if CHLEN is cleared (16-bit length), the data transfer is truncated to 16 bits even if DATLEN is different from 0. To avoid this situation, CHLEN must be set, if DATLEN = 1 or 2.

63.9.6 Additional serial interface flexibility

Variable frame length in slave

In slave mode, channel lengths different from 16 or 32 bits can be accepted, as long as the channel length is bigger than the data length. This is true for all protocols except for the I2S LSB-justified protocol.

Data ordering

For all data formats and communication standards, it is possible to select the data ordering (MSb or LSb first) thanks to the bit LSBFRST located into *SPI/I2S configuration register 2 (SPI_CFG2)*.

Selection of the CK sampling edge

The CKPOL bit located into *SPI/I2S configuration register (SPI_I2SCFGR)* allows the user to choose the sampling edge polarity of the CK for slave and master modes, for all protocols.

- When CKPOL = 0, serial data SDO and WS (when master) are changed on the falling edge of CK and the serial data SDI and WS (when slave) are read on the rising edge.
- When CKPOL = 1, serial data SDO and WS (when master) are changed on the rising edge of CK and the serial data SDI and WS (when slave) are read on the falling edge.

Control of the WS inversion

It is possible to invert the default WS signal polarity for master and slave modes, for all protocols, by setting WSINV. By default the WS polarity is the following:

- In I2S Philips standard, WS is LOW for left channel, and HIGH for right channel
- In MSB/LSB-justified mode, WS is HIGH for left channel, and LOW for right channel
- In PCM mode, the start of frame is indicated by a rising edge of WS.

When WSINV is set, the WS polarity is inverted, then:

- In I2S Philips standard, WS is HIGH for left channel, and LOW for right channel
- In MSB/LSB-justified mode, WS is LOW for left channel, and HIGH for right channel
- In PCM mode, the start of frame is indicated by a falling edge of WS.

WSINV is located in the *SPI/I2S configuration register (SPI_I2SCFGR)*.

Control of the I/Os

The SPI/I2S block allows the settling of the WS and CK signals to their inactive state before enabling the SPI/I2S thanks to the AFCNTR bit of *SPI/I2S configuration register 2 (SPI_CFG2)*.

This can be done by programming CKPOL and WSINV using the following sequence:

Assuming that AFCNTR is initially cleared:

- Set I2SMOD = 1, (to inform the hardware that the CK and WS polarity is controlled via CKPOL and WSINV).
- Set bits CKPOL and WSINV to the wanted value.
- Set AFCNTR = 1.
  Then the inactive level of CK and WS I/Os is set according to CKPOL and WSINV values, even if the SPI/I2S is not yet enabled.
- Then performs the activation sequence of the I2S/PCM

Table 694 shows the level of WS and CK signals, when the AFCNTR bit is set, and before the SPI/I2S block is enabled (that is inactive level). Note that the level of WS also depends on the protocol selected.

Table 694. WS and CK level before SPI/I2S is enabled when AFCNTR = 1

WSINV	I2SSTD		WS level before SPI/I2S is enabled
0	I2S Std (00)	→	High
	Others	→	Low
1	I2S Std (00)	→	Low
	Others	→	High

CKPOL		CK level before SPI/I2S is enabled
0	→	Low
1	→	High

Note: The bit AFCNTR must not be set when the SPI is in slave mode.

Serial data line swapping

The direction of SDI and SDO depends on the IOSWP bit of *SPI/I2S configuration register 2 (SPI_CFG2)*, and on the slave/master mode. *Table 695* gives details on this feature.

Table 695. Serial data line swapping

Direction	IOSWP	Master mode		Slave mode	
		Input line	Output line	Input line	Output line
RX	0	SDI	-	SDO	-
	1	SDO	-	SDI	-
TX	0	-	SDO	-	SDI
	1	-	SDI	-	SDO
Full-duplex	0	SDI	SDO	SDO	SDI
	1	SDO	SDI	SDI	SDO

63.9.7 Startup sequence

When the bit SPE is cleared, the user is not allowed to read and write from/to the SPI_RXDR and SPI_TXDR registers, but the access to other registers is allowed.

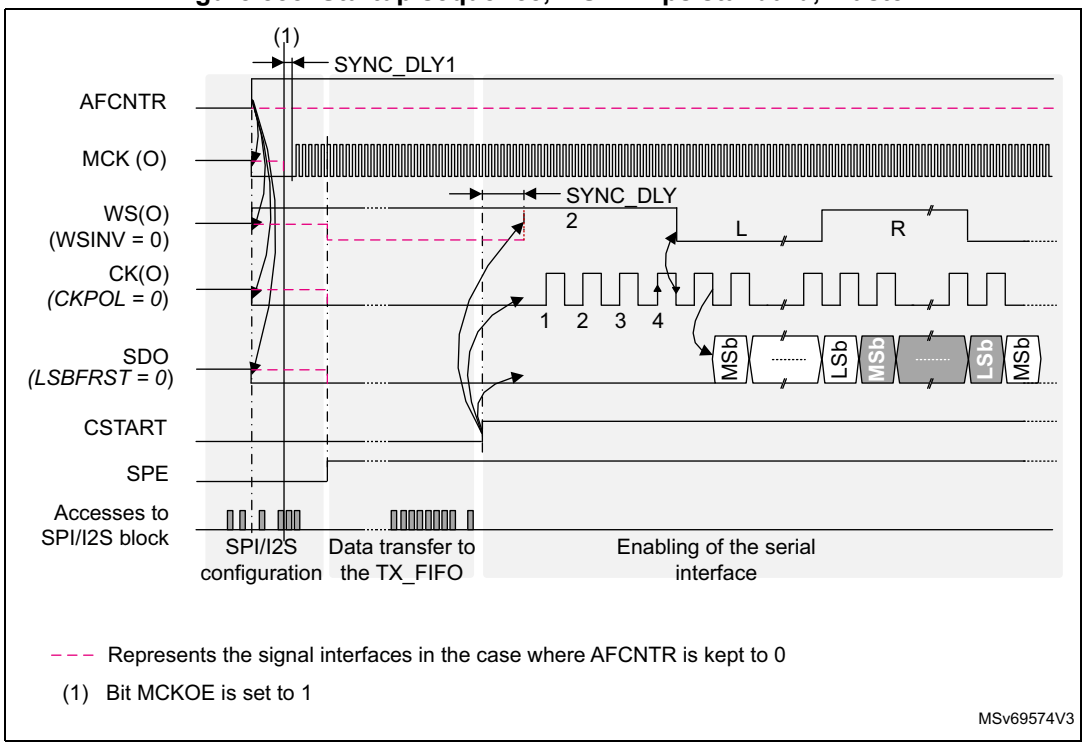
When the application wants to use the SPI/I2S block the user has to proceed as follows:

1. Ensure that the SPE is cleared, otherwise write SPE to 0.
2. Program all the configuration and control registers according to the wanted configuration. Refer to *Section 63.9.16* for detailed programming examples.
3. Clear all the status flags by setting the USPC, TIFREC, OVRC, and UDRC bits of the SPI_IFCR register. Note that if the flag SUSP is not cleared (via the SUSPC bit) the CSTART control bit has no effect.
4. Set the SPE bit to activate the SPI/I2S block. When this bit is set, the serial interface is still disabled, but the DMA and interrupt services are working, allowing for example, the data transfer into the TxFIFO.
5. Set bit CSTART to activate the serial interface.

As shown in *Figure 888*, in I2S Philips standard master TX, the generation of the WS and CK signals starts after a resynchronization delay (SYNC_DLY2) when CSTART goes to 1 and the TxFIFO is not empty. Note that the CK bit clock is activated four rising edges before

the falling edge of WS in order to ensure that the external slave device can detect properly WS transition. Other standards behave similarly.

Figure 888. Startup sequence, I2S Philips standard, master



2. When MCKOE is set, the MCK is generated after a synchronization delay (SYNC_DLY1). For more information, see MCK generation in *Section 63.9.9: Clock generator*.
3. Note that the level of WS and CK signals are controlled by the SPI/I2S block during the configuration phase as soon as the AFCNTR bit is set.

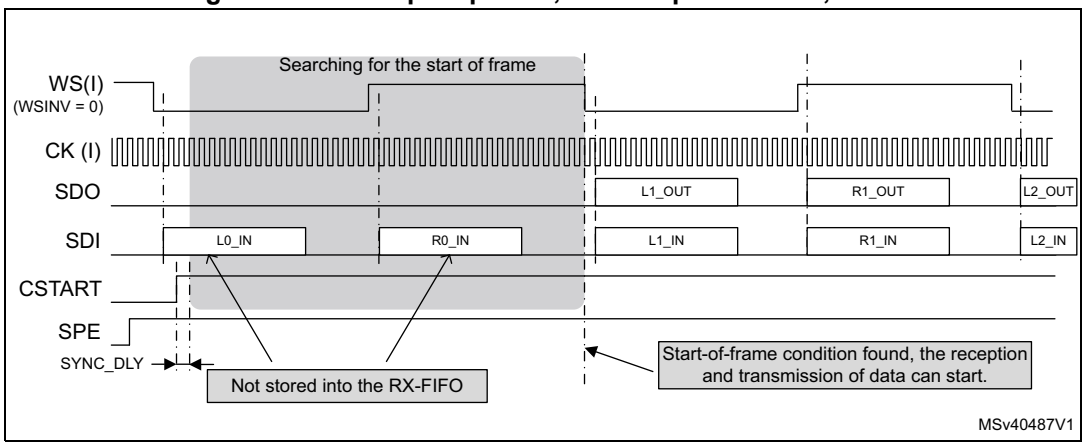
Note: Due to clock domain resynchronization, the CSTART bit is taken into account by the hardware after about three periods of CK clock (SYNC_DLY2).

In slave mode, once the bit CSTART is set, the data transfer starts when the start-of-frame condition is met:

- For the I2S Philips standard, the start-of-frame condition is a falling edge of the WS signal. The transmission/reception starts one bit clock later.
  If WSINV = 1, then the start-of-frame condition is a rising edge.
- For other protocols, the start-of-frame condition is a rising edge of the WS signal. The transmission/reception starts at the rising edge of WS for MSB-aligned protocol. The transmission/reception starts one bit clock later for PCM protocol.
  If WSINV = 1, then the start-of-frame condition is a falling edge.

Figure 889 shows an example of startup sequence in I2S Philips standard, slave mode.

Figure 889. Startup sequence, I2S Philips standard, slave



Note: Due to clock domain resynchronization, the CSTART bit is taken into account by the hardware after two periods of CK clock (SYNC_DLY).

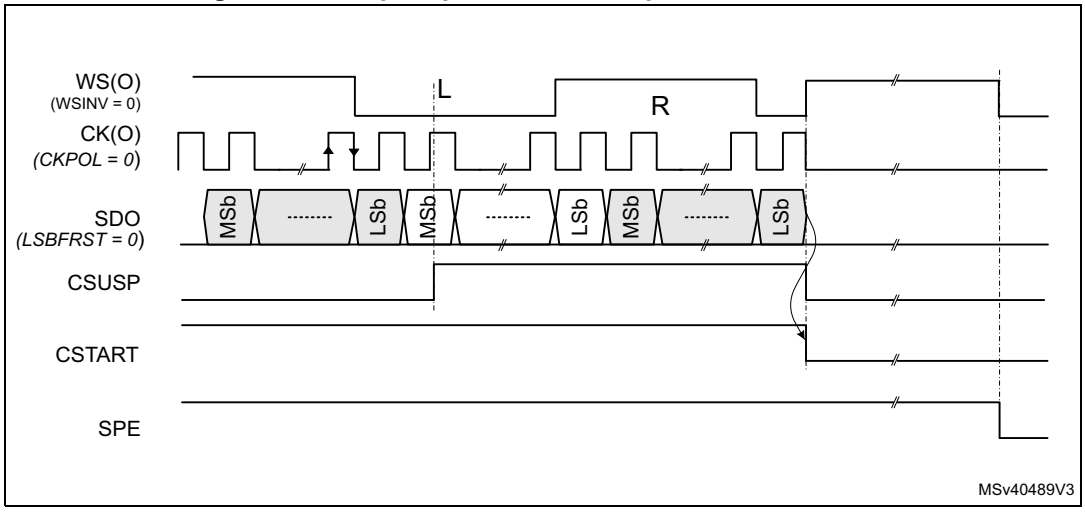
63.9.8 Stop sequence

The application can stop the I2S/PCM transfers by clearing the SPE bit. In that case the communication is stopped immediately, without waiting for the end of the current frame.

In master mode it is also possible to stop the I2S/PCM transfers at the end of the current frame. For that purpose, the user has to set the bit CSUSP, and polls the CSTART bit until it goes to 0. The CSTART bit goes to 0 when the current stereo (if an I2S mode was selected) or mono sample are completely shifted in or out. Then the SPE bit can be cleared.

Figure 890 shows an example of stop sequence in the case of master mode. The CSUSP bit is set during the transmission of the left sample, the transfer continue until the last bit of the right sample is transferred. Then CSTART and CSUSP go back to 0, CK and WS signals go back to their inactive state, and the user can clear the SPE bit.

Figure 890. Stop sequence, I2S Philips standard, master

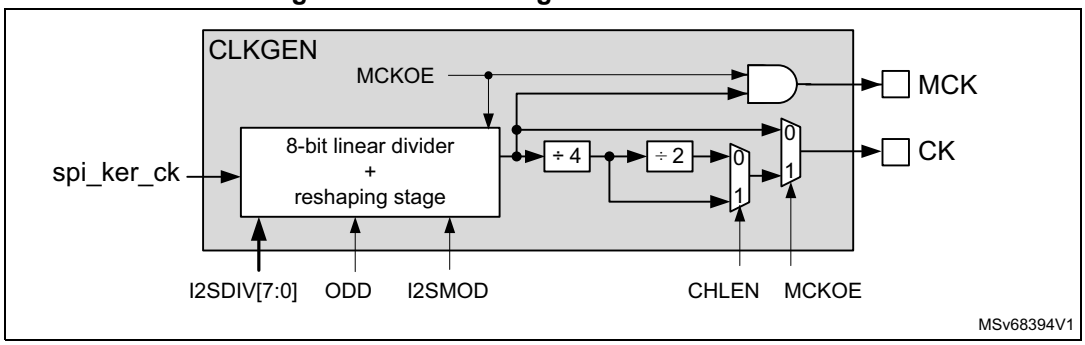


Note: In slave mode, the stop sequence is only controlled by the SPE bit.

63.9.9 Clock generator

When the I2S or PCM is configured in master mode, the user needs to program the clock generator in order to produce the frame synchronization (WS), the bit clock (CK) and the master clock (MCK) at the desired frequency.
If the I2S or PCM is used in slave mode, there is no need to configure the clock generator.

Figure 891. I²S clock generator architecture



The frequency generated on MCK, CK and WS depends mainly on I2SDIV, ODD, CHLEN, and MCKOE. The bit MCKOE indicates if a master clock need to be generated or not. The master clock has a frequency 256 or 128 times higher than the frame synchronization. This master clock is often required to provide a reference clock to external audio codecs.

Note: In master mode, there are no specific constraints on the ratio between the bus clock rate (F_{pclk}) and the bit clock (F_{CK}). The bus clock frequency must be high enough in order to support the data throughput.

When the master clock is generated (MCKOE = 1), the frequency of the frame synchronization is given by the following formula in I2S mode:

$$F_{WS} = \frac{F_{i2s_clk}}{256 \times \{(2 \times I2SDIV) + ODD\}}$$

And by this formula in PCM mode:

$$F_{WS} = \frac{F_{i2s_clk}}{128 \times \{(2 \times I2SDIV) + ODD\}}$$

In addition, the frequency of the MCK (F_{MCK}) is given by the formula:

$$F_{MCK} = \frac{F_{i2s_clk}}{\{(2 \times I2SDIV) + ODD\}}$$

When the master clock is disabled (MCKOE = 0), the frequency of the frame synchronization is given by the following formula in I2S mode:

$$F_{WS} = \frac{F_{i2s_clk}}{32 \times (CHLEN + 1) \times \{(2 \times I2SDIV) + ODD\}}$$

And by this formula in PCM mode:

$$F_{WS} = \frac{F_{i2s_clk}}{16 \times (CHLEN + 1) \times \{(2 \times I2SDIV) + ODD\}}$$

Where F_{WS} is the frequency of the frame synchronization, and F_{i2s_clk} is the frequency of the kernel clock provided to the SPI/I2S block.

Note: CHLEN and ODD can be either 0 or 1.

When I2SDIV = 0, then {(2 x I2SDIV) + ODD} is forced to 1.

Note: MCK duty cycle is 50 %, even for odd division ratios, when the kernel clock duty cycle is 50 %. When the division ratio is set (I2SDIV = 0), the MCK duty cycle is the same as the duty cycle of the kernel clock.

Table 696 provides examples of clock generator programming for I2S modes.

MCK generation

The master clock MCK is generated when the following conditions are met:

- I2SMOD must be equal to 1,
- I2SCFG must select a master mode,
- MCKOE must be set,

Table 696. CLKGEN programming examples for usual I2S frequencies

i2s_clk (MHz)	Channel length (bits)	I2SDIV	ODD	MCK	Sampling rate: F_{WS} (kHz)
12.288	16	12	0	No	16
12.288	32	6	0		16
12.288	16	6	0		32
12.288	32	3	0		32
49.152	16	16	0		48
49.152	32	8	0		48
49.152	16	8	0		96
49.152	32	4	0		96
49.152	16	4	0		192
49.152	32	2	0		192

Table 696. CLKGEN programming examples for usual I2S frequencies (continued)

i2s_clk (MHz)	Channel length (bits)	I2SDIV	ODD	MCK	Sampling rate: F_{WS} (kHz)
4.096	16 or 32	0	-	Yes	16
24.576	16 or 32	3	0		
49.152	16 or 32	3	0		32
12.288	16 or 32	0	-		48
49.152	16 or 32	2	0		
61.44	16 or 32	2	1		
98.304	16 or 32	2	0		96
196.608	16 or 32	2	0		192

63.9.10 Internal FIFOs

The I2S interface can use a dedicated FIFO for the RX and the TX path. The samples to transmit can be written into the TxFIFO via the SPI_TXDR register. The reading of RxFIFO is performed via the SPI_RXDR register.

Data alignment and ordering

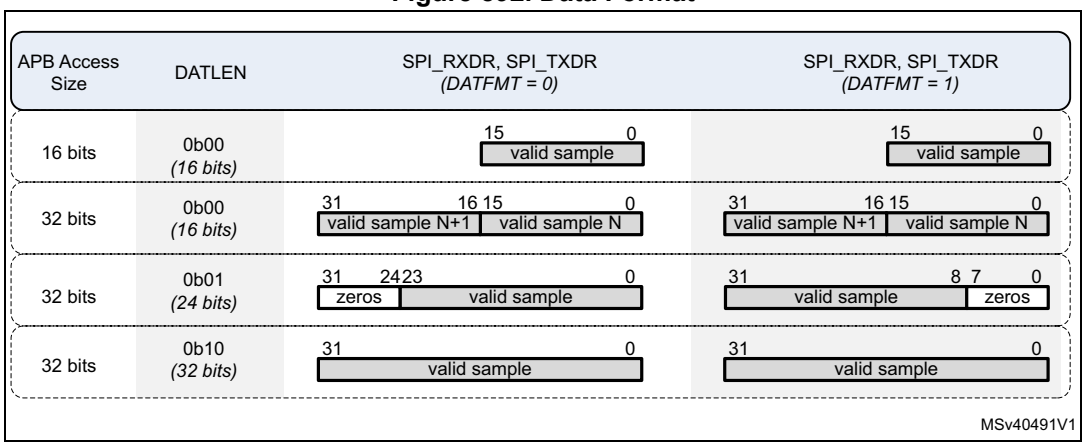
It is possible to select the data alignment into the SPI_RXDR and SPI_TXDR registers thanks to the DATFMT bit.

Note as well that the format of the data located into the SPI_RXDR or SPI_TXDR depends as well on the way those registers are accessed via the APB bus.

Figure 892 shows the allowed settings between APB access sizes, DATFMT, and DATLEN.

Note: Caution must be taken when the APB access size is 32 bits, and DATLEN = 0. For read operation the RxFIFO must contain at least two data, otherwise the read data are invalid. In the same way, for write operation, the TxFIFO must have at least two empty locations, otherwise a data can be lost.

Figure 892. Data Format



1. In I2S mode, the sample N represents the left sample, and the sample N+1 is the right sample.
2. Data width of 24 and 32 bits are not always supported (DATLEN = 01 or 10). Refer to *Section 63.3: SPI implementation* to check the supported data size.

It is possible to generate an interrupt or a DMA request according to a programmable FIFO threshold levels. The FIFO threshold is common to RX and TxFIFOs can be adjusted via FTHLV.

In I2S mode, the left and right audio samples are interleaved into the FIFOs. It means that for transmit operations, the user has to start to fill-up the TxFIFO with a left sample, followed by a right sample, and so on. For receive mode, the first data read from the RxFIFO is supposed to represent a left channel, the next one is a right channel, and so on.

Note that the read and write pointers of the FIFOs are reset when the bit SPE is cleared.

Refer to *Section 63.9.11* and *Section 63.9.15* for additional information.

FIFO size optimization

The basic element of the FIFO is the byte. This allows an optimization of the FIFO locations. For example when the data size is fixed to 24 bits, each audio sample takes three basic FIFO elements.

For example, a FIFO with 16 basic elements can have a depth of:

- 8 samples, if the DATLEN = 0 (16 bits),
- 5 samples, if the DATLEN = 1 (24 bits)[a],
- 4 samples, if the DATLEN = 2 (32 bits)[a].

63.9.11 FIFO status flags

Two status flags are provided for the application to fully monitor the state of the I2S interface. Both flags can generate an interrupt request. The receive interrupt is generated if RXPIE bit is enabled, the transmit interrupt is generated if TXPIE bit is enabled. Those bits are located into the SPI_IER register.

TxFIFO threshold reached (TXP)

When set, this flag indicates that the TxFIFO contains at least FTHLV empty locations. Thus, FTHLV new data to be transmitted can be written to SPI_TXDR. The TXP flag is reset when the number of empty locations is lower than FTHLV. Note that TXP = 1, when the I2S is disabled (SPE bit is reset).

RxFIFO threshold reached (RXP)

When set, this flag indicates that there is at least FTHLV valid data into the RxFIFO, thus the user can read those data via SPI_RXDR. It is reset when the RxFIFO contains less than FTHLV data.

See *Section 63.10* for additional information on the interrupt function in I2S mode.

63.9.12 Handling of underrun situation

In transmit mode, an underrun situation is detected when a new data needs to be loaded into the shift register while the TxFIFO is already empty. In such a situation the UDR flag is set, and at least one audio frame contains unexpected data.

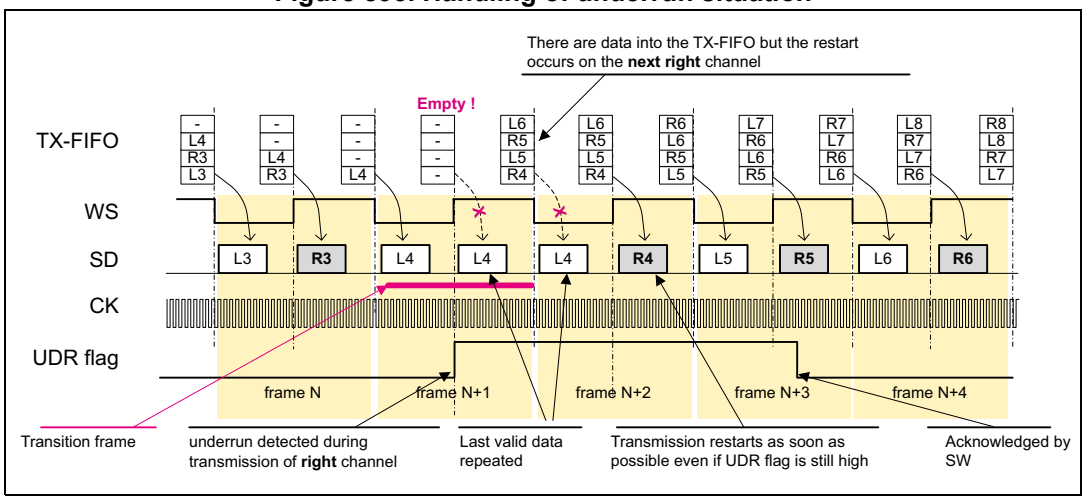
a. Not always available, refer to *Section 63.3: SPI implementation* in order to check if 24 and 32-bit data widths are supported.

For I2S modes, there is a hardware mechanism to prevent misalignment situations (left and right channel swapped). When an underrun situation is detected, the last valid data present in the shift register is repeated if the real channel length matches the length selected by the CHLEN bit. In the other cases, an undefined data is repeated. Typically, if the block is programmed in slave TX mode, and the external master audio device is using channel lengths other than 16 or 32 bits, the repeated data value is undefined in case of underrun.

The following figure shows the case where an underrun occurs and the peripheral replays the last valid data on left and right channels as long as conditions of restart are not met. The transmission restarts:

- When there is enough data into the TxFIFO, and
- When the restart condition is met:
  - If the underrun occurs when a right channel data needs to be transmitted, the transmission restarts when a right channel needs to be transmitted, or
  - If the underrun occurs when a left channel data needs to be transmitted, the transmission restarts when a left channel needs to be transmitted.

Figure 893. Handling of underrun situation



When the block is configured in one of the PCM modes, the transmission restarts at the start of the next frame, when there is enough data in the TxFIFO.

The UDR flag can trigger an interrupt if the UDRIE bit of the SPI_IER register is set. The UDR bit is cleared by setting the UDRC bit of the SPI_IFCR register.

Note: An underrun situation can occur in master or slave mode. In master mode, when an underrun occurs, the WS, CK, and MCK signals are not gated.

Due to resynchronization, any change of the UDR flag is taken into account by the hardware after at least two periods of CK clock.

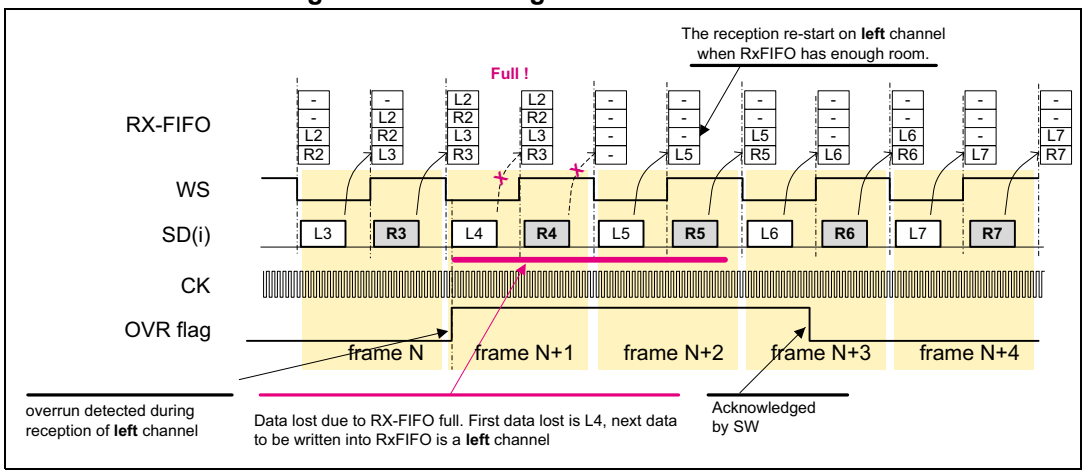
63.9.13 Handling of overrun situation

In receive mode, an overrun situation is detected when the shift register needs to store a new data into the RxFIFO, while the RxFIFO is full. In such a situation the OVR flag is set, and the incoming data is lost.

In I2S mode, there is a hardware mechanism in to prevent misalignment situations (left and right channel swapped). As shown in the following figure, when an overrun occurs, the peripheral stops writing data into the RxFIFO as long as restart conditions are not met.

The reception restarts when there is enough room into the RxFIFO. The block starts by writing next the right channel into the RxFIFO if the overrun occurs when a right channel data is received or by writing the next left channel if the overrun occurs when a left channel data is received.

Figure 894. Handling of overrun situation



When the block is configured in PCM mode, after an overrun error, the block stops writing data in the RxFIFO as long as conditions of restart are not met. When there is enough room in the RxFIFO, the next received data are written in the RxFIFO.

An interrupt can be generated if the OVRIE bit of the SPI_IER register is set. The OVR bit is cleared by setting the OVRC bit of the SPI_IFCR register.

Note: An overrun situation can occur in master or slave mode. In master mode when an overrun occurs, the WS, CK, and MCK signals are not gated.

63.9.14 Frame error detection

When configured in slave mode, the SPI/I2S block detects two kinds of frame errors:

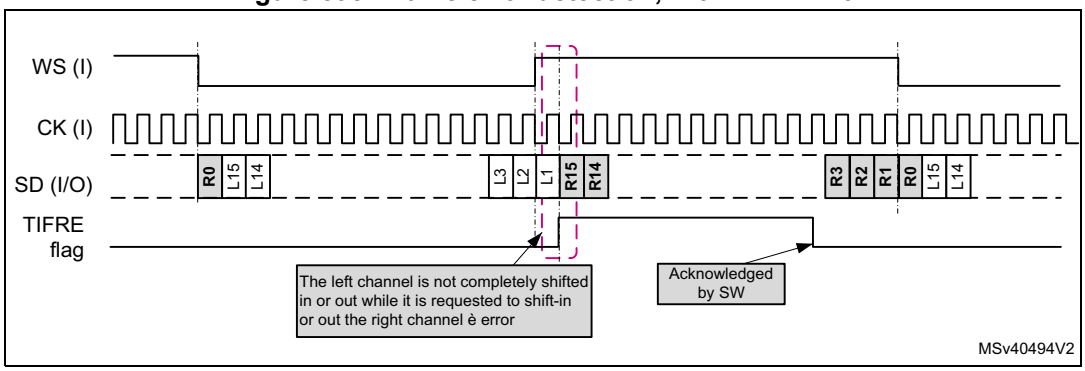
- A frame synchronization is received while the shift-in or shift-out of the previous data is not complete (early frame error). This mode is selected with FIXCH = 0.
- A frame synchronization occurs at an unexpected position. This mode is selected with FIXCH = 1.

In slave mode, if the frame length provided by the external master device is different from 32 or 64 bits, the user has to clear FIXCH. As the SPI/I2S synchronize each transfer with the WS there is no misalignment risk, but in a noisy environment, if a glitch occurs in the CK signal, a sample may be affected and the application is not aware of this.

If the frame length provided by the external master device is equal to 32 or 64 bits, then the user can set FIXCH and adjust accordingly CHLEN. As the SPI/I2S synchronize each transfer with the WS there is still no misalignment risk, and if the amount of bit clock between each channel boundary is different from CHLEN, the frame error flag (TIFRE) is set.

Figure 895 shows an example of frame error detection. The SPI/I2S block is in slave mode and the number of bit clock periods for the left channel are not enough to shift-in or shift-out the data. The figure shows that the ongoing transfer is interrupted and the next one is started in order to remain aligned to the WS signal.

Figure 895. Frame error detection, with FIXCH = 0

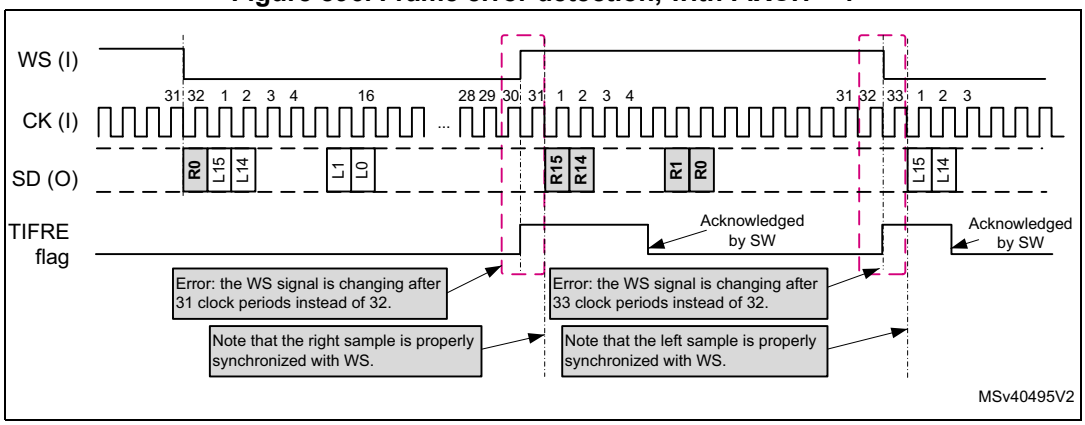


An interrupt can be generated if the TIFREIE bit is set. The frame error flag (TIFRE) is cleared by writing the TIFREC bit of the SPI_IFCR register to 1.

It is possible to extend the coverage of the frame error flag by setting the bit FIXCH. When this bit is set, then the SPI/I2S is expecting fixed channel lengths in slave mode. This means that the expected channel length can be 16 or 32 bits, according to CHLEN. As shown in *Figure 896*, in this mode, the SPI/I2S block is able to detect if the WS signal is changing at the expected moment (too early or too late).

Note: *Figure 895* and *Figure 896* show the mechanism for the slave transmit mode, but this is also true for slave receive and slave full-duplex.

Figure 896. Frame error detection, with FIXCH = 1



The frame error detection can be generally due to noisy environment disturbing the good reception of WS or CK signals.

Note: *The SPI/I2S is not able to recover properly if an overrun and an early frame occur within the same frame. In this case the user has to disable and re-enable the SPI/I2S.*

63.9.15 DMA interface

The I2S/PCM mode shares the same DMA requests lines than the SPI function. There is a separated DMA channel for TX and RX paths. Each DMA channel can be enabled via RXDMAEN and TXDMAEN bits of the SPI_CFG1 register.

In receive mode, the DMA interface is working as follows:

1. The hardware evaluates the RxFIFO level,
2. If the RxFIFO contains at least FTHLV samples, then FTHLV DMA requests are generated,
   – When the FTHLV DMA requests are completed, the hardware loops to step 1
3. If the RxFIFO contains less than FTHLV samples, no DMA request is generated, and the hardware loop to step 1

In transmit mode, the DMA interface is working as follows:

1. The hardware evaluates the TxFIFO level,
2. If the TxFIFO contains at least FTHLV empty locations, then FTHLV DMA requests are generated,
   – When the FTHLV DMA requests are completed, the hardware loops to step 1
3. If the TxFIFO contains less than FTHLV empty locations, no DMA request is generated, and the hardware loop to step 1

63.9.16 Programing examples

Master I2S Philips standard, full-duplex

This example shows how to program the interface for supporting the I2S Philips standard protocol in master full-duplex mode, with a sampling rate of 48 kHz, using the master clock. The assumption has been taken that the SPI/I2S is receiving a kernel clock (i2s_clk) of 61.44 MHz from the clock controller of the circuit. In the example above we took the assumption that the external audio codec needs to be programmed, for example via an I2C interface before starting the transfer. In addition, it is supposed that this external audio codec needs the MCK to accept I2C commands.

Procedure

1. Via the RCC block, enable the bus interface and the kernel clocks, assert and release the reset signal if needed.
2. Program the AFMUX in order to select the wanted I/Os. In the current example MCK, CK, WS, SDO, SDI are needed.
3. Program the clock generator to provide the MCK clock, and to have a frame synchronization rate at exactly 48 kHz. Set I2SDIV to 2, ODD to 1, and MCKOE to 1.
4. Program the serial interface protocol: CKPOL = 0, WSINV = 0, LSBFRST = 0, CHLEN = 1 (32 bits per channel) DATLEN = 1 (24 bits), I2SSTD = 0 (I2S Philips standard), I2SCFG = 5 (master full-duplex), I2SMOD = 1, for I2S/PCM mode.
5. Adjust the FIFO threshold by setting the wanted value into FTHLV. For example, if a threshold of two audio samples is required, FTHLV = 1.
6. If the application wishes to perform data transfer via DMA, set the bits TXDMAEN and RXDMAEN.
7. If needed, the application can then configure the external audio codec via an I2C interface.
8. Clear all interrupt enable fields located in the SPI_IER register.
9. Clear all status flags, by setting SUSPC, TIFREC, OVRC, UDRC of the SPI_IFCR register.
10. When the application wants to start the data transfer, set the SPE bit. Then:
    - If the data transfer uses DMA:
    a) Program the DMA peripheral: two channels, one for RX and one for TX.
    b) Initialize the memory buffer with valid audio samples for TX path.
    c) Enable the DMA channels.
    d) Enable interrupt events such as UDRIE and OVRIE if needed in order to detect transfer errors.
    e) Enable the DMA channel. If TXDMAEN was set, the TxFIFO is filled up.
    - If the data transfer is done via interrupt:

      Enable the interrupt events UDRIE, OVRIE, TXPIE, and RXPIE (by writing 1). An interrupt request is immediately activated allowing the interrupt handler to fill-up the TxFIFO.
11. Finally, the SPI/I2S serial interface can be enabled by setting the bit CSTART. CSTART bit is located into the SPI_CR1 register.

Stop procedure in master mode

1. Set the bit CSUSP, in order to stop ongoing transfers
2. Check the value of the CSTART bit until it goes to 0
3. Clear the SUSP flag by setting SUSPC
4. Stop DMA peripheral, bus clock...
5. Clear bit SPE in order to disable the SPI/I2S block

Slave I2S Philips standard, receive

This example shows how to program the interface for supporting the I2S Philips standard protocol in slave receiver mode, with a sampling rate of 48 kHz. Note that in slave mode the

SPI/I2S block cannot control the sample rate of the received samples. In this example we took the assumption that the external master device is delivering an I2S frame structure with a channel length of 24 bits. So, we cannot use the capability offered for frame error detection when FIXCH is set.

Procedure

1. Via the RCC block, enable the bus interface and the kernel clocks, assert and release the reset signal if needed,
2. Program the AFMUX in order to select the wanted I/Os. In the current example CK, WS, SDI,
3. Program the serial interface protocol: CKPOL = 0, WSINV = 0, LSBFRST = 0, FIXCH = 0 (because channel length is different from 16 and 32 bits), DATLEN = 0 (16 bits), I2SSTD = 0 (Philips protocol), I2SCFG = 1 (slave RX), I2SMOD = 1, for I2S mode.
4. Adjust the FIFO threshold by setting the wanted value into FTHLV. For example if a threshold of two audio samples is required, FTHLV = 1.
5. Clear all status flag registers.
6. Enable the flags that generate an interrupt such as OVRIE and TIFRE.
7. If the data transfer uses DMA:
   – Program the DMA peripheral: one RX channel
   – Enable the DMA channel,
   – In the SPI/I2S block, enable the DMA by setting the RXDMAEN bit.
8. If the data transfer is done via interrupt, then the user has to enable the interrupt by setting the RXPIE bit.
9. Set SPE.
10. Finally, the user can set the bit CSTART in order to enable the serial interface. The SPI/I2S starts to store data into the RxFIFO on the next occurrence of left data transmitted by the external master device.

Stop procedure in slave mode

1. Clear bit SPE in order to disable the SPI/I2S block
2. Stop DMA peripheral, bus clock...

63.10 I2S interrupts

In PCM/I2S mode an interrupt (**spi_it**) or a wake-up event signal (**spi_wkup**) can be generated according to the events described in the *Table 697*.

Interrupt events can be enabled and disabled separately.

Table 697. I2S interrupt requests

Interrupt vector	Interrupt event	Event flag	Event/Interrupt clearing method	Exit Sleep mode	Exit Stop modes	Exit Standby mode
SPI	TxFIFO threshold reached	TXP	When the TxFIFO contains less than FTHLV empty locations	Yes	Yes	No
	RxFIFO threshold reached	RXP	When the RxFIFO contains less than FTHLV samples			
	Overrun error	OVR	Write OVRC to 1			
	Underrun error	UDR	Write UDRC to 1			
	Frame error flag	TIFRE	Write TIFREC to 1		No	

63.11 SPI/I2S registers

63.11.1 SPI/I2S control register 1 (SPI_CR1)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IOLOCK
															rs
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TCRCINI	RCRCINI	CRC33_17	SSI	HDDIR	CSUSP	CSTART	MASRX	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SPE
rw	rw	rw	rw	rw	w	rs	rw								rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **IOLOCK**: locking the AF configuration of associated I/Os

This bit can be changed by software only when SPI is disabled (SPE = 0). It is cleared by hardware if a MODF event occurs

When this bit is set, the SPI_CFG2 register content cannot be modified. This bit is write-protected when SPI is enabled (SPE = 1).

0: AF configuration is not locked

1: AF configuration is locked

Bit 15 **TCRCINI**: CRC calculation initialization pattern control for transmitter

0: all zero pattern is applied

1: all ones pattern is applied

Bit 14 **RCRCINI**: CRC calculation initialization pattern control for receiver

0: All zero pattern is applied

1: All ones pattern is applied

Bit 13 **CRC33_17**: Full size (33-bit or 17-bit) CRC polynomial configuration

0: Full size (33-bit or 17-bit) CRC polynomial is not used

1: Full size (33-bit or 17-bit) CRC polynomial is used

Bit 12 **SSI:** Internal slave select signal input level

This bit has an effect only when the SSM bit is set. The value of this bit is forced onto the peripheral NSS input internally and the I/O value of the NSS pin is ignored.

Bit 11 **HDDIR:** Rx/Tx direction at half-duplex mode

In half-duplex configuration the HDDIR bit establishes the Rx/Tx direction of the data transfer. This bit is ignored in Full-Duplex or any Simplex configuration.

0: SPI is receiver

1: SPI is transmitter

Bit 10 **CSUSP:** master suspend request

This bit reads as zero.

In master mode, when this bit is set by software, the CSTART bit is reset at the end of the current frame and communication is suspended. The user has to check SUSP flag to check end of the frame transfer.

The master mode communication must be suspended (using this bit or keeping TXDR empty) before going to Low-power mode.

After software suspension, SUSP flag must be cleared and SPI disabled and re-enabled before the next transfer starts.

Bit 9 **CSTART:** master transfer start

This bit can be set by software if SPI is enabled only to start an SPI or I2S/PCM communication. In SPI mode, it is cleared by hardware when end of transfer (EOT) flag is set or when a transfer suspend request is accepted. In I2S/PCM mode, it is also cleared by hardware as described in the *Section 63.9.8: Stop sequence*.

In SPI mode, the bit is taken into account at master mode only. If transmission is enabled, communication starts or continues only if any data is available in the transmission FIFO.

0: master transfer is at idle

1: master transfer is ongoing or temporary suspended by automatic suspend

Bit 8 **MASRX:** master automatic suspension in Receive mode

This bit is set and cleared by software to control continuous SPI transfer in master receiver mode and automatic management in order to avoid overrun condition.

When SPI communication is suspended by hardware automatically, it may happen that few bits of next frame are already clocked out due to internal synchronization delay.

This is why, the automatic suspension is not quite reliable when size of data drops below 8 bits. In this case, a safe suspension can be achieved by combination with delay inserted between data frames applied when MIDI parameter keeps a non zero value; sum of data size and the interleaved SPI cycles must always produce interval at length of 8 SPI clock periods at minimum. After software clearing of the SUSP bit, the communication resumes and continues by subsequent bits transfer without any next constraint. Before the SUSP bit is cleared, the user must release the RxFIFO space as much as possible by reading out all the data packets available at RxFIFO based on the RXP flag indication to prevent any subsequent suspension.

0: SPI flow/clock generation is continuous, regardless of overrun condition. (data are lost)

1: SPI flow is suspended temporary on RxFIFO full condition, before reaching overrun condition. The SUSP flag is set when the SPI communication is suspended.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **SPE:** serial peripheral enable

This bit is set by and cleared by software.

When SPE = 1, SPI data transfer is enabled, the SPI_CFG1 and SPI_CFG2 configuration registers, CRCPOLY, UDRDR, IOLOCK bit in the SPI_CR1 register are write protected. They can be changed only when SPE = 0.

When SPE = 0 any SPI operation is stopped and disabled, all the pending requests of the events with enabled interrupt are blocked except the MODF interrupt request (but their pending still propagates the request of the spi_plck clock), the NSS output is deactivated at master, the RDY signal keeps not ready status at slave, the internal state machine is reseted, all the FIFOs content is flushed, CRC calculation initialized, receive data register is read zero. SPE is cleared and cannot be set when MODF error flag is active.

0: Serial peripheral disabled.

1: Serial peripheral enabled

63.11.2 SPI/I2S control register 2 (SPI_CR2)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSIZE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **TSIZE[15:0]**: number of data at current transfer

When these bits are changed by software, the SPI must be disabled.

Endless transfer is initialized when CSTART is set while zero value is stored in TSIZE. TSIZE cannot be set to 0xFFFF for a full-featured instance and 0x3FF for a limited-featured instance, when CRC is enabled.

Note: TSIZE[15:10] bits are reserved for limited-featured instances, and must be kept at reset value.

63.11.3 SPI/I2S configuration register 1 (SPI_CFG1)

Address offset: 0x008

Reset value: 0x0007 0007

The content of this register is write protected when SPI is enabled.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BPASS	MBR[2:0]			Res.	Res.	Res.	DRDS	Res.	CRCEN	Res.	CRCSIZE[4:0]				
rw	rw	rw	rw				rw		rw		rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXDMAEN	RXDMAEN	Res.	Res.	Res.	Res.	UDRCFG	FTHLV[3:0]				DSIZE[4:0]				
rw	rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **BPASS:** bypass of the prescaler at master baud rate clock generator
0: bypass is disabled
1: bypass is enabled

Bits 30:28 **MBR[2:0]:** master baud rate prescaler setting
000: SPI master clock/2
001: SPI master clock/4
010: SPI master clock/8
011: SPI master clock/16
100: SPI master clock/32
101: SPI master clock/64
110: SPI master clock/128
111: SPI master clock/256
Note: MBR setting is considered at slave working at TI mode, too (see Section 63.5.1: TI mode).

Bits 27:25 Reserved, must be kept at reset value.

Bit 24 **DRDS:** data sampling delay on master input (MISO)
This delay is used to compensate the delay on the MISO line (for example due to the signal optical isolation).
0: Sampling is performed on the configured SCK edge (no delay is applied)
1: Sampling is postponed by a fixed delay equal to a half SCK cycle (the sampling is performed just at the end of the bit validity interval at MISO line).
Note: The DRDS setting has no impact on the other SCK management nor on the data frame communication format. When the delay is applied together with CRC enabled, the CRC computation and evaluation is also delayed.

Bit 23 Reserved, must be kept at reset value.

Bit 22 **CRCEN:** hardware CRC computation enable
0: CRC calculation disabled
1: CRC calculation enabled

Bit 21 Reserved, must be kept at reset value.

Bits 20:16 **CRCSIZE[4:0]:** length of CRC frame to be transferred and compared

Most significant bits are taken into account from polynomial calculation when CRC result is transferred or compared. The length of the polynomial is not affected by this setting.

The value must be equal or a multiple of the data size configured through the DSIZE bitfield. Its maximum size corresponds to the instance maximum data size.

00000: not used
00001: not used
00010: not used
00011: 4 bits
00100: 5 bits
00101: 6 bits
00110: 7 bits
00111: 8 bits
.....
11101: 30 bits
11110: 31 bits
11111: 32 bits

Note: The most significant bit at CRCSIZE bit field is reserved for the peripheral instances where data size is limited to 16 bits.

The CRCSIZE[2:0] bits are fixed to 1 for the peripheral instances with a limited set of features.

Bit 15 **TXDMAEN:** Tx DMA stream enable

0: Tx DMA disabled
1: Tx DMA enabled

Bit 14 **RXDMAEN:** Rx DMA stream enable

0: Rx-DMA disabled
1: Rx-DMA enabled

Bits 13:10 Reserved, must be kept at reset value.

Bit 9 **UDRCFG:** behavior of slave transmitter at underrun condition

For more details see *Figure 877: Optional configurations of the slave behavior when an underrun condition is detected*.

0: slave sends a constant pattern defined by the user in the SPI_UDRDR register

1: Slave repeats the last received data from master. When slave is configured at transmit only mode (COMM[1:0] = 01), all zeros pattern is repeated.

Bits 8:5 **FTHLV[3:0]:** FIFO threshold level

Defines number of data frames in a single data packet. It is recommended that the size of the packet does not exceed 1/2 of FIFO space.

SPI interface is more efficient if configured packet sizes are aligned with data register access parallelism:

–If SPI data register is accessed as a 16-bit register and DSIZE ≤ 8 bits, better to select FTHLV = 2, 4, 6.

–If SPI data register is accessed as a 32-bit register and DSIZE > 8 bits, better to select FTHLV = 2, 4, 6, while if DSIZE ≤ 8 bits, better to select FTHLV = 4, 8, 12.

0000: 1-data
0001: 2-data
0010: 3-data
0011: 4-data
0100: 5-data
0101: 6-data
0110: 7-data
0111: 8-data
1000: 9-data
1001: 10-data
1010: 11-data
1011: 12-data
1100: 13-data
1101: 14-data
1110: 15-data
1111: 16-data

Note: FTHLV[3:2] bits are reserved for instances with a limited set of features.

Bits 4:0 **DSIZE[4:0]:** number of bits in a single SPI data frame

00000: not used
00001: not used
00010: not used
00011: 4 bits
00100: 5 bits
00101: 6 bits
00110: 7 bits
00111: 8 bits
.....
11101: 30 bits
11110: 31 bits
11111: 32 bits

Note: The most significant bit DSIZE[4] is reserved for instances which data size is limited to 16 bits.

DSIZE[2:0] bits are fixed to 1 for instances with a limited set of features.

63.11.4 SPI/I2S configuration register 2 (SPI_CFG2)

Address offset: 0x00C

Reset value: 0x0000 0000

The content of this register is write-protected when SPI is enabled or the IOLOCK bit is set in the SPI_CR1 register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AFCNTR	SSOM	SSOE	SSIOP	Res.	SSM	CPOL	CPHA	LSBFRST	MASTER	SP[2:0]			COMM[1:0]		Res.
rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IOSWP	RDIOP	RDIOM	Res.	Res.	Res.	Res.	Res.	MIDI[3:0]				MSSI[3:0]			
rw	rw	rw						rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **AFCNTR:** alternate function GPIOs control

This bit is taken into account when SPE = 0 only.

When SPI must be disabled temporary for a specific configuration reason (for example CRC reset, CPHA or HDDIR change) setting this bit prevents any glitches on the associated outputs configured at alternate function mode by keeping them forced at state corresponding the current SPI configuration.

0: The peripheral takes no control of GPIOs while it is disabled

1: The peripheral keeps always control of all associated GPIOs

Note: This bit can be also used in PCM and I2S modes.

The bit AFCNTR must not be set, when the block is in slave mode.

Bit 30 **SSOM**: NSS output management in master mode

This bit is taken into account in master mode when SSOE is enabled. It allows the NSS output to be configured between two consecutive data transfers.

0: NSS is kept at active level until data transfer is complete, it becomes inactive with EOT flag

1: SPI data frames are interleaved with NSS nonactive pulses when MIDI[3:0] > 1

Bit 29 **SSOE:** NSS output enable

This bit is taken into account in master mode only

0: NSS output is disabled and the SPI can work in multimaster configuration

1: NSS output is enabled. The SPI cannot work in a multimaster environment. It forces the NSS pin at inactive level after the transfer is complete or SPI is disabled with respect to SSOM, MIDI, MSSI, SSIOP bits setting

Bit 28 **SSIOP**: NSS input/output polarity

0: low level is active for NSS signal

1: high level is active for NSS signal

Bit 27 Reserved, must be kept at reset value.

Bit 26 **SSM:** Software management of internal slave select signal input

0: Input value of the internal slave select signal is determined by the external NSS hardware pin

1: Input value of the internal slave select signal is determined by the SSI bit controlled by software

Note: When master uses hardware NSS output (SSM = 0 and SSOE = 1), the internal slave select signal input is forced to not active state internally to prevent master mode fault error.

Bit 25 **CPOL:** clock polarity
0: SCK signal is at 0 when idle
1: SCK signal is at 1 when idle

Bit 24 **CPHA:** clock phase
0: the first clock transition is the first data capture edge
1: the second clock transition is the first data capture edge

Bit 23 **LSBFRST:** data frame format
0: MSB transmitted first
1: LSB transmitted first
Note: This bit can be also used in PCM and I2S modes.

Bit 22 **MASTER:** SPI master
0: SPI slave
1: SPI master

Bits 21:19 **SP[2:0]:** serial protocol
000: SPI Motorola
001: SPI TI
others: reserved, must not be used

Bits 18:17 **COMM[1:0]:** SPI Communication Mode
00: full-duplex
01: simplex transmitter
10: simplex receiver
11: half-duplex

Bit 16 Reserved, must be kept at reset value.

Bit 15 **IOSWP:** swap functionality of MISO and MOSI pins
When this bit is set, the function of MISO and MOSI pins alternate functions are inverted. Original MISO pin becomes MOSI and original MOSI pin becomes MISO.
0: no swap
1: MOSI and MISO are swapped
Note: This bit can be also used in PCM and I2S modes to swap SDO and SDI pins.

Bit 14 **RDIOP:** RDY signal input/output polarity
0: high level of the signal means the slave is ready for communication
1: low level of the signal means the slave is ready for communication

Bit 13 **RDIOM:** RDY signal input/output management
0: RDY signal is defined internally fixed as permanently active (RDIOP setting has no effect)
1: RDY signal is overtaken from alternate function input (at master case) or output (at slave case) of the dedicated pin (RDIOP setting takes effect)
Note: When DSIZE in the SPI_CFG1 register is configured shorter than 8 bits, the RDIOM bit must be kept at zero.

Bits 12:8 Reserved, must be kept at reset value.

Bits 7:4 **MIDI[3:0]**: Master Inter-Data Idleness

Specifies minimum time delay (expressed in SPI clock cycles periods) inserted between two consecutive data frames in master mode.

0000: no delay

0001: 1 clock cycle period delay

...

1111: 15 clock cycle periods delay

Note: This feature is not supported in TI mode.

Bits 3:0 **MSSI[3:0]**: Master NSS Idleness

Specifies an extra delay, expressed in number of SPI clock cycle periods, inserted additionally between active edge of NSS opening a session and the beginning of the first data frame of the session in master mode when SSOE is enabled.

0000: no extra delay

0001: 1 clock cycle period delay added

...

1111: 15 clock cycle periods delay added

Note: This feature is not supported in TI mode.
To include the delay, the SPI must be disabled and re-enabled between sessions.

63.11.5 SPI/I2S interrupt enable register (SPI_IER)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	MODFIE	TIFREIE	CRCEIE	OVRIE	UDRIE	TXTFIE	EOTIE	DXPIE	TXPIE	RXPIE
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:10 Reserved, must be kept at reset value.

Bit 9 **MODFIE**: mode Fault interrupt enable

0: MODF interrupt disabled

1: MODF interrupt enabled

Bit 8 **TIFREIE**: TIFRE interrupt enable

0: TIFRE interrupt disabled

1: TIFRE interrupt enabled

Bit 7 **CRCEIE:** CRC error interrupt enable

0: CRC interrupt disabled

1: CRC interrupt enabled

Bit 6 **OVRIE:** OVR interrupt enable

0: OVR interrupt disabled

1: OVR interrupt enabled

Bit 5 **UDRIE:** UDR interrupt enable
0: UDR interrupt disabled
1: UDR interrupt enabled

Bit 4 **TXTFIE:** TXTF interrupt enable
0: TXTF interrupt disabled
1: TXTF interrupt enabled

Bit 3 **EOTIE:** EOT, SUSP and TXC interrupt enable
0: EOT/SUSP/TXC interrupt disabled
1: EOT/SUSP/TXC interrupt enabled

Bit 2 **DXPIE**: DXP interrupt enabled
DXPIE is set by software and cleared by TXTF flag set event.
0: DXP interrupt disabled
1: DXP interrupt enabled

Bit 1 **TXPIE:** TXP interrupt enable
TXPIE is set by software and cleared by TXTF flag set event.
0: TXP interrupt disabled
1: TXP interrupt enabled

Bit 0 **RXPIE:** RXP interrupt enable
0: RXP interrupt disabled
1: RXP interrupt enabled

63.11.6 SPI/I2S status register (SPI_SR)

Address offset: 0x014

Reset value: 0x0000 1002

All the flags of this register are not cleared automatically when the SPI is reenabled. They require specific clearing access exclusively via the flag clearing register as noted in the bits descriptions below.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CTSIZE[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXWNE	RXPLVL[1:0]		TXC	SUSP	Res.	MODF	TIFRE	CRCE	OVR	UDR	TXTF	EOT	DXP	TXP	RXP
r	r	r	r	r		r	r	r	r	r	r	r	r	r	r

Bits 31:16 **CTSIZE[15:0]**: number of data frames remaining in current TSIZE session
The value is not quite reliable when traffic is ongoing on bus .
Note: CTSIZE[15:0] bits are not available in instances with limited set of features.

Bit 15 **RXWNE:** RxFIFO word not empty
0: less than four bytes of RxFIFO space is occupied by data
1: at least four bytes of RxFIFO space is occupied by data
Note: This bit value does not depend on DSIZE setting and keeps together with RXPLVL[1:0] information about RxFIFO occupancy by residual data.

Bits 14:13 **RXPLVL[1:0]:** RxFIFO packing level

When RXWNE = 0 and data size is set up to 16 bits, the value gives number of remaining data frames persisting at RxFIFO.

When data size is greater than 16 bits, these bits are always read as 00. As a result, the single data frame received in the FIFO cannot be detected neither by RWNE nor by RXPLVL bits if the data size is set from 17 to 24 bits. The user must then apply other methods to detect the number of data received, such as monitor the EOT event when TSIZE > 0 or RXP events when FTHLV = 0.

00: no next frame is available at RxFIFO

01: 1 frame is available

10: 2 frames are available*

11: 3 frames are available*

Note: (*): Possible value when data size is set up to 8 bits only.

Bit 12 **TXC:** TxFIFO transmission complete

The flag behavior depends on TSIZE setting.

When TSIZE = 0, the TXC is changed by hardware exclusively and it raises each time the TxFIFO becomes empty and there is no activity on the bus.

If TSIZE ≠ 0 there is no specific reason to monitor TXC as it just copies the EOT flag value including its software clearing. The TXC generates an interrupt when EOTIE is set.

This flag is set when SPI is reset or disabled.

0: current data transfer is still ongoing, data is available in TxFIFO or last frame transmission is on going.

1: last TxFIFO frame transmission complete

Bit 11 **SUSP:** suspension status

In master mode, SUSP is set by hardware either as soon as the current frame is complete after CSUSP request is done or at master automatic suspend receive mode (the MASRX bit is set in the SPI_CR1 register) on RxFIFO full condition.

SUSP generates an interrupt when EOTIE is set.

This bit must be cleared prior to disabling the SPI. This is done by setting the SUSPC bit of SPI_IFCR exclusively.

0: SPI not suspended (master mode active or other mode).

1: master mode is suspended (current frame completed).

Bit 10 Reserved, must be kept at reset value.

Bit 9 **MODF**: mode fault

When MODF is set, SPE and IOLOCK bits of the SPI_CR1 register are reset and setting SPE again is blocked until MODF is cleared.

This bit is cleared by writing 1 to the MODFC bit of the SPI_IFCR exclusively.

0: no mode fault

1: mode fault detected.

Bit 8 **TIFRE**: TI frame format error

This bit is cleared by writing 1 to the TIFREC bit of the SPI_IFCR exclusively.

0: no TI Frame Error

1: TI frame error detected

Bit 7 **CRCE:** CRC error

This bit is cleared when SPI is re-enabled or by writing 1 to the CRCEC bit of the SPI_IFCR optionally.

0: no CRC error

1: CRC error detected

Bit 6 **OVR:** overrun

This bit is cleared when SPI is re-enabled or by writing 1 to the OVRC bit of the SPI_IFCR optionally.

0: no overrun

1: overrun detected

Bit 5 **UDR:** underrun

This bit is cleared when SPI is re-enabled or by writing 1 to the UDRC bit of the SPI_IFCR optionally.

0: no underrun

1: underrun detected

Note: In SPI mode, the UDR flag applies to slave mode only. In I2S/PCM mode, (when available) this flag applies to master and slave mode.

Bit 4 **TXTF:** transmission transfer filled

TXTF is set by hardware as soon as all of the data packets in a transfer have been submitted for transmission by application software or DMA, that is when TSIZE number of data have been pushed into the TxFIFO.

This bit is cleared by software write 1 to the TXTFC bit of the SPI_IFCR exclusively.

The TXTF flag triggers an interrupt if the TXTFIE bit is set.

TXTF setting clears the TXPIE and DXPIE masks so to off-load application software from calculating when to disable TXP and DXP interrupts.

0: upload of TxFIFO is ongoing or not started

1: TxFIFO upload is finished

Bit 3 **EOT:** end of transfer

EOT is set by hardware as soon as a full transfer is complete, that is when SPI is re-enabled or when TSIZE number of data have been transmitted and/or received on the SPI. EOT is cleared when SPI is re-enabled or by writing 1 to the EOTC bit of the SPI_IFCR register optionally.

EOT flag triggers an interrupt if the EOTIE bit is set.

If DXP flag is used until TXTF flag is set and DXPIE is cleared, EOT can be used to download the last packets contained into RxFIFO in one-shot.

In master, EOT event terminates the data transfer and handles NSS output optionally. When CRC is applied, the EOT event is extended over the CRC frame transfer.

To restart the internal state machine properly, SPI is strongly suggested to be disabled and re-enabled before next transfer starts despite its setting is not changed.

0: transfer is ongoing or not started

1: transfer complete

Bit 2 **DXP**: duplex packet

DXP flag is set whenever both TXP and RXP flags are set regardless SPI mode.

0: TxFIFO is Full and/or RxFIFO is Empty

1: both TxFIFO has space for write and RxFIFO contains for read a single packet at least

Bit 1 **TXP:** Tx-packet space available

TXP flag can be changed only by hardware. Its value depends on the physical size of the FIFO and its threshold (FTHLV[3:0]), data frame size (DSIZE[4:0] in SPI mode and respective DATLEN[1:0] in I2S/PCM mode), and actual communication flow. If the data packet is stored by performing consecutive write operations to SPI_TXDR, TXP flag must be checked again once a complete data packet is stored at TxFIFO. TXP is set despite SPI TxFIFO becomes inaccessible when SPI is reset or disabled.

0: not enough free space at TxFIFO to host next data packet

1: enough free space at TxFIFO to host at least one data packet

Bit 0 **RXP:** Rx-packet available

The flag is changed by hardware. It monitors the total number of data currently available at RxFIFO if SPI is enabled. RXP value depends on the FIFO threshold (FTHLV[3:0]), data frame size (DSIZE[4:0] in SPI mode and DATLEN[1:0] in I2S/PCM mode), and actual communication flow. If the data packet is read by performing consecutive read operations from SPI_RXDR, RXP flag must be checked again once a complete data packet is read out from RxFIFO.

0: RxFIFO is empty or an incomplete data packet is received

1: RxFIFO contains at least one data packet

63.11.7 SPI/I2S interrupt/status flags clear register (SPI_IFCR)

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	SUSPC	Res.	MODFC	TIFREC	CRCEC	OVRC	UDRC	TXTFC	EOTC	Res.	Res.	Res.
				w		w	w	w	w	w	w	w			

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **SUSPC:** Suspend flag clear

Writing a 1 into this bit clears SUSP flag of the SPI_SR register

Bit 10 Reserved, must be kept at reset value.

Bit 9 **MODFC**: mode fault flag clear

Writing a 1 into this bit clears MODF flag of the SPI_SR register

Bit 8 **TIFREC**: TI frame format error flag clear

Writing a 1 into this bit clears TIFRE flag of the SPI_SR register

Bit 7 **CRCEC:** CRC error flag clear

Writing a 1 into this bit clears CRCE flag of the SPI_SR register

Bit 6 **OVRC:** overrun flag clear

Writing a 1 into this bit clears OVR flag of the SPI_SR register

Bit 5 **UDRC:** underrun flag clear

Writing a 1 into this bit clears UDR flag of the SPI_SR register

Bit 4 **TXTFC:** transmission transfer filled flag clear

Writing a 1 into this bit clears TXTF flag of the SPI_SR register

Bit 3 **EOTC:** end of transfer flag clear

Writing a 1 into this bit clears EOT flag of the SPI_SR register

Bits 2:0 Reserved, must be kept at reset value.

63.11.8 SPI/I2S transmit data register (SPI_TXDR)

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXDR[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXDR[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **TXDR[31:0]:** transmit data register

The register serves as an interface with TxFIFO. A write to it accesses TxFIFO.

Note: In SPI mode, data is always right-aligned. Alignment of data at I2S mode depends on DATLEN and DATFMT setting. Unused bits are ignored when writing to the register, and read as zero when the register is read.

Note: DR can be accessed byte-wise (8-bit access): in this case only one data-byte is written by single access.

half-word-wise (16 bit access) in this case 2 data-bytes or 1 half-word-data can be written by single access.

word-wise (32 bit access). In this case 4 data-bytes or 2 half-word-data or word-data can be written by single access.

Write access of this register less than the configured data size is forbidden.

63.11.9 SPI/I2S receive data register (SPI_RXDR)

Address offset: 0x030

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXDR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXDR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXDR[31:0]:** receive data register

The register serves as an interface with RxFIFO. When it is read, RxFIFO is accessed.

Note: In SPI mode, data is always right-aligned. Alignment of data at I2S mode depends on DATLEN and DATFMT setting. Unused bits are read as zero when the register is read. Writing to the register is ignored.

Note: DR can be accessed byte-wise (8-bit access): in this case only one data-byte is read by single access

half-word-wise (16 bit access) in this case 2 data-bytes or 1 half-word data can be read by single access

word-wise (32 bit access). In this case 4 data-bytes or 2 half-word data or word-data can be read by single access.

Read access of this register less than the configured data size is forbidden.

63.11.10 SPI/I2S polynomial register (SPI_CRCPOLY)

Address offset: 0x040

Reset value: 0x0000 0107

The content of this register is write protected when SPI is enabled.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CRCPOLY[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CRCPOLY[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CRCPOLY[31:0]:** CRC polynomial register

This register contains the polynomial for the CRC calculation.

The default 9-bit polynomial setting 0x107 corresponds to default 8-bit setting of DSIZE. It is compatible with setting 0x07 used in other ST products with fixed length of the polynomial string, where the most significant bit of the string is always kept hidden.

Length of the polynomial is given by the most significant bit of the value stored in this register. It must be set greater than DSIZE. CRC33_17 bit must be set additionally with CRCPOLY register when DSIZE is configured to maximum data size and CRC is enabled (to keep polynomial length grater than data size).

Note: CRCPOLY[31:16] bits are reserved for instances with data size limited to 16 bits. There is no constrain when 32-bit access is applied at these addresses. Reserved bits 31-16 are always read zero while any write to them is ignored.

63.11.11 SPI/I2S transmitter CRC register (SPI_TXCRC)

Address offset: 0x044

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXCRC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXCRC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXCRC[31:0]:** CRC register for transmitter

When CRC calculation is enabled, the TXCRC[31:0] bits contain the computed CRC value of the subsequently transmitted bytes. CRC calculation is initialized when the CRCEN bit of the SPI_CR1 register is set or when a data block is transferred completely. The CRC is calculated serially using the polynomial programmed in the SPI_CRCPOLY register.

The number of bits considered at calculation depends on the SPI_CRCPOLY register and CRCSIZE bits settings in the SPI_CFG1 register.

Note: A read to this register when the communication is ongoing may return an incorrect value.

Note: This bitfield is not used in I2S mode.

Note: TXCRC[31-16] bits are reserved for instances with data size limited to 16 bits. There is no constrain when 32-bit access is applied at these addresses. Reserved bits 31-16 are always read zero while any write to them is ignored.

Note: The configuration of the CRCSIZE bitfield is not taken into account when the content of this register is read by software. No masking is applied for unused bits in this case.

63.11.12 SPI/I2S receiver CRC register (SPI_RXCRC)

Address offset: 0x048

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXCRC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXCRC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXCRC[31:0]:** CRC register for receiver

When CRC calculation is enabled, the RXCRC[31:0] bits contain the computed CRC value of the subsequently received bytes. CRC calculation is initialized when the CRCEN bit of the SPI_CR1 register is set or when a data block is transferred completely. The CRC is calculated serially using the polynomial programmed in the SPI_CRCPOLY register.

The number of bits considered at calculation depends on the SPI_CRCPOLY register and CRCSIZE bits settings in the SPI_CFG1 register.

Note: A read to this register when the communication is ongoing may return an incorrect value.

Note: This bitfield is not used in I2S mode.

Note: RXCRC[31-16] bits are reserved for the peripheral instances with data size limited to 16 bits. There is no constrain when 32-bit access is applied at these addresses. Reserved bits 31-16 are always read zero while any write to them is ignored.

Note: The configuration of CRCSIZE bit field is not taken into account when the content of this register is read by software. No masking is applied for unused bits in this case.

63.11.13 SPI/I2S underrun data register (SPI_UDRDR)

Address offset: 0x04C

Reset value: 0x0000 0000

The content of this register is write protected when SPI is enabled.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UDRDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
UDRDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **UDRDR[31:0]:** data at slave underrun condition

The register is taken into account in slave mode and at underrun condition only. The number of bits considered depends on the DSIZE bit setting in the SPI_CFG1 register. Underrun condition handling depends on the UDRCFG bit setting in the SPI_CFG1 register.

Note: UDRDR[31-16] bits are reserved for the peripheral instances with data size limited to 16 bits. There is no constraint when 32-bit access is applied at these addresses. Reserved bits 31-16 are always read zero while any write to them is ignored.

63.11.14 SPI/I2S configuration register (SPI_I2SCFGR)

Address offset: 0x050

Reset value: 0x0000 0000

This register must be configured when the I2S is disabled (SPE = 0). The content of this register is not taken into account in SPI mode except for the I2SMOD bit, which needs to be kept at 0.

This register is reserved for instances not supporting I2S mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	MCKOE	ODD	I2SDIV[7:0]							
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	DATFMT	WSINV	FIXCH	CKPOL	CHLEN	DATLEN[1:0]		PCMSYNC	Res.	I2SSTD[1:0]		I2SCFG[2:0]			I2SMOD
	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **MCKOE**: master clock output enable

0: Master clock output is disabled

1: Master clock output is enabled

Bit 24 **ODD**: odd factor for the prescaler

Refer to *Section 63.9.9: Clock generator* for details

0: Real divider value is = I2SDIV *2

1: Real divider value is = (I2SDIV * 2) + 1

Bits 23:16 **I2SDIV[7:0]**: I^2S linear prescaler
Refer to *Section 63.9.9: Clock generator* for details

Bit 15 Reserved, must be kept at reset value.

Bit 14 **DATFMT**: data format
0: The data inside the SPI_RXDR or SPI_TXDR register are right aligned
1: The data inside the SPI_RXDR or SPI_TXDR register are left aligned.

Bit 13 **WSINV**: word select inversion
This bit is used to invert the default polarity of WS signal.
0: In I2S Philips standard, the left channel transfer starts one CK cycle after the WS falling edge, and the right channel one CK cycle after the WS rising edge.
In MSB- or LSB-justified mode, the left channel is transferred when WS is HIGH, and the right channel when WS is LOW.
In PCM short mode the data transfer starts at the falling edge of WS, while it starts at the rising edge of WS in PCM long mode.
1: In I2S Philips standard, the left channel transfer starts one CK cycle after the WS rising edge, and the right channel one CK cycle after the WS falling edge.
In MSB- or LSB-justified mode, the left channel is transfered when WS is LOW, and right channel when WS is HIGH.
In PCM short mode the data transfer starts at the rising edge of WS, while it starts at the falling edge of WS in PCM long mode.

Bit 12 **FIXCH**: fixed channel length in slave
0: the channel length in slave mode is different from 16 or 32 bits (CHLEN must be set)
1: the channel length in slave mode is supposed to be 16 or 32 bits (according to CHLEN)

Bit 11 **CKPOL**: serial audio clock polarity
0: the signals generated by the SPI/I2S (that is SDO and WS) are changed on the falling edge of CK and the signals received by the SPI/I2S (that is SDI and WS) are read of the rising edge of CK.
1: the signals generated by the SPI/I2S (that is SDO and WS) are changed on the rising edge of CK and the signals received by the SPI/I2S (that is SDI and WS) are read of the falling edge of CK.

Bit 10 **CHLEN**: channel length (number of bits per audio channel)
0: 16-bit wide
1: 32-bit wide

Bits 9:8 **DATLEN[1:0]**: data length to be transferred.
00: 16-bit data length
01: 24-bit data length
10: 32-bit data length
11: Not allowed
Note: Data width of 24 and 32 bits are not always supported, (DATLEN = 01 or 10), refer to Section 63.3: SPI implementation to check the supported data size.

Bit 7 **PCMSYNC**: PCM frame synchronization
0: short frame synchronization
1: long frame synchronization

Bit 6 Reserved, must be kept at reset value.

Bits 5:4 **I2SSTD[1:0]**: I²S standard selection
For more details on I²S standards, refer to *Section 63.9.5: Supported audio protocols*
00: I²S Philips standard.
01: MSB-justified standard (left justified)
10: LSB-justified standard (right justified)
11: PCM standard

Bits 3:1 **I2SCFG[2:0]**: I2S configuration mode
000: slave - transmit
001: slave - receive
010: master - transmit
011: master - receive
100: slave - Full Duplex
101: master - Full Duplex
others: not used

Bit 0 **I2SMOD**: I2S mode selection
0: SPI mode is selected
1: I2S/PCM mode is selected

63.11.15 SPI/I2S register map

Table 698. SPI register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	SPI_CR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IOLOCK	TCRCINI	RCRCINI	CRC33_17	SSI	HDDIR	CSUSP	CSTART	MASRX	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SPE
	Reset value																0	0	0	0	0	0	0	0	0								0
0x004	SPI_CR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSIZE[15:0](1)															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x008	SPI_CFG1	BPASS	MBR[2:0]			Res.	Res.	Res.	DRDS	Res.	CRCEN	Res.	CRCSIZE[4:0](1)					TXDMAEN	RXDMAEN	Res.	Res.	Res.	Res.	UDRCFG	FTHLV[3:0](1)				DSIZE[4:0](1)				
	Reset value	0	0	0	0				0		0		0	0	1	1	1	0	0					0	0	0	0	0	0	0	1	1	1
0x00C	SPI_CFG2	AFCNTR	SSOM	SSOE	SSIOP	Res.	SSM	CPOL	CPHA	LSBFRST	MASTER	SP[2:0]			COMM[1:0]		Res.	IOSWP	RDIOP	RDIOM	Res.	Res.	Res.	Res.	Res.	MIDI[3:0]				MSSI[3:0]			
	Reset value	0	0	0	0		0	0	0	0	0	0	0	0	0	0		0	0	0						0	0	0	0	0	0	0	0
0x010	SPI_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODFIE	TIFREIE	CRCEIE	OVRIE	UDRIE	TXTFIE	EOTIE	DXPIE	TXPIE	RXPIE
	Reset value																							0	0	0	0	0	0	0	0	0	0
0x014	SPI_SR	CTSIZE[15:0](1)																RXWNE	RXPLVL[1:0]		TXC	SUSP	Res.	MODF	TIFRE	CRCE	OVR	UDR	TXTF	EOT	DPXP	TXP	RXP
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		0	0	0	0	0	0	0	0	1	0
0x018	SPI_IFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUSPC	Res.	MODFC	TIFREC	CRCEC	OVRC	UDRC	TXTFC	EOTC	Res.	Res.	Res.
	Reset value																					0		0	0	0	0	0	0	0			
0x01C	Reserved	Res.																															
0x020	SPI_TXDR	TXDR[31:16]																TXDR[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 698. SPI register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x024-0x02C	Reserved	Res.																															
0x030	SPI_RXDR	RXDR[31:16]																RXDR[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x034 - 0x03C	Reserved	Res.																															
0x040	SPI_CRCPOLY	CRCPOLY[31:16](2)																CRCPOLY[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1
0x044	SPI_TXCRC	TXCRC[31:16](2)																TXCRC[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x048	SPI_RXCRC	RXCRC[31:16](2)																RXCRC[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04C	SPI_UDRDR	UDRDR[31:16](2)																UDRDR[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x050	SPI_I2SCFGR	Res.	Res.	Res.	Res.	Res.	Res.	MCKOE	ODD	I2SDIV[7:0]								Res.	Res.	WSINV	FIXCH	CKPOL	CHLEN	DATLEN[1:0]		PCMSYNC	Res.	I2SSTD[1:0]		I2SCFG[2:0]			I2SMOD
	Reset value							0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0		0	0	0	0	0	0

1. The configuration of this bitfield depends on the features of the SPI instance. For more details, refer to *Section 63.3: SPI implementation*.
2. The bits 31-16 are reserved for the peripheral instances with data size limited to 16 bits. There is no constraint when the 32-bit access is applied at these addresses. The bits 31-16, when reserved, are always read to zero while any write to them is ignored.

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

64 Serial audio interface (SAI)

64.1 SAI introduction

The SAI interface (serial audio interface) offers a wide set of audio protocols due to its flexibility and wide range of configurations. Many audio protocols can be addressed thanks to SAI “free protocol mode”. The free protocol mode allows the application to define the audio frame shape, number of slots, slot size, data size, and so on. For example, the SAI supports I2S standards, LSB- or MSB-justified, PCM/DSP, TDM, and AC’97 protocols. SPDIF output is offered when the audio block is configured as a transmitter.

To bring this level of flexibility and reconfigurability, the SAI contains two independent audio subblocks. Each block has it own clock generator and I/O line controller.

The SAI works in master or slave configuration. The audio subblocks are either receiver or transmitter and work synchronously or not (with respect to the other one).

The SAI can be connected with other SAIs to work synchronously.

64.2 SAI main features

- Two independent audio subblocks, which can be transmitters or receivers with their respective FIFO
- 8-word integrated FIFOs for each audio subblock
- Synchronous or asynchronous mode between the audio subblocks
- Possible synchronization between multiple SAIs
- Master or slave configuration independent for both audio subblocks
- Clock generator for each audio block to target independent audio frequency sampling when both audio subblocks are configured in master mode
- Data size configurable: 8-, 10-, 16-, 20-, 24-, 32-bit
- Audio protocol: I2S, LSB- or MSB-justified, PCM/DSP, TDM, AC’97
- PDM interface, supporting up to 4 microphone pairs
- SPDIF output available if required
- Up to 16 slots available with configurable size
- Number of bits by frame can be configurable
- Frame synchronization active level configurable (offset, bit length, level)
- First active bit position in the slot is configurable
- LSB first or MSB first for data transfer
- Mute mode
- Stereo/Mono audio frame capability
- Communication clock strobing edge configurable (SCK)
- Error flags with associated interrupts if enabled respectively
  - Overrun and underrun detection
  - Anticipated frame synchronization signal detection in slave mode
  - Late frame synchronization signal detection in slave mode
  - Codec not ready for the AC’97 mode in reception

- Interrupt sources when enabled:
  - Errors
  - FIFO requests
- 2-channel DMA interface

64.3 SAI implementation

Table 699. STM32H5E4/5F4 and STM32H5E5/5F5 SAI features (1)

SAI features	SAI1	SAI2
I2S, LSB or MSB-justified, PCM/DSP, TDM, AC'97	X	X
FIFO size	8 words	8 words
SPDIF	X	X
PDM	X(2)	-

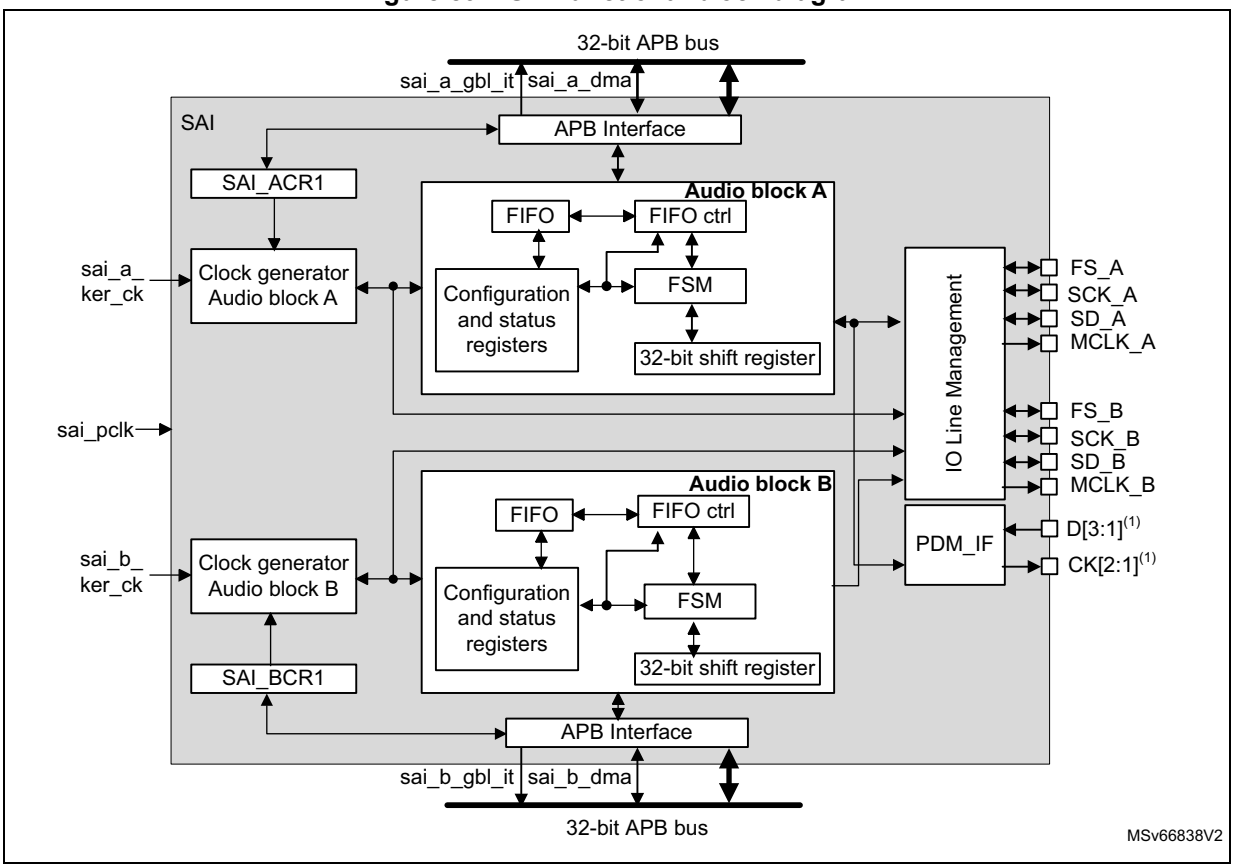
1. 'X' = supported, '-' = not supported.
2. Only signals D[3:1], and CK[2:1] are available.

64.4 SAI functional description

64.4.1 SAI block diagram

Figure 897 shows the SAI block diagram while *Table 700* and *Table 701* list SAI internal and external signals.

Figure 897. SAI functional block diagram



1. These signals might not be available for all SAI instances. Refer to *Section 64.3: SAI implementation* for details.

The SAI is mainly composed of two audio subblocks with their own clock generator. Each audio block integrates a 32-bit shift register controlled by their own functional state machine. Data are stored or read from the dedicated FIFO. FIFO may be accessed by the CPU, or by DMA to leave the CPU free during the communication. Each audio block is independent. They can be synchronous with each other.

An I/O line controller manages a set of 4 dedicated pins (SD, SCK, FS, MCLK) for a given audio block in the SAI. Some of these pins can be shared if the two subblocks are declared as synchronous to leave some free to be used as general purpose I/Os. The MCLK pin can be output, or not, depending on the application, the decoder requirement and whether the audio block is configured as the master.

If one SAI is configured to operate synchronously with another one, even more I/Os can be freed (except for pins SD_x).

The functional state machine can be configured to address a wide range of audio protocols. Some registers are present to set up the desired protocols (audio frame waveform generator).

The audio subblock can be a transmitter or receiver, in master or slave mode. The master mode means the SCK_x bit clock and the frame synchronization signal are generated from the SAI, whereas in slave mode, they come from another external or internal master. There is a particular case for which the FS signal direction is not directly linked to the master or slave mode definition. In AC'97 protocol, it is an SAI output even if the SAI (link controller) is set up to consume the SCK clock (and so to be in Slave mode).

Note: For ease of reading of this section, the notation SAI_x refers to SAI_A or SAI_B, where 'x' represents the SAI A or B subblock.

64.4.2 SAI pins and internal signals

Table 700. SAI internal input/output signals

Internal signal name	Signal type	Description
sai_a_gbl_it/ sai_b_gbl_it	Output	Audio block A and B global interrupts
sai_a_dma, sai_b_dma	Input/output	Audio block A and B DMA acknowledges and requests
sai_sync_out_sck, sai_sync_out_fs	Output	Internal clock and frame synchronization output signals exchanged with other SAI blocks
sai_sync_in_sck, sai_sync_in_fs	Input	Internal clock and frame synchronization input signals exchanged with other SAI blocks
sai_a_ker_ck/ sai_b_ker_ck	Input	Audio block A/B kernel clock
sai_pclk	Input	APB clock

Table 701. SAI input/output pins

Pin name	Pin type	Comments
SAI_SCK_A	Input/output	Audio block A bit clock
SAI_MCLK_A	Output	Audio block A master clock
SAI_FS_A	Input/output	Frame synchronization line for audio block A
SAI_SD_A	Input/output	Data line for block A
SAI_SCK_B	Input/output	Audio block B bit clock
SAI_MCLK_B	Output	Audio block B master clock
SAI_FS_B	Input/output	Frame synchronization line for audio block B
SAI_SD_B	Input/output	Data line for block B
SAI_CK[2:1]	Output	PDM bitstream clock(1)
SAI_D[3:1]	Input	PDM bitstream data(1)

1. These signals might not be available in all SAI instances. Refer to *Section 64.3: SAI implementation* for details.

64.4.3 Main SAI modes

Each audio subblock of the SAI can be configured to be master or slave via the MODE bits in the SAI_xCR1 register of the selected audio block.

Master mode

In master mode, the SAI delivers the timing signals to the external connected device:

- The bit clock and the frame synchronization are output on pin SCK_x and FS_x, respectively.
- If needed, the SAI can also generate a master clock on the MCLK_x pin.

Both SCK_x, FS_x and MCLK_x are configured as outputs.

Slave mode

The SAI expects to receive timing signals from an external device.

- If the SAI subblock is configured in asynchronous mode, then the SCK_x and FS_x pins are configured as inputs.
- If the SAI subblock is configured to operate synchronously with another SAI interface or with the second audio subblock, the corresponding SCK_x and FS_x pins are left free to be used as general purpose I/Os.

In slave mode, the MCLK_x pin is not used and can be assigned to another function.

It is recommended to enable the slave device before enabling the master.

Configuring and enabling SAI modes

Each audio block can use a different audio protocol. When PRTCFG[1:0] of the SAI_xCR1 register is set to 0, the free protocol mode is selected and each SAI subblock can emulate I2S standards, LSB- or MSB-justified, PCM/DSP, TDM, or AC’97 protocols.

Each audio subblock can be independently defined as a transmitter or receiver through the MODE bit in the SAI_xCR1 register of the corresponding audio block. As a result, the SAI_SD_x pin is respectively configured as an output or an input.

Two master audio blocks in the same SAI can be configured with two different MCLK and SCK clock frequencies. In this case, they have to be configured in asynchronous mode.

Each of the audio blocks in the SAI is enabled by the SAIEN bit in the SAI_xCR1 register. As soon as this bit is active, the transmitter or the receiver is sensitive to the activity on the clock, data, and synchronization lines in slave mode.

In master Tx mode, enabling the audio block immediately generates the bit clock for the external slaves even if there is no data in the FIFO. However, FS signal generation is conditioned by the presence of data in the FIFO. After the FIFO receives the first data to transmit, this data is output to external slaves. If there is no data to transmit in the FIFO, 0 values are then sent in the audio frame with an underrun flag generation.

In slave mode, the audio frame starts when the audio block is enabled and when a start of frame is detected.

In Slave Tx mode, no underrun event is possible on the first frame after the audio block is enabled, because the mandatory operating sequence in this case is:

1. Write into the SAI_xDR (by software or by DMA).
2. Wait until the FIFO threshold *(*FLH) flag is different from 0b000 (FIFO empty).
3. Enable the audio block in slave transmitter mode.

64.4.4 SAI synchronization mode

There are two levels of synchronization, either at audio subblock level or at SAI level.

Internal synchronization

An audio subblock can be configured to operate synchronously with the second audio subblock in the same SAI. In this case, the bit clock and the frame synchronization signals are shared to reduce the number of external pins used for the communication. The audio block configured in synchronous mode sees its own SCK_x, FS_x, and MCLK_x pins released back as GPIOs while the audio block configured in asynchronous mode is the one for which FS_x and SCK_x ad MCLK_x I/O pins are relevant (if the audio block is considered as master).

Typically, the audio block in synchronous mode can be used to configure the SAI in full duplex mode. One of the two audio blocks can be configured as a master and the other as slave, or both as slaves with one asynchronous block (corresponding SYNCEN[1:0] bits set to 00 in SAI_xCR1) and one synchronous block (corresponding SYNCEN[1:0] bits set to 01 in the SAI_xCR1 register).

Note: Due to internal resynchronization stages, PCLK APB frequency must be higher than twice the bit rate clock frequency.

External synchronization

The audio subblocks can also be configured to operate synchronously with another SAI. This can be done as follows:

1. The SAI, which is configured as the source from which the other SAI is synchronized, has to define which of its audio subblocks is supposed to provide the FS and SCK signals to other SAI. This is done by programming SYNCOUT[1:0] bits.
2. The SAI which receives the synchronization signals, has to select which SAI provides the synchronization by setting the proper value on SYNCIN[1:0] bits. For each of the two SAI audio subblocks, the user must then specify if it operates synchronously with the other SAI via the SYNCEN bit.

Note: The SYNCIN[1:0] and SYNCOUT[1:0] bits are located in the SAI_GCR register, and the SYNCEN bits in the SAI_xCR1 register.

If both audio subblocks in a given SAI need to be synchronized with another SAI, it is possible to choose one of the following configurations:

- Configure each audio block to be synchronous with another SAI block through the SYNCEN[1:0] bits.
- Configure one audio block to be synchronous with another SAI through the SYNCEN[1:0] bits. The other audio block is then configured as synchronous with the second SAI audio block through SYNCEN[1:0] bits.

The following table shows how to select the proper synchronization signal depending on the SAI block used. For example SAI2 can select the synchronization from SAI1 by setting SAI2 SYNCIN to 0. If SAI1 wants to select the synchronization coming from SAI2, SAI1 SYNCIN must be set to 1. Positions noted as ‘Reserved’ must not be used.

Table 702. External synchronization selection

Block instance	SYNCIN = 1	SYNCIN = 0
SAI1	SAI2 sync.	Reserved
SAI2	Reserved	SAI1 sync.

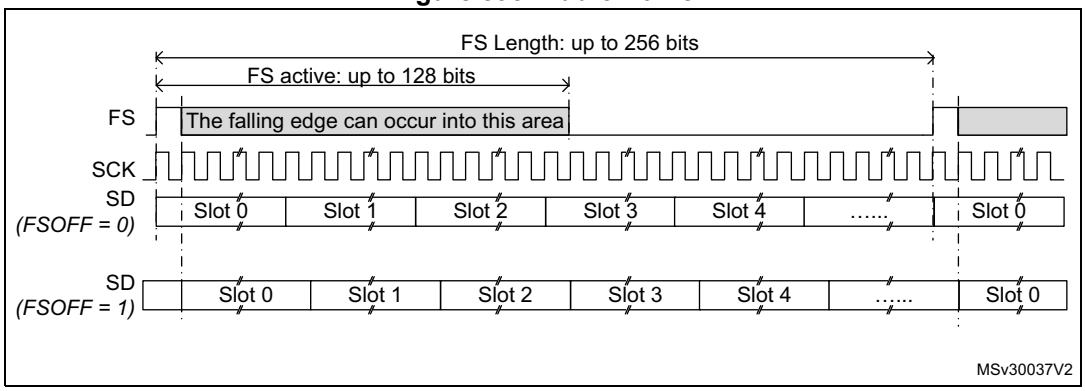
64.4.5 Audio data size

The audio frame can target different data sizes by configuring bit DS[2:0] in the SAI_xCR1 register. The data sizes may be 8, 10, 16, 20, 24, or 32 bits. During the transfer, either the MSB or the LSB of the data is sent first, depending on the configuration of the LSBFIRST bit in the SAI_xCR1 register.

64.4.6 Frame synchronization

The FS signal acts as the frame synchronization signal in the audio frame (start of frame). The shape of this signal is completely configurable to target the different audio protocols with their own specificities concerning this frame synchronization behavior. This reconfigurability is done using the SAI_xFRCR register. *Figure 898* illustrates this flexibility.

Figure 898. Audio frame



In AC'97 mode or in SPDIF mode (bit PRTCFG[1:0] = 10 or PRTCFG[1:0] = 01 in the SAI_xCR1 register), the frame synchronization shape is forced to match the AC'97 protocol. The SAI_xFRCR register value is ignored.

Each audio block is independent and consequently each one requires a specific configuration.

Frame length

- Master mode

  The audio frame length can be configured to up to 256-bit clock cycles, by configuring the FRL[7:0] field in the SAI_xFRCR register.

  If the frame length is greater than the number of declared slots for the frame, the remaining bits to transmit are extended to 0 or the SD line is released to high-Z

depending on the state of bit TRIS in the SAI_xCR2 register (refer to *FS signal role*). In reception mode, the remaining bit is ignored.

If bit NODIV is cleared, (FRL+1) must be equal to a power of 2, from 8 to 256, to ensure that an audio frame contains an integer number of MCLK pulses per bit clock cycle.

If bit NODIV is set, the (FRL+1) field can take any value from 8 to 256. Refer to *Section 64.4.8: SAI clock generator*"

- Slave mode

  The audio frame length is mainly used to specify to the slave the number of bit clock cycles per audio frame sent by the external master. It is used mainly to detect from the master any anticipated or late occurrence of the frame synchronization signal during an ongoing audio frame. In this case, an error is generated. For more details, refer to *Section 64.4.14: Error flags*.

  In slave mode, there are no constraints on the FRL[7:0] configuration in the SAI_xFRCR register.

The number of bits in the frame is equal to FRL[7:0] + 1.

The minimum number of bits to transfer in an audio frame is 8.

Frame synchronization polarity

The FSPOL bit in the SAI_xFRCR register sets the active polarity of the FS pin from which a frame is started. The start of the frame is edge sensitive.

In slave mode, the audio block waits for a valid frame to start transmitting or receiving. The start of the frame is synchronized to this signal. It is effective only if the start of the frame is not detected during an ongoing communication and assimilated to an anticipated start of frame (refer to *Section 64.4.14: Error flags*).

In master mode, the frame synchronization is sent continuously each time an audio frame is complete until the SAIEN bit in the SAI_xCR1 register is cleared. If no data are present in the FIFO at the end of the previous audio frame, an underrun condition is managed as described in *Section 64.4.14: Error flags*), but the audio communication flow is not interrupted.

Frame synchronization active level length

The FSALL[6:0] bits of the SAI_xFRCR register enable the configuration of the length of the active level of the frame synchronization signal. The length can be set from 1- to 128-bit clock cycles.

As an example, the active length can be half of the frame length in I2S, LSB or MSB-justified modes, or one-bit wide for PCM/DSP or TDM.

Frame synchronization offset

Depending on the audio protocol targeted in the application, the frame synchronization signal can be asserted when transmitting the last bit or the first bit of the audio frame (this is the case in I2S standard protocol and in MSB-justified protocol, respectively). The FSOFF bit in the SAI_xFRCR register enables the possibility to choose between two configurations.

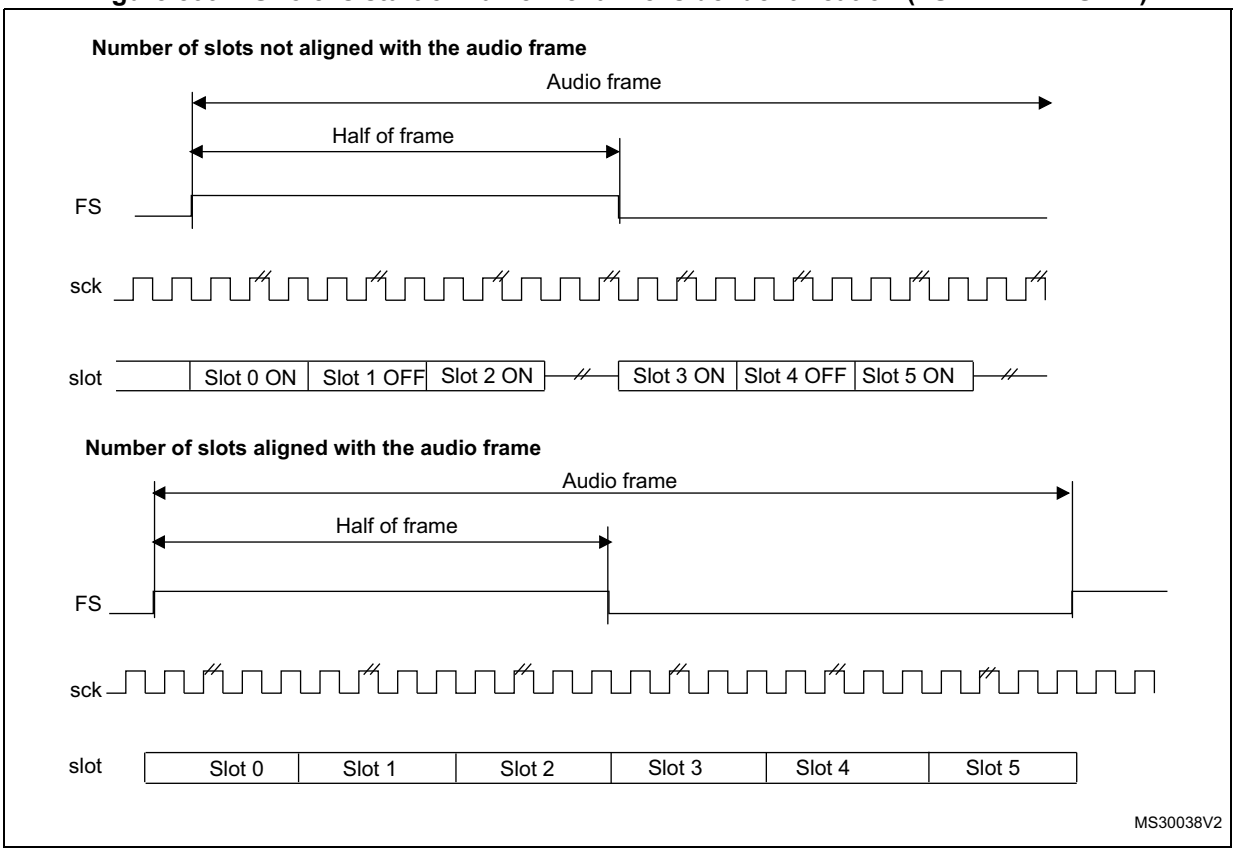
FS signal role

The FS signal can have a different meaning depending on the FS function. FSDEF bit in the SAI_xFRCR register selects which meaning it has:

- 0: start of frame, like, for instance, the PCM/DSP, TDM, AC'97, audio protocols,
- 1: start of frame and channel side identification within the audio frame like for the I2S or the MSB- or LSB-justified protocols.

When the FS signal is considered as a start of frame and channel side identification within the frame, the number of declared slots must be considered to be half the number for the left channel and half the number for the right channel. If the number of bit clock cycles on half audio frame is greater than the number of slots dedicated to a channel side, and TRIS = 0, 0 is sent for transmission for the remaining bit clock cycles in the SAI_xCR2 register. Otherwise, if TRIS = 1, the SD line is released to high-Z. In reception mode, the remaining bit clock cycles are not considered until the channel side changes.

Figure 899. FS role is start of frame + channel side identification (FSDEF = TRIS = 1)

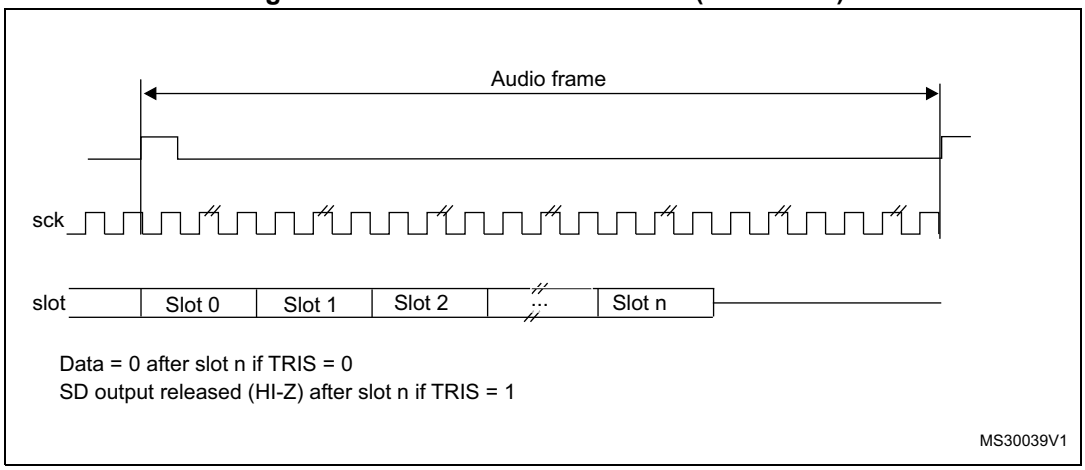


1. The frame length must be even.

If the FSDEF bit in SAI_xFRCR is kept clear, so FS signal is equivalent to a start of frame, and if the number of slots defined in NBSLOT[3:0] in SAI_xSLOTR multiplied by the number of bits by slot configured in SLOTSZ[1:0] in SAI_xSLOTR is less than the frame size (bit FRL[7:0] in the SAI_xFRCR register), then:

- If TRIS = 0 in the SAI_xCR2 register, the remaining bit after the last slot is forced to 0 until the end of frame in case of transmitter,
- If TRIS = 1, the line is released to high-Z during the transfer of these remaining bits. In reception mode, these bits are discarded.

Figure 900. FS role is start of frame (FSDEF = 0)



The FS signal is not used when the audio block in transmitter mode is configured to get the SPDIF output on the SD line. The corresponding FS I/O is released and left free for other purposes.

64.4.7 Slot configuration

The slot is the basic element in the audio frame. The number of slots in the audio frame is equal to NBSLOT[3:0] + 1.

The maximum number of slots per audio frame is fixed at 16.

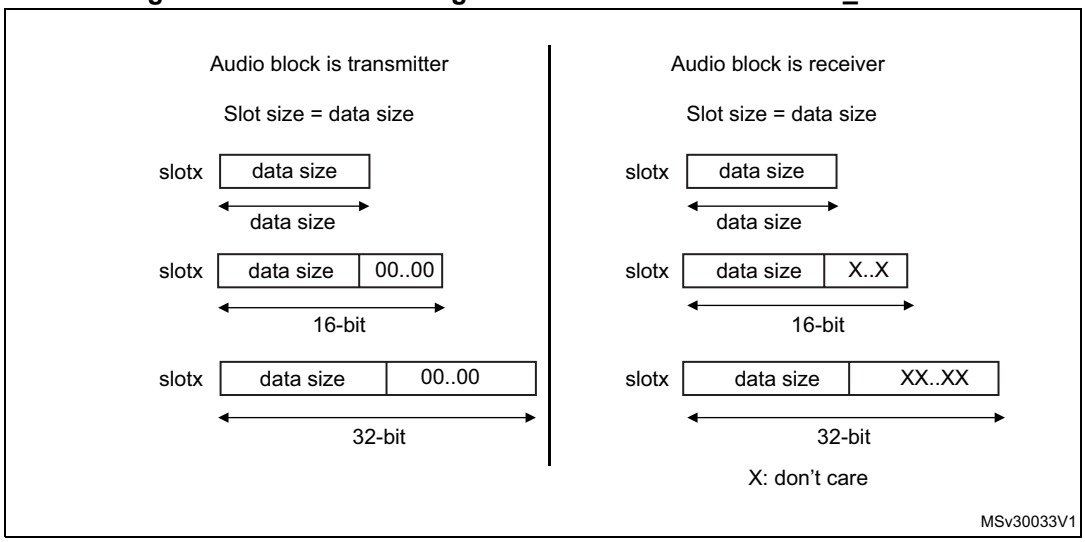
For AC'97 protocol or SPDIF (when bit PRTCFG[1:0] = 10 or PRTCFG[1:0] = 01), the number of slots is automatically set to target the protocol specification, and the value of NBSLOT[3:0] is ignored.

Each slot can be defined as a valid slot, or not, by setting SLOTEN[15:0] bits of the SAI_xSLOTR register.

When an invalid slot is transferred, the SD data line is either forced to 0 or released to high-Z depending on the TRIS bit configuration (refer to *Output data line management on an inactive slot*) in transmitter mode. In receiver mode, the received value from the end of this slot is ignored. Consequently, there is no FIFO access and so no request to read or write the FIFO linked to this inactive slot status.

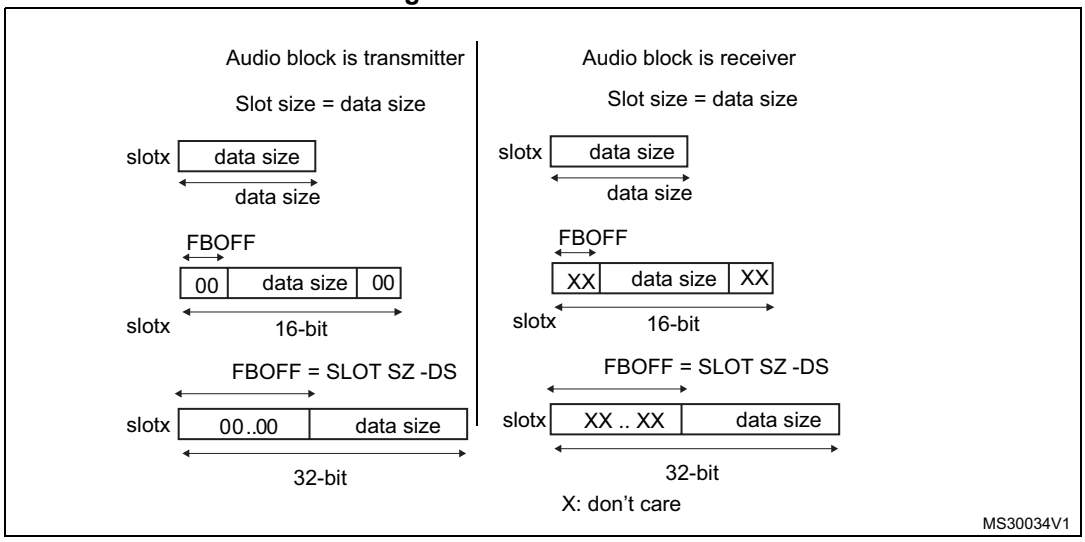
The slot size is also configurable as shown in *Figure 901.* The size of the slots is selected by configuring the SLOTSZ[1:0] bits in the SAI_xSLOTR register. The size is applied identically for each slot in an audio frame.

Figure 901. Slot size configuration with FBOFF = 0 in SAI_xSLOTR



It is possible to choose the position of the first data bit to transfer within the slots. This offset is configured by FBOFF[4:0] bits in the SAI_xSLOTR register. 0 values are injected in transmitter mode from the beginning of the slot until this offset position is reached. In reception, the bit in the offset phase is ignored. This feature targets the LSB justified protocol (if the offset is equal to the slot size minus the data size).

Figure 902. First bit offset



It is mandatory to respect the following conditions to avoid bad SAI behavior:

- FBOFF ≤ (SLOTSZ - DS)
- DS ≤ SLOTSZ
- NBSLOT x SLOTSZ ≤ FRL (frame length)

The number of slots must be even when bit FSDEF in the SAI_xFRCR register is set.

In AC'97 and SPDIF protocol (bit PRTCFG[1:0] = 10 or PRTCFG[1:0] = 01), the slot size is automatically set as defined in *Section 64.4.11: AC'97 link controller*.

64.4.8 SAI clock generator

Each audio block has its own clock generator. The clock generator builds the master clock (MCLK_x) and bit clock (SCK_x) signals from the sai_x_ker_ck. The sai_x_ker_ck clock is delivered by the clock controller of the product (RCC).

Generation of the master clock (MCLK_x)

The clock generator provides the master clock (MCLK_x) when the audio block is defined as Master or Slave. The master clock is generated as soon as the MCKEN bit is set to 1 even if the SAIEN bit for the corresponding block is set to 0. This feature can be useful if the MCLK_x clock is used as system clock for an external audio device, since it enables the generation of the MCLK_x before activating the audio stream.

To generate a master clock on MCLK_x output before transferring the audio samples, the user application has to follow the sequence below:

1. Check that SAIEN = 0.
2. Program the MCKDIV[5:0] divider to the required value.
3. Set the MCKEN bit to 1.
4. Later, the application can configure other parts of the SAI, and sets the SAIEN bit to 1 to start the transfer of audio samples.

To avoid disturbances on the clock generated on MCLK_x output, the following operations are not recommended:

- Changing MCKDIV when MCKEN = 1
- Setting MCKEN to 0 if the SAIEN = 1

The SAI makes sure that there are no spurs on MCLK_x output when the MCLK_x is switched ON and OFF via the MCKEN bit (with SAIEN = 0).

Table 703 shows MCLK_x activation conditions.

Table 703. MCLK_x activation conditions

MCLKEN	NODIV	SAIEN for block x	MCLK_x
0	X	0	Disabled
1			Enabled
0	1	1	Disabled
1			Enabled
X	0		Enabled

Note: MCLK_x can also be generated in AC'97 mode, when MCLKEN is set to 1.

Generation of the bit clock (SCK_x)

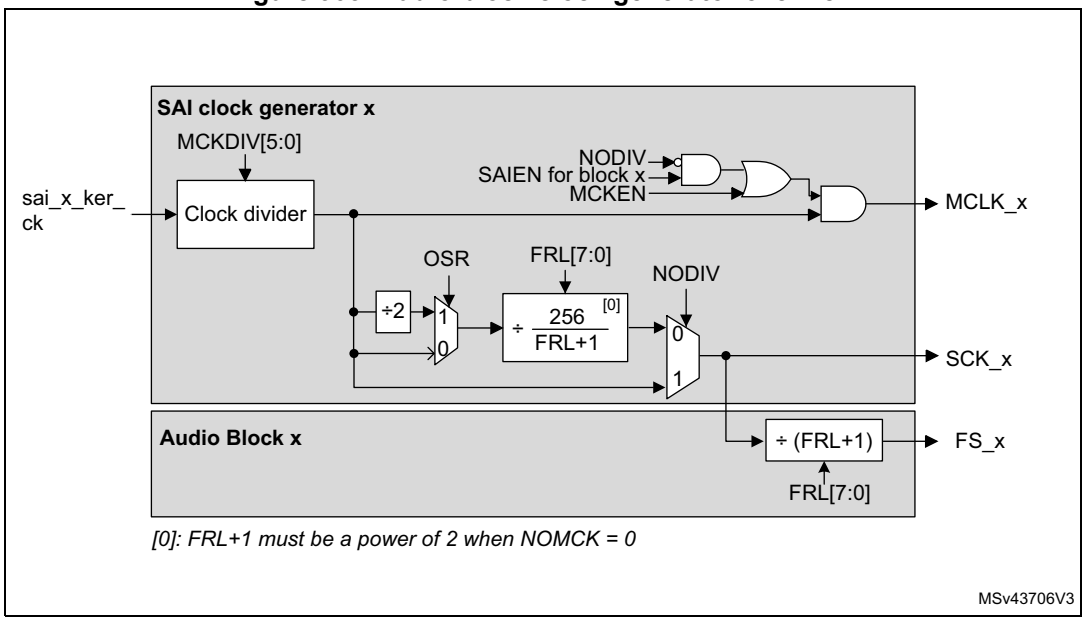
The clock generator provides the bit clock (SCK_x) when the audio block is defined as Master. The frame synchronization (FS_x) is also derived from the signals provided by the clock generator.

In Slave mode, the value of NODIV and OSR fields are ignored, and the SCK_x clock is not generated.

The bit clock strobing edge of SCK_x can be configured through the CKSTR fields, which is functional both in master and slave mode.

Figure 903 illustrates the architecture of the audio block clock generator.

Figure 903. Audio block clock generator overview



The NODIV bit must be used to force the ratio between the master clock (MCLK_x) and the frame synchronization (FS_x) frequency to 256 or 512.

- If NODIV is set to 0, the frequency ratio between the frame synchronization and the master clock is fixed to 512 or 256, according to OSR value, but the frame length must be a power of 2. More details are given below.
- If NODIV is set to 1, the application can adjust the frequency of the bit clock (SCK_x) via MCKDIV. In addition, there is no restriction on the frame length value as long as the frame length is bigger or equal to 8 (that is, FRL[7:0] > 6). The frame synchronization frequency depends on MCKDIV and frame length (FRL[7:0]). In that case, the frequency of the MCLK_x is equal to the SCK_x.

The NODIV, MCKEN, SAIEN, OVR, CKSTR, and MCKDIV[5:0] bits belong to the SAI_xCR1 register, while FRL[7:0] belongs to SAI_xFRCR.

Clock generator programming when NODIV = 0

In that case, the MCLK_x frequency is:

- $F_{MCLK_x} = 256 \times F_{FS_x}$ if OSR = 0
- $F_{MCLK_x} = 512 \times F_{FS_x}$ if OSR = 1

When MCKDIV is different from 0, the MCLK_x frequency is given by the formula below:

$$F_{MCLK_x} = \frac{F_{sai_x_ker_ck}}{MCKDIV}$$

The frame synchronization frequency is given by:

$$F_{FS_x} = \frac{F_{sai_x_ker_ck}}{MCKDIV \times (OSR + 1) \times 256}$$

The bit clock frequency (SCK_x) is given by the following formula:

$$F_{SCK_x} = \frac{F_{sai_x_ker_ck} \times (FRL + 1)}{MCKDIV \times (OSR + 1) \times 256}$$

Note: When NODIV is equal to 0, (FRL+1) must be a power of two. In addition, (FRL+1) must range between 8 and 256. (FRL +1) represents the number of bit clock in the audio frame.

When the MCKDIV division ratio is odd, the MCLK duty cycle is not 50%. The bit clock signal (SCK_x) can also have a duty cycle different from 50% if MCKDIV is odd, if OSR is equal to 0, and if (FRL+1) = 2^8.

It is recommended, to program MCKDIV to an even value or to large values (higher than 10).

Note that MCKDIV = 0 gives the same result as MCKDIV = 1.

Clock generator programming when NODIV = 1

When MCKDIV is different from 0, the frequency of the bit clock (SCK_x) is given in the formula below:

$$F_{SCK_x} = F_{MCLK_x} = \frac{F_{sai_x_ker_ck}}{MCKDIV}$$

The frequency of the frame synchronization (FS_x) in given by the following formula:

$$F_{FS_x} = \frac{F_{sai_x_ker_ck}}{(FRL + 1) \times MCKDIV}$$

Note: When NODIV is set to 1, (FRL+1) can take any values from 8 to 256.

MCKDIV = 0 gives the same result as MCKDIV = 1.

Clock generator programming examples

Table 704 gives programming examples for 48, 96, and 192 kHz.

Table 704. Clock generator programming examples

Input sai_x_ker_ck clock frequency	MCLK	F_{MCLK}/ F_{FS}	FRL (1)	OSR	NODIV	MCKEN	MCKDIV[5:0]	Audio sampling frequency (F_{FS})
98.304 MHz	Y	512	2^N-1	1	0	1	0 or 1	192 kHz
		512	2^N-1	1	0	1	2	96 kHz
		512	2^N-1	1	0	1	4	48 kHz
		256	2^N-1	0	0	1	2	192 kHz
		256	2^N-1	0	0	1	4	96 kHz
		256	2^N-1	0	0	1	8	48 kHz
	N	-	63	-	1	0	8	192 kHz
		-	63	-	1	0	16	96 kHz
		-	63	-	1	0	32	48 kHz

1. N is an integer value between 3 and 8.

64.4.9 Internal FIFOs

Each audio block in the SAI has its own FIFO. Depending on if the block is defined to be a transmitter or a receiver, the FIFO can be written or read, respectively. Thus, there is only one FIFO request linked to the FREQ bit in the SAI_xSR register.

An interrupt is generated if the FREQIE bit is enabled in the SAI_xIM register. This depends on:

- The FIFO threshold setting (FLVL bits in SAI_xCR2).
- Communication direction (transmitter or receiver). Refer to *Interrupt generation in transmitter mode* and *Interrupt generation in reception mode*.

Interrupt generation in transmitter mode

The interrupt generation depends on the FIFO configuration in transmitter mode:

- When the FIFO threshold bits in the SAI_xCR2 register are configured as FIFO empty (FTH[2:0] set to 0b000), an interrupt is generated (FREQ bit set by hardware to 1 in the SAI_xSR register) if no data are available in the SAI_xDR register (FLVL[2:0] bits in SAI_xSR are less than 0b001). This interrupt (FREQ bit in the SAI_xSR register) is cleared by hardware when the FIFO is no longer empty (FLVL[2:0] bits in SAI_xSR are different from 0b000), that is, one or more data are stored in the FIFO.
- When the FIFO threshold bits in the SAI_xCR2 register are configured as FIFO quarter full (FTH[2:0] set to 0b001), an interrupt is generated (FREQ bit set by hardware to 1 in the SAI_xSR register) if less than a quarter of the FIFO contains data (FLVL[2:0] bits in SAI_xSR are less than 0b010). This interrupt (FREQ bit in the SAI_xSR register) is cleared by hardware when at least a quarter of the FIFO contains data (FLVL[2:0] bits in SAI_xSR are higher than or equal to 0b010).

- When the FIFO threshold bits in the SAI_xCR2 register are configured as FIFO half full (FTH[2:0] set to 0b010), an interrupt is generated (FREQ bit set by hardware to 1 in the SAI_xSR register) if less than half of the FIFO contains data (FLVL[2:0] bits in SAI_xSR are less than 0b011). This interrupt (FREQ bit in the SAI_xSR register) is cleared by hardware when at least half of the FIFO contains data (FLVL[2:0] bits in SAI_xSR are higher than or equal to 0b011).
- When the FIFO threshold bits in the SAI_xCR2 register are configured as FIFO three quarter (FTH[2:0] set to 0b011), an interrupt is generated (FREQ bit is set by hardware to 1 in the SAI_xSR register) if less than three quarters of the FIFO contains data (FLVL[2:0] bits in SAI_xSR are less than 0b100). This interrupt (FREQ bit in the SAI_xSR register) is cleared by hardware when at least three quarters of the FIFO contains data (FLVL[2:0] bits in SAI_xSR are higher than or equal to 0b100).
- When the FIFO threshold bits in the SAI_xCR2 register are configured as FIFO full (FTH[2:0] set to 0b100), an interrupt is generated (FREQ bit is set by hardware to 1 in the SAI_xSR register) if the FIFO is not full (FLVL[2:0] bits in SAI_xSR are less than 0b101). This interrupt (FREQ bit in the SAI_xSR register) is cleared by hardware when the FIFO is full (FLVL[2:0] bits in SAI_xSR are equal to 0b101).

Interrupt generation in reception mode

The interrupt generation depends on the FIFO configuration in reception mode:

- When the FIFO threshold bits in the SAI_xCR2 register are configured as FIFO empty (FTH[2:0] set to 0b000), an interrupt is generated (FREQ bit is set by hardware to 1 in the SAI_xSR register) if at least one data is available in the SAI_xDR register (FLVL[2:0] bits in SAI_xSR are higher than or equal to 0b001). This interrupt (FREQ bit in the SAI_xSR register) is cleared by hardware when the FIFO becomes empty (FLVL[2:0] bits in the SAI_xSR are equal to 0b000), that is, no data are stored in FIFO.
- When the FIFO threshold bits in the SAI_xCR2 register are configured as FIFO quarter full (FTH[2:0] set to 0b001), an interrupt is generated (FREQ bit is set by hardware to 1 in the SAI_xSR register) if at least one quarter of the FIFO data locations are available (FLVL[2:0] bits in SAI_xSR are higher than or equal to 0b010). This interrupt (FREQ bit in the SAI_xSR register) is cleared by hardware when less than a quarter of the FIFO data locations become available (FLVL[2:0] bits in SAI_xSR are less than 0b010).
- When the FIFO threshold bits in the SAI_xCR2 register are configured as FIFO half full (FTH[2:0] set to 0b010), an interrupt is generated (FREQ bit is set by hardware to 1 in the SAI_xSR register) if at least half of the FIFO data locations are available (FLVL[2:0] bits in SAI_xSR are higher than or equal to 0b011). This interrupt (FREQ bit in the SAI_xSR register) is cleared by hardware when less than half of the FIFO data locations become available (FLVL[2:0] bits in SAI_xSR are less than 0b011).
- When the FIFO threshold bits in the SAI_xCR2 register are configured as FIFO three quarter full (FTH[2:0] set to 0b011), an interrupt is generated (FREQ bit is set by hardware to 1 in the SAI_xSR register) if at least three quarters of the FIFO data locations are available (FLVL[2:0] bits in SAI_xSR are higher than or equal to 0b100). This interrupt (FREQ bit in the SAI_xSR register) is cleared by hardware when the FIFO has less than three quarters of the FIFO data locations available (FLVL[2:0] bits in SAI_xSR is less than 0b100).
- When the FIFO threshold bits in the SAI_xCR2 register are configured as FIFO full (FTH[2:0] set to 0b100), an interrupt is generated (FREQ bit is set by hardware to 1 in the SAI_xSR register) if the FIFO is full (FLVL[2:0] bits in SAI_xSR are equal to 0b101). This

interrupt (FREQ bit in the SAI_xSR register) is cleared by hardware when the FIFO is not full (FLVL[2:0] bits in SAI_xSR are less than 0b101).

Like interrupt generation, the SAI can use the DMA if the DMAEN bit in the SAI_xCR1 register is set. The FREQ bit assertion mechanism is the same as the interrupt generation mechanism described above for FREQIE.

Each FIFO is an 8-word FIFO. Each read or write operation from/to the FIFO targets one word FIFO location whatever the access size. Each FIFO word contains one audio slot. FIFO pointers are incremented by one word after each access to the SAI_xDR register.

Data must be right-aligned when written in the SAI_xDR register.

Data received are right-aligned in the SAI_xDR register.

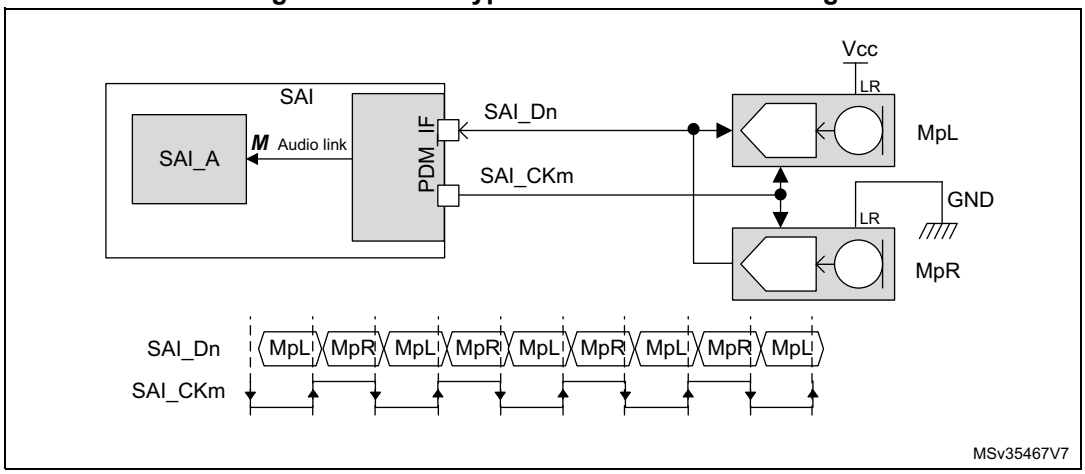
The FIFO pointers can be reinitialized when the SAI is disabled by configuring the FFLUSH bit in the SAI_xCR2 register. If FFLUSH is set when the SAI is enabled, the data present in the FIFO are lost automatically.

64.4.10 PDM interface

The PDM (pulse density modulation) interface is provided in order to support digital microphones. Up to 4 digital microphone pairs can be connected in parallel. Depending on product implementation, less microphones can be supported (refer to *Section 64.3: SAI implementation*).

Figure 904 shows a typical connection of a digital microphone pair via a PDM interface. Both microphones share the same bitstream clock and data line. Thanks to a configuration pin (LR), a microphone can provide valid data on SAI_CK[m] rising edge while the other provides valid data on SAI_CK[m] falling edge (m being the number of clock lines).

Figure 904. PDM typical connection and timing



1. **n** refers to the number of data lines and **p** to the number of microphone pairs.

The PDM function is intended to be used in conjunction with SAI_A subblock configured in TDM master mode. It cannot be used with SAI_B subblock. The PDM interface uses the timing signals provided by the serial audio interface of SAI_A and adapts them to generate a bitstream clock (SAI_CK[m]).

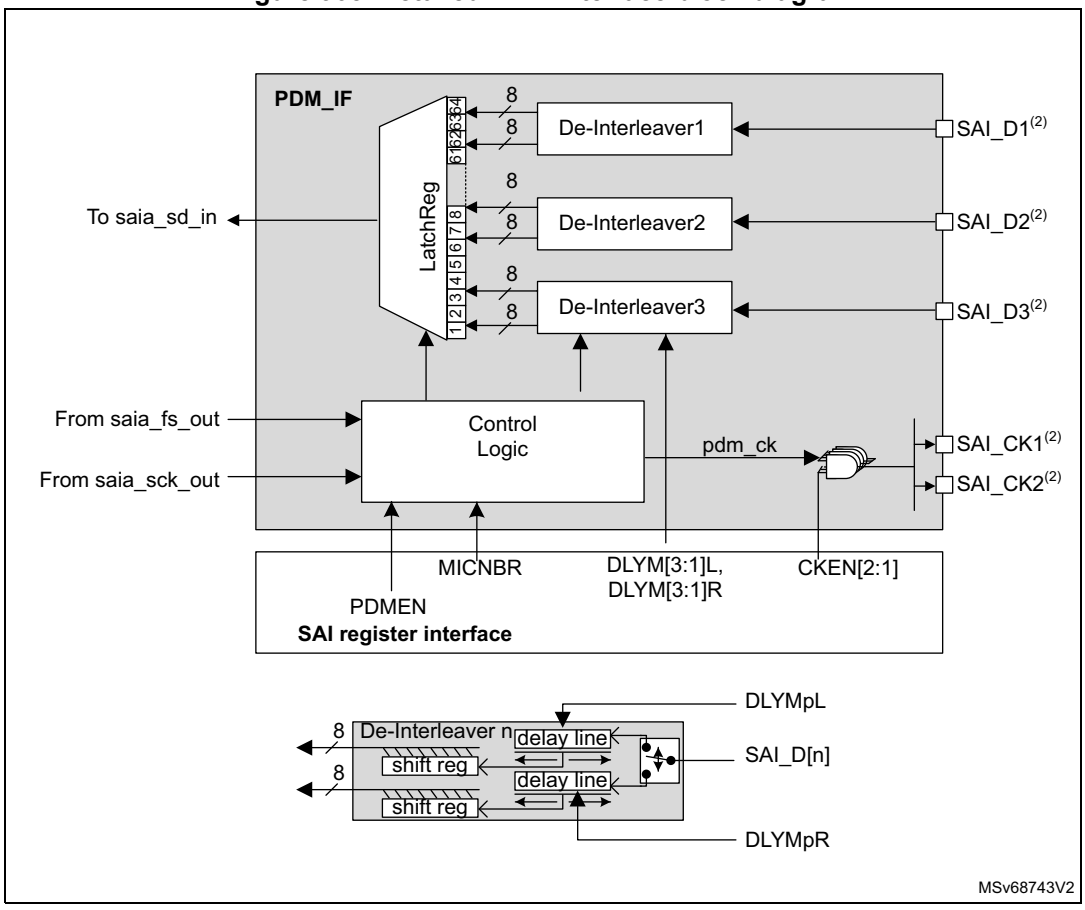
The processing performed into the PDM interface is the following:

1. The PDM interface builds the bitstream clock from the bit clock received from the serial audio interface of SAI_A.
2. The bitstream data received from the microphones (SAI_D[n]) are de-interleaved and go through a 7-bit delay line to fine-tune the delay of each microphone with the accuracy of the bitstream clock.
3. The shift registers translate each serial bitstream into bytes.
4. The last operation consists in shifting-out the resulting bytes to SAI_A through the data line of the serial audio interface.

Figure 905 below shows the block diagram of the PDM interface, with a detailed view of a de-interleaver.

Note: The PDM interface does not embed the decimation filter required to build-up the PCM audio samples from the bitstream. It is up to the application software to perform this operation.

Figure 905. Detailed PDM interface block diagram



1. **n** refers to the number of data lines and **p** to the number of microphone pairs.
2. These signals might not be available in all SAI instances. Refer to *Section 64.3: SAI implementation* for details.

The PDM interface can be enabled through the PDMEN bit in the SAI_PDMCR register. However, the PDM interface must be enabled prior to enabling the SAI_A block.

To reduce the memory footprint, the user can select the number of microphones the application needs. This can be done through the MICNBR[1:0] bits. It is possible to choose between 2, 4, 6, or 8 microphones. For example, if the application is using 3 microphones, the user has to select 4.

Enabling the PDM interface

To enable the PDM interface, follow the sequence below:

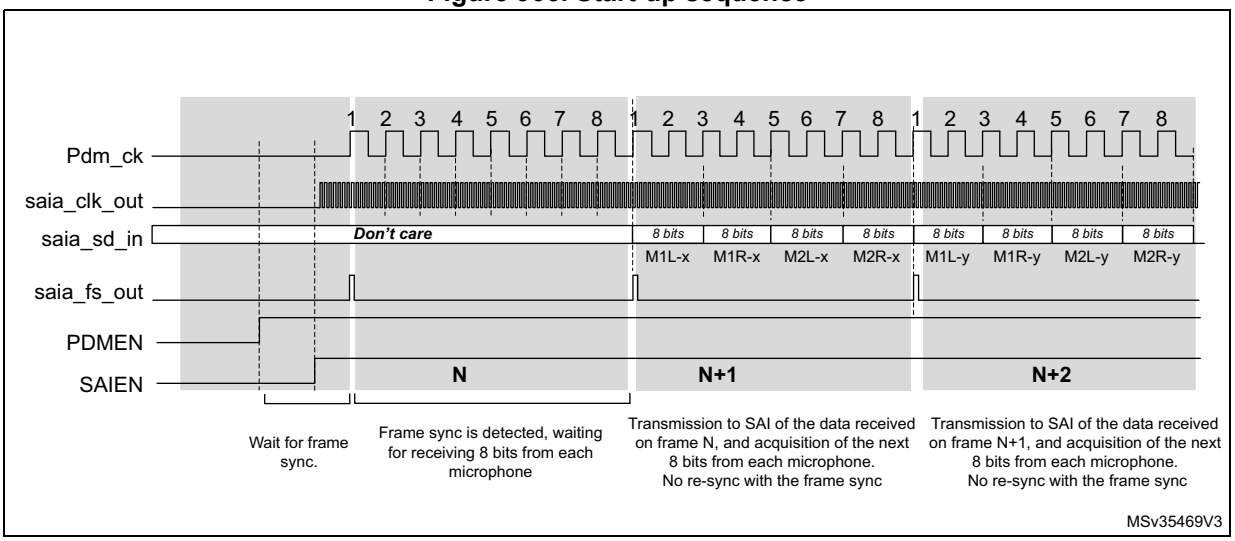
1. Configure SAI_A in TDM master mode (see *Table 705*).
2. Configure the PDM interface as follows:
   a) Define the number of digital microphones via MICNBR.
   b) Enable the bitstream clock needed in the application by setting the corresponding bits on CKEN to 1.
3. Enable the PDM interface, via the PDMEN bit.
4. Enable the SAI_A.

Note: Once the PDM interface and SAI_A are enabled, the first two frames received on SAI_ADR are invalid and must be dropped.

Startup sequence

Figure 906 shows the startup sequence: Once the PDM interface is enabled, it waits for the frame synchronization event prior to starting the acquisition of the microphone samples. After 8 SAI_CK clock periods, a data byte coming from each microphone is available, and transferred to the SAI, via the serial audio interface.

Figure 906. Start-up sequence



SAI_ADR data format

The arrangement of the data coming from the microphone into the SAI_ADR register depends on the following parameters:

- Number of microphones
- Slot width selected
- LSBFIRST bit

The slot width defines the number of significant bits into each word available into the SAI_ADR.

When a slot width of 32 bits is selected, each data available into the SAI_ADR contains 32 useful bits. This reduces the number of words stored into the memory. However, the counterpart is that the software has to perform some operations to de-interleave the data of each microphone.

On the other hand, when the slot width is set to 8 bits, each data available into the SAI_ADR contains 8 useful bits. This increases the number of words stored in the memory. However, it offers the advantage of avoiding extra processing since each word contains information from one microphone.

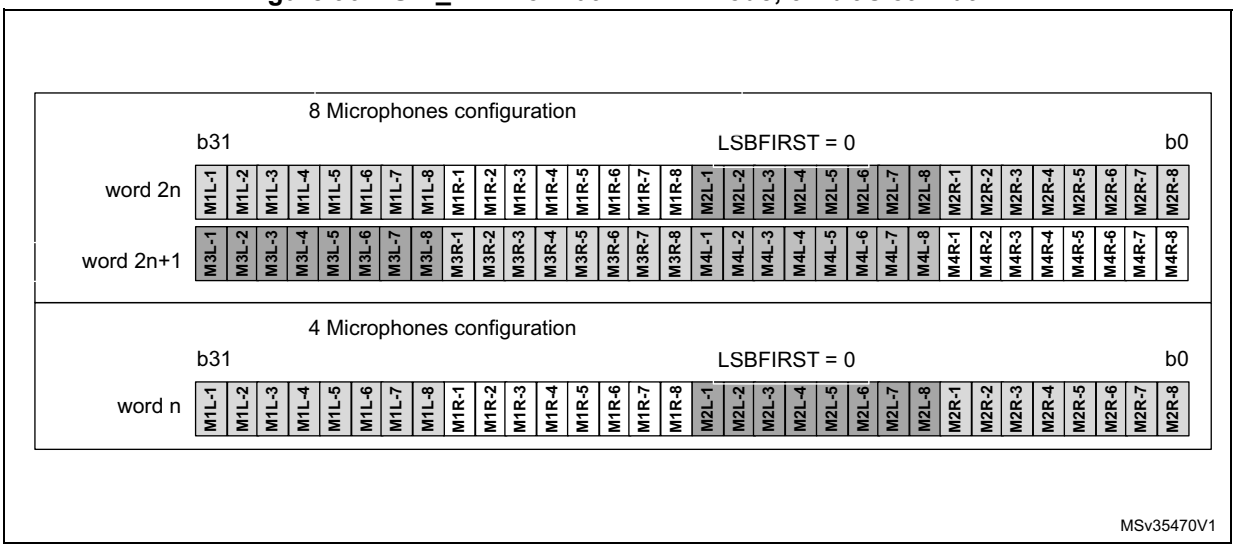
SAI_ADR data format example

- **32-bit slot width** (DS = 0b111 and SLOTSZ = 0). Refer to *Figure 907*.

  For an 8 microphone configuration, two consecutive words read from the SAI_ADR register contain a data byte from each microphone.

  For a 4 microphones configuration, each word read from the SAI_ADR register contains a data byte from each microphone.

Figure 907. SAI_ADR format in TDM mode, 32-bit slot width

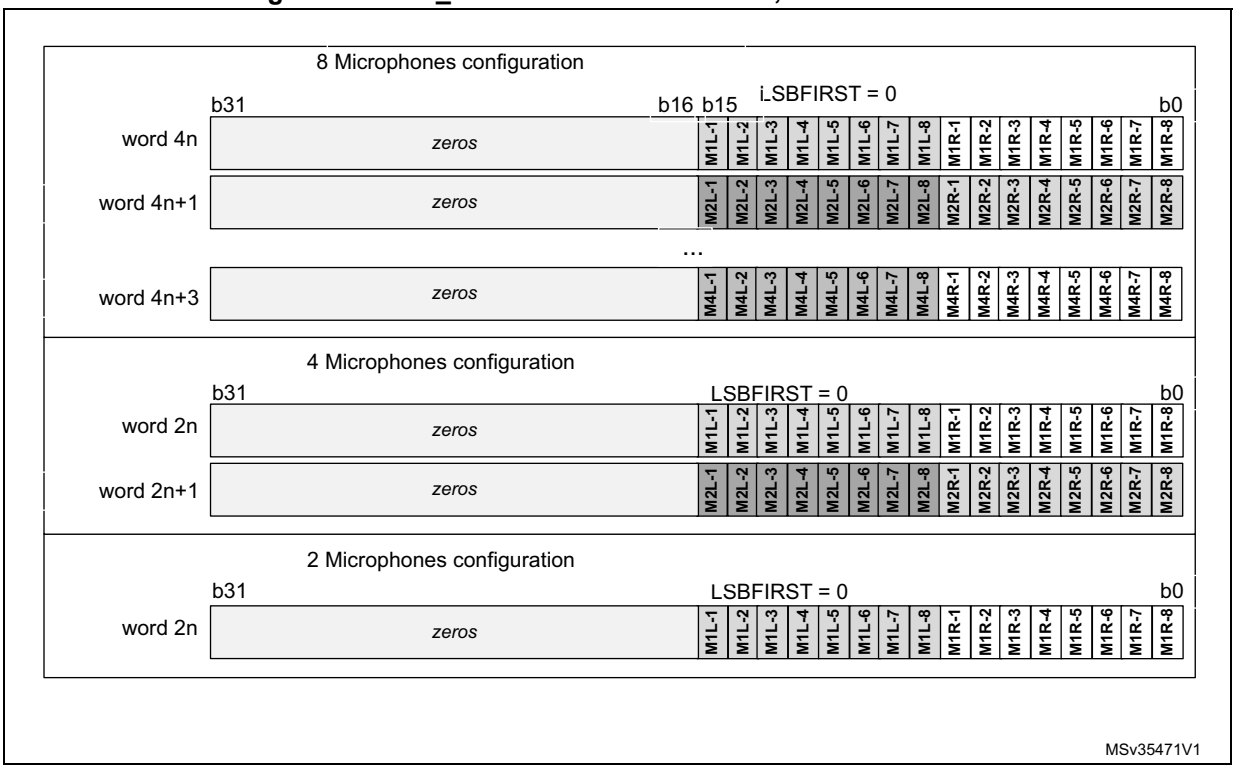


- **16-bit slot width** (DS = 0b100 and SLOTSZ = 0). Refer to *Figure 908*.

  For an 8-microphone configuration, four consecutive words read from the SAI_ADR register contain a data byte from each microphone. Note that the 16-bit data of SAI_ADR are right-aligned.

  For a 4- or 2-microphone configuration, the SAI behavior is similar to the 8-microphone configuration. Up to 2 words of 16 bits are required to acquire a byte from 4 microphones and a single word for 2 microphones.

Figure 908. SAI_ADR format in TDM mode, 16-bit slot width

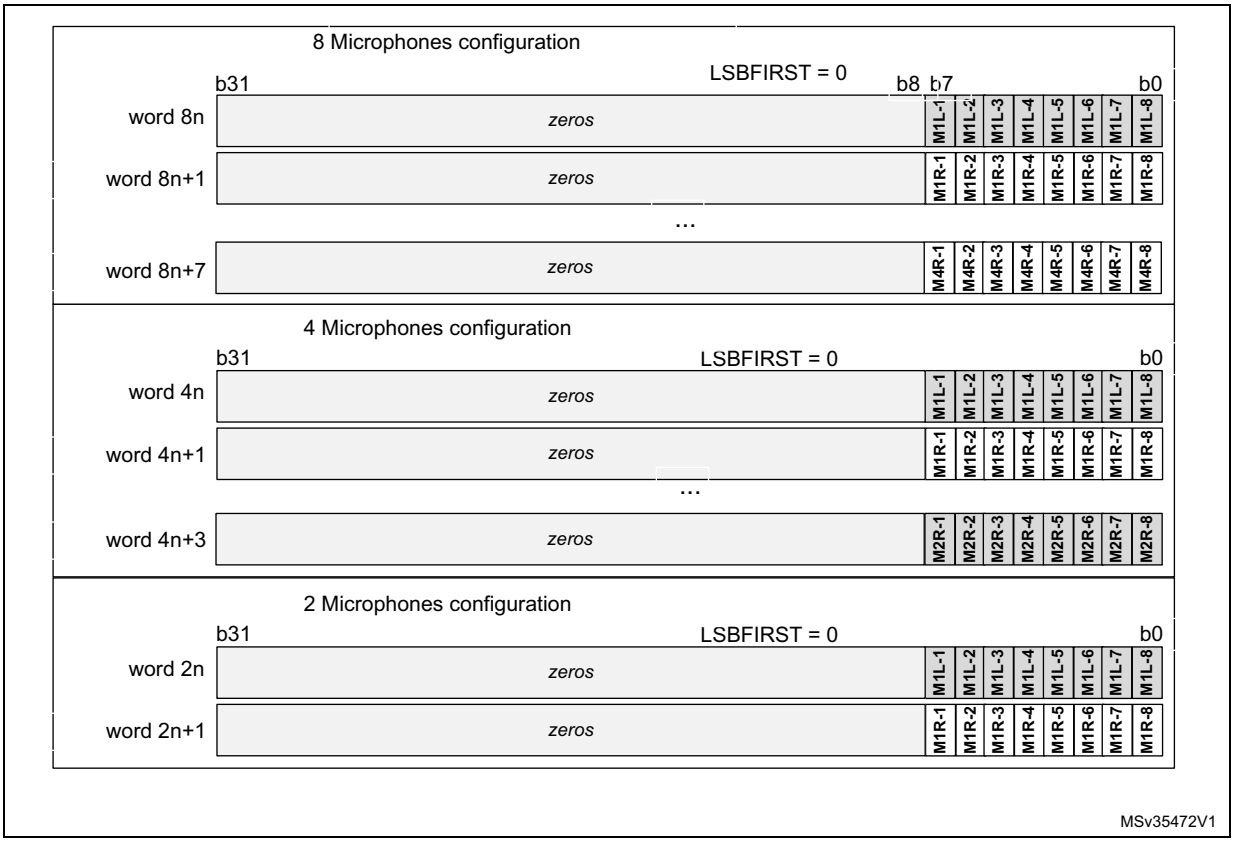


- **Using an 8-bit slot width** (DS = 0b010 and SLOTSZ = 0). Refer to *Figure 909*.

  For an 8-microphone configuration, eight consecutive words read from the SAI_ADR register contain a byte of data from each microphone. Note that the 8-bit data of SAI_ADR are right-aligned.

  For a 4- or 2-microphone configuration, the SAI behavior is similar to the 8-microphone configuration. Up to four words of eight bits are required to acquire a byte from four microphones and two words from two microphones.

Figure 909. SAI_ADR format in TDM mode, 8-bit slot width



TDM mode configuration for PDM interface

The SAI_A serial audio interface is internally connected to the PDM interface to get the microphone samples. The user application must configure the SAI_A serial audio interface as shown in *Table 705* to ensure a good connection with the PDM interface.

Table 705. SAI_A configuration for TDM mode

Bit Fields	Values	Comments
MODE	0b01	Mode must be MASTER receiver.
PRTCFG	0b00	Free protocol for TDM.
DS	X	To be adjusted according to the required data format, in accordance with the frame length and the number of slots (FRL and NBSLOT). See *Table 706*.
LSBFIRST	X	This parameter can be used according to the desired data format.
CKSTR	0	Signal transitions occur on the rising edge of the SCK_A bit clock. Signals are stable on the falling edge of the bit clock.
MONO	0	Stereo mode.
FRL	X	To be adjusted according to the number of microphones (MICNBR). See *Table 706*.
FSALL	0	Pulse width is one bit clock cycle.

Table 705. SAI_A configuration for TDM mode (continued)

Bit Fields	Values	Comments
FSDEF	0	FS signal is a start of frame.
FSPOL	1	FS is active high.
FSOFF	0	FS is asserted on the first bit of slot 0.
FBOFF	0	No offset on slot.
SLOTSZ	0	Slot size = data size.
NBSLOT	X	To be adjusted according to the required data format, in accordance with the slot size, and the frame length (FRL and DS). See *Table 706*.
SLOTEN	X	To be adjusted according to NBSLOT.
NODIV	1	No need to generate a master clock MCLK.
MCKDIV	X	Depends on the frequency provided to sai_a_ker_ck input. This parameter must be adjusted to generate the proper bitstream clock frequency. See *Table 706*.

Adjusting the bitstream clock rate

To program the serial audio interface properly, the user application must take into account the settings given in *Table 705*, and follow the sequence below:

1. Adjust the bit clock frequency (F_{SCK_A}) according to the required frequency for the PDM bitstream clock, using the following formula:

$$F_{SCK_A} = F_{PDM_CK} \times (MICNBR + 1) \times 2$$

   MICNBR can be 0, 1, 2 or 3 (0 = 2 microphones; see *Section 64.6.18*)

2. Set the frame length (FRL) using the following formula:

$$FRL = (16 \times (MICNBR + 1)) - 1$$

Table 706. TDM frame configuration examples(1)(2)

Microphone sampling rate	Nber of microphones	Wanted SAI_CKn frequency	bit clock (SCK_A) frequency	Frame sync. (FS_A) frequency	FRL	DS	NBSLOT	Comments
48 kHz	up to 8	3.072 MHz	24.576 MHz	384 kHz	63	0b111	1	2 slots of 32 bits per frame
		3.072 MHz	24.576 MHz	384 kHz	63	0b100	3	4 slots of 16 bits per frame
		3.072 MHz	24.576 MHz	384 kHz	63	0b010	7	8 slots of 8 bits per frame
	up to 6	3.072 MHz	18.432 MHz	384 kHz	47	0b110	1	2 slots of 24 bits per frame
		3.072 MHz	18.432 MHz	384 kHz	47	0b100	2	3 slots of 16 bits per frame
		3.072 MHz	18.432 MHz	384 kHz	47	0b010	5	6 slots of 8 bits per frame
	up to 4	3.072 MHz	12.288 MHz	384 kHz	31	0b111	0	1 slot of 32 bits per frame
		3.072 MHz	12.288 MHz	384 kHz	31	0b100	1	2 slots of 16 bits per frame
		3.072 MHz	12.288 MHz	384 kHz	31	0b010	3	4 slots of 8 bits per frame
	up to 2	3.072 MHz	6.144 MHz	384 kHz	15	0b100	0	1 slots of 16 bits per frame
		3.072 MHz	6.144 MHz	384 kHz	15	0b010	1	2 slots of 8 bits per frame
16 kHz	up to 8	1.024 MHz	8.192 MHz	128 kHz	63	0b111	1	2 slots of 32 bits per frame
		1.024 MHz	8.192 MHz	128 kHz	63	0b100	3	4 slots of 16 bits per frame
		1.024 MHz	8.192 MHz	128 kHz	63	0b010	7	8 slots of 8 bits per frame
	up to 6	1.024 MHz	6.144 MHz	128 kHz	47	0b110	1	2 slots of 24 bits per frame
		1.024 MHz	6.144 MHz	128 kHz	47	0b010	5	6 slots of 8 bits per frame
	up to 4	1.024 MHz	4.096 MHz	128 kHz	31	0b111	0	1 slot of 32 bits per frame
		1.024 MHz	4.096 MHz	128 kHz	31	0b100	1	2 slots of 16 bits per frame
		1.024 MHz	4.096 MHz	128 kHz	31	0b010	3	4 slots of 8 bits per frame
	up to 2	1.024 MHz	2.048 MHz	128 kHz	15	0b100	0	1 slot of 16 bits per frame
		1.024 MHz	2.048 MHz	128 kHz	15	0b010	1	2 slots of 8 bits per frame

1. Refer to *Table 705: SAI_A configuration for TDM mode* for additional information on TDM configuration. The sai_a_ker_ck clock frequency provided to the SAI must be a multiple of the SCK_A frequency, and MCKDIV must be programmed accordingly.
2. The above sai_a_ker_ck frequencies are given as examples only. Refer to section *Reset and clock controller (RCC) to check if they can be generated on the device*.
3. The table above gives allowed settings for a decimation ratio of 64.

Adjusting the delay lines

When the PDM interface is enabled, the application can adjust on-the-fly the delay cells of each microphone input via the SAI_PDMDLY register.

The new delay values become effective after two audio frames.

64.4.11 AC’97 link controller

The SAI is able to work as an AC’97 link controller. In this protocol:

- The slot number and the slot size are fixed.
- The frame synchronization signal is perfectly defined and has a fixed shape.

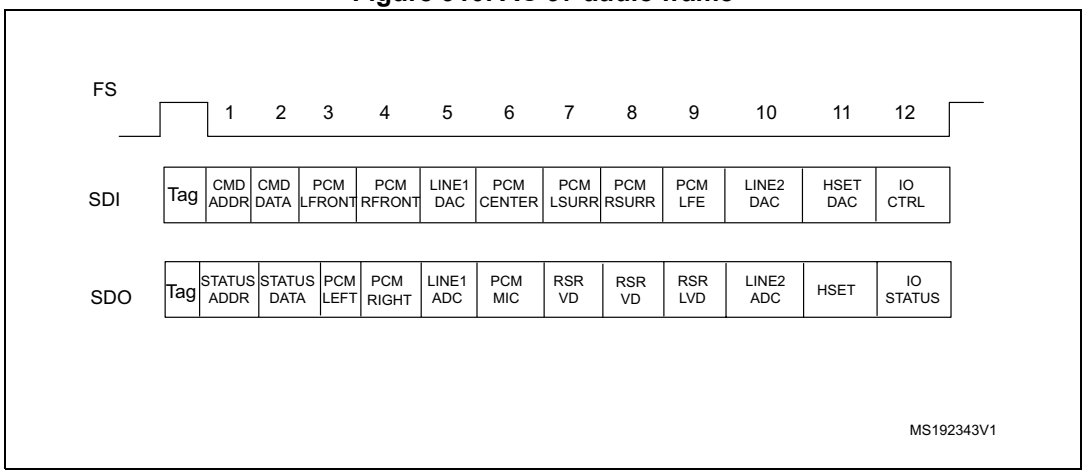
To select this protocol, set the PRTCFG[1:0] bits in the SAI_xCR1 register to 10. When AC’97 mode is selected, only data sizes of 16 or 20 bits can be used, otherwise the SAI behavior is not guaranteed.

- The NBSLOT[3:0] and SLOTSZ[1:0] bits are consequently ignored.
- The number of slots is fixed at 13 slots. The first one is 16 bits wide and all the others are 20 bits wide (data slots).
- The FBOFF[4:0] bits in the SAI_xSLOTR register are ignored.
- The SAI_xFRCR register is ignored.
- The MCLK is not used.

The FS signal from the block defined as asynchronous is configured automatically as an output, since the AC’97 controller link drives the FS signal whatever the master or slave configuration.

Figure 910 shows an AC’97 audio frame structure.

Figure 910. AC’97 audio frame



Note: In the AC’97 protocol, bit 2 of the tag is reserved (always 0), so bit 2 of the TAG is forced to 0 level whatever the value written in the SAI FIFO.

For more details about tag representation, refer to the AC’97 protocol standard.

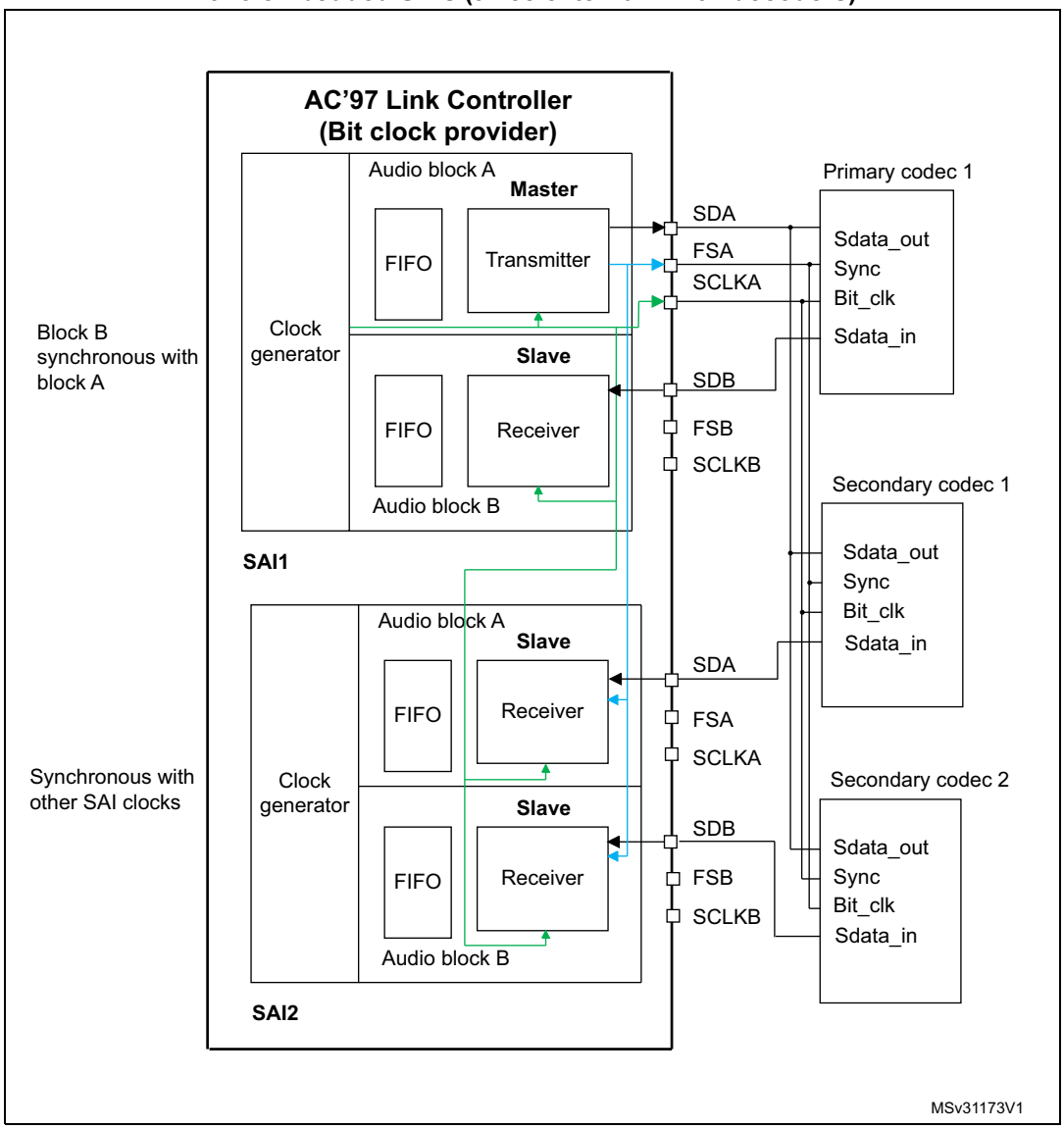
One SAI can be used to target an AC’97 point-to-point communication.

Using two SAIs (for devices featuring two embedded SAIs) enables the control of three external AC’97 decoders as illustrated in *Figure 911*.

In SAI1, the audio block A must be declared as asynchronous master transmitter, whereas the audio block B is defined to be slave receiver and internally synchronous to the audio block A.

The SAI2 is configured for audio block A and B both synchronous with the external SAI1 in slave receiver mode.

Figure 911. Example of typical AC'97 configuration on devices featuring at least two embedded SAIs (three external AC'97 decoders)



In receiver mode, the SAI acting as an AC'97 link controller requires no FIFO request and so no data storage in the FIFO when the codec-ready bit in slot 0 is decoded low. If bit CNRDYIE is enabled in the SAI_xIM register, flag CNRDY is set in the SAI_xSR register and an interrupt is generated. This flag is dedicated to the AC'97 protocol.

Clock generator programming in AC'97 mode

In AC'97 mode, the frame length is fixed at 256 bits, and its frequency must be set to 48 kHz. The formulas given in *Section 64.4.8: SAI clock generator* must be used with FRL = 255, to generate the proper frame rate (F_{FS_x}).

64.4.12 SPDIF output

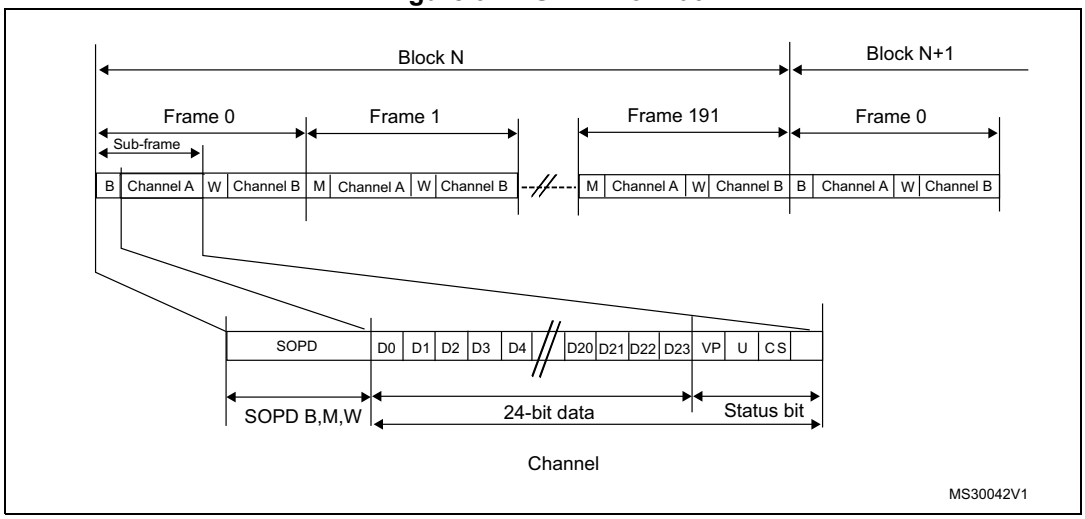
The SPDIF interface is available in transmitter mode only. It supports the audio IEC60958.

To select SPDIF mode, set the PRTCFG[1:0] bits to 01 in the SAI_xCR1 register.

For SPDIF protocol:

- Only the SD data line is enabled.
- The FS, SCK, and MCLK I/Os pins are left free.
- The MODE[1] bit is forced to 0 to select the master mode to enable the clock generator of the SAI and manage the data rate on the SD line.
- The data size is forced to 24 bits. The value set in the DS[2:0] bits in the SAI_xCR1 register is ignored.
- The clock generator must be configured to define the symbol-rate, knowing that the bit clock must be twice the symbol-rate. The data is coded in Manchester protocol.
- The SAI_xFRCR and SAI_xSLOTR registers are ignored. The SAI is configured internally to match the SPDIF protocol requirements as shown in *Figure 912*.

Figure 912. SPDIF format



An SPDIF block contains 192 frames. Each frame is composed of two 32-bit subframes, generally one for the left channel and one for the right channel. Each subframe is composed of a SOPD pattern (4-bit) to specify if the subframe is the start of a block (and so is identifying a channel A) or if it is identifying a channel A somewhere in the block, or if it is referring to channel B (see *Table 707*). The next 28 bits of channel information are composed of 24 data bits + 4 status bits.

Table 707. SOPD pattern

SOPD	Preamble coding		Description
	last bit is 0	last bit is 1	
B	11101000	00010111	Channel A data at the start of block
W	11100100	00011011	Channel B data somewhere in the block
M	11100010	00011101	Channel A data

The data stored in SAI_xDR has to be filled as follows:

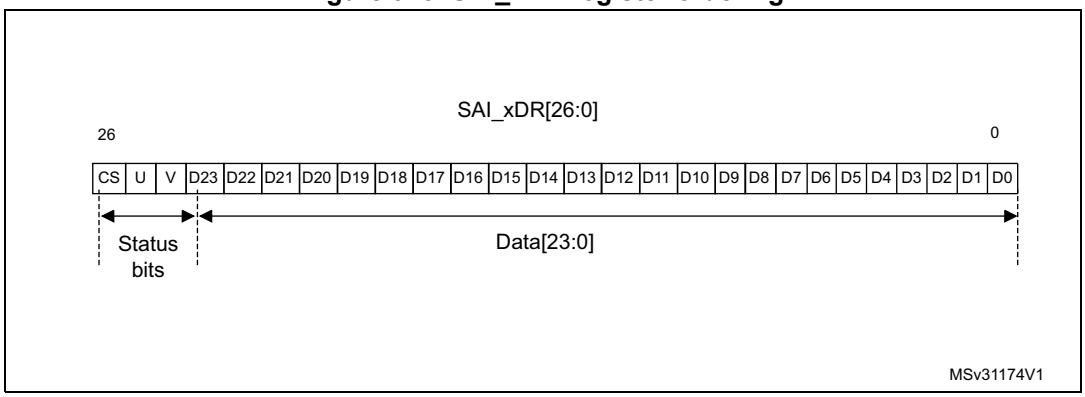
- SAI_xDR[26:24] contain the channel status, user, and validity bits.
- SAI_xDR[23:0] contain the 24-bit data for the considered channel.

If the data size is 20 bits, the data must be mapped on SAI_xDR[23:4].

If the data size is 16 bits, the data must be mapped on SAI_xDR[23:8].

SAI_xDR[23] always represents the MSB.

Figure 913. SAI_xDR register ordering



Note: The transfer is always performed with LSB first.

The SAI first sends the adequate preamble for each subframe in a block. The SAI_xDR is then sent on the SD line (Manchester coded). The SAI ends the subframe by transferring the parity bit calculated as described in *Table 708*.

Table 708. Parity bit calculation

SAI_xDR[26:0]	Parity bit P value transferred
odd number of 0	0
odd number of 1	1

The underrun is the only error flag available in the SAI_xSR register for SPDIF mode since the SAI can only operate in transmitter mode. As a result, the following sequence must be executed to recover from an underrun error detected via the underrun interrupt or the underrun status bit:

1. Disable the DMA stream (via the DMA peripheral) if the DMA is used.
2. Disable the SAI and check that the peripheral is physically disabled by polling the SAIEN bit in the SAI_xCR1 register.
3. Clear the COVRUNDR flag in the SAI_xCLRFR register.
4. Flush the FIFO by setting the FFLUSH bit in SAI_xCR2.

   The software needs to point to the address of the future data corresponding to the start of a new block (data for preamble B). If the DMA is used, the DMA source base address pointer must be updated accordingly.
5. Enable the DMA stream (DMA peripheral) again if the DMA is used to manage data transfers according to the new source base address.
6. Enable the SAI again by configuring the SAIEN bit in the SAI_xCR1 register.

Clock generator programming in SPDIF generator mode

For the SPDIF generator, the SAI provides a bit clock twice as fast as the symbol-rate. The table below shows examples of symbol rates with respect to the audio sampling rate.

Table 709. Audio sampling frequency versus symbol rates

Audio sampling frequencies (F_S)	Symbol-rate
44.1 kHz	2.8224 MHz
48 kHz	3.072 MHz
96 kHz	6.144 MHz
192 kHz	12.288 MHz

More generally, the relationship between the audio sampling frequency (F_S) and the bit clock rate (F_{SCK_X}) is given by the formula:

$$F_S = \frac{F_{SCK_x}}{128}$$

The bit clock rate is obtained as follows:

$$F_{SCK_x} = \frac{F_{sai_x_ker_ck}}{MCKDIV}$$

Note: The above formulas are valid only if NODIV is set to 1 in the SAI_ACR1 register.

64.4.13 Specific features

The SAI interface embeds specific features that can be useful depending on the audio protocol selected. These functions are accessible through specific bits of the SAI_xCR2 register.

Mute mode

The mute mode can be used when the audio subblock is a transmitter or a receiver.

Audio subblock in transmission mode

In transmitter mode, the mute mode can be selected at any time. The mute mode is active for entire audio frames. The MUTE bit in the SAI_xCR2 register enables the mute mode when it is configured during an ongoing frame.

The mute mode bit is strobed only at the end of the frame. If it is set at this time, the mute mode is active at the beginning of the new audio frame and for a complete frame, until the next end of frame. The bit is then strobed to determine if the next frame is still a mute frame.

If the number of slots set through the NBSLOT[3:0] bits in the SAI_xSLOTR register is lower than or equal to 2, it is possible to specify if the value sent in mute mode is 0 or if it is the last value of each slot. The selection is done via the MUTEVAL bit in the SAI_xCR2 register.

If the number of slots set in the NBSLOT[3:0] bits in the SAI_xSLOTR register is greater than 2, the MUTEVAL bit in the SAI_xCR2 register is meaningless as 0 values are sent on each bit on each slot.

The FIFO pointers are still incremented in mute mode. This means that data present in the FIFO and for which the mute mode is requested are discarded.

Audio subblock in reception mode

In reception mode, it is possible to detect a mute mode sent from the external transmitter when all the declared and valid slots of the audio frame receive 0 for a given consecutive number of audio frames (MUTECNT[5:0] bits in the SAI_xCR2 register).

When the number of MUTE frames is detected, the MUTEDET flag in the SAI_xSR register is set and an interrupt can be generated if the MUTEDETIE bit is set in SAI_xCR2.

The mute frame counter is cleared when the audio subblock is disabled or when a valid slot receives at least one data in an audio frame. The interrupt is generated just once, when the counter reaches the value specified in the MUTECNT[5:0] bits. The interrupt event is then reinitialized when the counter is cleared.

Note: The mute mode is not available for SPDIF audio blocks.

Mono/stereo mode

In transmitter mode, the mono mode can be addressed without any data preprocessing in memory, assuming the number of slots is equal to 2 (NBSLOT[3:0] = 0001 in SAI_xSLOTR). In this case, the access time to and from the FIFO is reduced by 2 since the data for slot 0 is duplicated into data slot 1.

To enable the mono mode:

1. Set the MONO bit to 1 in the SAI_xCR1 register.
2. Set NBSLOT to 1 and SLOTEN to 3 in SAI_xSLOTR.

In reception mode, the MONO bit can be set and is meaningful only if the number of slots is equal to 2, like in transmitter mode. When it is set, only slot 0 data are stored in the FIFO. The data belonging to slot 1 are discarded since, in this case, it is supposed to be the same as the previous slot. If the data flow in reception mode is a real stereo audio flow with a distinct and different left and right data, the MONO bit is meaningless. The conversion from the output stereo file to the equivalent mono file is done by software.

Companding mode

Telecommunication applications can require processing the data to be transmitted or received using a data companding algorithm.

Depending on the COMP[1:0] bits in the SAI_xCR2 register (used only when free protocol mode is selected), the application software can choose to process or not the data before sending it on the SD serial output line (compression) or to expand the data after the reception on the SD serial input line (expansion), as illustrated in *Figure 914*. The two companding modes supported are the µ-Law and the A-Law logs, which are a part of the CCITT G.711 recommendation.

The companding standard used in the United States and Japan is the µ-Law. It supports 14 bits of dynamic range (COMP[1:0] = 10 in the SAI_xCR2 register).

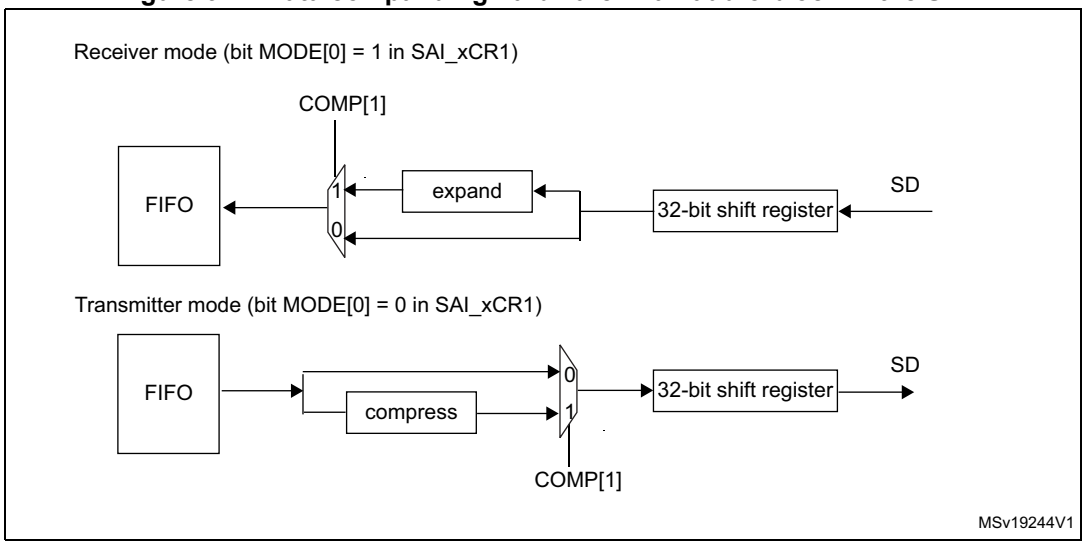
The European companding standard is A-Law and supports 13 bits of dynamic range (COMP[1:0] = 11 in the SAI_xCR2 register).

Both µ-Law and A-Law companding standard can be computed based on 1's complement or 2's complement representation, depending on the CPL bit setting in the SAI_xCR2 register.

In µ-Law and A-Law standards, data are coded as 8 bits with MSB alignment. Companded data are always 8 bits wide. For this reason, the DS[2:0] bits in the SAI_xCR1 register are forced to 010 when the SAI audio block is enabled (the SAIEN bit = 1 in the SAI_xCR1 register) and when one of these two companding modes is selected through the COMP[1:0] bits.

If no companding processing is required, the COMP[1:0] bits must be kept clear.

Figure 914. Data companding hardware in an audio block in the SAI



1. Not applicable when AC'97 or SPDIF are selected.

Expansion and compression mode are automatically selected through SAI_xCR2:

- If the SAI audio block is configured to be a transmitter, and if the COMP[1] bit is set in the SAI_xCR2 register, the compression mode is applied.
- If the SAI audio block is declared as a receiver, the expansion algorithm is applied.

Output data line management on an inactive slot

In transmitter mode, it is possible to choose the behavior of the SD line output when an inactive slot is sent on the data line (via the TRIS bit).

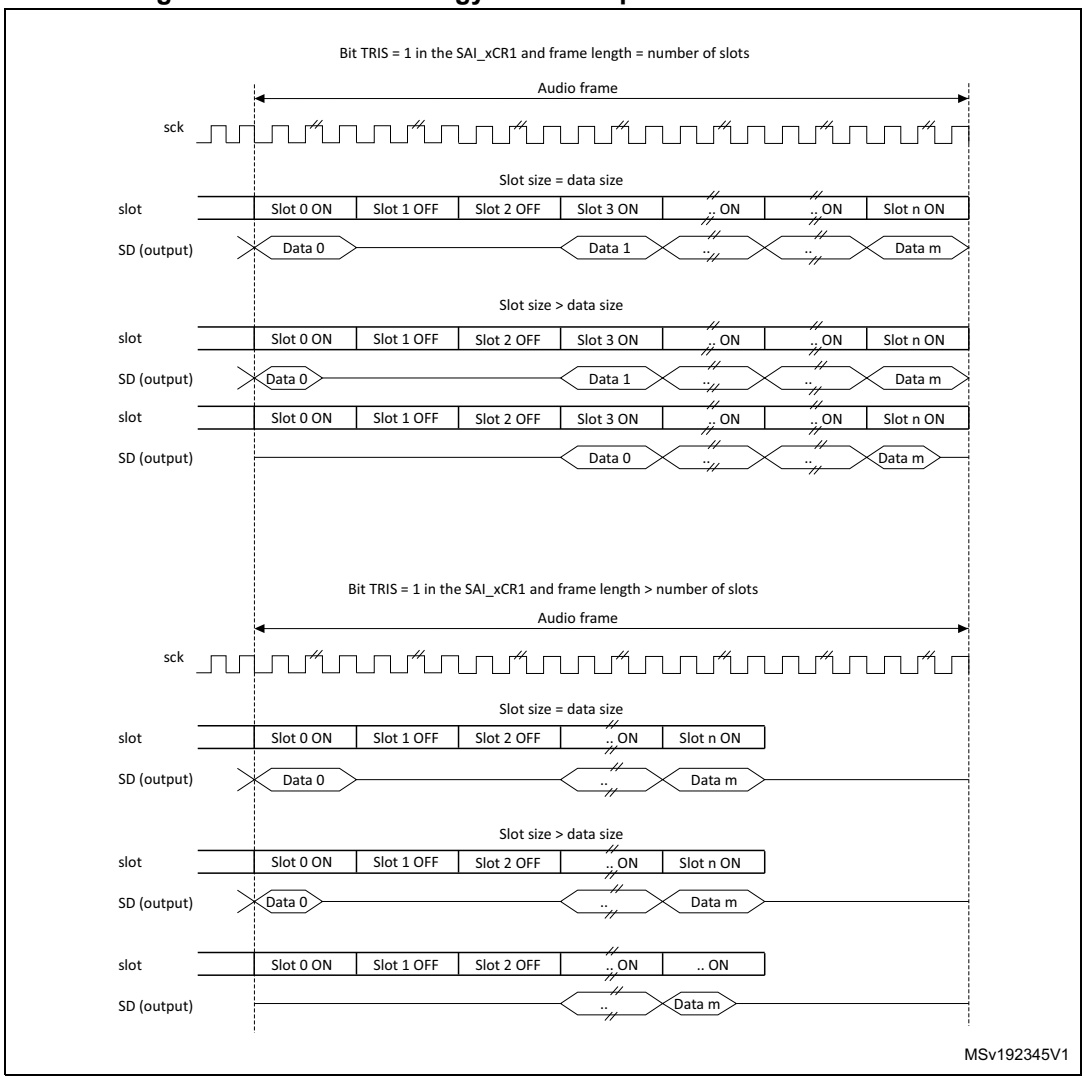
- Either the SAI forces 0 on the SD output line when an inactive slot is transmitted, or
- The line is released in high-Z state at the end of the last bit of data transferred, to release the line for other transmitters connected to this node.

It is important to note that the two transmitters cannot attempt to drive the same SD output pin simultaneously, which may result in a short circuit. To ensure a gap between transmissions, if the data is lower than 32-bit, the data can be extended to 32-bit by setting the bit SLOTSZ[1:0] = 10 in the SAI_xSLOTR register. The SD output pin is then tri-stated at the end of the LSB of the active slot (during the padding to 0 phase to extend the data to 32-bit) if the following slot is declared inactive.

In addition, if the number of slots multiplied by the slot size is lower than the frame length, the SD output line is tri-stated when the padding to 0 is done to complete the audio frame.

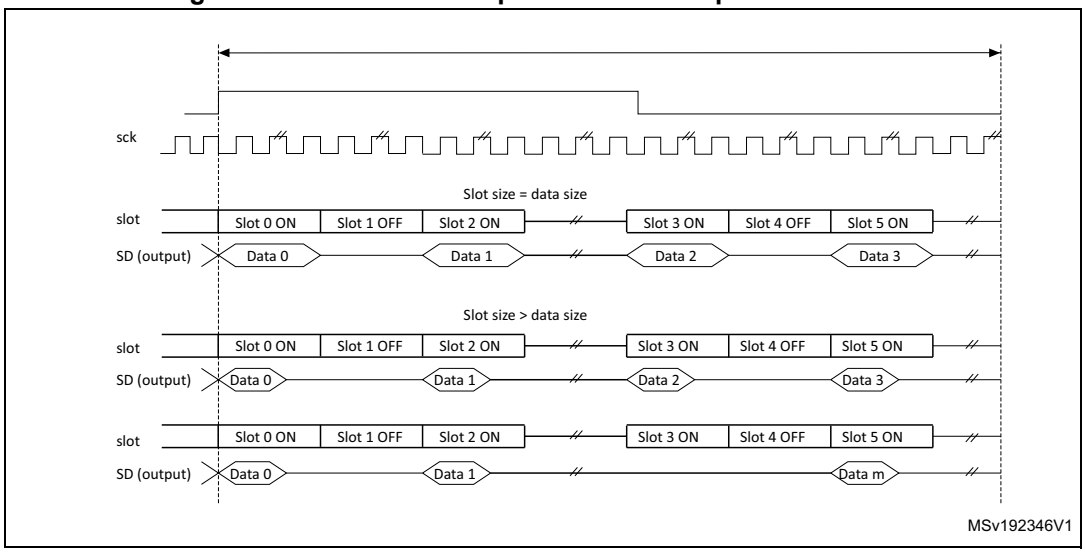
Figure 915 illustrates these behaviors.

Figure 915. Tristate strategy on SD output line on an inactive slot



When the selected audio protocol uses the FS signal as a start of frame and a channel side identification (bit FSDEF = 1 in the SAI_xFRCR register), the tristate mode is managed according to *Figure 916* (where the bit TRIS in the SAI_xCR1 register = 1, and FSDEF=1, and half frame length is higher than number of slots/2, and NBSLOT=6).

Figure 916. Tristate on output data line in a protocol like I2S



If the TRIS bit in the SAI_xCR2 register is cleared, all the high impedance states on the SD output line in *Figure 915* and *Figure 916* are replaced by a drive with a value of 0.

64.4.14 Error flags

The SAI implements the following error flags:

- FIFO overrun/underrun.
- Anticipated frame synchronization detection.
- Late frame synchronization detection.
- Codec not ready (AC'97 exclusively).
- Wrong clock configuration in master mode.

FIFO overrun/underrun (OVRUDR)

The FIFO overrun/underrun bit is called OVRUDR in the SAI_xSR register.

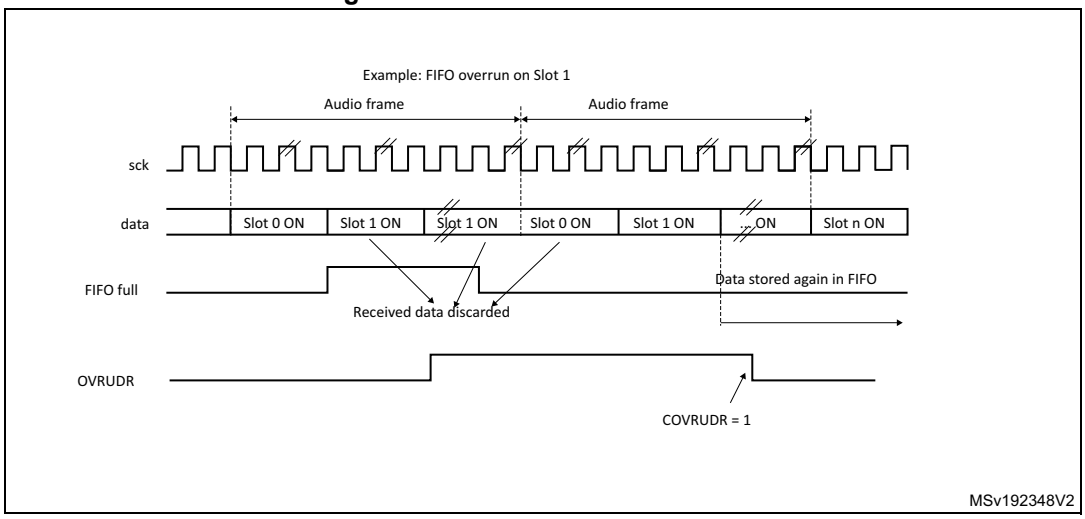
The overrun or underrun errors share the same bit since an audio block can be either receiver or transmitter and each audio block in a given SAI has its own SAI_xSR register.

Overrun

When the audio block is configured as receiver, an overrun condition may appear if data are received in an audio frame when the FIFO is full and not able to store the received data. In this case, the received data are lost, the OVRUDR flag in the SAI_xSR register is set, and an interrupt is generated if the OVRUDRIE bit is set in the SAI_xIM register. The slot number, from which the overrun occurs, is stored internally. No more data are stored into the FIFO until it becomes free to store new data. When the FIFO has at least one data free, the SAI audio block receiver stores new data (from a new audio frame) from the slot number that was stored internally when the overrun condition was detected. This avoids data slot dealignment in the destination memory (refer to *Figure 917*).

The OVRUDR flag is cleared when the COVRUDR bit is set in the SAI_xCLRFR register.

Figure 917. Overrun detection error



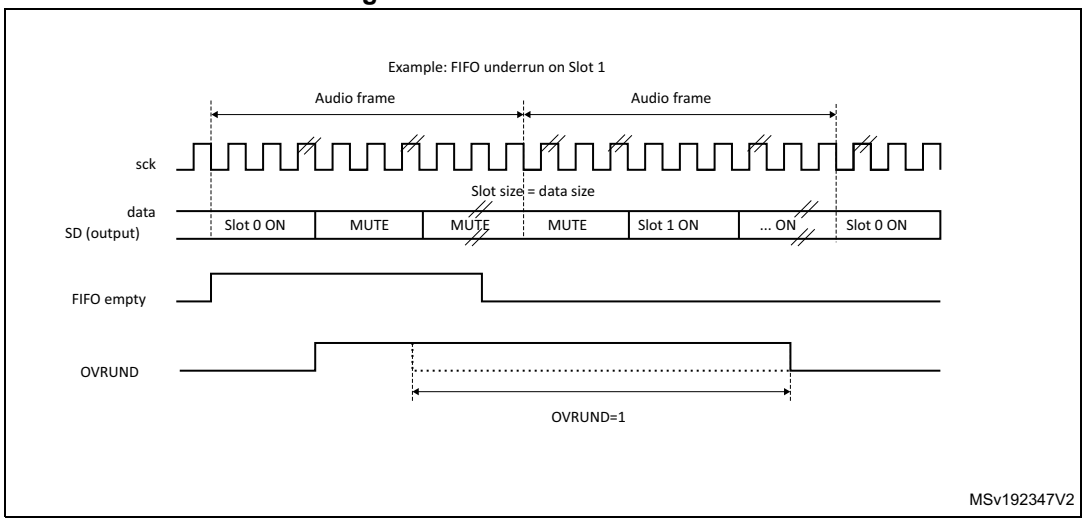
Underrun

An underrun may occur when the audio block in the SAI is a transmitter and the FIFO is empty when data need to be transmitted. If an underrun is detected, the slot number for which the event occurs is stored and the MUTE value (00) is sent until the FIFO is ready to transmit the data corresponding to the slot for which the underrun was detected (refer to *Figure 918*). This avoids desynchronization between the memory pointer and the slot in the audio frame.

The underrun event sets the OVRUDR flag in the SAI_xSR register and an interrupt is generated if the OVRUDRIE bit is set in the SAI_xIM register. To clear this flag, set the COVRUDR bit in the SAI_xCLRFR register.

The underrun event can occur when the audio subblock is configured as master or slave.

Figure 918. FIFO underrun event



Anticipated frame synchronization detection (AFSDET)

The AFSDET flag is used only in slave mode. It is never asserted in master mode. It indicates that a frame synchronization (FS) has been detected earlier than expected since the frame length, the frame polarity, and the frame offset are defined and known.

Anticipated frame detection sets the AFSDET flag in the SAI_xSR register.

This detection has no effect on the current audio frame, which is not sensitive to the anticipated FS. This means that “parasitic” events on signal FS are flagged without any perturbation of the current audio frame.

An interrupt is generated if the AFSDETIE bit is set in the SAI_xIM register. To clear the AFSDET flag, the CAFSDET bit must be set in the SAI_xCLRFR register.

To resynchronize with the master after an anticipated frame detection error, four steps are required:

1. Disable the SAI block by resetting the SAIEN bit in the SAI_xCR1 register. To make sure that the SAI is disabled, read back the SAIEN bit and check it is set to 0.
2. Flush the FIFO via the FFLUS bit in the SAI_xCR2 register.
3. Enable the SAI peripheral again (SAIEN bit set to 1).
4. The SAI block waits for the assertion on FS to restart the synchronization with master.

Note: The AFSDET flag is not asserted in AC’97 mode since the SAI audio block acts as a link controller and generates the FS signal even when declared as slave.It has no meaning in SPDIF mode since the FS signal is not used.

Late frame synchronization detection

The LFSDET flag in the SAI_xSR register can be set only when the SAI audio block operates as a slave. The frame length, the frame polarity, and the frame-offset configuration are known in register SAI_xFRCR.

If the external master does not send the FS signal at the expected time, thus generating the signal too late, the LFSDET flag is set and an interrupt is generated if the LFSDETIE bit is set in the SAI_xIM register.

The LFSDET flag is cleared when the CLFSDET bit is set in the SAI_xCLRFR register.

The late frame synchronization detection flag is set when the corresponding error is detected. The SAI needs to be resynchronized with the master (see sequence described in *Anticipated frame synchronization detection (AFSDET)*).

In a noisy environment, glitches on the SCK clock may be wrongly detected by the audio block state machine and shift the SAI data at a wrong frame position. This event can be detected by the SAI and reported as a late frame synchronization detection error.

There is no corruption if the external master is not managing the audio data frame transfer in continuous mode, which must not be the case in most applications. In this case, the LFSDET flag is set.

Note: The LFSDET flag is not asserted in AC’97 mode since the SAI audio block acts as a link controller and generates the FS signal even when declared as slave.It has no meaning in SPDIF mode since the signal FS is not used by the protocol.

Codec not ready (CNRDY AC'97)

The CNRDY flag in the SAI_xSR register is relevant only if the SAI audio block is configured to operate in AC'97 mode (PRTCFG[1:0] = 10 in the SAI_xCR1 register). If the CNRDYIE bit is set in the SAI_xIM register, an interrupt is generated when the CNRDY flag is set.

CNRDY is asserted when the codec is not ready to communicate during the reception of the TAG 0 (slot 0) of the AC'97 audio frame. In this case, no data are automatically stored into the FIFO since the codec is not ready, until the TAG 0 indicates that the codec is ready. All the active slots defined in the SAI_xSLOTR register are captured when the codec is ready.

To clear the CNRDY flag, the CCNRDY bit must be set in the SAI_xCLRFR register.

Wrong clock configuration in master mode (with NODIV = 0)

When the audio block operates as a master (MODE[1] = 0) and the NODIV bit is equal to 0, the WCKCFG flag is set as soon as the SAI is enabled if the following conditions are met:

- (FRL+1) is not a power of 2, and
- (FRL+1) is not between 8 and 256.

The MODE, NODIV, and SAIEN bits belong to the SAI_xCR1 register and FRL to the SAI_xFRCR register.

If the WCKCFGIE bit is set, an interrupt is generated when the WCKCFG flag is set in the SAI_xSR register. To clear this flag, set the CWCKCFG bit in the SAI_xCLRFR register.

When the WCKCFG bit is set, the audio block is automatically disabled, thus performing a hardware clear of the SAIEN bit.

64.4.15 Disabling the SAI

The SAI audio block can be disabled at any moment by clearing the SAIEN bit in the SAI_xCR1 register. All the already started frames are automatically completed before the SAI stops working. The SAIEN bit remains high until the SAI is completely switched off at the end of the current audio frame transfer.

If an audio block in the SAI operates synchronously with the other one, the one that is the master must be disabled first.

64.4.16 SAI DMA interface

To free the CPU and to optimize bus bandwidth, each SAI audio block has an independent DMA interface to read/write from/to the SAI_xDR register (to access the internal FIFO). There is one DMA channel per audio subblock supporting the basic DMA request/acknowledge protocol.

To configure the audio subblock for DMA transfer, set the DMAEN bit in the SAI_xCR1 register. The DMA request is managed directly by the FIFO controller depending on the FIFO threshold level (for more details refer to *Section 64.4.9: Internal FIFOs*). The DMA transfer direction is linked to the SAI audio subblock configuration:

- If the audio block operates as a transmitter, the audio block FIFO controller outputs a DMA request to load the FIFO with data written in the SAI_xDR register.
- If the audio block operates as a receiver, the DMA request is related to read operations from the SAI_xDR register.

Follow the sequence below to configure the SAI interface in DMA mode:

1. Configure the SAI and FIFO threshold levels to specify when the DMA request is launched.
2. Configure the SAI DMA channel.
3. Enable the DMA.
4. Enable the SAI interface.

64.5 SAI interrupts

The SAI supports 7 interrupt sources, as shown in *Table 710*.

Table 710. SAI interrupt sources

Interrupt acronym	Interrupt source	Interrupt group	Audio block mode	Interrupt enable	Interrupt clear
SAI	FREQ	FREQ	Master or slave Receiver or transmitter	FREQIE in SAI_xIM register	Depends on: – FIFO threshold setting (FLVL bits in SAI_xCR2) – Communication direction (transmitter or receiver) For more details refer to *Section 64.4.9: Internal FIFOs*
	OVRUDR	ERROR	Master or slave Receiver or transmitter	OVRUDRIE in SAI_xIM register	COVRUDR = 1 in SAI_xCLRFR register
	AFSDET	ERROR	Slave (not used in AC'97 mode and SPDIF mode)	AFSDETIE in SAI_xIM register	CAFSDET = 1 in SAI_xCLRFR register
	LFSDET	ERROR	Slave (not used in AC'97 mode and SPDIF mode)	LFSDETIE in SAI_xIM register	CLFSDET = 1 in SAI_xCLRFR register
	CNRDY	ERROR	Slave (only in AC'97 mode)	CNRDYIE in SAI_xIM register	CCNRDY = 1 in SAI_xCLRFR register
	MUTEDET	MUTE	Master or slave Receiver mode only	MUTEDETIE in SAI_xIM register	CMUTEDET = 1 in SAI_xCLRFR register
	WCKCFG	ERROR	Master with NODIV = 0 in SAI_xCR1 register	WCKCFGIE in SAI_xIM register	CWCKCFG = 1 in SAI_xCLRFR register

Follow the sequence below to enable an interrupt:

1. Disable SAI interrupt.
2. Configure SAI.
3. Configure SAI interrupt source.
4. Enable SAI.

64.6 SAI registers

The peripheral registers have to be accessed by words (32 bits).

64.6.1 SAI global configuration register (SAI_GCR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYNCOUT[1:0]		Res.	Res.	SYNCIN[1:0]	
										rw	rw			rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:4 **SYNCOUT[1:0]**: Synchronization outputs

These bits are set and cleared by software.

00: No synchronization output signals. SYNCOUT[1:0] must be configured as “No synchronization output signals” when audio block is configured as SPDIF

01: Block A used for further synchronization for others SAI

10: Block B used for further synchronization for others SAI

11: Reserved. These bits must be set when both audio block (A and B) are disabled.

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **SYNCIN[1:0]**: Synchronization inputs

These bits are set and cleared by software.

Refer to *Table 702: External synchronization selection* for information on how to program this field.

These bits must be set when both audio blocks (A and B) are disabled.

They are meaningful if one of the two audio blocks is defined to operate in synchronous mode with an external SAI (SYNCEN[1:0] = 10 in SAI_ACR1 or in SAI_BCR1 registers).

64.6.2 SAI configuration register 1 (SAI_ACR1)

Address offset: 0x04

Reset value: 0x0000 0040

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	MCKEN	OSR	MCKDIV[5:0]						NODIV	Res.	DMAEN	SAIEN
				rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	OUTDRIV	MONO	SYNCEN[1:0]		CKSTR	LSBFIRST	DS[2:0]			Res.	PRTCFG[1:0]		MODE[1:0]	
		rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **MCKEN:** Master clock generation enable
0: The master clock is not generated
1: The master clock is generated independently of SAIEN bit

Bit 26 **OSR:** Oversampling ratio for master clock
This bit is meaningful only when NODIV bit is set to 0.
0: Master clock frequency = F_{FS} x 256
1: Master clock frequency = F_{FS} x 512

Bits 25:20 **MCKDIV[5:0]**: Master clock divider
These bits are set and cleared by software.
000000: Divides by 1 the kernel clock input (sai_x_ker_ck).
Otherwise, The master clock frequency is calculated according to the formula given in *Section 64.4.8: SAI clock generator*.
These bits have no meaning when the audio block is slave.
They have to be configured when the audio block is disabled.

Bit 19 **NODIV:** No divider
This bit is set and cleared by software.
0: the ratio between the Master clock generator and frame synchronization is fixed to 256 or 512
1: the ratio between the Master clock generator and frame synchronization depends on FRL[7:0]

Bit 18 Reserved, must be kept at reset value.

Bit 17 **DMAEN**: DMA enable
This bit is set and cleared by software.
0: DMA disabled
1: DMA enabled
Note: Since the audio block defaults to operate as a transmitter after reset, the MODE[1:0] bits must be configured before setting DMAEN to avoid a DMA request in receiver mode.

Bit 16 **SAIEN**: Audio block enable
This bit is set by software.
To switch off the audio block, the application software must program this bit to 0 and poll the bit till it reads back 0, meaning that the block is completely disabled. Before setting this bit to 1, check that it is set to 0, otherwise the enable command is not taken into account.
This bit enables to control the state of the SAI audio block. If it is disabled when an audio frame transfer is ongoing, the ongoing transfer completes and the cell is fully disabled at the end of this audio frame transfer.
0: SAI audio block disabled
1: SAI audio block enabled.
Note: When the SAI block (A or B) is configured in master mode, the clock must be present on the SAI block input before setting SAIEN bit.

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **OUTDRIV**: Output drive
This bit is set and cleared by software.
0: Audio block output driven when SAIEN is set
1: Audio block output driven immediately after the setting of this bit.
Note: This bit has to be set before enabling the audio block and after the audio block configuration.

Bit 12 **MONO**: Mono mode

This bit is set and cleared by software. It is meaningful only when the number of slots is equal to 2. When the mono mode is selected, slot 0 data are duplicated on slot 1 when the audio block operates as a transmitter. In reception mode, the slot1 is discarded and only the data received from slot 0 are stored. Refer to *Section : Mono/stereo mode* for more details.

0: Stereo mode

1: Mono mode.

Bits 11:10 **SYNCEN[1:0]:** Synchronization enable

These bits are set and cleared by software. They must be configured when the audio subblock is disabled.

00: audio subblock in asynchronous mode.

01: audio subblock is synchronous with the other internal audio subblock. In this case, the audio subblock must be configured in slave mode

10: audio subblock is synchronous with an external SAI embedded peripheral. In this case the audio subblock must be configured in Slave mode.

11: Reserved

Note: The audio subblock must be configured as asynchronous when SPDIF mode is enabled.

Bit 9 **CKSTR:** Clock strobing edge

This bit is set and cleared by software. It must be configured when the audio block is disabled. This bit has no meaning in SPDIF audio protocol.

0: Signals generated by the SAI change on SCK rising edge, while signals received by the SAI are sampled on the SCK falling edge.

1: Signals generated by the SAI change on SCK falling edge, while signals received by the SAI are sampled on the SCK rising edge.

Bit 8 **LSBFIRST:** Least significant bit first

This bit is set and cleared by software. It must be configured when the audio block is disabled. This bit has no meaning in AC'97 audio protocol since AC'97 data are always transferred with the MSB first. This bit has no meaning in SPDIF audio protocol since in SPDIF data are always transferred with LSB first.

0: Data are transferred with MSB first

1: Data are transferred with LSB first

Bits 7:5 **DS[2:0]:** Data size

These bits are set and cleared by software. These bits are ignored when the SPDIF protocols are selected (bit PRTCFG[1:0]), because the frame and the data size are fixed in such case. When the companding mode is selected through COMP[1:0] bits, DS[1:0] are ignored since the data size is fixed to 8 bits by the algorithm.

These bits must be configured when the audio block is disabled.

000: Reserved

001: Reserved

010: 8 bits

011: 10 bits

100: 16 bits

101: 20 bits

110: 24 bits

111: 32 bits

Bit 4 Reserved, must be kept at reset value.

Bits 3:2 **PRTCFG[1:0]:** Protocol configuration

These bits are set and cleared by software. These bits have to be configured when the audio block is disabled.

00: Free protocol. Free protocol enables to use the powerful configuration of the audio block to address a specific audio protocol (such as I2S, LSB/MSB justified, TDM, PCM/DSP...) by setting most of the configuration register bits as well as frame configuration register.

01: SPDIF protocol

10: AC'97 protocol

11: Reserved

Bits 1:0 **MODE[1:0]:** SAIx audio block mode

These bits are set and cleared by software. They must be configured when SAIx audio block is disabled.

00: Master transmitter

01: Master receiver

10: Slave transmitter

11: Slave receiver

Note: When the audio block is configured in SPDIF mode, the master transmitter mode is forced (MODE[1:0] = 00).

64.6.3 SAI configuration register 2 (SAI_ACR2)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
COMP[1:0]		CPL	MUTECNT[5:0]						MUTE VAL	MUTE	TRIS	F FLUSH	FTH[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:14 **COMP[1:0]**: Companding mode.

These bits are set and cleared by software. The µ-Law and the A-Law log are a part of the CCITT G.711 recommendation, the type of complement that is used depends on *CPL bit*.

The data expansion or data compression are determined by the state of bit MODE[0].

The data compression is applied if the audio block is configured as a transmitter.

The data expansion is automatically applied when the audio block is configured as a receiver.

Refer to *Section : Companding mode* for more details.

00: No companding algorithm

01: Reserved.

10: µ-Law algorithm

11: A-Law algorithm

Note: Companding mode is applicable only when Free protocol mode is selected.

Bit 13 **CPL**: Complement bit.

This bit is set and cleared by software.

It defines the type of complement to be used for companding mode

0: 1's complement representation.

1: 2's complement representation.

Note: This bit has effect only when the companding mode is µ-Law algorithm or A-Law algorithm.

Bits 12:7 **MUTECNT[5:0]**: Mute counter.

These bits are set and cleared by software. They are used only in reception mode.

The value set in these bits is compared to the number of consecutive mute frames detected in reception. When the number of mute frames is equal to this value, the flag MUTEDET is set and an interrupt is generated if bit MUTEDETIE is set.

Refer to *Section : Mute mode* for more details.

Bit 6 **MUTEVAL**: Mute value.

This bit is set and cleared by software. It is meaningful only when the audio block operates as a transmitter, the number of slots is lower or equal to 2 and the MUTE bit is set.

If more slots are declared, the bit value sent during the transmission in mute mode is equal to 0, whatever the value of MUTEVAL.

if the number of slot is lower or equal to 2 and MUTEVAL = 1, the MUTE value transmitted for each slot is the one sent during the previous frame.

Refer to *Section : Mute mode* for more details.

0: Bit value 0 is sent during the mute mode.

1: Last values are sent during the mute mode.

Note: This bit is meaningless and must not be used for SPDIF audio blocks.

Bit 5 **MUTE:** Mute.

This bit is set and cleared by software. It is meaningful only when the audio block operates as a transmitter. The MUTE value is linked to value of MUTEVAL if the number of slots is lower or equal to 2, or equal to 0 if it is greater than 2.

Refer to *Section : Mute mode* for more details.

0: No mute mode.

1: Mute mode enabled.

Note: This bit is meaningless and must not be used for SPDIF audio blocks.

Bit 4 **TRIS**: Tristate management on data line.

This bit is set and cleared by software. It is meaningful only if the audio block is configured as a transmitter. This bit is not used when the audio block is configured in SPDIF mode. It must be configured when SAI is disabled.

Refer to *Section : Output data line management on an inactive slot* for more details.

0: SD output line is still driven by the SAI when a slot is inactive.

1: SD output line is released (HI-Z) at the end of the last data bit of the last active slot if the next one is inactive.

Bit 3 **FFLUSH:** FIFO flush.

This bit is set by software. It is always read as 0. This bit must be configured when the SAI is disabled.

0: No FIFO flush.

1: FIFO flush. Programming this bit to 1 triggers the FIFO Flush. All the internal FIFO pointers (read and write) are cleared. In this case data still present in the FIFO are lost (no more transmission or received data lost). Before flushing, SAI DMA stream/interrupt must be disabled

Bits 2:0 **FTH[2:0]:** FIFO threshold.
This bit is set and cleared by software.
000: FIFO empty
001: ¼ FIFO
010: ½ FIFO
011: ¾ FIFO
100: FIFO full
101: Reserved
110: Reserved
111: Reserved

64.6.4 SAI frame configuration register (SAI_AFRCR)

Address offset: 0x0C

Reset value: 0x0000 0007

Note: This register has no meaning in AC'97 and SPDIF audio protocol.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSOFF	FSPOL	FSDEF
													rw	rw	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	FSALL[6:0]							FRL[7:0]							
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **FSOFF**: Frame synchronization offset.
This bit is set and cleared by software. It is meaningless and is not used in AC'97 or SPDIF audio block configuration. This bit must be configured when the audio block is disabled.
0: FS is asserted on the first bit of the slot 0.
1: FS is asserted one bit before the first bit of the slot 0.

Bit 17 **FSPOL**: Frame synchronization polarity.
This bit is set and cleared by software. It is used to configure the level of the start of frame on the FS signal. It is meaningless and is not used in AC'97 or SPDIF audio block configuration.
This bit must be configured when the audio block is disabled.
0: FS is active low (falling edge)
1: FS is active high (rising edge)

Bit 16 **FSDEF**: Frame synchronization definition.
This bit is set and cleared by software.
0: FS signal is a start frame signal
1: FS signal is a start of frame signal + channel side identification
When the bit is set, the number of slots defined in the SAI_xSLOTR register has to be even. It means that half of this number of slots are dedicated to the left channel and the other slots for the right channel (e.g: this bit has to be set for I2S or MSB/LSB-justified protocols...).
This bit is meaningless and is not used in AC'97 or SPDIF audio block configuration. It must be configured when the audio block is disabled.

Bit 15 Reserved, must be kept at reset value.

Bits 14:8 **FSALL[6:0]**: Frame synchronization active level length.

These bits are set and cleared by software. They specify the length in number of bit clock (SCK) + 1 (FSALL[6:0] + 1) of the active level of the FS signal in the audio frame

These bits are meaningless and are not used in AC'97 or SPDIF audio block configuration.

They must be configured when the audio block is disabled.

Bits 7:0 **FRL[7:0]**: Frame length.

These bits are set and cleared by software. They define the audio frame length expressed in number of SCK clock cycles: the number of bits in the frame is equal to FRL[7:0] + 1.

The minimum number of bits to transfer in an audio frame must be equal to 8, otherwise the audio block behaves in an unexpected way. This is the case when the data size is 8 bits and only one slot 0 is defined in NBSLOT[4:0] of SAI_xSLOTR register (NBSLOT[3:0] = 0000).

In master mode, if the master clock (available on MCLK_x pin) is used, the frame length must be aligned with a number equal to a power of 2, ranging from 8 to 256. When the master clock is not used (NODIV = 1), it is recommended to program the frame length to an value ranging from 8 to 256.

These bits are meaningless and are not used in AC'97 or SPDIF audio block configuration. They must be configured when the audio block is disabled.

64.6.5 SAI slot register (SAI_ASLOTR)

Address offset: 0x10

Reset value: 0x0000 0000

Note: This register has no meaning in AC'97 and SPDIF audio protocol.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SLOTEN[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	NBSLOT[3:0]				SLOTSZ[1:0]		Res.	FBOFF[4:0]				
				rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:16 **SLOTEN[15:0]**: Slot enable.
These bits are set and cleared by software.
Each SLOTEN bit corresponds to a slot position from 0 to 15 (maximum 16 slots).
0: Inactive slot.
1: Active slot.
The slot must be enabled when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **NBSLOT[3:0]**: Number of slots in an audio frame.
These bits are set and cleared by software.
The value set in this bitfield represents the number of slots in the audio frame (including the number of inactive slots). The maximum number of slots is 16.
The number of slots must be even if FSDEF bit in the SAI_xFRCR register is set.
The number of slots must be configured when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.
0000: Number of slots is 1.
0001: Number of slots is 2.
...
1111: Number of slots is 16.

Bits 7:6 **SLOTSZ[1:0]**: Slot size
This bits is set and cleared by software.
The slot size must be higher or equal to the data size. If this condition is not respected, the behavior of the SAI is undetermined.
Refer to *Output data line management on an inactive slot* for information on how to drive SD line.
These bits must be set when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.
00: The slot size is equivalent to the data size (specified in DS[3:0] in the SAI_xCR1 register).
01: 16-bit
10: 32-bit
11: Reserved

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **FBOFF[4:0]**: First bit offset
These bits are set and cleared by software.
The value set in this bitfield defines the position of the first data transfer bit in the slot. It represents an offset value. In transmission mode, the bits outside the data field are forced to 0. In reception mode, the extra received bits are discarded.
These bits must be set when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.

64.6.6 SAI interrupt mask register (SAI_AIM)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LFSDETIE	AFSDETIE	CNRDYIE	FREQIE	WCKCFGIE	MUTEDETIE	OVRUDRIE
									rw	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **LFSDETIE**: Late frame synchronization detection interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the LFSDET bit is set in the SAI_xSR register.
This bit is meaningless in AC'97, SPDIF mode or when the audio block operates as a master.

Bit 5 **AFSDETIE**: Anticipated frame synchronization detection interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the AFSDET bit in the SAI_xSR register is set.
This bit is meaningless in AC'97, SPDIF mode or when the audio block operates as a master.

Bit 4 **CNRDYIE**: Codec not ready interrupt enable (AC'97).
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When the interrupt is enabled, the audio block detects in the slot 0 (tag0) of the AC'97 frame if the Codec connected to this line is ready or not. If it is not ready, the CNRDY flag in the SAI_xSR register is set and an interrupt is generated.
This bit has a meaning only if the AC'97 mode is selected through PRTCFG[1:0] bits and the audio block is operates as a receiver.

Bit 3 **FREQIE**: FIFO request interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the FREQ bit in the SAI_xSR register is set.
Since the audio block defaults to operate as a transmitter after reset, the MODE bit must be configured before setting FREQIE to avoid a parasitic interrupt in receiver mode,

Bit 2 **WCKCFGIE**: Wrong clock configuration interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
This bit is taken into account only if the audio block is configured as a master (MODE[1] = 0) and NODIV = 0.
It generates an interrupt if the WCKCFG flag in the SAI_xSR register is set.
Note: This bit is used only in Free protocol mode *and is meaningless in other modes.*

Bit 1 **MUTEDETIE**: Mute detection interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the MUTEDET bit in the SAI_xSR register is set.
This bit has a meaning only if the audio block is configured in receiver mode.

Bit 0 **OVRUDRIE**: Overrun/underrun interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the OVRUDR bit in the SAI_xSR register is set.

64.6.7 SAI status register (SAI_ASR)

Address offset: 0x18

Reset value: 0x0000 0008

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLVL[2:0]		
													r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LFSDET	AFSDET	CNRDY	FREQ	WCKCFG	MUTEDET	OVRUDR
									r	r	r	r	r	r	r

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **FLVL[2:0]**: FIFO level threshold.
This bit is read only. The FIFO level threshold flag is managed only by hardware and its setting depends on SAI block configuration (transmitter or receiver mode).
000: FIFO empty (transmitter and receiver modes)
001: FIFO ≤ ¼ but not empty (transmitter mode), FIFO < ¼ but not empty (receiver mode)
010: ¼ < FIFO ≤ ½ (transmitter mode), ¼ ≤ FIFO < ½ (receiver mode)
011: ½ < FIFO ≤ ¾ (transmitter mode), ½ ≤ FIFO < ¾ (receiver mode)
100: ¾ < FIFO but not full (transmitter mode), ¾ ≤ FIFO but not full (receiver mode)
101: FIFO full (transmitter and receiver modes)
Others: Reserved

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **LFSDET**: Late frame synchronization detection.
This bit is read only.
0: No error.
1: Frame synchronization signal is not present at the right time.
This flag can be set only if the audio block is configured in slave mode.
It is not used in AC’97 or SPDIF mode.
It can generate an interrupt if LFSDETIE bit is set in the SAI_xIM register.
This flag is cleared when the software sets bit CLFSDET in SAI_xCLRFR register

Bit 5 **AFSDET**: Anticipated frame synchronization detection.
This bit is read only.
0: No error.
1: Frame synchronization signal is detected earlier than expected.
This flag can be set only if the audio block is configured in slave mode.
It is not used in AC'97 or SPDIF mode.
It can generate an interrupt if AFSDETIE bit is set in SAI_xIM register.
This flag is cleared when the software sets CAFSDET bit in SAI_xCLRFR register.

Bit 4 **CNRDY**: Codec not ready.
This bit is read only.
0: External AC'97 Codec is ready
1: External AC'97 Codec is not ready
This bit is used only when the AC'97 audio protocol is selected in the SAI_xCR1 register and configured in receiver mode.
It can generate an interrupt if CNRDYIE bit is set in SAI_xIM register.
This flag is cleared when the software sets CCNRDY bit in SAI_xCLRFR register.

Bit 3 **FREQ**: FIFO request.
This bit is read only.
0: No FIFO request.
1: FIFO request to read or to write the SAI_xDR.
The request depends on the audio block configuration:
– If the block is configured in transmission mode, the FIFO request is related to a write request operation in the SAI_xDR.
– If the block configured in reception, the FIFO request related to a read request operation from the SAI_xDR.
This flag can generate an interrupt if FREQIE bit is set in SAI_xIM register.

Bit 2 **WCKCFG**: Wrong clock configuration flag.
This bit is read only.
0: Clock configuration is correct
1: Clock configuration does not respect the rule concerning the frame length specification defined in *Section 64.4.6: Frame synchronization* (configuration of FRL[7:0] bit in the SAI_xFRCR register)
This bit is used only when the audio block operates in master mode (MODE[1] = 0) and NODIV = 0.
It can generate an interrupt if WCKCFGIE bit is set in SAI_xIM register.
This flag is cleared when the software sets CWCKCFG bit in SAI_xCLRFR register.

Bit 1 **MUTEDET**: Mute detection.
This bit is read only.
0: No MUTE detection on the SD input line
1: MUTE value detected on the SD input line (0 value) for a specified number of consecutive audio frame
This flag is set if consecutive 0 values are received in each slot of a given audio frame and for a consecutive number of audio frames (set in the MUTECNT bit in the SAI_xCR2 register).
It can generate an interrupt if MUTEDETIE bit is set in SAI_xIM register.
This flag is cleared when the software sets bit CMUTEDET in the SAI_xCLRFR register.

Bit 0 **OVRUDR**: Overrun / underrun.
This bit is read only.
0: No overrun/underrun error.
1: Overrun/underrun error detection.
The overrun and underrun conditions can occur only when the audio block is configured as a receiver and a transmitter, respectively.
It can generate an interrupt if OVRUDRIE bit is set in SAI_xIM register.
This flag is cleared when the software sets COVRUDR bit in SAI_xCLRFR register.

64.6.8 SAI clear flag register (SAI_ACLRFR)

Address offset: 0x1C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLFSDET	CAFSDET	CCNRDY	Res.	CWCKCFG	CMUTEDET	COVRUDR
									w	w	w		w	w	w

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **CLFSDET**: Clear late frame synchronization detection flag.
This bit is write only.
Programming this bit to 1 clears the LFSDET flag in the SAI_xSR register.
This bit is not used in AC’97 or SPDIF mode
Reading this bit always returns the value 0.

Bit 5 **CAFSDET**: Clear anticipated frame synchronization detection flag.
This bit is write only.
Programming this bit to 1 clears the AFSDET flag in the SAI_xSR register.
It is not used in AC’97 or SPDIF mode.
Reading this bit always returns the value 0.

Bit 4 **CCNRDY**: Clear Codec not ready flag.
This bit is write only.
Programming this bit to 1 clears the CNRDY flag in the SAI_xSR register.
This bit is used only when the AC’97 audio protocol is selected in the SAI_xCR1 register.
Reading this bit always returns the value 0.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **CWCKCFG**: Clear wrong clock configuration flag.
This bit is write only.
Programming this bit to 1 clears the WCKCFG flag in the SAI_xSR register.
This bit is used only when the audio block is set as master (MODE[1] = 0) and NODIV = 0 in the SAI_xCR1 register.
Reading this bit always returns the value 0.

Bit 1 **CMUTEDET**: Mute detection flag.
This bit is write only.
Programming this bit to 1 clears the MUTEDET flag in the SAI_xSR register.
Reading this bit always returns the value 0.

Bit 0 **COVRUDR**: Clear overrun / underrun.
This bit is write only.
Programming this bit to 1 clears the OVRUDR flag in the SAI_xSR register.
Reading this bit always returns the value 0.

64.6.9 SAI data register (SAI_ADR)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DATA[31:0]**: Data
A write to this register loads the FIFO provided the FIFO is not full.
A read from this register empties the FIFO if the FIFO is not empty.

64.6.10 SAI configuration register 1 (SAI_BCR1)

Address offset: 0x24

Reset value: 0x0000 0040

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	MCKEN	OSR	MCKDIV[5:0]						NODIV	Res.	DMAEN	SAIEN
				rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	OUTDRIV	MONO	SYNCEN[1:0]		CKSTR	LSBFIRST	DS[2:0]			Res.	PRTCFG[1:0]		MODE[1:0]	
		rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **MCKEN:** Master clock generation enable
0: The master clock is not generated
1: The master clock is generated independently of SAIEN bit

Bit 26 **OSR:** Oversampling ratio for master clock
This bit is meaningful only when NODIV bit is set to 0.
0: Master clock frequency = F_{FS} x 256
1: Master clock frequency = F_{FS} x 512

Bits 25:20 **MCKDIV[5:0]**: Master clock divider
These bits are set and cleared by software.
000000: Divides by 1 the kernel clock input (sai_x_ker_ck).
Otherwise, the master clock frequency is calculated according to the formula given in *Section 64.4.8*.
These bits have no meaning when the audio block is slave.
They have to be configured when the audio block is disabled.

Bit 19 **NODIV:** No divider
This bit is set and cleared by software.
0: the ratio between the Master clock generator and frame synchronization is fixed to 256 or 512
1: the ratio between the Master clock generator and frame synchronization depends on FRL[7:0]

Bit 18 Reserved, must be kept at reset value.

Bit 17 **DMAEN**: DMA enable
This bit is set and cleared by software.
0: DMA disabled
1: DMA enabled
Note: Since the audio block defaults to operate as a transmitter after reset, the MODE[1:0] bits must be configured before setting DMAEN to avoid a DMA request in receiver mode.

Bit 16 **SAIEN**: Audio block enable
This bit is set by software.
To switch off the audio block, the application software must program this bit to 0 and poll the bit till it reads back 0, meaning that the block is completely disabled. Before setting this bit to 1, check that it is set to 0, otherwise the enable command is not taken into account.
This bit enables to control the state of the SAI audio block. If it is disabled when an audio frame transfer is ongoing, the ongoing transfer completes and the cell is fully disabled at the end of this audio frame transfer.
0: SAI audio block disabled
1: SAI audio block enabled.
Note: When the SAI block (A or B) is configured in master mode, the clock must be present on the SAI block input before setting SAIEN bit.

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **OUTDRIV**: Output drive
This bit is set and cleared by software.
0: Audio block output driven when SAIEN is set
1: Audio block output driven immediately after the setting of this bit.
Note: This bit has to be set before enabling the audio block and after the audio block configuration.

Bit 12 **MONO**: Mono mode
This bit is set and cleared by software. It is meaningful only when the number of slots is equal to 2. When the mono mode is selected, slot 0 data are duplicated on slot 1 when the audio block operates as a transmitter. In reception mode, the slot1 is discarded and only the data received from slot 0 are stored. Refer to *Section : Mono/stereo mode* for more details.
0: Stereo mode
1: Mono mode.

Bits 11:10 **SYNCEN[1:0]:** Synchronization enable

These bits are set and cleared by software. They must be configured when the audio subblock is disabled.

00: audio subblock in asynchronous mode.

01: audio subblock is synchronous with the other internal audio subblock. In this case, the audio subblock must be configured in slave mode

10: audio subblock is synchronous with an external SAI embedded peripheral. In this case the audio subblock must be configured in Slave mode.

11: Reserved

Note: The audio subblock must be configured as asynchronous when SPDIF mode is enabled.

Bit 9 **CKSTR:** Clock strobing edge

This bit is set and cleared by software. It must be configured when the audio block is disabled. This bit has no meaning in SPDIF audio protocol.

0: Signals generated by the SAI change on SCK rising edge, while signals received by the SAI are sampled on the SCK falling edge.

1: Signals generated by the SAI change on SCK falling edge, while signals received by the SAI are sampled on the SCK rising edge.

Bit 8 **LSBFIRST:** Least significant bit first

This bit is set and cleared by software. It must be configured when the audio block is disabled. This bit has no meaning in AC'97 audio protocol since AC'97 data are always transferred with the MSB first. This bit has no meaning in SPDIF audio protocol since in SPDIF data are always transferred with LSB first.

0: Data are transferred with MSB first

1: Data are transferred with LSB first

Bits 7:5 **DS[2:0]:** Data size

These bits are set and cleared by software. These bits are ignored when the SPDIF protocols are selected (bit PRTCFG[1:0]), because the frame and the data size are fixed in such case. When the companding mode is selected through COMP[1:0] bits, DS[1:0] are ignored since the data size is fixed to 8 bits by the algorithm.

These bits must be configured when the audio block is disabled.

000: Reserved

001: Reserved

010: 8 bits

011: 10 bits

100: 16 bits

101: 20 bits

110: 24 bits

111: 32 bits

Bit 4 Reserved, must be kept at reset value.

Bits 3:2 **PRTCFG[1:0]:** Protocol configuration

These bits are set and cleared by software. These bits have to be configured when the audio block is disabled.

00: Free protocol. Free protocol enables to use the powerful config uration of the audio block to address a specific audio protocol (such as I2S, LSB/MSB justified, TDM, PCM/DSP...) by setting most of the configuration register bits as well as frame configuration register.

01: SPDIF protocol

10: AC'97 protocol

11: Reserved

Bits 1:0 **MODE[1:0]:** SAIx audio block mode

These bits are set and cleared by software. They must be configured when SAIx audio block is disabled.

00: Master transmitter

01: Master receiver

10: Slave transmitter

11: Slave receiver

Note: When the audio block is configured in SPDIF mode, the master transmitter mode is forced (MODE[1:0] = 00). In Master transmitter mode, the audio block starts generating the FS and the clocks immediately.

64.6.11 SAI configuration register 2 (SAI_BCR2)

Address offset: 0x28

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
COMP[1:0]		CPL	MUTECNT[5:0]						MUTE VAL	MUTE	TRIS	F FLUSH	FTH[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:14 **COMP[1:0]**: Companding mode.

These bits are set and cleared by software. The µ-Law and the A-Law log are a part of the CCITT G.711 recommendation, the type of complement that is used depends on *CPL bit*.

The data expansion or data compression are determined by the state of bit MODE[0].

The data compression is applied if the audio block is configured as a transmitter.

The data expansion is automatically applied when the audio block is configured as a receiver.

Refer to *Section : Companding mode* for more details.

00: No companding algorithm

01: Reserved.

10: µ-Law algorithm

11: A-Law algorithm

Note: Companding mode is applicable only when Free protocol mode is selected.

Bit 13 **CPL**: Complement bit.

This bit is set and cleared by software.

It defines the type of complement to be used for companding mode

0: 1’s complement representation.

1: 2’s complement representation.

Note: This bit has effect only when the companding mode is µ-Law algorithm or A-Law algorithm.

Bits 12:7 **MUTECNT[5:0]**: Mute counter.

These bits are set and cleared by software. They are used only in reception mode.

The value set in these bits is compared to the number of consecutive mute frames detected in reception. When the number of mute frames is equal to this value, the flag MUTEDET is set and an interrupt is generated if bit MUTEDETIE is set.

Refer to *Section : Mute mode* for more details.

Bit 6 **MUTEVAL**: Mute value.

This bit is set and cleared by software. It is meaningful only when the audio block operates as a transmitter, the number of slots is lower or equal to 2 and the MUTE bit is set.

If more slots are declared, the bit value sent during the transmission in mute mode is equal to 0, whatever the value of MUTEVAL.

if the number of slot is lower or equal to 2 and MUTEVAL = 1, the MUTE value transmitted for each slot is the one sent during the previous frame.

Refer to *Section : Mute mode* for more details.

0: Bit value 0 is sent during the mute mode.

1: Last values are sent during the mute mode.

Note: This bit is meaningless and must not be used for SPDIF audio blocks.

Bit 5 **MUTE:** Mute.

This bit is set and cleared by software. It is meaningful only when the audio block operates as a transmitter. The MUTE value is linked to value of MUTEVAL if the number of slots is lower or equal to 2, or equal to 0 if it is greater than 2.

Refer to *Section : Mute mode* for more details.

0: No mute mode.

1: Mute mode enabled.

Note: This bit is meaningless and must not be used for SPDIF audio blocks.

Bit 4 **TRIS**: Tristate management on data line.

This bit is set and cleared by software. It is meaningful only if the audio block is configured as a transmitter. This bit is not used when the audio block is configured in SPDIF mode. It must be configured when SAI is disabled.

Refer to *Section : Output data line management on an inactive slot* for more details.

0: SD output line is still driven by the SAI when a slot is inactive.

1: SD output line is released (HI-Z) at the end of the last data bit of the last active slot if the next one is inactive.

Bit 3 **FFLUSH:** FIFO flush.

This bit is set by software. It is always read as 0. This bit must be configured when the SAI is disabled.

0: No FIFO flush.

1: FIFO flush. Programming this bit to 1 triggers the FIFO Flush. All the internal FIFO pointers (read and write) are cleared. In this case data still present in the FIFO are lost (no more transmission or received data lost). Before flushing, SAI DMA stream/interrupt must be disabled

Bits 2:0 **FTH[2:0]:** FIFO threshold.

This bit is set and cleared by software.

000: FIFO empty

001: ¼ FIFO

010: ½ FIFO

011: ¾ FIFO

100: FIFO full

101: Reserved

110: Reserved

111: Reserved

64.6.12 SAI frame configuration register (SAI_BFRCR)

Address offset: 0x2C

Reset value: 0x0000 0007

Note: This register has no meaning in AC'97 and SPDIF audio protocol

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSOFF	FSPOL	FSDEF
													rw	rw	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	FSALL[6:0]							FRL[7:0]							
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **FSOFF**: Frame synchronization offset.
This bit is set and cleared by software. It is meaningless and is not used in AC'97 or SPDIF audio block configuration. This bit must be configured when the audio block is disabled.
0: FS is asserted on the first bit of the slot 0.
1: FS is asserted one bit before the first bit of the slot 0.

Bit 17 **FSPOL**: Frame synchronization polarity.
This bit is set and cleared by software. It is used to configure the level of the start of frame on the FS signal. It is meaningless and is not used in AC'97 or SPDIF audio block configuration.
This bit must be configured when the audio block is disabled.
0: FS is active low (falling edge)
1: FS is active high (rising edge)

Bit 16 **FSDEF**: Frame synchronization definition.
This bit is set and cleared by software.
0: FS signal is a start frame signal
1: FS signal is a start of frame signal + channel side identification
When the bit is set, the number of slots defined in the SAI_xSLOTR register has to be even. It means that half of this number of slots is dedicated to the left channel and the other slots for the right channel (e.g: this bit has to be set for I2S or MSB/LSB-justified protocols...).
This bit is meaningless and is not used in AC'97 or SPDIF audio block configuration. It must be configured when the audio block is disabled.

Bit 15 Reserved, must be kept at reset value.

Bits 14:8 **FSALL[6:0]**: Frame synchronization active level length.
These bits are set and cleared by software. They specify the length in number of bit clock (SCK) + 1 (FSALL[6:0] + 1) of the active level of the FS signal in the audio frame
These bits are meaningless and are not used in AC'97 or SPDIF audio block configuration.
They must be configured when the audio block is disabled.

Bits 7:0 **FRL[7:0]**: Frame length.

These bits are set and cleared by software. They define the audio frame length expressed in number of SCK clock cycles: the number of bits in the frame is equal to FRL[7:0] + 1.

The minimum number of bits to transfer in an audio frame must be equal to 8, otherwise the audio block behaves in an unexpected way. This is the case when the data size is 8 bits and only one slot 0 is defined in NBSLOT[4:0] of SAI_xSLOTR register (NBSLOT[3:0] = 0000).

In master mode, if the master clock (available on MCLK_x pin) is used, the frame length must be aligned with a number equal to a power of 2, ranging from 8 to 256. When the master clock is not used (NODIV = 1), it is recommended to program the frame length to an value ranging from 8 to 256.

These bits are meaningless and are not used in AC'97 or SPDIF audio block configuration.

64.6.13 SAI slot register (SAI_BSLOTR)

Address offset: 0x30

Reset value: 0x0000 0000

Note: This register has no meaning in AC'97 and SPDIF audio protocol.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SLOTEN[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	NBSLOT[3:0]				SLOTSZ[1:0]		Res.	FBOFF[4:0]				
				rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:16 **SLOTEN[15:0]**: Slot enable.

These bits are set and cleared by software.

Each SLOTEN bit corresponds to a slot position from 0 to 15 (maximum 16 slots).

0: Inactive slot.

1: Active slot.

The slot must be enabled when the audio block is disabled.

They are ignored in AC'97 or SPDIF mode.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **NBSLOT[3:0]**: Number of slots in an audio frame.

These bits are set and cleared by software.

The value set in this bitfield represents the number of slots in the audio frame (including the number of inactive slots). The maximum number of slots is 16.

The number of slots must be even if FSDEF bit in the SAI_xFRCR register is set.

The number of slots must be configured when the audio block is disabled.

They are ignored in AC'97 or SPDIF mode.

0000: Number of slots is 1.

0001: Number of slots is 2.

...

1111: Number of slots is 16.

Bits 7:6 **SLOTSZ[1:0]**: Slot size
This bits is set and cleared by software.
The slot size must be higher or equal to the data size. If this condition is not respected, the behavior of the SAI is undetermined.
Refer to *Output data line management on an inactive slot* for information on how to drive SD line.
These bits must be set when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.
00: The slot size is equivalent to the data size (specified in DS[3:0] in the SAI_xCR1 register).
01: 16-bit
10: 32-bit
11: Reserved

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **FBOFF[4:0]**: First bit offset
These bits are set and cleared by software.
The value set in this bitfield defines the position of the first data transfer bit in the slot. It represents an offset value. In transmission mode, the bits outside the data field are forced to 0. In reception mode, the extra received bits are discarded.
These bits must be set when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.

64.6.14 SAI interrupt mask register (SAI_BIM)

Address offset: 0x34

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LFSDETIE	AFSDETIE	CNRDYIE	FREQIE	WCKCFGIE	MUTEDETIE	OVRUDRIE
									rw	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **LFSDETIE**: Late frame synchronization detection interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the LFSDET bit is set in the SAI_xSR register.
This bit is meaningless in AC'97, SPDIF mode or when the audio block operates as a master.

Bit 5 **AFSDETIE**: Anticipated frame synchronization detection interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the AFSDET bit in the SAI_xSR register is set.
This bit is meaningless in AC'97, SPDIF mode or when the audio block operates as a master.

Bit 4 **CNRDYIE**: Codec not ready interrupt enable (AC'97).
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When the interrupt is enabled, the audio block detects in the slot 0 (tag0) of the AC'97 frame if the Codec connected to this line is ready or not. If it is not ready, the CNRDY flag in the SAI_xSR register is set and an interrupt is generated.
This bit has a meaning only if the AC'97 mode is selected through PRTCFG[1:0] bits and the audio block is operates as a receiver.

Bit 3 **FREQIE**: FIFO request interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the FREQ bit in the SAI_xSR register is set.
Since the audio block defaults to operate as a transmitter after reset, the MODE bit must be configured before setting FREQIE to avoid a parasitic interrupt in receiver mode,

Bit 2 **WCKCFGIE**: Wrong clock configuration interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
This bit is taken into account only if the audio block is configured as a master (MODE[1] = 0) and NODIV = 0.
It generates an interrupt if the WCKCFG flag in the SAI_xSR register is set.
Note: This bit is used only in Free protocol mode and is meaningless in other modes.

Bit 1 **MUTEDETIE**: Mute detection interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the MUTEDET bit in the SAI_xSR register is set.
This bit has a meaning only if the audio block is configured in receiver mode.

Bit 0 **OVRUDRIE**: Overrun/underrun interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the OVRUDR bit in the SAI_xSR register is set.

64.6.15 SAI status register (SAI_BSR)

Address offset: 0x38

Reset value: 0x0000 0008

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLVL[2:0]		
													r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LFSDET	AFSDET	CNRDY	FREQ	WCKCFG	MUTEDET	OVRUDR
									r	r	r	r	r	r	r

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **FLVL[2:0]**: FIFO level threshold.
This bit is read only. The FIFO level threshold flag is managed only by hardware and its setting depends on SAI block configuration (transmitter or receiver mode).
000: FIFO empty (transmitter and receiver modes)
001: FIFO ≤ ¼ but not empty (transmitter mode), FIFO < ¼ but not empty (receiver mode)
010: ¼ < FIFO ≤ ½ (transmitter mode), ¼ ≤ FIFO < ½ (receiver mode)
011: ½ < FIFO ≤ ¾ (transmitter mode), ½ ≤ FIFO < ¾ (receiver mode)
100: ¾ < FIFO but not full (transmitter mode), ¾ ≤ FIFO but not full (receiver mode)
101: FIFO full (transmitter and receiver modes)
Others: Reserved

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **LFSDET**: Late frame synchronization detection.
This bit is read only.
0: No error.
1: Frame synchronization signal is not present at the right time.
This flag can be set only if the audio block is configured in slave mode.
It is not used in AC'97 or SPDIF mode.
It can generate an interrupt if LFSDETIE bit is set in the SAI_xIM register.
This flag is cleared when the software sets bit CLFSDET in SAI_xCLRFR register

Bit 5 **AFSDET**: Anticipated frame synchronization detection.
This bit is read only.
0: No error.
1: Frame synchronization signal is detected earlier than expected.
This flag can be set only if the audio block is configured in slave mode.
It is not used in AC'97or SPDIF mode.
It can generate an interrupt if AFSDETIE bit is set in SAI_xIM register.
This flag is cleared when the software sets CAFSDET bit in SAI_xCLRFR register.

Bit 4 **CNRDY**: Codec not ready.
This bit is read only.
0: External AC'97 Codec is ready
1: External AC'97 Codec is not ready
This bit is used only when the AC'97 audio protocol is selected in the SAI_xCR1 register and configured in receiver mode.
It can generate an interrupt if CNRDYIE bit is set in SAI_xIM register.
This flag is cleared when the software sets CCNRDY bit in SAI_xCLRFR register.

Bit 3 **FREQ**: FIFO request.
This bit is read only.
0: No FIFO request.
1: FIFO request to read or to write the SAI_xDR.
The request depends on the audio block configuration:
– If the block is configured in transmission mode, the FIFO request is related to a write request operation in the SAI_xDR.
– If the block configured in reception, the FIFO request related to a read request operation from the SAI_xDR.
This flag can generate an interrupt if FREQIE bit is set in SAI_xIM register.

Bit 2 **WCKCFG**: Wrong clock configuration flag.
This bit is read only.
0: Clock configuration is correct
1: Clock configuration does not respect the rule concerning the frame length specification defined in *Section 64.4.6: Frame synchronization* (configuration of FRL[7:0] bit in the SAI_xFRCR register)
This bit is used only when the audio block operates in master mode (MODE[1] = 0) and NODIV = 0.
It can generate an interrupt if WCKCFGIE bit is set in SAI_xIM register.
This flag is cleared when the software sets CWCKCFG bit in SAI_xCLRFR register.

Bit 1 **MUTEDET**: Mute detection.
This bit is read only.
0: No MUTE detection on the SD input line
1: MUTE value detected on the SD input line (0 value) for a specified number of consecutive audio frame
This flag is set if consecutive 0 values are received in each slot of a given audio frame and for a consecutive number of audio frames (set in the MUTECNT bit in the SAI_xCR2 register).
It can generate an interrupt if MUTEDETIE bit is set in SAI_xIM register.
This flag is cleared when the software sets bit CMUTEDET in the SAI_xCLRFR register.

Bit 0 **OVRUDR**: Overrun / underrun.
This bit is read only.
0: No overrun/underrun error.
1: Overrun/underrun error detection.
The overrun and underrun conditions can occur only when the audio block is configured as a receiver and a transmitter, respectively.
It can generate an interrupt if OVRUDRIE bit is set in SAI_xIM register.
This flag is cleared when the software sets COVRUDR bit in SAI_xCLRFR register.

64.6.16 SAI clear flag register (SAI_BCLRFR)

Address offset: 0x3C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLFSDET	CAFSDET	CCNRDY	Res.	CWCKCFG	CMUTEDET	COVRUDR
									w	w	w		w	w	w

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **CLFSDET**: Clear late frame synchronization detection flag.
This bit is write only.
Programming this bit to 1 clears the LFSDET flag in the SAI_xSR register.
This bit is not used in AC'97or SPDIF mode
Reading this bit always returns the value 0.

Bit 5 **CAFSDET**: Clear anticipated frame synchronization detection flag.
This bit is write only.
Programming this bit to 1 clears the AFSDET flag in the SAI_xSR register.
It is not used in AC'97or SPDIF mode.
Reading this bit always returns the value 0.

Bit 4 **CCNRDY**: Clear Codec not ready flag.
This bit is write only.
Programming this bit to 1 clears the CNRDY flag in the SAI_xSR register.
This bit is used only when the AC'97 audio protocol is selected in the SAI_xCR1 register.
Reading this bit always returns the value 0.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **CWCKCFG**: Clear wrong clock configuration flag.
This bit is write only.
Programming this bit to 1 clears the WCKCFG flag in the SAI_xSR register.
This bit is used only when the audio block is set as master (MODE[1] = 0) and NODIV = 0 in the SAI_xCR1 register.
Reading this bit always returns the value 0.

Bit 1 **CMUTEDET**: Mute detection flag.
This bit is write only.
Programming this bit to 1 clears the MUTEDET flag in the SAI_xSR register.
Reading this bit always returns the value 0.

Bit 0 **COVRUDR**: Clear overrun / underrun.
This bit is write only.
Programming this bit to 1 clears the OVRUDR flag in the SAI_xSR register.
Reading this bit always returns the value 0.

64.6.17 SAI data register (SAI_BDR)

Address offset: 0x40

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DATA[31:0]**: Data
A write to this register loads the FIFO provided the FIFO is not full.
A read from this register empties the FIFO if the FIFO is not empty.

64.6.18 SAI PDM control register (SAI_PDMCR)

Address offset: 0x44

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CKEN2	CKEN1	Res.	Res.	MICNBR[1:0]		Res.	Res.	Res.	PDMEN
						rw	rw			rw	rw				rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **CKEN2**: Clock enable of bitstream clock number 2

This bit is set and cleared by software.

0: SAI_CK2 clock disabled

1: SAI_CK2 clock enabled

Note: It is not recommended to configure this bit when PDMEN = 1.

SAI_CK2 might not be available for all SAI instances. Refer to Section 64.3: SAI implementation for details.

Bit 8 **CKEN1**: Clock enable of bitstream clock number 1

This bit is set and cleared by software.

0: SAI_CK1 clock disabled

1: SAI_CK1 clock enabled

Note: It is not recommended to configure this bit when PDMEN = 1.

SAI_CK1 might not be available for all SAI instances. Refer to Section 64.3: SAI implementation for details.

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **MICNBR[1:0]**: Number of microphones

This bit is set and cleared by software.

00: Configuration with 2 microphones

01: Configuration with 4 microphones

10: Configuration with 6 microphones

11: Configuration with 8 microphones

*Note: It is not recommended to configure this field when PDMEN = 1.**

The complete set of data lines might not be available for all SAI instances. Refer to Section 64.3: SAI implementation for details.

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **PDMEN**: PDM enable

This bit is set and cleared by software. This bit enables to control the state of the PDM interface block.

Make sure that the SAI in already operating in TDM master mode before enabling the PDM interface.

0: PDM interface disabled

1: PDM interface enabled

64.6.19 SAI PDM delay register (SAI_PDMDLY)

Address offset: 0x48

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	DLYM4R[2:0]			Res.	DLYM4L[2:0]			Res.	DLYM3R[2:0]			Res.	DLYM3L[2:0]		
	rw	rw	rw		rw	rw	rw		rw	rw	rw		rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	DLYM2R[2:0]			Res.	DLYM2L[2:0]			Res.	DLYM1R[2:0]			Res.	DLYM1L[2:0]		
	rw	rw	rw		rw	rw	rw		rw	rw	rw		rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:28 **DLYM4R[2:0]**: Delay line for second microphone of **pair 4**

This bitfield is set and cleared by software.

000: No delay

001: Delay of 1 T_{SAI_CK} period

010: Delay of 2 T_{SAI_CK} periods

...

111: Delay of 7 T_{SAI_CK} periods

This bitfield can be changed on-the-fly.

Note: This bitfield can be used only if D4 line is available.Refer to Section 64.3: SAI implementation to check if it is available.

Bit 27 Reserved, must be kept at reset value.

Bits 26:24 **DLYM4L[2:0]**: Delay line for first microphone of pair 4

This bitfield is set and cleared by software.

000: No delay

001: Delay of 1 T_{SAI_CK} period

010: Delay of 2 T_{SAI_CK} periods

...

111: Delay of 7 of T_{SAI_CK} periods

This bitfield can be changed on-the-fly.

Note: This bitfield can be used only if D4 line is available.Refer to Section 64.3: SAI implementation to check if it is available.

Bit 23 Reserved, must be kept at reset value.

Bits 22:20 **DLYM3R[2:0]**: Delay line for second microphone of pair 3
This bitfield is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This bitfield can be changed on-the-fly.

Note: This bitfield can be used only if D3 line is available.Refer to Section 64.3: SAI implementation to check if it is available.

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **DLYM3L[2:0]**: Delay line for first microphone of pair 3
This bitfield is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This bitfield can be changed on-the-fly.

Note: This bitfield can be used only if D3 line is available.Refer to Section 64.3: SAI implementation to check if it is available.

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **DLYM2R[2:0]**: Delay line for second microphone of pair 2
This bitfield is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This bitfield can be changed on-the-fly.

Note: This bitfield can be used only if D2 line is available.Refer to Section 64.3: SAI implementation to check if it is available.

Bit 11 Reserved, must be kept at reset value.

Bits 10:8 **DLYM2L[2:0]**: Delay line for first microphone of pair 2
This bitfield is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This bitfield can be changed on-the-fly.

Note: This bitfield can be used only if D2 line is available.Refer to Section 64.3: SAI implementation to check if it is available.

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **DLYM1R[2:0]**: Delay line adjust for second microphone of pair 1
This bitfield is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This bitfield can be changed on-the-fly.

Note: This bitfield can be used only if D1 line is available.Refer to Section 64.3: SAI implementation to check if it is available.

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **DLYM1L[2:0]**: Delay line adjust for first microphone of pair 1
This bitfield is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This bitfield can be changed on-the-fly.

Note: This bitfield can be used only if D1 line is available.Refer to Section 64.3: SAI implementation to check if it is available.

64.6.20 SAI register map

Table 711. SAI register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0000	SAI_GCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYNCOUT[1:0]		Res.	Res.	SYNCIN[1:0]	
	Reset value																											0	0			0	0
0x04 or 0x24	SAI_xCR1	Res.	Res.	Res.	Res.	MCKEN	OSR	MCKDIV[5:0]						NODIV	Res.	DMAEN	SAIEN	Res.	Res.	OUTDRIV	MONO	SYNCEN[1:0]		CKSTR	LSBFIRST	DS[2:0]			Res.	PRTCFG[1:0]		MODE[1:0]	
	Reset value					0	0	0	0	0	0	0	0	0		0	0			0	0	0	0	0	0	0	1	0		0	0	0	0
0x08 or 0x28	SAI_xCR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COMP[1:0]		CPL	MUTECN[5:0]							MUTE VAL	MUTE	TRIS	FFLUS	FTH[2:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C or 0x2C	SAI_xFRCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSOFF	FSPOL	FSDEF	Res.	FSALL[6:0]							FRL[7:0]							
	Reset value														0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	1	1	1

Table 711. SAI register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x10 or 0x30	SAI_xSLOTR	SLOTEN[15:0]																Res.	Res.	Res.	Res.	NBSLOT[3:0]				SLOTSZ[1:0]		Res.	FBOFF[4:0]				
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0		0	0	0	0	0
0x14 or 0x34	SAI_xIM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LFSDETIE	AFSDETIE	CNRDYIE	FREQIE	WCKCFGIE	MUTEDETIE	OVRUDRIE
	Reset value																										0	0	0	0	0	0	0
0x18 or 0x38	SAI_xSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLVL[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LFSDET	AFSDET	CNRDY	FREQ	WCKCFG	MUTEDET	OVRUDR
	Reset value														0	0	0										0	0	0	1	0	0	0
0x1C or 0x3C	SAI_xCLRFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLFSDET	CAFSDET	CCNRDY	Res.	CWCKCFG	CMUTEDET	COVRUDR
	Reset value																										0	0	0		0	0	0
0x20 or 0x40	SAI_xDR	DATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x44	SAI_PDMCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CKEN2	CKEN1	Res.	Res.	MICNBR[1:0]		Res.	Res.	Res.	PDMEN
	Reset value																							0	0			0	0				0
0x48	SAI_PDMDLY	Res.	DLYM4R[2:0]			Res.	DLYM4L[2:0]			Res.	DLYM3R[2:0]			Res.	DLYM3L[2:0]			Res.	DLYM2R[2:0]			Res.	DLYM2L[2:0]			Res.	DLYM1R[2:0]			Res.	DLYM1L[2:0]		
	Reset value		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

65 FD controller area network (FDCAN)

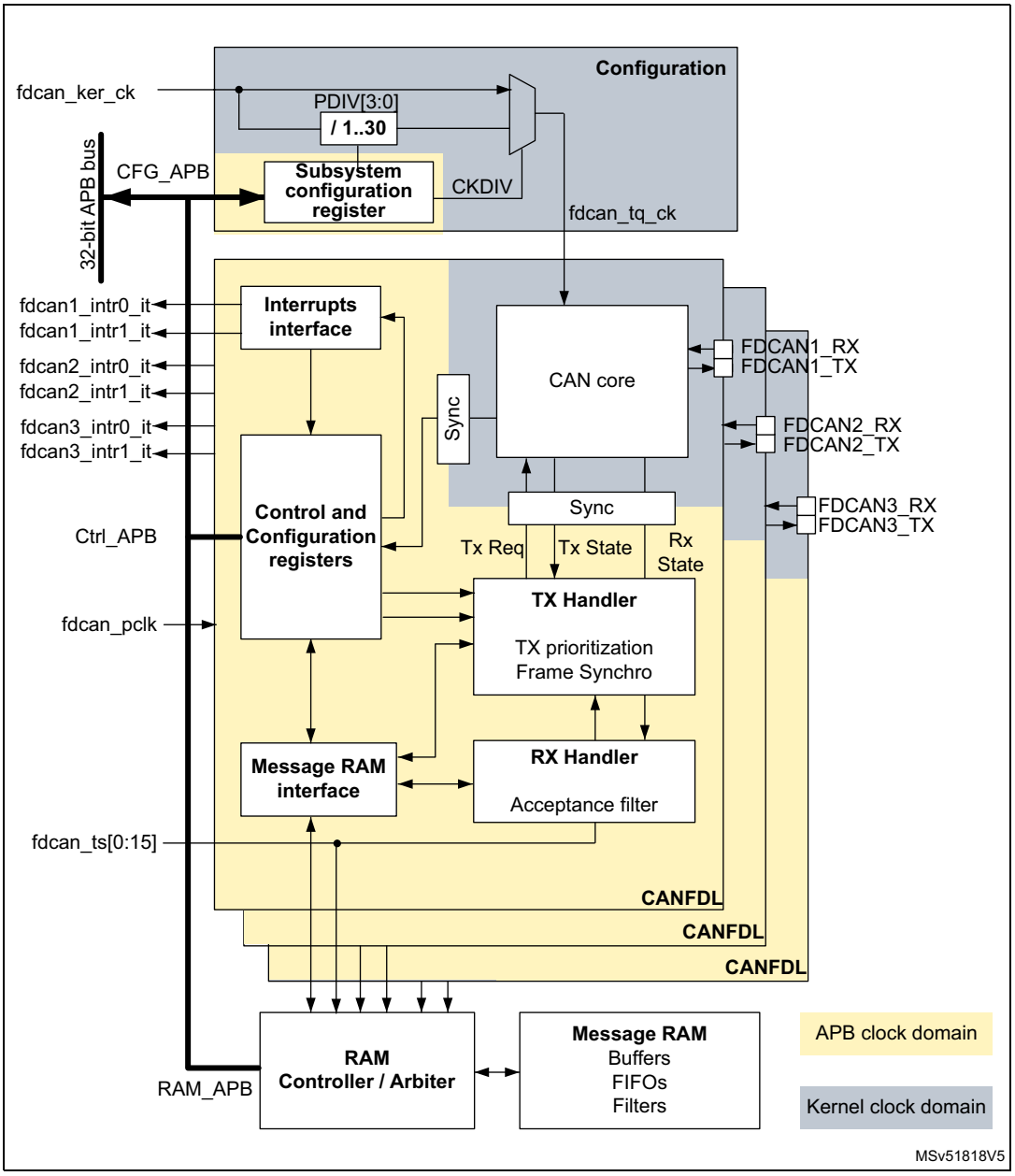
65.1 FDCAN introduction

The controller area network (CAN) subsystem (see *Figure 919*) consists of three CAN modules, a shared message RAM, and a configuration block. Refer to the memory map for the base address of each of these parts.

The modules (FDCAN) are compliant with ISO 11898-1: 2015 (CAN protocol specification version 2.0 part A, B) and CAN FD protocol specification version 1.0.

A 0.8-Kbyte message RAM per FDCAN instance is used for filtering, transmitting event FIFOs, and receiving and transmitting FIFOs.

Figure 919. CAN subsystem.



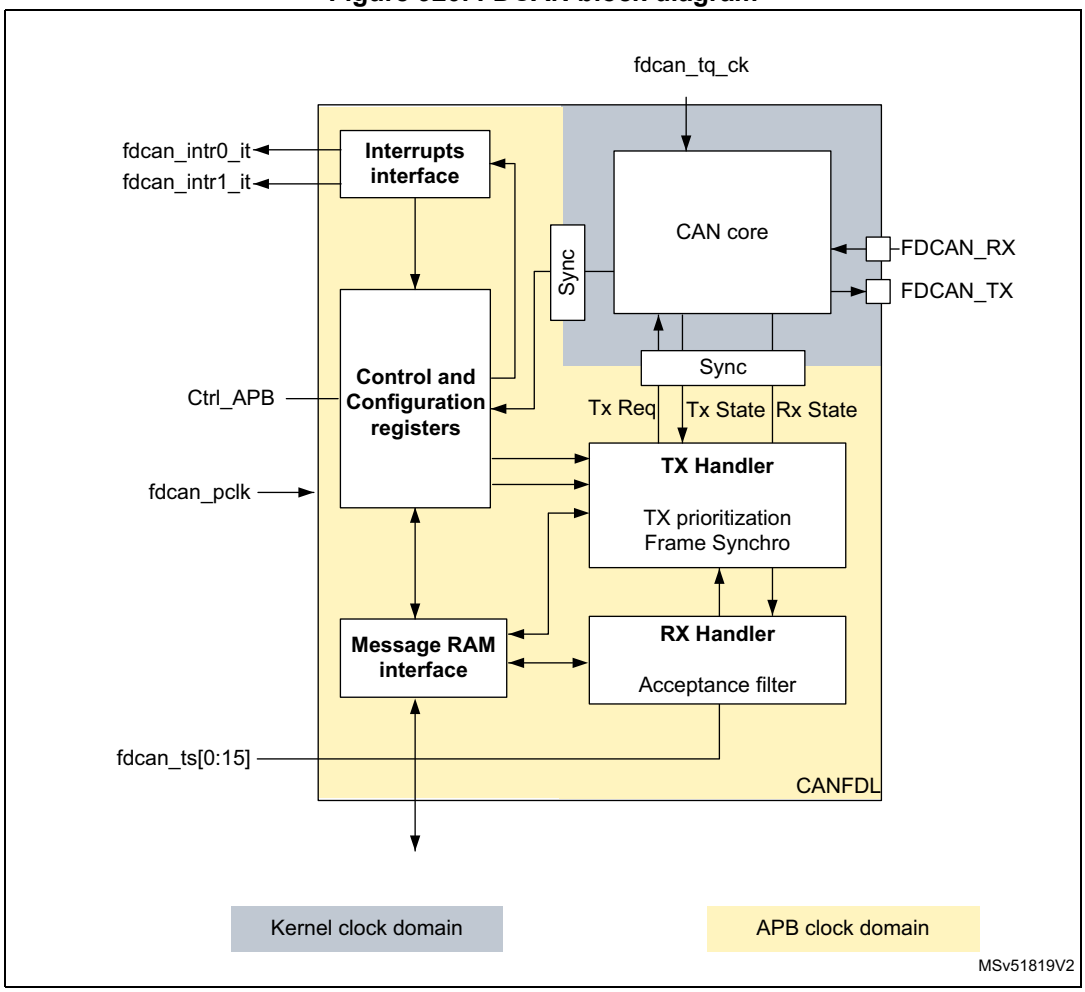
65.2 FDCAN main features

- Conform with CAN protocol version 2.0 part A, B, and ISO 11898-1: 2015
- CAN FD with maximum 64 data bytes supported
- CAN error logging
- AUTOSAR and J1939 support
- Improved acceptance filtering
- Two receive FIFOs of three payloads each (up to 64 bytes per payload)
- Separate signaling on reception of high priority messages
- Configurable transmit FIFO/queue of three payloads (up to 64 bytes per payload)
- Transmit event FIFO
- Programmable loop-back test mode
- Maskable module interrupts
- Two clock domains: APB bus interface and CAN core kernel clock
- Power-down support

65.3 FDCAN functional description

65.3.1 FDCAN block diagram

Figure 920. FDCAN block diagram



Dual interrupt lines

The FDCAN peripheral provides two interrupt lines, fdcan_intr0_it and fdcan_intr1_it.

By programming the EINT0 and EINT1 bits of the FDCAN_ILE register, the interrupt lines can be independently enabled or disabled.

CAN core

The CAN core contains the protocol controller and receive/transmit shift registers. It handles all ISO 11898-1: 2015 protocol functions and supports both 11-bit and 29-bit identifiers.

Sync

This block synchronizes signals from the APB clock domain to the CAN kernel clock domain and vice versa.

Tx handler

The Tx handler controls the message transfer from the message RAM to the CAN core. A maximum of three Tx buffers is available for transmission. The Tx buffer can be used as Tx FIFO or as a Tx queue. Tx event FIFO stores Tx timestamps together with the corresponding message ID. Transmit cancellation is also supported.

Rx handler

The Rx handler controls the transfer of received messages from the CAN core to the external message RAM. The Rx handler supports two receive FIFOs, for storage of all messages that have passed acceptance filtering. An Rx timestamp is stored together with each message. Up to 28 filters can be defined for 11-bit IDs; up to eight filters for 29-bit IDs.

APB interface

The APB interface connects the FDCAN to the APB bus for configuration registers, controller configuration, and RAM access.

Message RAM interface

The message RAM interface connects the FDCAN access to an external 1-Kbyte message RAM through a RAM controller/arbiter.

65.3.2 FDCAN pins and internal signals

The CAN subsystem I/O signals and pins are detailed, respectively, in *Table 712*, *Table 713*, and *Figure 919*.

Table 712. CAN subsystem I/O signals

Name	Type	Description
fdcan_ker_ck	Digital input	CAN subsystem kernel clock input
fdcan_pclk		CAN subsystem APB interface clock input
fdcan*n*_intr0_it	Digital output	FDCAN interrupt0
fdcan*n*_intr1_it		FDCAN interrupt1
fdcan_ts[0:15]	-	External timestamp vector
APB interface	Digital input/output	Single APP with multiple psel for configuration, control and RAM access

Table 713. CAN subsystem I/O pins

Name	Type	Description
FDCAN*n*_RX	Digital input	FDCAN receive pin
FDCAN*n*_TX	Digital output	FDCAN transmit pin

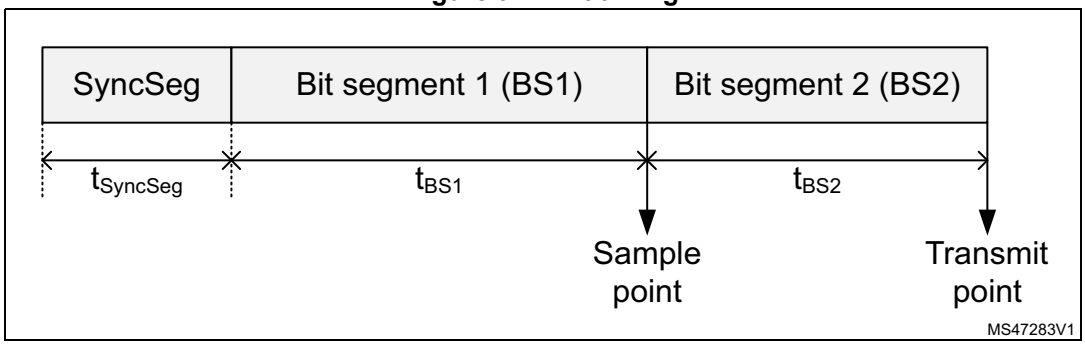
65.3.3 Bit timing

The bit timing logic monitors the serial bus-line and performs sampling and adjustment of the sample point by synchronizing on the start-bit edge and resynchronizing on the following edges.

As shown in *Figure 921*, this operation can be explained simply by splitting the bit time in three segments, as follows:

- Synchronization segment (SYNC_SEG): a bit change is expected to occur within this time segment, having a fixed length of one time quantum ($1 \times t_q$).
- Bit segment 1 (BS1): defines the location of the sample point. It includes the PROP_SEG and PHASE_SEG1 of the CAN standard. Its duration is programmable from 1 to 32 time quanta, but can be automatically lengthened to compensate for positive phase drifts due to differences in the frequency of various nodes of the network.
- Bit segment 2 (BS2): defines the location of the transmit point. It represents the PHASE_SEG2 of the CAN standard, its duration is programmable between 1 and 16 time quanta, but can also be automatically shortened to compensate for negative phase drifts.

Figure 921. Bit timing



The baud rate is the inverse of the bit time (baud rate = 1 / bit time), which, in turn, is the sum of three components (see *Figure 921*):

bit time = $t_{SyncSeg} + t_{BS1} + t_{BS2}$

Where:

– For the nominal bit time

$t_q = (NBRP[8:0] + 1) \times t_{fdcan_tq_clk}$

$t_{SyncSeg} = 1 \times t_q$

$t_{BS1} = t_q \times (NTSEG1[7:0] + 1)$

$t_{BS2} = t_q \times (NTSEG2[6:0] + 1)$

Where NBRP[8:0], NTSEG1[7:0], and NTSEG2[6:0] bitfields belong to the FDCAN_NBTP register.

– For the data bit time

$t_q = (DBRP[4:0] + 1) \times t_{fdcan_tq_clk}$

$t_{SyncSeg} = 1 \times t_q$

$t_{BS1} = t_q \times (DTSEG1[4:0] + 1)$

$t_{BS2} = t_q \times (DTSEG2[3:0] + 1)$

Where DBRP[4:0], DTSEG1[4:0], and DTSEG2[3:0] belong to the FDCAN_DBTP register.

The (re)synchronization jump width (SJW) defines an upper bound for the amount of lengthening or shortening of the bit segments. It is programmable between one and four time quanta.

A valid edge is defined as the first transition in a bit time from dominant to recessive bus level, provided the controller itself does not send a recessive bit.

If a valid edge is detected in BS1 instead of SYNC_SEG, BS1 is extended by up to SJW, so that the sample point is delayed.

Conversely, if a valid edge is detected in BS2 instead of SYNC_SEG, BS2 is shortened by up to SJW, so that the transmit point is moved earlier.

As a safeguard against programming errors, the configuration of the bit timing register is only possible while the device is in Standby mode. The FDCAN_DBTP and FDCAN_NBTP registers (dedicated, respectively, to data and nominal bit timing) are only accessible when the CCE and INIT of the FDCA_CCCR register are set.

The FDCAN requires that the CAN time quanta clock is always below or equal to the APB clock ($f_{dcan_tq_ck} \leq f_{dcan_pclk}$).

Note: For a detailed description of the CAN bit timing and resynchronization mechanism, refer to the ISO 11898-1 standard.

65.3.4 Operating modes

Configuration

Access to peripheral version, hardware, and input clock divider configuration. When the clock divider is set to 0, the primary input clock is used as it is.

The reachable FDCAN bitrates are:

- Nominal bitrate: up to 1 Mbit/s
- Data bitrate: between nominal bitrate and 8 Mbit/s

Software initialization

Software initialization is started by setting the INIT bit of the FDCAN_CCCR register, by software, by a hardware reset, or by entering bus-off state. While the INIT bit is set, message transfers from and to the CAN bus are stopped, and the status of the CAN bus output FDCAN_TX is recessive (high). The EML (error management logic) counters are unchanged. Setting the INIT bit does not change any configuration register. Clearing INIT bit of FDCAN_CCCR finishes the software initialization. Afterwards the bit stream processor (BSP) synchronizes itself to the data transfer on the CAN bus by waiting for the occurrence of a sequence of 11 consecutive recessive bits (bus-idle) before it can take part in bus activities and start the message transfer.

Access to the FDCAN configuration registers is only enabled when the INIT bit and the CCE bit of the FDCAN_CCCR register are both set.

The CCE bit of the FDCAN_CCCR register can only be set/cleared while the INIT bit of FDCAN_CCCR is set. The CCE bit is automatically cleared when the INIT bit is cleared.

The following registers are reset when the CCE bit of the FDCAN_CCCR register is set:

- FDCAN_HPMS: High priority message status
- FDCAN_RXF0S: Rx FIFO 0 status
- FDCAN_RXF1S: Rx FIFO 1 status
- FDCAN_TXFQS: Tx FIFO/queue status
- FDCAN_TXBRP: Tx buffer request pending
- FDCAN_TXBTO: Tx buffer transmission occurred
- FDCAN_TXBCF: Tx buffer cancellation finished
- FDCAN_TXEFS: Tx event FIFO status

The timeout counter value (TOC[15:0] bit of the FDCAN_TOCV register) is preset to the value configured by the TOP[15:0] of the FDCAN_TOCC register when the CCE bit of the FDCAN_CCCR is set.

In addition, the state machines of the Tx handler and Rx handler are held in idle state while the CCE bit is set.

The following registers can be written only when the CCE bit is cleared:

- FDCAN_TXBAR: Tx buffer add request
- FDCAN_TXBCR: Tx buffer cancellation request

The TEST and the MON bits of the FDCAN_CCCR register can be set only by software while the INIT and the CCE bits of the FDCAN_CCCR register are both set. Both bits can be reset at any time. The DAR bit of FDCAN_CCCR can only be set/cleared while the INIT and CCE bits are both set.

Normal operation

The FDCAN default operating mode after hardware reset is event-driven CAN communication. TT operation mode is not supported.

Once the FDCAN is initialized and the INIT bit of the FDCAN_CCCR register is cleared, the FDCAN synchronizes itself to the CAN bus and is ready for communication.

After passing the acceptance filtering, received messages including message ID and DLC are stored into the Rx FIFO 0 or Rx FIFO 1.

For messages to be transmitted, the Tx FIFO or the Tx queue can be initialized or updated. Automated transmission on reception of remote frames is not supported.

CAN FD operation

There are two variants in the FDCAN protocol:

- Long frame mode (LFM), where the data field of a CAN frame may be longer than eight bytes.
- Fast frame mode (FFM), where the control field, data field, and CRC field of a CAN frame are transmitted with a higher bit rate compared to the beginning and to the end of the frame.

The fast frame mode can be used in combination with the long frame mode.

The previously reserved bit in CAN frames with 11-bit identifiers and the first previously reserved bit in CAN frames with 29-bit identifiers are decoded as FDF bit: FDF recessive signifies a CAN FD frame, while FDF dominant signifies a classic CAN frame.

In a CAN FD frame, the two bits following FDF (res and BRS) decide whether the bit rate inside this CAN FD frame is switched. A CAN FD bit rate switch is signified by res dominant and BRS recessive. The coding of res recessive is reserved for future expansion of the protocol. In case the FDCAN receives a frame with FDF recessive and res recessive, it signals a protocol exception event by setting the PXE bit of the FDCAN_PSR register. When protocol exception handling is enabled (PXHD = 0 in FDCAN_CCCR), this causes the operation state to change from receiver (ACT[1:0] = 10 in FDCAN_PSR) to integrating (ACT[1:0] = 00 in FDCAN_PSR) at the next sample point. If protocol exception handling is disabled (PXHD = 1 in FDCAN_CCCR), the FDCAN treats a recessive res bit as a form error and responds with an error frame.

CAN FD operation is enabled by programming the FDOE bit of the FDCAN_CCCR register. In case FDOE = 1, transmission and reception of CAN FD frames are enabled. Transmission and reception of classic CAN frames are always possible. Whether a CAN FD frame or a classic CAN frame is transmitted can be configured via the FDF bit in the respective Tx buffer element. With FDOE = 0, received frames are interpreted as classic CAN frames, which leads to the transmission of an error frame when receiving a CAN FD frame. When CAN FD operation is disabled, no CAN FD frames are transmitted even if the FDF bit of a Tx buffer element is set. The FDOE and BRSE bits of the FDCAN_CCCR register can only be changed while the INIT and CCE bits are both set.

With FDOE = 0, the setting of the FDF and BRS bits is ignored, and frames are transmitted in classic CAN format. With FDOE = 1 and BRSE = 0, only the FDF bit of a Tx buffer element is evaluated. With FDOE = 1 and BRSE = 1, transmission of CAN FD frames with bit rate switching is enabled. All Tx buffer elements with FDF and BRS bits set are transmitted in CAN FD format with bit rate switching.

A mode change during CAN operation is recommended only under the following conditions:

- The failure rate in the CAN FD data phase is significant higher than in the CAN FD arbitration phase. In this case, disable the CAN FD bit rate switching option for transmissions.
- During system startup, all nodes transmit classic CAN messages until it is verified that they are able to communicate in CAN FD format. If this is true, all nodes switch to CAN FD operation.
- Wake-up messages in CAN partial networking have to be transmitted in classic CAN format.
- End-of-line programming in case not all nodes are CAN FD capable. Non-CAN FD nodes are held in silent mode until programming is complete. Then all nodes switch back to classic CAN communication.

In the FDCAN format, the coding of the DLC differs from that of the standard CAN format. The DLC codes 0 to 8 have the same coding as in standard CAN, the codes 9 to 15 (that in standard CAN all code a data field of 8 bytes) are coded according to *Table 714*.

Table 714. DLC coding in FDCAN

DLC	9	10	11	12	13	14	15
Number of data bytes	12	16	20	24	32	48	64

In CAN FD fast frames, the bit timing is switched inside the frame, after the BRS (bit rate switch) bit, if this bit is recessive. Before the BRS bit, in the FDCAN arbitration phase, the standard CAN bit timing is used as defined by the FDCAN_DBTP register. In the following

FDCAN data phase, the fast CAN bit timing is used as defined by the FDCAN_DBTP register. The bit timing is switched back from the fast timing at the CRC delimiter or when an error is detected, whichever occurs first.

The maximum configurable bit rate in the CAN FD data phase depends on the FDCAN kernel clock frequency. For example, with an FDCAN kernel clock frequency of 20 MHz and the shortest configurable bit time of four time quanta (t_q), the bit rate in the data phase is 5 Mbit/s.

In both data frame formats (CAN FD long frames and CAN FD fast frames), the value of bit ESI (error status indicator) is determined by the transmitter error state at the start of the transmission. If the transmitter is error passive, ESI is transmitted recessive, else it is transmitted dominant. In CAN FD remote frames, the ESI bit is always transmitted dominant, independent of the transmitter error state. The data length code of CAN FD remote frames is transmitted as 0.

In case an FDCAN Tx buffer is configured for FDCAN transmission with DLC > 8, the first eight bytes are transmitted as configured in the Tx buffer while the remaining part of the data field is padded with 0xCC. When the FDCAN receives a FDCAN frame with DLC > 8, the first eight bytes of that frame are stored into the matching Rx FIFO. The remaining bytes are discarded.

Transceiver delay compensation

During the data phase of an FDCAN transmission, only one node is transmitting, all others are receivers. The length of the bus line has no impact. When transmitting via pin FDCAN_TX, the protocol controller receives the transmitted data from its local CAN transceiver via pin FDCAN_RX. The received data is delayed by the CAN transceiver loop delay. If this delay is greater than TSEG1 (time segment before sample point), and a bit error is detected. Without transceiver delay compensation, the bit rate in the data phase of an FDCAN frame is limited by the transceiver loop delay.

The FDCAN implements a delay compensation mechanism to compensate the CAN transceiver loop delay, thereby enabling transmission with higher bit rates during the FDCAN data phase independent of the delay of a specific CAN transceiver.

To check for bit errors during the data phase of transmitting nodes, the delayed transmit data is compared against the received data at the secondary sample point (SSP). If a bit error is detected, the transmitter reacts on this bit error at the next following regular sample point. During the arbitration phase, the delay compensation is always disabled.

The transmitter delay compensation enables configurations where the data bit time is shorter than the transmitter delay. This is enabled by setting the TDC bit of the FDCAN_DBTP register, and described in detail in the ISO11898-1 specification.

The received bit is compared against the transmitted bit at the SSP. The SSP position is defined as the sum of the measured delay from the FDCAN transmit output pin FDCAN_TX through the transceiver to the receive input pin FDCAN_RX plus the transmitter delay compensation offset as configured by TDCO[6:0] of FDCAN_TDCR. The transmitter delay compensation offset is used to adjust the position of the SSP inside the received bit (for example, half of the bit time in the data phase). The position of the secondary sample point is rounded down to the next integer number of mt_q (minimum time quantum, one period of fdcan_tq_ck clock).

The TDCV[6:0] bitfield of the FDCAN_PSR register shows the actual transmitter delay compensation value. TDCV[6:0] is cleared when the INIT is set in the FDCAN_CCCR. It is

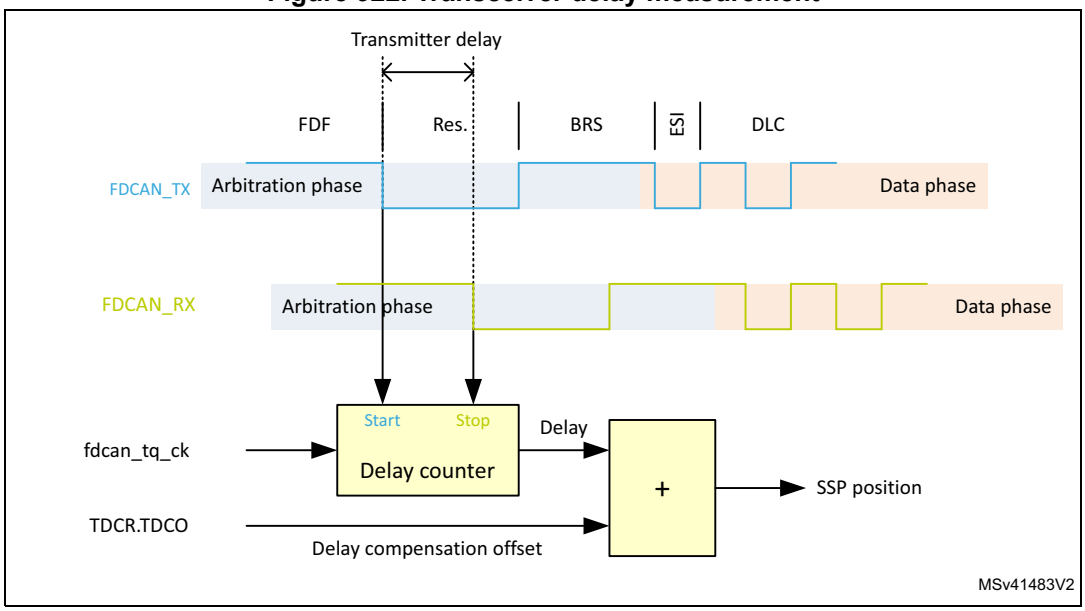
updated at each transmission of an FD frame while the TDC bit of the FDCAN_DBTP register is set.

The following boundary conditions have to be considered for the transmitter delay compensation implemented in the FDCAN:

- The sum of the measured delay from FDCAN_Tx to FDCAN_Rx and the configured transmitter delay compensation offset TDCO[6:0] has to be lower than 6-bit times in the data phase.
- The sum of the measured delay from FDCAN_TX to FDCAN_RX and the configured transmitter delay compensation offset TDCO[6:0] has to be lower than or equal to 127 × mt_q. If the sum exceeds this value, the maximum value (127 × mt_q) is used for transmitter delay compensation.
- The data phase ends at the sample point of the CRC delimiter, which stops checking received bits at the SSPs.

If transmitter delay compensation is enabled by setting the TDC bit of the FDCAN_DBTP; the measurement is started within each transmitted CAN FD frame at the falling edge of bit FDF to bit res. The measurement is stopped when this edge is seen at the receive input pin FDCAN_TX of the transmitter. The resolution of this measurement is one mt_q.

Figure 922. Transceiver delay measurement



To avoid that a dominant glitch inside the received FDF bit ends the delay compensation measurement before the falling edge of the received res bit (resulting in a too early SSP position), the use of a transmitter delay compensation filter window can be enabled by programming the TDCF[6:0] bitfield of the FDCAN_TDCR register. This defines a minimum value for the SSP position. Dominant edges on FDCAN_RX that would result in an earlier SSP position are ignored for transmitter delay measurement. The measurement is stopped when the SSP position is at least TDCF[6:0] and FDCAN_RX is low.

Restricted operation mode

In restricted operation mode, the node is able to receive data and remote frames, and to give acknowledge to valid frames, but it does not send data frames, remote frames, active error frames, or overload frames. In case of an error condition or overload condition, it does not send dominant bits. Instead, it waits for the occurrence of a bus-idle condition to resynchronize itself to the CAN communication. The error counters (REC[6:0] and TEC[7:0] in FDCAN_ECR) are frozen while the error logging (CEL[7:0]) is active. The software can set the FDCAN into restricted operation mode by setting the ASM bit of FDCAN_CCCR. The bit can only be set by software when both CCE and INIT bits are set in FDCAN_CCCR. The bit can be cleared by software at any time.

Restricted operation mode is automatically entered when the Tx handler is not able to read data from the message RAM in time. To leave restricted operation mode, the software has to clear the ASM bit of FDCAN_CCCR.

The restricted operation mode can be used in applications that adapt themselves to different CAN bit rates. In this case, the application tests different bit rates and leaves the restricted operation mode after it has received a valid frame.

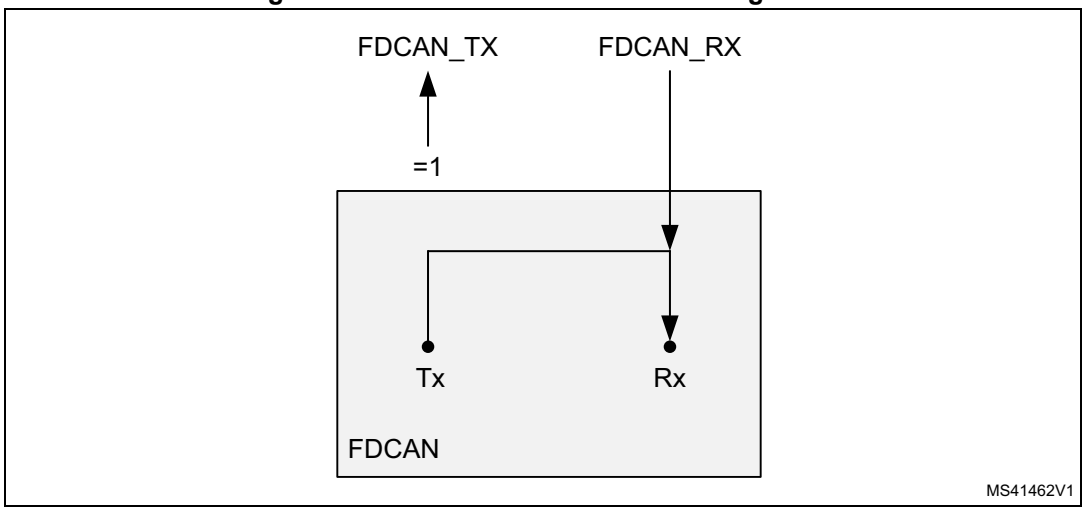
Note: The restricted operation mode must not be combined with the loop-back mode (internal or external).

Bus monitoring mode

The FDCAN is set in bus monitoring mode by setting the MON bit of the FDCAN_CCCR register. In bus monitoring mode (for more details refer to ISO11898-1, 10.12 bus monitoring), the FDCAN is able to receive valid data frames and valid remote frames, but cannot start a transmission. In this mode, it sends only recessive bits on the CAN bus. If the FDCAN is required to send a dominant bit (ACK bit, overload flag, active error flag), the bit is rerouted internally so that the FDCAN can monitor it, even if the CAN bus remains in recessive state. In bus monitoring mode, the FDCAN_TXBRP register is held in reset state.

The bus monitoring mode can be used to analyze the traffic on a CAN bus without affecting it by the transmission of dominant bits. *Figure 923* shows the connection of FDCAN_TX and FDCAN_RX signals to the FDCAN in bus monitoring mode.

Figure 923. Pin control in bus monitoring mode



Disabled automatic retransmission mode (DAR)

According to the CAN specification (see ISO11898-1, 6.3.3 Recovery Management), the FDCAN provides means for automatic retransmission of frames that have lost arbitration or have been disturbed by errors during transmission. By default, automatic retransmission is enabled. The DAR mode can be disabled through the DAR bit of the FDCAN_CCCR register.

Frame transmission in DAR mode

In DAR mode, all transmissions are automatically canceled after they have been started on the CAN bus. A Tx buffer Tx request pending bit (TRPx in FDCAN_TXBRP) is reset after successful transmission, when a transmission has not yet been started at the point of cancellation, when it has been aborted due to lost arbitration, or when an error has occurred during frame transmission.

- Successful transmission
  - The corresponding Tx buffer transmission occurred bit TOx is set in FDCAN_TXBTO register.
  - The corresponding Tx buffer cancellation finished bit CFx is cleared in the FDCAN_TXBCF register.
- Successful transmission in spite of cancellation
  - The corresponding Tx buffer transmission occurred bit TOx is set in the FDCAN_TXBTO register.
  - The corresponding Tx buffer cancellation finished bit CFx is set in the FDCAN_TXBCF register.
- Arbitration loss or frame transmission disturbed
  - The corresponding Tx buffer transmission occurred bit TOx is cleared in the FDCAN_TXBTO register.
  - The corresponding Tx buffer cancellation finished bit CFx is set in the FDCAN_TXBCF register.

In case of a successful frame transmission, and if the storage of Tx events is enabled, a Tx event FIFO element is written with event type ET = 10 (transmission in spite of cancellation).

Power-down (Sleep mode)

Power-down entry

The FDCAN can be set into power-down mode controlled by setting the CSR bit of the FDCAN_CCCR register. As long as the clock stop request is active, CSR is read as 1.

When all pending transmission requests have completed, the FDCAN waits until the bus-idle state is detected. The FDCAN then sets the INIT bit of the FDCAN_CCCR register to prevent any further CAN transfers. Now, the FDCAN acknowledges that it is ready for power-down by setting the CSA bit of the FDCAN_CCCR register. In this state, before the clocks are switched off, further register accesses can be made. A write access to the INIT bit has no effect. Now, the module clock inputs can be switched off.

Power-down exit

To leave power-down mode, the application has to turn on the module clocks before clearing the CSR bit. The FDCAN acknowledges this by clearing the CSA bit. Afterwards, the application can restart CAN communication by clearing the INIT bit.

Test modes

To enable write access to *FDCAN test register (FDCAN_TEST)*, the TEST bit of the FDCAN_CCCR register must be set, thus enabling the configuration of test modes and functions.

Four output functions are available for the CAN transmit pin FDCAN_TX by programming the TX[1:0] bitfield of the FDCAN_TEST register. In addition to its default function (the serial data output), it can drive the CAN sample point signal to monitor the FDCAN bit timing as well as drive constant dominant or recessive values. The actual value at pin FDCAN_RX can be read from the RX bit of FDCAN_TEST. Both functions can be used to check the CAN bus physical layer.

Due to the synchronization mechanism between CAN kernel clock and APB clock domain, there can be a delay of several APB clock periods between writing to TX[1:0] until the new configuration is visible at FDCAN_TX output pin. This applies also when reading FDCAN_RX input pin via RX.

Note: Test modes must be used for production tests or self-test only. The software control for FDCAN_TX pin interferes with all CAN protocol functions. It is not recommended to use test modes for application.

External loop-back mode

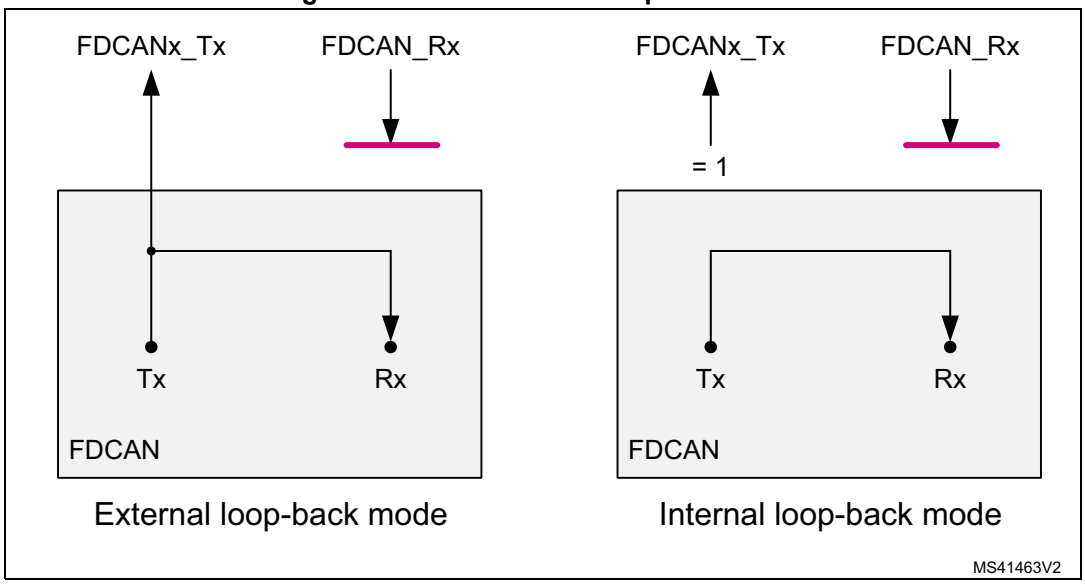
The FDCAN can be set in external loop-back mode by setting the LBCK bit of the FDCAN_TEST register. In loop-back mode, the FDCAN treats its own transmitted messages as received messages and stores them (if they pass acceptance filtering) into Rx FIFOs. *Figure 924* shows the connection of transmit and receive signals FDCAN_TX and FDCAN_RX to the FDCAN in external loop-back mode.

This mode is provided for hardware self-test. To be independent from external stimulation, the FDCAN ignores acknowledge errors (recessive bit sampled in the acknowledge slot of a data/remote frame) in loop-back mode. In this mode, the FDCAN performs an internal feedback from its transmit output to its receive input. The actual value of the FDCAN_RX input pin is disregarded by the FDCAN. The transmitted messages can be monitored at the FDCAN_TX transmit pin.

Internal loop-back mode

Internal loop-back mode is entered by setting both the LBCK bit of FDCAN_TEST and the MON bit of FDCAN_CCR. This mode can be used for a “hot self-test”, meaning the FDCAN can be tested without affecting a running CAN system connected to the FDCAN_TX and FDCAN_RX pins. In this mode, FDCAN_RX pin is disconnected from the FDCAN and FDCAN_TX pin is held recessive. *Figure 924* shows the connection of FDCAN_TX and FDCAN_RX pins to the FDCAN in case of internal loop-back mode.

Figure 924. Pin control in loop-back mode



Timestamp generation

For timestamp generation, the FDCAN supplies a 16-bit wrap-around counter. A prescaler (TCP[3:0] of FDCAN_TSCC) can be configured to clock the counter in multiples of CAN bit times (1 to 16). The counter is readable via the TCV[15:0] bitfield of the FDCAN_TSCV register. A write access to TSCV15:0] resets the counter to 0. When the timestamp counter wraps around, the interrupt flag (TSW bit of FDCAN_ISR) is set.

On start of frame reception/transmission, the counter value is captured and stored into the timestamp section of an Rx FIFO (RXTS[15:0]) or Tx event FIFO (TXTS[15:0]) element.

By programming TSS[1:0] of FDCAN_TSCC, a 16-bit timestamp can be used.

Debug mode behavior

In debug mode, the set/reset on read feature is automatically disabled during the debugger register access, and enabled during normal MCU operation

Timeout counter

To signal timeout conditions for Rx FIFO 0, Rx FIFO 1, and the Tx event FIFO the FDCAN supplies a 16-bit timeout counter. It operates as a down-counter and uses the same prescaler controlled by TCP[3:0] of FDCAN_TSCC as the timestamp counter. The timeout counter is configured via the FDCAN_TOCC register. The actual counter value can be read from the TOC[15:0] bitfield of FDCAN_TOCV. The timeout counter can only be started while the INIT bit of FDCAN_CCCR is cleared. It is stopped when INIT is set, for example, when the FDCAN enters bus-off state.

The operation mode is selected by TOS[1:0] of FDCAN_TOCC. When operating in continuous mode, the counter starts when INIT is cleared. A write to FDCAN_TOCV presets the counter to the value configured by TOP[15:0] in FDCAN_TOCC and continues down-counting.

When the timeout counter is controlled by one of the FIFOs, an empty FIFO presets the counter to the value configured by TOP[15:0]. Down-counting is started when the first FIFO element is stored. Writing to FDCAN_TOCV has no effect.

When the counter reaches 0, the TOO interrupt flag is set in the FDCAN_IR register. In continuous mode, the counter is immediately restarted at TOP[15:0].

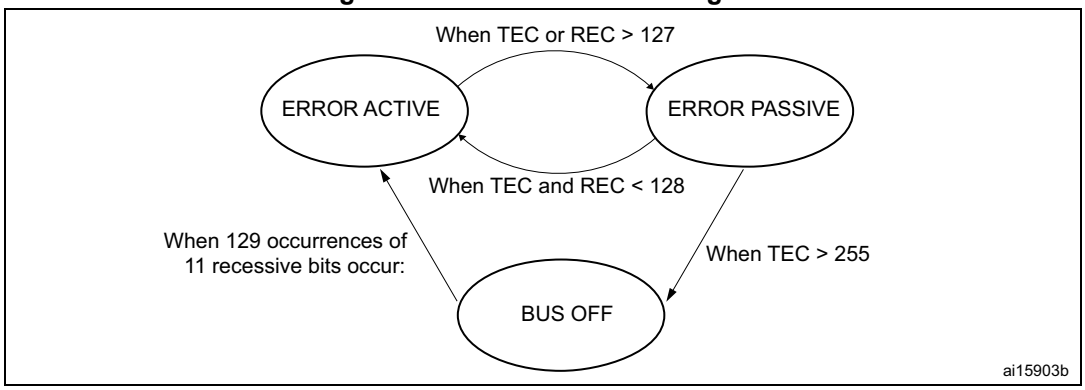
Note: The clock signal for the timeout counter is derived from the CAN core sample point signal. Therefore, the point in time where the timeout counter is decremented may vary due to the synchronization/resynchronization mechanism of the CAN core. If the baud rate switch feature in FDCAN is used, the timeout counter is clocked differently in the arbitration and data fields.

65.3.5 Error management

As described in the CAN protocol, the error management is handled entirely by hardware using the transmit error counter (the TEC[7:0] bitfield of the *FDCAN error counter register (FDCAN_ECR)*) and the receive error counter (the REC[6:0] bitfield of the *FDCAN error counter register (FDCAN_ECR)*). These values are incremented or decremented according to the error condition. For detailed information on TEC[7:0] and REC[6:0] management, refer to the CAN standard. Both values can be read by software to determine the stability of the network.

The bus-off state is reached when TEC[7:0] is greater than 255. This state is also indicated by the BO flag of the *FDCAN protocol status register (FDCAN_PSR)*. In bus-off state, the CAN is no longer able to transmit and receive messages. It has to wait at least for the duration of the recovery sequence specified in the CAN standard (129 occurrences of 11 consecutive recessive bits monitored on FDCAN_RX input).

Figure 925. CAN error state diagram

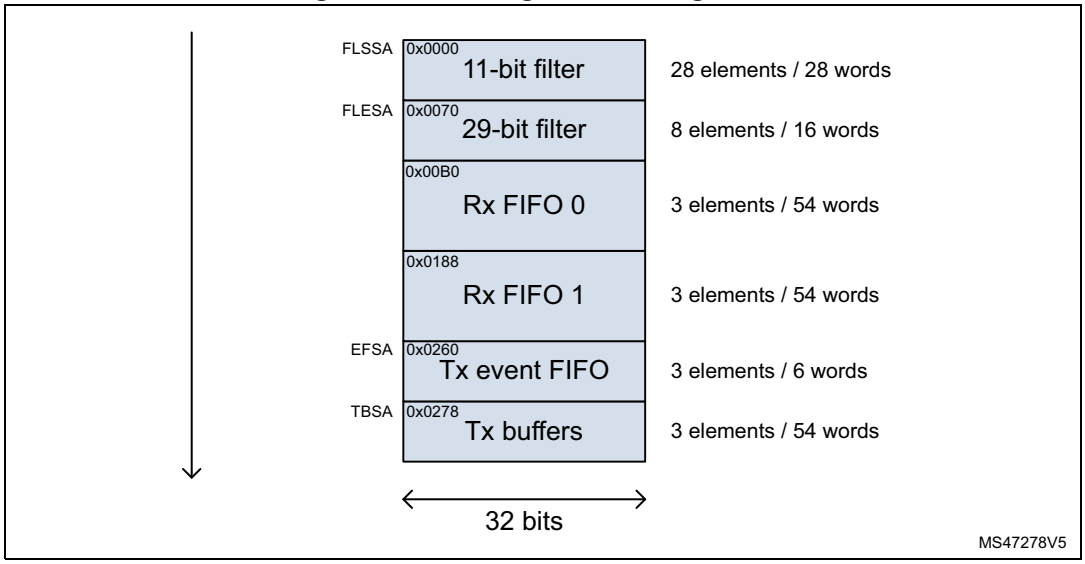


Note: In initialization mode, the CAN does not monitor the FDCAN_RX *signal, and therefore cannot complete the recovery sequence. To recover from an error state, the CAN must operate in normal mode.*

65.3.6 Message RAM

The message RAM is 32-bit wide, and the FDCAN module is configured to allocate up to 212 words in it. It is not necessary to configure each of the sections shown in *Figure 926*.

Figure 926. Message RAM configuration



When the FDCAN addresses the message RAM, it addresses 32-bit words (aligned), not a single byte. The RAM addresses are 32-bit words, that is, only bits 15 to 2 are evaluated, the two least significant bits are ignored.

In case of multiple instances, the RAM start address for the FDCANn is computed by end address + 4 of FDCANn - 1, and the FDCANn end address is computed by FDCANn start address + 0x0350 - 4.

As an example, for two instances:

- FDCAN1:
  - Start address 0x0000
  - End address 0x034C (as in *Figure 926*)
- FDCAN2:
  - Start address = 0x034C (FDCAN1 end address) + 4 = 0x0350
  - End address = 0x0350 (FDCAN2 start address) + 0x0350 - 4 = 0x069C.

Rx handling

The Rx handler controls the acceptance filtering, the transfer of received messages to one of the two Rx FIFOs, as well as the Rx FIFO put and get indices.

Acceptance filter

The FDCAN offers the possibility to configure two sets of acceptance filters, one for standard identifiers and another for extended identifiers. These filters can be assigned to Rx FIFO 0 or Rx FIFO 1. For acceptance filtering, each list of filters is executed from element #0 until the first matching element. Acceptance filtering stops at the first matching element, and the following filter elements are not evaluated for this message.

The main features are:

- Each filter element can be configured as
  - Range filter (from - to)
  - Filter for one or two dedicated IDs
  - Classic bit mask filter
- Each filter element is configurable for acceptance or rejection filtering.
- Each filter element can be enabled/disabled individually.
- Filters are checked sequentially, execution stops with the first matching filter element

Related configuration registers are:

- Global filter configuration (RXGFC)
- Extended ID AND mask (XIDAM)

Depending on the configuration of the filter element (SFEC[2:0]/EFEC[2:0]), a match triggers one of the following actions:

- Store received frame in FIFO 0 or FIFO 1
- Reject received frame
- Set the high priority message interrupt flag HPM in FDCAN_IR
- Set the high priority message interrupt flag HPM in FDCAN_IR, and store the received frame in FIFO 0 or FIFO 1.

Acceptance filtering is started after the complete identifier has been received. After acceptance filtering has completed, and if a matching Rx FIFO has been found, the message handler starts writing the received message data in 32-bit portions to the matching Rx FIFO. If the CAN protocol controller has detected an error condition (for example, CRC error), this message is discarded with the following impact:

- **Rx FIFO**

  The put index of the matching Rx FIFO is not updated, but the related Rx FIFO element is partly overwritten with the received data. For error type, see LEC[2:0] and DLEC[2:0] bitfields of the FDCAN_PSR register. In case the matching Rx FIFO is operated in overwrite mode, the boundary conditions described in *Rx FIFO overwrite mode* have to be considered.

Note: When an accepted message is written to one of the two Rx FIFOs, the unmodified received identifier is stored independently from the used filters. The result of the acceptance filter process strongly depends on the sequence of configured filter elements.

Range filter

The filter matches for all received frames with message IDs in the range defined by SF1ID/SF2ID and EF1ID/EF2ID.

There are two possibilities when range filtering is used together with extended frames:

- EFT[1:0] = 00: the message ID of received frames is AND-ed with the extended ID AND mask (XIDAM) before the range filter is applied.
- EFT[1:0] = 11: the extended ID AND mask (XIDAM) is not used for range filtering.

Filter for dedicated IDs

A filter element can be configured to filter for one or two specific message IDs. To filter for one specific message ID, the filter element has to be configured with SF1ID = SF2ID and EF1ID = EF2ID.

Classic bit mask filter

The classic bit mask filtering is intended to filter groups of message IDs by masking single bits of a received message ID. With classic bit mask filtering SF1ID/EF1ID is used as message ID filter, while SF2ID/EF2ID is used as filter mask.

0 bit at the filter mask masks out the corresponding bit position of the configured ID filter. For example, the value of the received message ID at that bit position is not relevant for acceptance filtering. Only the bits of the received message ID where the corresponding mask bits are 1 are relevant for acceptance filtering.

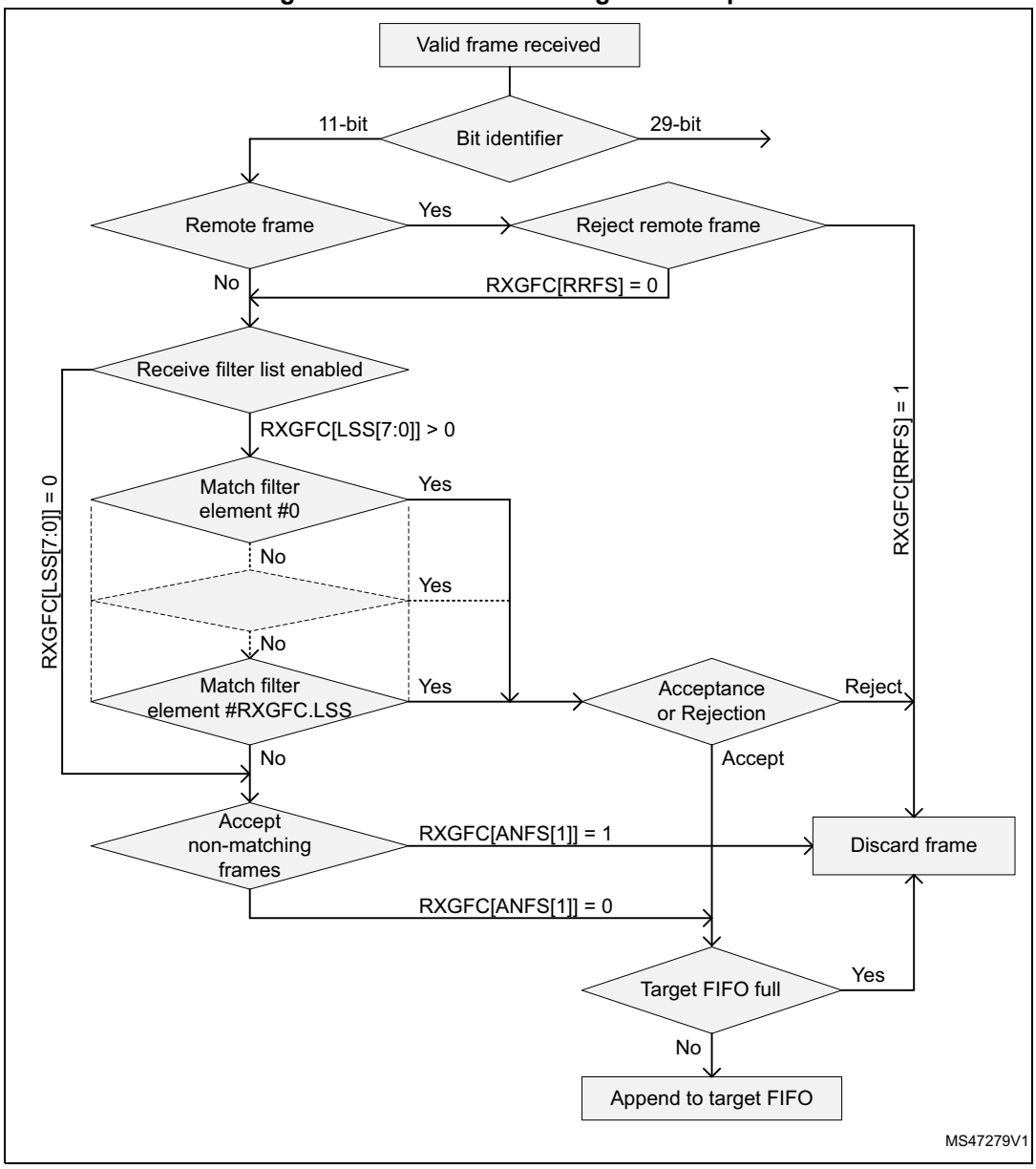
In case all mask bits are 1, a match occurs only when the received message ID and the message ID filter are identical. If all mask bits are 0, all message IDs match.

Standard message ID filtering

Figure 927 shows the flow for standard message ID (11-bit identifier) filtering. The standard message ID filter element is described in *Section 65.3.11*.

The standard message filtering is controlled by the FDCAN_RXGFC register. The standard message ID, the remote transmission request bit (RTR), and the identifier extension bit (IDE) of the received frames are compared against the list of configured filter elements.

Figure 927. Standard message ID filter path

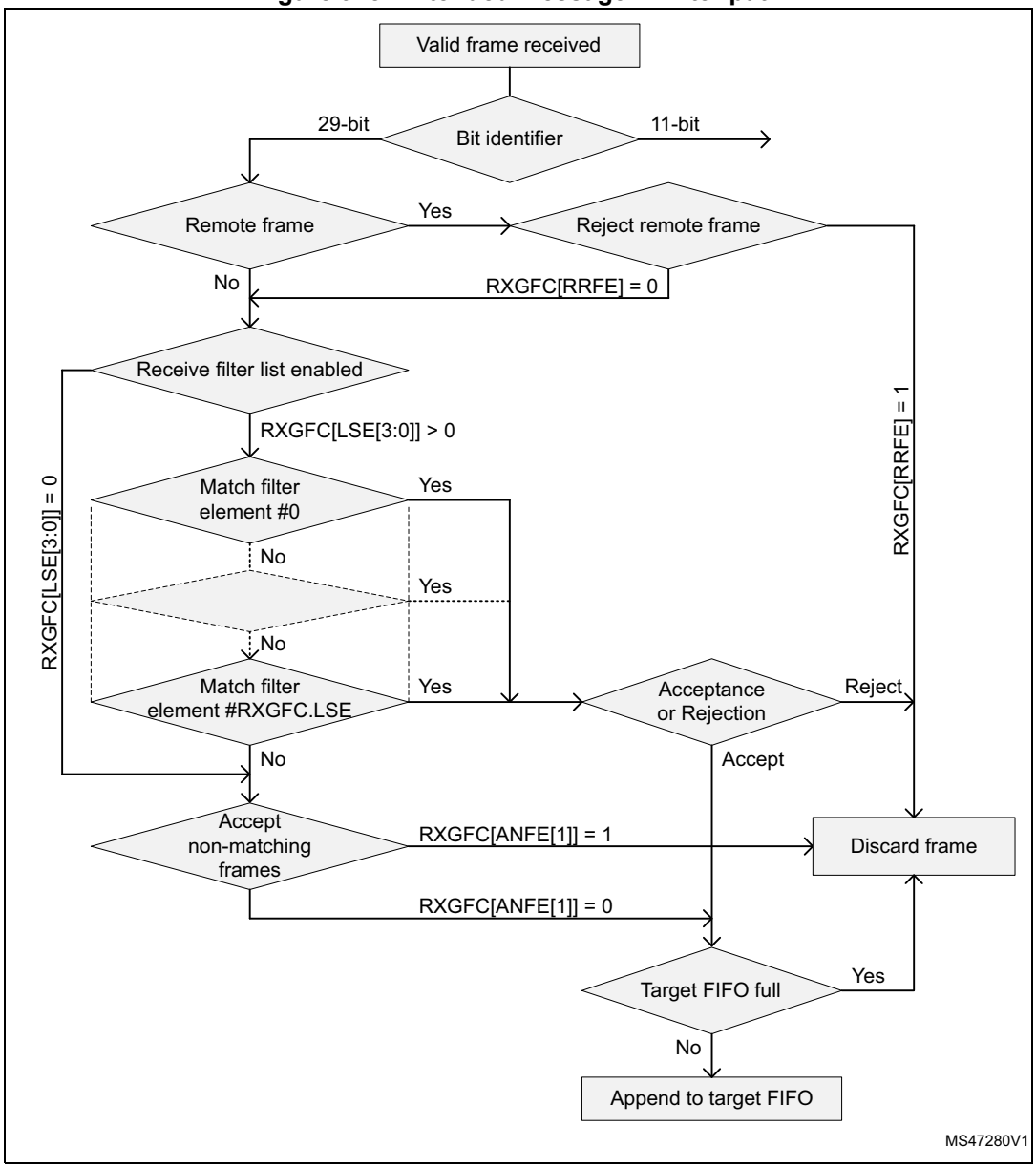


Extended message ID filtering

Figure 928 shows the flow for extended message ID (29-bit identifier) filtering. The extended message ID filter element is described in *Section 65.3.12*.

The extended message filtering is controlled by the FDCAN_RXGFC register. The extended message ID, the remote transmission request bit (RTR), and the identifier extension bit (IDE) of the received frames are compared against the list of configured filter elements.

Figure 928. Extended message ID filter path



The extended ID AND mask (XIDAM) is AND-ed with the received identifier before the filter list is executed.

Rx FIFOs

Rx FIFO 0 and Rx FIFO 1 can hold up to three elements each.

Received messages that passed acceptance filtering are transferred to the Rx FIFO as configured by the matching filter element. For a description of the filter mechanisms available for Rx FIFO 0 and Rx FIFO 1, see *Acceptance filter*. The Rx FIFO element is described in *Section 65.3.8*.

When an Rx FIFO full condition is signaled by RFnF in FDCAN_IR (where n is the FIFO number), no further messages are written to the corresponding Rx FIFO until at least one message has been read out, and the Rx FIFO get index has been incremented. In case a message is received while the corresponding Rx FIFO is full, this message is discarded, and the interrupt flag RFnL is set in the FDCAN_IR register.

When reading from an Rx FIFO, the Rx FIFO get index (FnGI of FDCAN_RXFnS) + FIFO element size has to be added to the corresponding Rx FIFO start address (FnSA).

Rx FIFO blocking mode

The Rx FIFO blocking mode is configured by clearing the FnOM bit in the FDCAN_RXGFC register. This is the default operation mode for the Rx FIFOs.

When an Rx FIFO full condition is reached (FnPI = FnGI in FDCAN_RXFnS), no further messages are written to the corresponding Rx FIFO until at least one message has been read out and the Rx FIFO get index has been incremented. An Rx FIFO full condition is signaled by FnF = 1 in FDCAN_RXFnS. In addition, the RFnF interrupt flag is set in FDCAN_IR.

In case a message is received while the corresponding Rx FIFO is full, this message is discarded, and the message lost condition is signaled by setting RFnL bit in FDCAN_RXFnS. In addition, the RFnL interrupt flag is set in FDCAN_IR.

Rx FIFO overwrite mode

The Rx FIFO overwrite mode is configured by setting the FnOM bit of the FDCAN_RXGFC register.

When an Rx FIFO full condition (FnPI = FnGI of FDCAN_RXFnS) is signaled by FnF = 1 in FDCAN_RXFnS, the next message accepted for the FIFO overwrites the oldest FIFO message. Put and get indices are both incremented by one.

When an Rx FIFO is operated in overwrite mode and an Rx FIFO full condition is signaled, reading from the Rx FIFO elements must start at least at get index + 1. This is because it may happen that a received message is written to the message RAM (put index) while the CPU is reading from the message RAM (get index). In this case, inconsistent data can be read from the respective Rx FIFO element. Adding an offset to the get index when reading from the Rx FIFO avoids this problem. The offset depends on how fast the CPU accesses the Rx FIFO.

After reading from the Rx FIFO, the number of the last element read has to be written to the Rx FIFO acknowledge index (FnA of FDCAN_RXFnA). This increments the get index to that element number. In case the put index has not been incremented to this Rx FIFO element, the Rx FIFO full condition is reset (FnF = 0 in FDCAN_RXFnS).

Tx handling

The Tx handler handles transmission requests for the Tx FIFO and the Tx queue. It controls the transfer of transmit messages to the CAN core, the put and get indices, and the Tx event FIFO. Up to three Tx buffers can be set up for message transmission. The CAN message data field is configured to 64 bytes. the Tx FIFO allocates eighteen 32-bit words for storage of a Tx element.

Table 715. Possible configurations for frame transmission

CCCR		Tx buffer element		Frame transmission
BRSE	FDOE	FDF	BRS	
Ignored	0	Ignored	Ignored	Classic CAN
0	1	0	Ignored	Classic CAN
0	1	1	Ignored	FD without bit rate switching
1	1	0	Ignored	Classic CAN
1	1	1	0	FD without bit rate switching
1	1	1	1	FD with bit rate switching

Note: AUTOSAR requires at least three Tx queue buffers and support of transmit cancellation.

The Tx handler starts a Tx scan to check for the highest priority pending Tx request (Tx buffer with lowest message ID) when the Tx buffer request pending register (FDCAN_TXBRP) is updated, or when a transmission has been started.

Transmit pause

The transmit pause feature is intended for use in CAN systems where the CAN message identifiers are permanently specified to specific values and cannot easily be changed. These message identifiers can have a higher CAN arbitration priority than other defined messages, while in a specific application their relative arbitration priority must be inverse. This may lead to a case where one ECU sends a burst of CAN messages that cause another ECU CAN messages to be delayed because that other messages have a lower CAN arbitration priority.

As an example, if CAN ECU-1 has the feature enabled and is requested by its application software to transmit four messages, it waits, after the first successful message transmission, for two CAN bit times of bus-idle before it is allowed to start the next requested message. If there are other ECUs with pending messages, these messages are started in the idle time, and they would not need to arbitrate with the next message of ECU-1. After having received a message, ECU-1 is allowed to start its next transmission as soon as the received message releases the CAN bus.

The feature is controlled by the TXP bit of the CCCR register. If the bit is set, the FDCAN, each time it has successfully transmitted a message, pauses for two CAN bit times before starting the next transmission. This enables other CAN nodes in the network to transmit messages even if their messages have lower prior identifiers. By default, this feature is disabled (TXP = 0 in FDCAN_CCCR).

This feature looses up burst transmissions coming from a single node and it protects against "babbling idiot" scenarios where the application program erroneously requests too many transmissions.

Tx FIFO

Tx FIFO operation is configured by clearing the TFQM bit of the FDCAN_TXBC register. Messages stored in the Tx FIFO are transmitted starting with the message referenced by the get index (TFGI[1:0] bitfield of FDCAN_TXFQS). After each transmission, the get index is incremented cyclically until the Tx FIFO is empty. The Tx FIFO enables transmission of messages with the same message ID from different Tx buffers in the order that these messages have been written to the Tx FIFO. The FDCAN calculates the Tx FIFO free level (TFFL[2:0] bitfield of FDCAN_TXFQS) as the difference between the get and put index. It indicates the number of available (free) Tx FIFO elements.

New transmit messages have to be written to the Tx FIFO starting with the Tx buffer referenced by the put index (TFQPI[1:0] bitfield of FDCAN_TXFQS). An add request increments the put index to the next free Tx FIFO element. When the put index reaches the get index, Tx FIFO full (TFQF = 1 in FDCAN_TXFQS) is signaled. In this case, no further messages must be written to the Tx FIFO until the next message has been transmitted and the get index has been incremented.

When a single message is added to the Tx FIFO, the transmission is requested by setting the FDCAN_TXBAR bit related to the Tx buffer referenced by the Tx FIFO put index.

When multiple (n) messages are added to the Tx FIFO, they are written to n consecutive Tx buffers starting with the put index. The transmissions are then requested via the FDCA_TXBAR register. The put index is then cyclically incremented by n. The number of requested Tx buffers must not exceed the number of free Tx buffers as indicated by the Tx FIFO free level.

When a transmission request for the Tx buffer referenced by the get index is canceled, the get index is incremented to the next Tx buffer with a transmission request is pending and the Tx FIFO free level is recalculated. When transmission cancellation is applied to any other Tx buffer, the get index and the FIFO Free Level remain unchanged.

A Tx FIFO element allocates eighteen 32-bit words in the message RAM. The Therefore, the start address of the next available (free) Tx FIFO buffer, is calculated by adding 18 times the put index TFQPI[1:0] (0 … 2) to the Tx buffer start address TBSA.

Tx queue

Tx queue operation is configured by setting the TFQM of the FDCAN_TXBC register. Messages stored in the Tx queue are transmitted starting with the message with the lowest message ID (highest priority).

In case of mixing of standard and extended message IDs, the standard message IDs are compared to bits [28:18] of extended message IDs.

In case multiple queue buffers are configured with the same message ID, the queue buffer with the lowest buffer number is transmitted first.

New messages have to be written to the Tx buffer referenced by the put index (TFQPI[1:0] in FDCAN_TXFQS). An add request cyclically increments the put index to the next free Tx buffer. In case the Tx queue is full (TFQF = 1 in FDCAN_TXFQS), the put index is not valid and no further message must be written to the Tx queue until at least one of the requested messages has been sent out or a pending transmission request has been canceled.

The application can use the FDCAN_TXBRP register instead of the put index and can place messages to any Tx buffer without pending transmission request.

A Tx queue buffer allocates eighteen 32-bit words in the message RAM. The start address of Therefore, the next available (free) Tx queue buffer is calculated by adding 18 times the Tx queue put index TFQPI[1:0] (0 ... 2) to the Tx buffer start address TBSA.

Transmit cancellation

The FDCAN supports transmit cancellation. To cancel a requested transmission from a Tx queue buffer, the host has to write 1 to the corresponding bit position (= number of Tx buffer) of the FDCAN_TXBCR register. Transmit cancellation is not intended for Tx FIFO operation.

Successful cancellation is signaled by setting the corresponding bit of the FDCAN_TXBCF register.

In case a transmit cancellation is requested while a transmission from a Tx buffer is already ongoing, the corresponding FDCAN _TXBRP bit remains set as long as the transmission is in progress. If the transmission is successful, the corresponding FDCAN_TXBTO and FDCAN_TXBCF bits are set. If the transmission is not successful, it is not repeated and only the corresponding FDCAN_TXBCF bit is set.

Note: In case a pending transmission is canceled immediately before it has been started, there is a short time window where no transmission is started even if another message is pending in the node. This can enable another node to transmit a message that can have a priority lower than that of the second message in the node.

Tx event handling

To support Tx event handling the FDCAN has implemented a Tx event FIFO. After the FDCAN has transmitted a message on the CAN bus, message ID and timestamp are stored in a Tx event FIFO element. To link a Tx event to a Tx event FIFO element, the message marker from the transmitted Tx buffer is copied into the Tx event FIFO element.

The Tx event FIFO is configured to three elements. The Tx event FIFO element is described in *Tx FIFO*.

The purpose of the Tx event FIFO is to decouple handling transmit status information from transmit message handling that is, a Tx buffer holds only the message to be transmitted, while the transmit status is stored separately in the Tx event FIFO. This has the advantage, especially when operating a dynamically managed transmit queue, that a Tx buffer can be used for a new message immediately after successful transmission. There is no need to save transmit status information from a Tx buffer before overwriting that Tx buffer.

When a Tx event FIFO full condition is signaled by the TEFF bit of the FDCAN_IR, no further elements are written to the Tx event FIFO until at least one element has been read out and the Tx event FIFO get index has been incremented. In case a Tx event occurs while the Tx event FIFO is full, this event is discarded and the TEFL interrupt flag is set in the FDCAN_IR register.

When reading from the Tx event FIFO, the Tx event FIFO get index (EFGI[1:0] of FDCAN_TXEFS) has to be added twice to the Tx event FIFO start address EFSA.

65.3.7 FIFO acknowledge handling

The get indices of Rx FIFO 0, Rx FIFO 1, and the Tx event FIFO are controlled by writing to the corresponding FIFO acknowledge index (see *Section 65.4.23* and *Section 65.4.25*). Writing to the FIFO acknowledge index sets the FIFO get index to the FIFO acknowledge index plus one and thereby updates the FIFO fill level. There are two use cases:

- When only a single element has been read from the FIFO (the one being pointed to by the get index), this get index value is written to the FIFO acknowledge index.
- When a sequence of elements has been read from the FIFO, it is sufficient to write the FIFO acknowledge index only once at the end of that read sequence (value = index of the last element read), to update the FIFO get index.

Because the CPU has free access to the FDCAN message RAM, special care has to be taken when reading FIFO elements in an arbitrary order (get index not considered). This might be useful when reading a high priority message from one of the two Rx FIFOs. In this case, the FIFO acknowledge index must not be written because this would set the get index to a wrong position and alter the FIFO fill level. In this case, some of the older FIFO elements would be lost.

Note: The application has to ensure that a valid value is written to the FIFO acknowledge index. The FDCAN does not check for erroneous values.

65.3.8 FDCAN Rx FIFO element

Two Rx FIFOs are configured in the message RAM. Each Rx FIFO section can be configured to store up to three received messages. The structure of an Rx FIFO element is described in *Table 716*. The description is provided in *Table 717*.

Table 716. Rx FIFO element

Bit	31			24	23							16	15	8	7	0
R0	ESI	XTD	RTR	ID[28:0]												
R1	ANMF	FIDX[6:0]			Res.			FDF	BRS	DLC[3:0]			RXTS[15:0]			
R2	DB3[7:0]				DB2[7:0]								DB1[7:0]		D[7:0]	
R3	DB7[7:0]				DB6[7:0]								DB5[7:0]		DB4[7:0]	
⋮	⋮				⋮								⋮			
Rn	DBm[7:0]				DBm-1[7:0]								DBm-2[7:0]		DBm-3[7:0]	

The element size configured for storage of CAN FD messages is set to 64-byte data field.

Table 717. Rx FIFO element description

Field	Description
R0 Bit 31 ESI	Error state indicator – 0: Transmitting node is error active – 1: Transmitting node is error passive
R0 Bit 30 XTD	Extended identifier Signals to the host whether the received frame has a standard or extended identifier. – 0: 11-bit standard identifier – 1: 29-bit extended identifier

Table 717. Rx FIFO element description (continued)

Field	Description
R0 Bit 29 RTR	Remote transmission request Signals to the host whether the received frame is a data frame or a remote frame. – 0: Received frame is a data frame – 1: Received frame is a remote frame
R0 Bits 28:0 ID[28:0]	Identifier Standard or extended identifier depending on bit XTD. A standard identifier is stored into ID[28:18].
R1 Bit 31 ANMF	Accepted non-matching frame Acceptance of non-matching frames can be enabled via ANFS[1:0] and ANFE[1:0] bitfield of FDCAN_RXGFC. – 0: Received frame matching filter index FIDX – 1: Received frame did not match any Rx filter element
R1 Bits 30:24 FIDX[6:0]	Filter index 0-27=Index of matching Rx acceptance filter element (invalid if ANMF = 1). Range: 0 to LSS[4:0] - 1 or LSE[3:0] - 1 in FDCAN_RXGFC.
R1 Bit 21 FDF	FD format – 0: Standard frame format – 1: FDCAN frame format (new DLC-coding and CRC)
R1 Bit 20 BRS	Bit rate switch – 0: Frame received without bit rate switching – 1: Frame received with bit rate switching
R1 Bits 19:16 DLC[3:0]	Data length code – 0-8: Classic CAN + CAN FD: received frame has 0-8 data bytes – 9-15: Classic CAN: received frame has 8 data bytes – 9-15: CAN FD: received frame has 12/16/20/24/32/48/64 data bytes
R1 Bits 15:0 RXTS[15:0]	Rx timestamp Timestamp Counter value captured on start of frame reception. Resolution depending on configuration of the timestamp counter prescaler TCP[3:0] of FDCAN_TSCC.
R2 Bits 31:24 DB3[7:0]	Data byte 3
R2 Bits 23:16 DB2[7:0]	Data byte 2
R2 Bits 15:8 DB1[7:0]	Data byte 1
R2 Bits 7:0 D[7:0]	Data byte 0
R3 Bits 31:24 DB7[7:0]	Data byte 7
R3 Bits 23:16 DB6[7:0]	Data byte 6

Table 717. Rx FIFO element description (continued)

Field	Description
R3 Bits 15:8 DB5[7:0]	Data byte 5
R3 Bits 7:0 DB4[7:0]	Data byte 4
⋮	⋮
Rn Bits 31:24 DBm[7:0]	Data byte m
Rn Bits 23:16 DBm-1[7:0]	Data byte m-1
Rn Bits 15:8 DBm-2[7:0]	Data byte m-2
Rn Bits 7:0 DBm-3[7:0]	Data byte m-3

65.3.9 FDCAN Tx buffer element

The Tx buffers section (three elements) can be configured to hold Tx FIFO or Tx queue. The Tx handler distinguishes between Tx FIFO and Tx queue using the Tx buffer configuration TFQM bit of the FDCAN_TXBC register. The element size is configured for storage of CAN FD messages with up to 64-byte data.

Table 718. Tx buffer and FIFO element

Bit	31			24	23					16	15	8	7	0
T0	ESI	XTD	RTR	ID[28:0]										
T1	MM[7:0]				EFC	Res.	FDF	BRS	DLC[3:0]		Res.			
T2	DB3[7:0]				DB2[7:0]						DB1[7:0]		D[7:0]	
T3	DB7[7:0]				DB6[7:0]						DB5[7:0]		DB4[7:0]	
⋮	⋮				⋮						⋮			
Tn	DBm[7:0]				DBm-1[7:0]						DBm-2[7:0]		DBm-3[7:0]	

Table 719. Tx buffer element description

Field	Description
T0 Bit 31 ESI(1)	Error state indicator – 0: ESI bit in CAN FD format depends only on error passive flag – 1: ESI bit in CAN FD format transmitted recessive
T0 Bit 30 XTD	Extended identifier – 0: 11-bit standard identifier – 1: 29-bit extended identifier

Table 719. Tx buffer element description (continued)

Field	Description
T0 Bit 29 RTR(2)	Remote transmission request – 0: Transmit data frame – 1: Transmit remote frame
T0 Bits 28:0 ID[28:0]	Identifier Standard or extended identifier depending on bit XTD. A standard identifier has to be written to ID[28:18].
T1 Bits 31:24 MM[7:0]	Message marker Written by CPU during Tx buffer configuration. Copied into Tx event FIFO element for identification of Tx message status.
T1 Bit 23 EFC	Event FIFO control – 0: Do not store Tx events – 1: Store Tx events
T1 Bit 21 FDF	FD format – 0: Frame transmitted in classic CAN format – 1: Frame transmitted in CAN FD format
T1 Bit 20 BRS(3)	Bit rate switching – 0: CAN FD frames transmitted without bit rate switching – 1: CAN FD frames transmitted with bit rate switching
T1 Bits 19:16 DLC[3:0]	Data length code – 0 - 8: Classic CAN + CAN FD: received frame has 0-8 data bytes – 9 - 15: Classic CAN: received frame has 8 data bytes – 9 - 15: CAN FD: received frame has 12/16/20/24/32/48/64 data bytes
T2 Bits 31:24 DB3[7:0]	Data byte 3
T2 Bits 23:16 DB2[7:0]	Data byte 2
T2 Bits 15:8 DB1[7:0]	Data byte 1
T2 Bits 7:0 D[7:0]	Data byte 0
T3 Bits 31:24 DB7[7:0]	Data byte 7
T3 Bits 23:16 DB6[7:0]	Data byte 6
T3 Bits 15:8 DB5[7:0]	Data byte 5
T3 Bits 7:0 DB4[7:0]	Data byte 4
⋮	⋮

Table 719. Tx buffer element description (continued)

Field	Description
Tn Bits 31:24 DBm[7:0]	Data byte m
Tn Bits 23:16 DBm-1[7:0]	Data byte m-1
Tn Bits 15:8 DBm-2[7:0]	Data byte m-2
Tn Bits 7:0 DBm-3[7:0]	Data byte m-3

1. The ESI bit of the transmit buffer is OR-ed with the error passive flag to decide the value of the ESI bit in the transmitted FD frame. As required by the CAN FD protocol specification, an error active node can optionally transmit the ESI bit recessive, but an error passive node always transmits the ESI bit recessive.
2. When RTR = 1, the FDCAN transmits a remote frame according to ISO11898-1, even if the transmission in CAN FD format is enabled by the FDOE bit of the FDCAN_CCCR.
3. Bits ESI, FDF, and BRS are only evaluated when CAN FD operation is enabled by setting the FDOE bit of the FDCAN_CCCR. Bit BRS is only evaluated when in addition BRSE bit is set in FDCAN_CCCR.

65.3.10 FDCAN Tx event FIFO element

Each element stores information about transmitted messages. By reading the Tx event, FIFO the host CPU gets this information in the order that the messages were transmitted. Status information about the Tx event FIFO can be obtained from FDCAN_TXEFS register.

Table 720. Tx event FIFO element

Bit	31			24	23						16	15		8	7		0
E0	ESI	XTD	RTR	ID[28:0]													
E1	MM[7:0]				ET[1:0]		EDL	BRS	DLC[3:0]			TXTS[15:0]					

Table 721. Tx event FIFO element description

Field	Description
E0 Bit 31 ESI	Error state indicator – 0: Transmitting node is error active – 1: Transmitting node is error passive
E0 Bit 30 XTD	Extended identifier – 0: 11-bit standard identifier – 1: 29-bit extended identifier
E0 Bit 29 RTR	Remote transmission request – 0: Transmit data frame – 1: Transmit remote frame
E0 Bits 28:0 ID[28:0]	Identifier Standard or extended identifier depending on bit XTD. A standard identifier has to be written to ID[28:18].

Table 721. Tx event FIFO element description (continued)

Field	Description
E1 Bits 31:24 MM[7:0]	Message marker Copied from Tx buffer into Tx event FIFO element for identification of Tx message status.
E1 Bits 23:22 EFC	Event type – 00: Reserved – 01: Tx event – 10: Transmission in spite of cancellation (always set for transmissions in DAR mode) – 11: Reserved
E1 Bit 21 EDL	Extended data length – 0: Standard frame format – 1: FDCAN frame format (new DLC-coding and CRC)
E1 Bit 20 BRS	Bit rate switching – 0: Frame transmitted without bit rate switching – 1: Frame transmitted with bit rate switching
T1 Bits 19:16 DLC[3:0]	Data length code 0 - 8: Frame with 0-8 data bytes transmitted 9 - 15: Frame with 8 data bytes transmitted
E1 Bits 15:0 TXTS[15:0]	Tx Timestamp Timestamp counter value captured on start of frame transmission. Resolution depending on configuration of the timestamp counter prescaler TCP[3:0] of FDCAN_TSCC.

65.3.11 FDCAN standard message ID filter element

Up to 28 filter elements can be configured for 11-bit standard IDs. When accessing a standard message ID filter element, its address is the filter list standard start address FLSSA plus the index of the filter element (0 … 27).

Table 722. Standard message ID filter element

Bit	31		24	23	16	15	8	7	0
S0	SFT[1:0]	SFEC[2:0]		SFID1[10:0]		Res.		SFID2[10:0]	

Table 723. Standard message ID filter element field description

Field	Description
Bit 31:30 SFT[1:0](1)	Standard filter type – 00: Range filter from SFID1 to SFID2 – 01: Dual ID filter for SFID1 or SFID2 – 10: Classic filter: SFID1 = filter, SFID2 = mask – 11: Filter element disabled
Bit 29:27 SFEC[2:0]	Standard filter element configuration All enabled filter elements are used for acceptance filtering of standard frames. Acceptance filtering stops at the first matching enabled filter element or when the end of the filter list is reached. If SFEC[2:0] = 100, 101 or 110 a match sets interrupt flag IR.HPM and, if enabled, an interrupt is generated. In this case register HPMS is updated with the status of the priority match. – 000: Disable filter element – 001: Store in Rx FIFO 0 if filter matches – 010: Store in Rx FIFO 1 if filter matches – 011: Reject ID if filter matches – 100: Set priority if filter matches – 101: Set priority and store in FIFO 0 if filter matches – 110: Set priority and store in FIFO 1 if filter matches – 111: Not used
Bits 26:16 SFID1[10:0]	Standard filter ID 1 First ID of standard ID filter element.
Bits 10:0 SFID2[10:0]	Standard filter ID 2 Second ID of standard ID filter element.

1. With SFT[1:0] = 11 the filter element is disabled and the acceptance filtering continues (same behavior as with SFEC[2:0] = 000).

Note: In case a reserved value is configured, the filter element is considered disabled.

65.3.12 FDCAN extended message ID filter element

Up to eight filter elements can be configured for 29-bit extended IDs. When accessing an extended message ID filter element, its address is the filter list extended start address FLESA plus twice the index of the filter element (0 … 7).

Table 724. Extended message ID filter element

Bit	31		24	23 16	15 8	7 0
F0	EFEC[2:0]		EFID1[28:0]			
F1	EFT[1:0]	Res.	EFID2[28:0]			

Table 725. Extended message ID filter element field description

Field	Description
F0 Bits 31:29 EFEC[2:0]	Extended filter element configuration All enabled filter elements are used for acceptance filtering of extended frames. Acceptance filtering stops at the first matching enabled filter element or when the end of the filter list is reached. If EFEC[2:0] = 100, 101 or 110 a match sets interrupt flag IR[HPM] and, if enabled, an interrupt is generated. In this case register HPMS is updated with the status of the priority match. – 000: Disable filter element – 001: Store in Rx FIFO 0 if filter matches – 010: Store in Rx FIFO 1 if filter matches – 011: Reject ID if filter matches – 100: Set priority if filter matches – 101: Set priority and store in FIFO 0 if filter matches – 110: Set priority and store in FIFO 1 if filter matches – 111: Not used
F0 Bits 28:0 EFID1[28:0]	Extended filter ID 1 First ID of extended ID filter element. When filtering for Rx FIFO, this field defines the ID of an extended message to be stored. The received identifiers must match exactly, only XIDAM masking mechanism.
F1 Bits 31:30 EFT[1:0]	Extended filter type – 00: Range filter from EF1ID to EF2ID (EF2ID ≥ EF1ID) – 01: Dual ID filter for EF1ID or EF2ID – 10: Classic filter: EF1ID = filter, EF2ID = mask – 11: Range filter from EF1ID to EF2ID (EF2ID ≥ EF1ID), XIDAM mask not applied
F1 Bit 29	Not used
F1 Bits 28:0 EFID2[28:0]	Extended filter ID 2 Second ID of extended ID filter element.

65.4 FDCAN registers

65.4.1 FDCAN core release register (FDCAN_CREL)

Address offset: 0x0000

Reset value: 0x3214 1218

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REL[3:0]				STEP[3:0]				SUBSTEP[3:0]				YEAR[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MON[7:0]								DAY[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 **REL[3:0]**: 3

Bits 27:24 **STEP[3:0]**: 2

Bits 23:20 **SUBSTEP[3:0]**: 1

Bits 19:16 **YEAR[3:0]**: 4

Bits 15:8 **MON[7:0]**: 12

Bits 7:0 **DAY[7:0]**: 18

65.4.2 FDCAN endian register (FDCAN_ENDN)

Address offset: 0x0004

Reset value: 0x8765 4321

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ETV[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **ETV[31:0]**: Endianness test value
The endianness test value is 0x8765 4321.

Note: The register read must give the reset value to ensure no endianness issue.

65.4.3 FDCAN data bit timing and prescaler register (FDCAN_DBTP)

Address offset: 0x000C

Reset value: 0x0000 0A33

This register is only writable if the CCE and INIT bits of the FDCAN_CCCR are set. The CAN time quantum can be programmed in the range of 1 to 32 FDCAN clock periods:
t_q = (DBRP[4:0] + 1) FDCAN clock periods.

DTSEG1[4:0] is the sum of PROP_SEG and PHASE_SEG1. DTSEG2[3:0] is PHASE_SEG2. Therefore, the length of the bit time is
(programmed values) × [DTSEG1[4:0] + DTSEG2[3:0] + 3] × t_q or
(functional values) × [SYNC_SEG + PROP_SEG + PHASE_SEG1 + PHASE_SEG2] × t_q.

The information processing time (IPT) is 0, meaning the data for the next bit is available at the first clock edge after the sample point.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDC	Res.	Res.	DBRP[4:0]				
								rw			rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DTSEG1[4:0]					DTSEG2[3:0]				DSJW[3:0]			
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **TDC**: Transceiver delay compensation
0: Transceiver delay compensation disabled
1: Transceiver delay compensation enabled

Bits 22:21 Reserved, must be kept at reset value.

Bits 20:16 **DBRP[4:0]**: Data bit rate prescaler
The value by which the oscillator frequency is divided to generate the bit time quanta. The bit time is built up from a multiple of this quantum. Valid values for the baud rate prescaler are 0 to 31. The hardware interpreters this value as the value programmed plus 1.

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **DTSEG1[4:0]**: Data time segment before sample point
Valid values are 0 to 31. The value used by the hardware is the one programmed, incremented by 1, that is t_{BS1} = (DTSEG1[4:0] + 1) × t_q.

Bits 7:4 **DTSEG2[3:0]**: Data time segment after sample point
Valid values are 0 to 15. The value used by the hardware is the one programmed, incremented by 1, i.e. t_{BS2} = (DTSEG2[3:0] + 1) × t_q.

Bits 3:0 **DSJW[3:0]**: Synchronization jump width
Valid values are 0 to 15. The value used by the hardware is the one programmed, incremented by 1: t_{SJW} = (DSJW[3:0] + 1) × t_q.

Note: With an FDCAN clock of 8 MHz, the reset value 0x0000 0A33 configures the FDCAN for a fast bit rate of 500 kbit/s.

The data phase bit rate must be higher than or equal to the nominal bit rate.

65.4.4 FDCAN test register (FDCAN_TEST)

Write access to this register is enabled by setting the TEST bit of the FDCAN_CCCR register. All register functions are set to their reset values when this bit is cleared.

Loop-back mode and software control of Tx pin FDCANx_TX are hardware test modes. Programming TX[1:0] differently from 00 can disturb the message transfer on the CAN bus.

Address offset: 0x0010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RX	TX[1:0]		LBCK	Res.	Res.	Res.	Res.
								r	rw	rw	rw				

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **RX**: Receive pin

This bit is used to monitor the actual value of FDCANx_RX. It is synchronized with the FDCANx_RX pin, so it is set after reset if the FDCAN is connected to a network.

0: The CAN bus is dominant (FDCANx_RX = 0)

1: The CAN bus is recessive (FDCANx_RX = 1)

Bits 6:5 **TX[1:0]**: Control of transmit pin

00: Reset value, FDCANx_TX TX is controlled by the CAN core, updated at the end of the CAN bit time

01: Sample point can be monitored at pin FDCANx_TX

10: Dominant (0) level at pin FDCANx_TX

11: Recessive (1) at pin FDCANx_TX

Bit 4 **LBCK**: Loop-back mode

0: Reset value, loop-back mode is disabled

1: Loop-back mode is enabled (see *Power-down (Sleep mode)*)

Bits 3:0 Reserved, must be kept at reset value.

65.4.5 FDCAN RAM watchdog register (FDCAN_RWD)

The RAM watchdog monitors the READY output of the message RAM. A message RAM access starts the message RAM watchdog counter with the value configured through the WDC[7:0] bitfield of the FDCAN_RWD register.

The counter is reloaded with WDC[7:0] when the message RAM signals successful completion by activating its READY output. In case there is no response from the message RAM until the counter has counted down to 0, the counter stops, and the interrupt flag WDI is set in the FDCAN_IR register. The RAM watchdog counter is clocked by the fdcan_pclk clock.

Address offset: 0x0014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WDV[7:0]								WDC[7:0]							
r	r	r	r	r	r	r	r	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **WDV[7:0]**: Watchdog value
Actual message RAM watchdog counter value.

Bits 7:0 **WDC[7:0]**: Watchdog configuration
Start value of the message RAM watchdog counter. With the reset value of 00, the counter is disabled.
This bitfield is write-protected (P): write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

65.4.6 FDCAN CC control register (FDCAN_CCCR)

Address offset: 0x0018

Reset value: 0x0000 0001

For details about setting and clearing single bits, see *Software initialization*.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NISO	TXP	EFBI	PXHD	Res.	Res.	BRSE	FDOE	TEST	DAR	MON	CSR	CSA	ASM	CCE	INIT
rw	rw	rw	rw			rw	rw	rw	rw	rw	rw	r	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **NISO**: Non-ISO operation
If this bit is set, the FDCAN uses the CAN FD frame format as specified by the Bosch CAN FD Specification V1.0.
0: CAN FD frame format according to ISO11898-1
1: CAN FD frame format according to Bosch CAN FD Specification V1.0

Bit 14 **TXP:** Transmit pause enable
If this bit is set, the FDCAN pauses for two CAN bit times before starting the next transmission after successfully transmitting a frame.
0: Disabled
1: Enabled

Bit 13 **EFBI**: Edge filtering during bus integration
0: Edge filtering disabled
1: Two consecutive dominant t_q required to detect an edge for hard synchronization

Bit 12 **PXHD**: Protocol exception handling disable
0: Protocol exception handling enabled
1: Protocol exception handling disabled

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **BRSE**: FDCAN bit rate switching
0: Bit rate switching for transmissions disabled
1: Bit rate switching for transmissions enabled

Bit 8 **FDOE**: FD operation enable
0: FD operation disabled
1: FD operation enabled

Bit 7 **TEST**: Test mode enable
0: Normal operation, FDCAN_TEST holds reset values
1: Test mode, write access to FDCAN_TEST enabled

Bit 6 **DAR**: Disable automatic retransmission
0: Automatic retransmission of messages not transmitted successfully enabled
1: Automatic retransmission disabled

Bit 5 **MON**: Bus monitoring mode
This bit can only be set by software when both CCE and INIT are set. The bit can be cleared by the host at any time.
0: Bus monitoring mode disabled
1: Bus monitoring mode enabled

Bit 4 **CSR**: Clock stop request
0: No clock stop requested
1: Clock stop requested. When clock stop is requested, first INIT and then CSA is set after all pending transfer requests have been completed and the CAN bus is idle.

Bit 3 **CSA**: Clock stop acknowledge
0: No clock stop acknowledged
1: FDCAN can be set in power-down by stopping APB clock and kernel clock.

Bit 2 **ASM**: ASM restricted operation mode
The restricted operation mode is intended for applications that adapt themselves to different CAN bit rates. The application tests different bit rates and leaves the restricted operation mode after it has received a valid frame. In the optional restricted operation mode the node is able to transmit and receive data and remote frames and it gives acknowledge to valid frames, but it does not send active error frames or over.load frames. In case of an error condition or overload condition, it does not send dominant bits, instead it waits for the occurrence of bus-idle condition to resynchronize itself to the CAN communication. The error counters are not incremented. Bit ASM can only be set by software when both CCE and INIT are set. The bit can be cleared by the software at any time.
0: Normal CAN operation
1: Restricted operation mode active

Bit 1 **CCE**: Configuration change enable
0: The CPU has no write access to the protected configuration registers.
1: The CPU has write access to the protected configuration registers (while INIT set in FDCAN_CCCR).

Bit 0 **INIT**: Initialization
0: Normal operation
1: Initialization started

Note: Due to the synchronization mechanism between the two clock domains, there can be a delay until the value written to INIT can be read back. Therefore, the programmer has to assure that the previous value written to INIT has been accepted by reading INIT before setting INIT to a new value.

65.4.7 FDCAN nominal bit timing and prescaler register (FDCAN_NBTP)

Address offset: 0x001C

Reset value: 0x0600 0A03

This register is only writable if the CCE and INIT bits of the FDCAN_CCCR register are both set. The CAN bit time can be programed in the range of 4 to 81 × t_q. The CAN time quantum can be programmed in the range of 1 to 1024 FDCAN kernel clock periods:
t_q = (BRP + 1) × FDCAN clock period fdcan_ker_ck.

NTSEG1[7:0] is the sum of PROP_SEG and PHASE_SEG1. NTSEG2[6:0] is PHASE_SEG2. Therefore, the length of the bit time is
(programmed values) × [NTSEG1[7:0] + NTSEG2[6:0] + 3] × t_q or
(functional values) × [SYNC_SEG + PROP_SEG + PHASE_SEG1 + PHASE_SEG2] × t_q.

The information processing time (IPT) is 0, meaning the data for the next bit is available at the first clock edge after the sample point.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NSJW[6:0]							NBRP[8:0]								
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NTSEG1[7:0]								Res.	NTSEG2[6:0]						
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:25 **NSJW[6:0]**: Nominal (re)synchronization jump width

Valid values are 0 to 127. The actual interpretation by the hardware of this value is such that the used value is the one programmed incremented by one.

This bitfield is write-protected (P): write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bits 24:16 **NBRP[8:0]**: Bit rate prescaler

Value by which the oscillator frequency is divided for generating the bit time quanta. The bit time is built up from a multiple of this quantum. Valid values are 0 to 511. The actual interpretation by the hardware of this value is such that one more than the value programmed here is used.

This bitfield is write-protected (P): write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bits 15:8 **NTSEG1[7:0]**: Nominal time segment before sample point

Valid values are 0 to 255. The actual interpretation by the hardware of this value is such that one more than the programmed value is used.

This bitfield is write-protected write (P): write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bit 7 Reserved, must be kept at reset value.

Bits 6:0 **NTSEG2[6:0]**: Nominal time segment after sample point

Valid values are 0 to 127. The actual interpretation by the hardware of this value is such that one more than the programmed value is used.

Note: With a CAN kernel clock of 8 MHz, the reset value 0x0600 0A03 configures the FDCAN for a bit rate of 500 kBit/s.

65.4.8 FDCAN timestamp counter configuration register (FDCAN_TSCC)

Address offset: 0x0020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCP[3:0]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSS[1:0]	
														rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:16 **TCP[3:0]**: Timestamp counter prescaler

Configures the timestamp and timeout counters time unit in multiples of CAN bit times [1…16].

The actual interpretation by the hardware of this value is such that one more than the value programmed here is used.

In CAN FD mode, the internal timestamp counter TCP does not provide a constant time base due to the different CAN bit times between arbitration phase and data phase. Thus CAN FD requires an external counter for timestamp generation (TSS[1:0] = 10).

This bitfield is write-protected (P): write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bits 15:2 Reserved, must be kept at reset value.

Bits 1:0 **TSS[1:0]**: Timestamp select

00: Timestamp counter value always 0x0000

01: Timestamp counter value incremented according to TCP

10: External timestamp counter from TIM3 value (tim3_cnt[0:15])

11: Same as 00.

These bits are write-protected write (P): write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

65.4.9 FDCAN timestamp counter value register (FDCAN_TSCV)

Address offset: 0x0024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSC[15:0]															
rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **TSC[15:0]**: Timestamp counter

The internal/external timestamp counter value is captured on start of frame (both Rx and Tx). When TSS[1:0] = 01 in FDCAN_TSCC, the timestamp counter is incremented in multiples of CAN bit times [1 … 16] depending on the configuration of TCP[3:0] in FDCAN_TSCC. A wrap around sets the TSW interrupt flag in FDCAN_IR. Write access resets the counter to 0.
When TSS[1:0] = 10, TSC[15:0] reflects the external timestamp counter value. A write access has no impact.

Note: A "wrap around" is a change of the timestamp counter value from non-0 to 0 that is not caused by write access to FDCAN_TSCV.

65.4.10 FDCAN timeout counter configuration register (FDCAN_TOCC)

Address offset: 0x0028

Reset value: 0xFFFF 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TOP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TOS[1:0]		ETOC
													rw	rw	rw

Bits 31:16 **TOP[15:0]**: Timeout period

Start value of the timeout counter (down-counter). Configures the timeout period.
This bitfield is write-protected (P), write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bits 15:3 Reserved, must be kept at reset value.

Bits 2:1 **TOS[1:0]**: Timeout select

When operating in continuous mode, a write to FDCAN_TOCV presets the counter to the value configured by TOP[15:0] in FDCAN_TOCC and continues down-counting. When the timeout counter is controlled by one of the FIFOs, an empty FIFO presets the counter to the value configured by TOP[15:0]. Down-counting is started when the first FIFO element is stored.
00: Continuous operation
01: Timeout controlled by Tx event FIFO
10: Timeout controlled by Rx FIFO 0
11: Timeout controlled by Rx FIFO 1
This bitfield is write-protected (P), write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bit 0 **ETOC**: Timeout counter enable

0: Timeout counter disabled
1: Timeout counter enabled
This bit is write-protected (P), write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

For more details, see *Timeout counter*.

65.4.11 FDCAN timeout counter value register (FDCAN_TOCV)

Address offset: 0x002C

Reset value: 0x0000 FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TOC[15:0]															
rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **TOC[15:0]**: Timeout counter

The timeout counter is decremented in multiples of CAN bit times [1 … 16] depending on the configuration of the TCP[3:0] bitfield of the FDCAN_TSCC register. When decremented to 0, the TOO interrupt flag is set in FDCAN_IR and the timeout counter is stopped. Start and reset/restart conditions are configured via TOS[1:0] in FDCAN_TOCC.

65.4.12 FDCAN error counter register (FDCAN_ECR)

Address offset: 0x0040

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CEL[7:0]							
								rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RP	REC[6:0]							TEC[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **CEL[7:0]**: CAN error logging

The counter is incremented each time when a CAN protocol error causes the transmit error counter or the receive error counter to be incremented. It is reset by read access to CEL[7:0]. The counter stops at 0xFF; the next increment of TEC[7:0] or REC[6:0] sets the ELO interrupt flag in FDCAN_IR.

Access type is rc_r: cleared on read.

Bit 15 **RP**: Receive error passive

0: The receive error counter is below the error passive level of 128.

1: The receive error counter has reached the error passive level of 128.

Bits 14:8 **REC[6:0]:** Receive error counter

Actual state of the receive error counter, values between 0 and 127.

Bits 7:0 **TEC[7:0]**: Transmit error counter

Actual state of the transmit error counter, values between 0 and 255.

When the ASM bit of the FDCAN_CCCR is set, the CAN protocol controller does not increment TEC and REC when a CAN protocol error is detected, but CEL[7:0] is still incremented.

65.4.13 FDCAN protocol status register (FDCAN_PSR)

Address offset: 0x0044

Reset value: 0x0000 0707

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDCV[6:0]						
									r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	PXE	REDL	RBRS	RESI	DLEC[2:0]			BO	EW	EP	ACT[1:0]		LEC[2:0]		
	rc_r	rc_r	rc_r	rc_r	rs	rs	rs	r	r	r	r	r	rs	rs	rs

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:16 **TDCV[6:0]**: Transmitter delay compensation value

Position of the secondary sample point, defined by the sum of the measured delay from FDCAN_TX to FDCAN_RX and TDCO[6:0] in FDCAN_TDCR. The SSP position is, in the data phase, the number of minimum time quanta (mt_q) between the start of the transmitted bit and the secondary sample point. Valid values are 0 to 127 × mt_q.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **PXE**: Protocol exception event

0: No protocol exception event occurred since last read access

1: Protocol exception event occurred

Bit 13 **REDL**: Received FDCAN message

This bit is set independent of acceptance filtering.

0: Since this bit was cleared by the CPU, no FDCAN message has been received.

1: Message in FDCAN format with EDL flag set has been received.

Access type is rc_r: cleared on read.

Bit 12 **RBRS:** BRS flag of last received FDCAN message

This bit is set together with REDL, independent of acceptance filtering.

0: Last received FDCAN message did not have its BRS flag set.

1: Last received FDCAN message had its BRS flag set.

Access type is rc_r: cleared on read.

Bit 11 **RESI**: ESI flag of last received FDCAN message

This bit is set together with REDL, independent of acceptance filtering.

0: Last received FDCAN message did not have its ESI flag set.

1: Last received FDCAN message had its ESI flag set.

Access type is rc_r: cleared on read.

Bits 10:8 **DLEC[2:0]**: Data last error code

Type of last error that occurred in the data phase of a FDCAN format frame with its BRS flag set. Coding is the same as for LEC[2:0]. This field is cleared when a FDCAN format frame with its BRS flag set has been transferred (reception or transmission) without error.

Access type is rs: set on read.

Bit 7 **BO**: Bus-off status

0: The FDCAN is not in bus-off state.

1: The FDCAN is in bus-off state.

Bit 6 **EW**: Warning status

0: Both error counters are below the error-warning limit of 96.

1: At least one of error counter has reached the error-warning limit of 96.

Bit 5 **EP**: Error passive

0: The FDCAN is in the error-active state. It normally takes part in bus communication and sends an active error flag when an error has been detected.

1: The FDCAN is in the error-passive state.

Bits 4:3 **ACT[1:0]**: Activity

Monitors the module's CAN communication state.

00: Synchronizing: node is synchronizing on CAN communication.

01: Idle: node is neither receiver nor transmitter.

10: Receiver: node is operating as receiver.

11: Transmitter: node is operating as transmitter.

Bits 2:0 **LEC[2:0]:** Last error code

LEC[2:0] indicates the type of the last error to occur on the CAN bus. This bitfield is cleared when a message has been transferred (reception or transmission) without error.

000: No error occurred since LEC[2:0] has been cleared by successful reception or transmission.

001: Stuff error. More than five equal bits in a sequence have occurred in a part of a received message where this is not allowed.

010: Form error. A fixed format part of a received frame has the wrong format.

011: Ack error. The message transmitted by the FDCAN was not acknowledged by another node.

100: Bit1 error. During the transmission of a message (with the exception of the arbitration field), the device wanted to send a recessive level (bit of logical value 1), but the monitored bus value was dominant.

101: Bit0 error. During the transmission of a message (or acknowledge bit, or active error flag, or overload flag), the device wanted to send a dominant level (data or identifier bit logical value 0), but the monitored bus value was recessive. During bus-off recovery this status is set each time a sequence of 11 recessive bits has been monitored. This enables the CPU to monitor the proceeding of the bus-off recovery sequence (indicating the bus is not stuck at dominant or continuously disturbed).

110: CRC error. The CRC check sum of a received message was incorrect. The CRC of an incoming message does not match with the CRC calculated from the received data.

111: No change. Any read access to the protocol status register reinitializes LEC[2:0] to 7. When the LEC[2:0] shows the value 7, no CAN bus event was detected since the last CPU read access to the protocol status register.

Access type is rs: set on read.

Note: When a frame in FDCAN format has reached the data phase with the BRS flag set, the next CAN event (error or valid frame) is shown in DLEC[2:0] instead of LEC[2:0]. An error in a fixed stuff bit of an FDCAN CRC sequence is shown as a form error, not as a stuff error.

The bus-off recovery sequence (see CAN Specification Rev. 2.0 or ISO11898-1) cannot be shortened by setting or clearing the INIT bit of the FDCAN_CCCR register. If the device enters bus-off, it sets the INIT bit of its own, stopping all bus activities. Once INIT has been cleared by the CPU, the device waits for 129 occurrences of bus-idle (129 × 11 consecutive recessive bits) before resuming normal operation. At the end of the bus-off recovery sequence, the error management counters are reset. During the waiting time after clearing INIT, each time a sequence of 11 recessive bits has been monitored, a bit0 error code is written to LEC[2:0] of FDCAN_PSR, enabling the CPU to check up whether the CAN bus is

stuck at dominant or continuously disturbed, and to monitor the bus-off recovery sequence. The REC[6:0] bitfield of the FDCAN_ECR register is used to count these sequences.

65.4.14 FDCAN transmitter delay compensation register (FDCAN_TDCR)

Address offset: 0x0048

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TDCO[6:0]							Res.	TDCF[6:0]						
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:15 Reserved, must be kept at reset value.

Bits 14:8 **TDCO[6:0]**: Transmitter delay compensation offset

Offset value defining the distance between the measured delay from FDCAN_TX to FDCAN_RX and the secondary sample point. Valid values are 0 to 127 × mt_q.

This bitfield is write-protected (P), which means that write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bit 7 Reserved, must be kept at reset value.

Bits 6:0 **TDCF[6:0]**: Transmitter delay compensation filter window length

Defines the minimum value for the SSP position, dominant edges on FDCAN_RX that would result in an earlier SSP position are ignored for transmitter delay measurements.

This bitfield is write-protected (P), which means that write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

65.4.15 FDCAN interrupt register (FDCAN_IR)

The flags are set when one of the listed conditions is detected (edge-sensitive). The flags remain set until the host clears them. A flag is cleared by writing 1 to the corresponding bit position.

Writing 0 has no effect. A hard reset clears the register. The configuration of FDCAN_IE controls whether an interrupt is generated. The configuration of FDCAN_ILS controls on which interrupt line an interrupt is signaled.

Address offset: 0x0050

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARA	PED	PEA	WDI	BO	EW	EP	ELO
								rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TOO	MRAF	TSW	TEFL	TEFF	TEFN	TFE	TCF	TC	HPM	RF1L	RF1F	RF1N	RF0L	RF0F	RF0N
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **ARA**: Access to reserved address
0: No access to reserved address occurred
1: Access to reserved address occurred

Bit 22 **PED**: Protocol error in data phase (data bit time is used)
0: No protocol error in data phase
1: Protocol error in data phase detected (DLEC[2:0] different from 0 and 7 in FDCAN_PSR)

Bit 21 **PEA**: Protocol error in arbitration phase (nominal bit time is used)
0: No protocol error in arbitration phase
1: Protocol error in arbitration phase detected (LEC[2:0] different from 0 and 7 in FDCAN_PSR)

Bit 20 **WDI**: Watchdog interrupt
0: No message RAM watchdog event occurred
1: Message RAM watchdog event due to missing READY

Bit 19 **BO**: Bus-off status
0: Bus-off status unchanged
1: Bus-off status changed

Bit 18 **EW**: Warning status
0: Error-warning status unchanged
1: Error-warning status changed

Bit 17 **EP**: Error passive
0: Error-passive status unchanged
1: Error-passive status changed

Bit 16 **ELO**: Error logging overflow
0: CAN error logging counter did not overflow.
1: Overflow of CAN error logging counter occurred.

Bit 15 **TOO**: Timeout occurred
0: No timeout
1: Timeout reached

Bit 14 **MRAF**: Message RAM access failure
The flag is set when the Rx handler:
- has not completed acceptance filtering or storage of an accepted message until the arbitration field of the following message has been received. In this case acceptance filtering or message storage is aborted and the Rx handler starts processing of the following message.
- was unable to write a message to the message RAM. In this case message storage is aborted.

In both cases the FIFO put index is not updated. The partly stored message is overwritten when the next message is stored to this location.
The flag is also set when the Tx handler was not able to read a message from the message RAM in time. In this case message transmission is aborted. In case of a Tx handler access failure, the FDCAN is switched into restricted operation mode (see *Restricted operation mode*). To leave restricted operation mode, the host CPU has to clear the ASM of the FDCAN_CCCR register.
0: No message RAM access failure occurred
1: Message RAM access failure occurred

Bit 13 **TSW**: Timestamp wraparound
0: No timestamp counter wrap-around
1: Timestamp counter wrapped around

Bit 12 **TEFL**: Tx event FIFO element lost
0: No Tx event FIFO element lost
1: Tx event FIFO element lost

Bit 11 **TEFF**: Tx event FIFO full
0: Tx event FIFO Not full
1: Tx event FIFO full

Bit 10 **TEFN**: Tx event FIFO new entry
0: Tx event FIFO unchanged
1: Tx handler wrote Tx event FIFO element.

Bit 9 **TFE**: Tx FIFO empty
0: Tx FIFO non-empty
1: Tx FIFO empty

Bit 8 **TCF**: Transmission cancellation finished
0: No transmission cancellation finished
1: Transmission cancellation finished

Bit 7 **TC**: Transmission completed
0: No transmission completed
1: Transmission completed

Bit 6 **HPM**: High-priority message
0: No high-priority message received
1: High-priority message received

Bit 5 **RF1L**: Rx FIFO 1 message lost
0: No Rx FIFO 1 message lost
1: Rx FIFO 1 message lost

Bit 4 **RF1F**: Rx FIFO 1 full
0: Rx FIFO 1 not full
1: Rx FIFO 1 full

Bit 3 **RF1N**: Rx FIFO 1 new message
0: No new message written to Rx FIFO 1
1: New message written to Rx FIFO 1

Bit 2 **RF0L**: Rx FIFO 0 message lost
0: No Rx FIFO 0 message lost
1: Rx FIFO 0 message lost

Bit 1 **RF0F**: Rx FIFO 0 full
0: Rx FIFO 0 not full
1: Rx FIFO 0 full

Bit 0 **RF0N**: Rx FIFO 0 new message
0: No new message written to Rx FIFO 0
1: New message written to Rx FIFO 0

65.4.16 FDCAN interrupt enable register (FDCAN_IE)

The settings in the interrupt enable register determine which status changes in the interrupt register are signaled on an interrupt line.

Address offset: 0x0054

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARAE	PEDE	PEAE	WDIE	BOE	EWE	EPE	ELOE
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TOOE	MRAFE	TSWE	TEFLE	TEFFE	TEFNE	TFEE	TCFE	TCE	HPME	RF1LE	RF1FE	RF1NE	RF0LE	RF0FE	RF0NE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **ARAE**: Access to reserved address enable

Bit 22 **PEDE**: Protocol error in data phase enable

Bit 21 **PEAE**: Protocol error in arbitration phase enable

Bit 20 **WDIE**: Watchdog interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 19 **BOE**: Bus-off status
0: Interrupt disabled
1: Interrupt enabled

Bit 18 **EWE**: Warning status interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 17 **EPE**: Error passive interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 16 **ELOE**: Error logging overflow interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 15 **TOOE**: Timeout occurred interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 14 **MRAFE:** Message RAM access failure interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 13 **TSWE**: Timestamp wraparound interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 12 **TEFLE**: Tx event FIFO element lost interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 11 **TEFFE**: Tx event FIFO full interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 10 **TEFNE**: Tx event FIFO new entry interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 9 **TFEE**: Tx FIFO empty interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 8 **TCFE**: Transmission cancellation finished interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 7 **TCE**: Transmission completed interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 6 **HPME**: High-priority message interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 5 **RF1LE**: Rx FIFO 1 message lost interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 4 **RF1FE**: Rx FIFO 1 full interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 3 **RF1NE**: Rx FIFO 1 new message interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 2 **RF0LE**: Rx FIFO 0 message lost interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 1 **RF0FE**: Rx FIFO 0 full interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 0 **RF0NE**: Rx FIFO 0 new message interrupt enable
0: Interrupt disabled
1: Interrupt enabled

65.4.17 FDCAN interrupt line select register (FDCAN_ILS)

This register assigns an interrupt generated by a specific group of interrupt flags from the interrupt register to one of the two module interrupt lines. For interrupt generation, the respective interrupt line must be enabled via the EINT0 and EINT1 bit of the FDCAN_ILE register. 0 indicates that the interrupt is assigned to interrupt line fdcan1_intr0_it, 1 indicates that the interrupt is assigned to interrupt line fdcan1_intr1_it.

Address offset: 0x0058

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PERR	BERR	MISC	TFERR	SMSG	RXFIFO1	RXFIFO0
									rw	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **PERR:** Protocol error grouping the following interruption
- ARAL: Access to reserved address line
- PEDL: Protocol error in data phase line
- PEAL: Protocol error in arbitration phase line
- WDIL: Watchdog interrupt line
- BOL: Bus-off status
- EWL: Warning status interrupt line

Bit 5 **BERR:** Bit and line error grouping the following interruption
- EPL Error passive interrupt line
- ELOL: Error logging overflow interrupt line

Bit 4 **MISC:** Interrupt regrouping the following interruption
- TOOL: Timeout occurred interrupt line
- MRAFL: Message RAM access failure interrupt line
- TSWL: Timestamp wraparound interrupt line

Bit 3 **TFERR:** Tx FIFO ERROR grouping the following interruption
- TEFLL: Tx event FIFO element lost interrupt line
- TEFFL: Tx event FIFO full interrupt line
- TEFNL: Tx event FIFO new entry interrupt line
- TFEL: Tx FIFO empty interrupt line

Bit 2 **SMSG:** Status message bit grouping the following interruption
- TCFL: Transmission cancellation finished interrupt line
- TCL: Transmission completed interrupt line
- HPML: High-priority message interrupt line

Bit 1 **RXFIFO1:** RX FIFO bit grouping the following interruption
- RF1LL: Rx FIFO 1 message lost interrupt line
- RF1FL: Rx FIFO 1 full interrupt line
- RF1NL: Rx FIFO 1 new message interrupt line

Bit 0 **RXFIFO0:** RX FIFO bit grouping the following interruption
RF0LL: Rx FIFO 0 message lost interrupt line
RF0FL: Rx FIFO 0 full interrupt line
RF0NL: Rx FIFO 0 new message interrupt line

65.4.18 FDCAN interrupt line enable register (FDCAN_ILE)

Each of the two interrupt lines to the CPU can be enabled/disabled separately by programming the EINT0 and EINT1 bits.

Address offset: 0x005C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EINT1	EINT0
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **EINT1**: Enable interrupt line 1
0: Interrupt line fdcan_intr0_it disabled
1: Interrupt line fdcan_intr0_it enabled

Bit 0 **EINT0**: Enable interrupt line 0
0: Interrupt line fdcan_intr1_it disabled
1: Interrupt line fdcan_intr1_it enabled

65.4.19 FDCAN global filter configuration register (FDCAN_RXGFC)

Global settings for message ID filtering. The global filter configuration controls the filter path for standard and extended messages as described in *Figure 927* and *Figure 928*.

Address offset: 0x0080

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	LSE[3:0]				Res.	Res.	Res.	LSS[4:0]				
				rw	rw	rw	rw				rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	F0OM	F1OM	Res.	Res.	ANFS[1:0]		ANFE[1:0]		RRFS	RRFE
						rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **LSE[3:0]**: Number of extended filter elements in the list
0: No extended message ID filter
1 to 8: Number of extended message ID filter elements
> 8: Values greater than 8 are interpreted as 8.
This bitfield is write-protected (P), which means that write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bits 23:21 Reserved, must be kept at reset value.

Bits 20:16 **LSS[4:0]**: Number of standard filter elements in the list
0: No standard message ID filter
1 to 28: Number of standard message ID filter elements
> 28: Values greater than 28 are interpreted as 28.
This bitfield is write protected (P), which means that write access by the bits is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **F0OM**: FIFO 0 operation mode (overwrite or blocking)
This bit is write-protected (P), which means that write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bit 8 **F1OM**: FIFO 1 operation mode (overwrite or blocking)
This bit is write-protected (P), which means that write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **ANFS[1:0]**: Accept Non-matching frames standard
Defines how received messages with 11-bit IDs that do not match any element of the filter list are treated.
00: Accept in Rx FIFO 0
01: Accept in Rx FIFO 1
10: Reject
11: Reject
This bitfield is write-protected (P), which means write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bits 3:2 **ANFE[1:0]**: Accept non-matching frames extended
Defines how received messages with 29-bit IDs that do not match any element of the filter list are treated.
00: Accept in Rx FIFO 0
01: Accept in Rx FIFO 1
10: Reject
11: Reject
This bitfield is write-protected (P), which means that write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bit 1 **RRFS**: Reject remote frames standard
0: Filter remote frames with 11-bit standard IDs
1: Reject all remote frames with 11-bit standard IDs
This bit is write-protected (P), which means that write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bit 0 **RRFE**: Reject remote frames extended
0: Filter remote frames with 29-bit standard IDs
1: Reject all remote frames with 29-bit standard IDs
This bit is write-protected (P), which means that write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

65.4.20 FDCAN extended ID and mask register (FDCAN_XIDAM)

Address offset: 0x0084

Reset value: 0x1FFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	EIDM[28:16]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EIDM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:0 **EIDM[28:0]**: Extended ID mask
For acceptance filtering of extended frames the extended ID AND mask is AND-ed with the message ID of a received frame. Intended for masking of 29-bit IDs in SAE J1939. With the reset value of all bits set, the mask is not active.
This bitfield is write-protected (P), which means that write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

65.4.21 FDCAN high-priority message status register (FDCAN_HPMS)

This register is updated every time a message ID filter element configured to generate a priority event match. This can be used to monitor the status of incoming high priority messages and to enable fast access to these messages.

Address offset: 0x0088

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLST	Res.	Res.	FIDX[4:0]					MSI[1:0]		Res.	Res.	Res.	BIDX[2:0]		
r			r	r	r	r	r	r	r				r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **FLST**: Filter list
Indicates the filter list of the matching filter element:
0: Standard filter list
1: Extended filter list

Bits 14:13 Reserved, must be kept at reset value.

Bits 12:8 **FIDX[4:0]**: Filter index
Index of matching filter element.
Range: 0 to LSS[4:0] - 1 or LSE[3:0] - 1 in FDCAN_RXGFC.

Bits 7:6 **MSI[1:0]**: Message storage indicator
00: No FIFO selected
01: FIFO overrun
10: Message stored in FIFO 0
11: Message stored in FIFO 1

Bits 5:3 Reserved, must be kept at reset value.

Bits 2:0 **BIDX[2:0]**: Buffer index
Index of Rx FIFO element to which the message was stored. Only valid when MSI[1] = 1.

65.4.22 FDCAN Rx FIFO 0 status register (FDCAN_RXF0S)

Address offset: 0x0090

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	RF0L	F0F	Res.	Res.	Res.	Res.	Res.	Res.	F0PI[1:0]	
						r	r							r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	F0GI[1:0]		Res.	Res.	Res.	Res.	F0FL[3:0]			
						r	r					r	r	r	r

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **RF0L**: Rx FIFO 0 message lost
This bit is a copy of the RF0L interrupt flag of the FDCAN_IR register. When RF0L is cleared, this bit is also cleared.
0: No Rx FIFO 0 message lost
1: Rx FIFO 0 message lost, also set after write attempt to Rx FIFO 0 of size 0

Bit 24 **F0F**: Rx FIFO 0 full
0: Rx FIFO 0 not full
1: Rx FIFO 0 full

Bits 23:18 Reserved, must be kept at reset value.

Bits 17:16 **F0PI[1:0]**: Rx FIFO 0 put index
Rx FIFO 0 write index pointer.
Range: 0 to 2.

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **F0GI[1:0]**: Rx FIFO 0 get index
Rx FIFO 0 read index pointer.
Range: 0 to 2.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **F0FL[3:0]**: Rx FIFO 0 fill level
Number of elements stored in Rx FIFO 0.
Range: 0 to 3.

65.4.23 CAN Rx FIFO 0 acknowledge register (FDCAN_RXF0A)

Address offset: 0x0094

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	F0AI[2:0]		
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **F0AI[2:0]**: Rx FIFO 0 acknowledge index

After the host has read a message or a sequence of messages from Rx FIFO 0, it has to write the buffer index of the last element read from Rx FIFO 0 to F0AI[2:0]. This sets the Rx FIFO 0 get index (F0GI[1:0] of FDCAN_RXF0S) to F0AI[2:0] + 1 and updates the FIFO 0 fill level (F0FL[3:0] FDCAN_RXF0S).

65.4.24 FDCAN Rx FIFO 1 status register (FDCAN_RXF1S)

Address offset: 0x0098

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	RF1L	F1F	Res.	Res.	Res.	Res.	Res.	Res.	F1PI[1:0]	
						r	r							r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	F1GI[1:0]		Res.	Res.	Res.	Res.	F1FL[3:0]			
						r	r					r	r	r	r

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **RF1L**: Rx FIFO 1 message lost

This bit is a copy of the RF1L interrupt flag of the FDCAN_IR register. When RF1L is cleared, this bit is also cleared.

0: No Rx FIFO 1 message lost

1: Rx FIFO 1 message lost, also set after write attempt to Rx FIFO 1 of size 0

Bit 24 **F1F**: Rx FIFO 1 full

0: Rx FIFO 1 not full

1: Rx FIFO 1 full

Bits 23:18 Reserved, must be kept at reset value.

Bits 17:16 **F1PI[1:0]**: Rx FIFO 1 put index

Rx FIFO 1 write index pointer.

Range: 0 to 2.

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **F1GI[1:0]**: Rx FIFO 1 get index
Rx FIFO 1 read index pointer.
Range: 0 to 2.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **F1FL[3:0]**: Rx FIFO 1 fill level
Number of elements stored in Rx FIFO 1.
Range: 0 to 3.

65.4.25 FDCAN Rx FIFO 1 acknowledge register (FDCAN_RXF1A)

Address offset: 0x009C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	F1AI[2:0]		
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **F1AI[2:0]**: Rx FIFO 1 acknowledge index
After the host has read a message or a sequence of messages from Rx FIFO 1, it has to write the buffer index of the last element read from Rx FIFO 1 to F1AI[2:0]. This sets the Rx FIFO 1 get index (F1GI[1:0] of FDCAN_RXF1S) to F1AI[2:0] + 1 and updates the FIFO 1 fill level (F1FL[3:0] FDCAN_RXF1S).

65.4.26 FDCAN Tx buffer configuration register (FDCAN_TXBC)

Address offset: 0x00C0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	TFQM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
							rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **TFQM**: Tx FIFO/queue mode
0: Tx FIFO operation
1: Tx queue operation.
This bit is write-protected (P), which means that write access is possible only when the CCE and INIT bits of the FDCAN_CCCR register are both set.

Bits 23:0 Reserved, must be kept at reset value.

65.4.27 FDCAN Tx FIFO/queue status register (FDCAN_TXFQS)

The Tx FIFO/queue status is related to the pending Tx requests listed in the FDCAN_TXBRP register. Therefore, the effect of add/cancellation requests can be delayed due to a running Tx scan (FDCAN_TXBRP not yet updated).

Address offset: 0x00C4

Reset value: 0x0000 0003

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TFQF	Res.	Res.	Res.	TFQPI[1:0]	
										r				r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	TFGI[1:0]		Res.	Res.	Res.	Res.	Res.	TFFL[2:0]		
						r	r						r	r	r

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **TFQF**: Tx FIFO/queue full
0: Tx FIFO/queue not full
1: Tx FIFO/queue full

Bits 20:18 Reserved, must be kept at reset value.

Bits 17:16 **TFQPI[1:0]**: Tx FIFO/queue put index
Tx FIFO/queue write index pointer, range 0 to 3

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **TFGI[1:0]**: Tx FIFO get index
Tx FIFO read index pointer, range 0 to 3. Read as 0 when Tx queue operation is configured (TFQM = 1 in FDCAN_TXBC)

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **TFFL[2:0]**: Tx FIFO free level
Number of consecutive free Tx FIFO elements starting from TFGI, range 0 to 3. Read as 0 when Tx queue operation is configured (TFQM = 1 in FDCAN_TXBC).

65.4.28 FDCAN Tx buffer request pending register (FDCAN_TXBRP)

Address offset: 0x00C8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRP[2:0]		
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **TRP[2:0]**: Transmission request pending

Each Tx buffer has its own transmission request pending bit. The bits are set via the FDCAN_TXBAR register. The bits are cleared after a requested transmission has completed or has been canceled via the FDCAN_TXBCR register.

After the FDCAN_TXBRP bit has been set, a Tx scan is started to check for the pending Tx request with the highest priority (Tx buffer with lowest message ID).

A cancellation request resets the corresponding transmission request pending bit of the FDCAN_TXBRP register. In case a transmission has already been started when a cancellation is requested, this is done at the end of the transmission, regardless whether the transmission was successful or not. The cancellation request bits are directly cleared after the corresponding FDCAN_TXBRP bit has been cleared.

After a cancellation has been requested, a finished cancellation is signaled via the FDCAN_TXBCF in the following cases:

- after successful transmission together with the corresponding TXBTO bit
- when the transmission has not yet been started at the point of cancellation
- when the transmission has been aborted due to lost arbitration
- when an error occurred during frame transmission

In DAR mode, all transmissions are automatically canceled if they are not successful. The corresponding FDCAN_TXBCF bit is set for all unsuccessful transmissions.

0: No transmission request pending

1: Transmission request pending

Note: FDCAN_TXBRP bits set while a Tx scan is in progress are not considered during this particular Tx scan. In case a cancellation is requested for such a Tx buffer, this add request is canceled immediately. The corresponding FDCAN_TXBRP bit is cleared.

65.4.29 FDCAN Tx buffer add request register (FDCAN_TXBAR)

Address offset: 0x00CC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AR[2:0]		
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **AR[2:0]**: Add request

Each Tx buffer has its own add request bit. Writing a 1 sets the corresponding add request bit; writing a 0 has no impact. This enables the host to set transmission requests for multiple Tx buffers with one write to FDCAN_TXBAR. When no Tx scan is running, the bits are cleared immediately, else the bits remain set until the Tx scan process has completed.

0: No transmission request added

1: Transmission requested added.

Note: If an add request is applied for a Tx buffer with pending transmission request (corresponding FDCAN_TXBRP bit already set), the request is ignored.

65.4.30 FDCAN Tx buffer cancellation request register (FDCAN_TXBCR)

Address offset: 0x00D0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CR[2:0]		
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **CR[2:0]**: Cancellation request

Each Tx buffer has its own cancellation request bit. Writing a 1 sets the corresponding CR bit; writing a 0 has no impact.

This enables the host to set cancellation requests for multiple Tx buffers with one write to FDCAN_TXBCR. The bits remain set until the corresponding FDCAN_TXBRP bit is cleared.

0: No cancellation pending

1: Cancellation pending

65.4.31 FDCAN Tx buffer transmission occurred register (FDCAN_TXBTO)

Address offset: 0x00D4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TO[2:0]		
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **TO[2:0]**: Transmission occurred.

Each Tx buffer has its own TO bit. The bits are set when the corresponding FDCAN_TXBRP bit is cleared after a successful transmission. The bits are cleared when a new transmission is requested by writing a 1 to the corresponding bit of register FDCAN_TXBAR.

0: No transmission occurred

1: Transmission occurred

65.4.32 FDCAN Tx buffer cancellation finished register (FDCAN_TXBCF)

Address offset: 0x00D8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CF[2:0]		
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **CF[2:0]**: Cancellation finished

Each Tx buffer has its own CF bit. The bits are set when the corresponding FDCAN_TXBRP bit is cleared after a cancellation was requested via FDCAN_TXBCR. In case the corresponding FDCAN_TXBRP bit was not set at the point of cancellation, CF is set immediately. The bits are cleared when a new transmission is requested by writing a 1 to the corresponding bit of the FDCAN_TXBAR register.

0: No transmit buffer cancellation

1: Transmit buffer cancellation finished

65.4.33 FDCAN Tx buffer transmission interrupt enable register (FDCAN_TXBTIE)

Address offset: 0x00DC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIE[2:0]		
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **TIE[2:0]**: Transmission interrupt enable

Each Tx buffer has its own TIE bit.

0: Transmission interrupt disabled

1: Transmission interrupt enable

65.4.34 FDCAN Tx buffer cancellation finished interrupt enable register (FDCAN_TXBCIE)

Address offset: 0x00E0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CFIE[2:0]		
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **CFIE[2:0]**: Cancellation finished interrupt enable.
Each Tx buffer has its own CFIE bit.
0: Cancellation finished interrupt disabled
1: Cancellation finished interrupt enabled

65.4.35 FDCAN Tx event FIFO status register (FDCAN_TXEFS)

Address offset: 0x00E4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	TEFL	EFF	Res.	Res.	Res.	Res.	Res.	Res.	EFPI[1:0]	
						r	r							r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	EFGI[1:0]		Res.	Res.	Res.	Res.	Res.	EFFL[2:0]		
						r	r						r	r	r

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **TEFL**: Tx event FIFO element lost
This bit is a copy of the TEFL interrupt flag of the FDCAN_IR. When TEFL is cleared, this bit is also cleared.
0 No Tx event FIFO element lost
1 Tx event FIFO element lost, also set after write attempt to Tx event FIFO of size 0.

Bit 24 **EFF**: Event FIFO full
0: Tx event FIFO not full
1: Tx event FIFO full

Bits 23:18 Reserved, must be kept at reset value.

Bits 17:16 **EFPI[1:0]**: Event FIFO put index
Tx event FIFO write index pointer.
Range: 0 to 3.

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **EFGI[1:0]**: Event FIFO get index
Tx event FIFO read index pointer.
Range: 0 to 3.

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **EFFL[2:0]**: Event FIFO fill level
Number of elements stored in Tx event FIFO.
Range: 0 to 3.

65.4.36 FDCAN Tx event FIFO acknowledge register (FDCAN_TXEFA)

Address offset: 0x00E8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EFAI[1:0]	
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bits 1:0 **EFAI[1:0]**: Event FIFO acknowledge index
After the host has read an element or a sequence of elements from the Tx event FIFO, it has to write the index of the last element read from Tx event FIFO to EFAI[1:0]. This sets the Tx event FIFO get index (EFGI[1:0] of FDCAN_TXEFS) to EFAI[1:0] + 1 and updates the FIFO 0 fill level (EFFL[2:0] of FDCAN_TXEFS).

65.4.37 FDCAN CFG clock divider register (FDCAN_CKDIV)

Address offset: 0x0100

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PDIV[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **PDIV[3:0]**: input clock divider

The CAN kernel clock can be divided prior to be used by the CAN subsystem. The rate must be computed using the divider output clock.

0000: Divide by 1
0001: Divide by 2
0010: Divide by 4
0011: Divide by 6
0100: Divide by 8
0101: Divide by 10
0110: Divide by 12
0111: Divide by 14
1000: Divide by 16
1001: Divide by 18
1010: Divide by 20
1011: Divide by 22
1100: Divide by 24
1101: Divide by 26
1110: Divide by 28
1111: Divide by 30

This bitfield is write-protected (P): which means that write access is possible only when the CCE bit of the FDCAN_CCCR register is set.

Note: The clock divider is common to all FDCAN instances. Only FDCAN1 instance has FDCAN_CKDIV register, which changes clock divider for all instances.

If several FDCAN instances are present, the input clock divider must be modified before configuring the other FDCAN instances.

65.4.38 FDCAN register map

Table 726. FDCAN register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0000	FDCAN_CREL	REL[3:0]				STEP[3:0]				SUBSTEP [3:0]				YEAR[3:0]				MON[7:0]								DAY[7:0]							
	Reset value	0	0	0	0	0	0	0	1	1	1	1	0	1	0	1	0	0	1	1	0	1	1	1	1	1	0	1	0	0	0	1	0
0x0004	FDCAN_ENDN	ETV[31:0]																															
	Reset value	1	0	0	0	0	1	1	1	0	1	1	0	0	1	0	1	0	1	0	0	0	0	1	1	0	0	1	0	0	0	0	1
0x0008	Reserved	Reserved																															
0x000C	FDCAN_DBTP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDC	Res.	Res.	DBRP[4:0]					Res.	Res.	Res.	DTSEG1[4:0]					DTSEG2[3:0]				DSJW[3:0]			
	Reset value									0	0	0	0	0	0	0	0				0	1	0	1	0	0	0	1	1	0	0	1	1
0x0010	FDCAN_TEST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RX	TX[1:0]		LBCK	Res.	Res.	Res.	Res.
	Reset value																									0	0	0	0				

Table 726. FDCAN register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0014	FDCAN_RWD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDV[7:0]								WDC[7:0]							
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0018	FDCAN_CCCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NISO	TXP	EFBI	PXHD	Res.	Res.	BRSE	FDOE	TEST	DAR	MON	CSR	CSA	ASM	CCE	INT
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x001C	FDCAN_NBTP	NSJW[6:0]							NBRP[8:0]									NTSEG1[7:0]								Res.	NTSEG2[6:0]						
	Reset value	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	1
0x0020	FDCAN_TSCC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCP[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSS[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0024	FDCAN_TSCV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSC[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0028	FDCAN_TOCC	TOP[15:0]																Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TOS[1:0]		ETOC
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x002C	FDCAN_TOCV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TOC[15:0]															
	Reset value																	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0030-0x003C	Reserved	Reserved																															
0x0040	FDCAN_ECR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CEL[7:0]								RP	REC[6:0]							TEC[7:0]							
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0044	FDCAN_PSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDCV[6:0]							Res.	PXE	REDL	RBRSRESI1	RESI	DLEC[2:0]			BO	EW	EP	ACT[1:0]		LEC[2:0]		
	Reset value									0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
0x0048	FDCAN_TDCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDCO[6:0]							Res.	TDCF[6:0]						
	Reset value																		0	0	0	0	0	0		0	0	0	0	0	0	0	0
0x004C	Reserved	Reserved																															
0x0050	FDCAN_IR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARA	PED	PEA	WDI	BO	EW	EP	ELO	TOO	MRAF	TSW	TEFL	TEFF	TEFN	TFE	TCF	TC	HPM	RF1L	RF1F	RF1N	RF0L	RF0F	RF0N
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0054	FDCAN_IE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARAE	PEDE	PEAE	WDIE	BOE	EWE	EPE	ELOE	TOOE	MRAFE	TSWE	TEFLE	TEFFE	TEFNE	TFEE	TCFE	TCE	HPME	RF1LE	RF1FE	RF1NE	RF0LE	RF0FE	RF0NE
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 726. FDCAN register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0058	FDCAN_ILS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PERR	BERR	MISC	TFERR	SMSG	RXFIFO1	RXFIFO0
	Reset value	0																									0	0	0	0	0	0	0
0x005C	FDCAN_ILE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EINT1	EINT0
	Reset value																															0	0
0x0060-0x007C	Reserved	Reserved																															
0x0080	FDCAN_RXGFC	Res.	Res.	Res.	Res.	LSE[3:0].				Res.	Res.	Res.	LSS[4:0]					Res.	Res.	Res.	Res.	Res.	Res.	F0OM	F1OM	Res.	Res.	ANFS[1:0]		ANFE[1:0]		RRFS	RRFE
	Reset value					0	0	0	0				0	0	0	0	0							0	0			0	0	0	0	0	0
0x0084	FDCAN_XIDAM	Res.	Res.	Res.	EIDM[28:0]																												
	Reset value				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0088	FDCAN_HPMS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLST	Res.	Res.	FIDX[4:0]						MSI[1:0]		Res.	Res.	Res.	BIDX[2:0]		
	Reset value																	0			0	0	0	0	0	0	0	0				0	0	0
0x0090	FDCAN_RXF0S	Res.	Res.	Res.	Res.	Res.	Res.	RF0L	F0F	Res.	Res.	Res.	Res.	Res.	Res.	F0PI[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	F0GI[1:0]		Res.	Res.	Res.	Res.	Res.	F0FL[3:0]		
	Reset value							0	0							0	0							0	0						0	0	0	0
0x0094	FDCAN_RXF0A	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	F0AI[2:0]		
	Reset value																														0	0	0
0x0098	FDCAN_RXF1S	Res.	Res.	Res.	Res.	Res.	Res.	RF1L	F1F	Res.	Res.	Res.	Res.	Res.	Res.	F1PI[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	F1GI[1:0]		Res.	Res.	Res.	Res.	Res.	F1FL[3:0]		
	Reset value							0	0							0	0							0	0						0	0	0	0
0x009C	FDCAN_RXF1A	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	F1AI[2:0]		
	Reset value																														0	0	0
0x00A0-0x00BC	Reserved	Reserved																															
0x00C0	FDCAN_TXBC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TFQM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value								0	0																							
0x00C4	FDCAN_TXFQS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TFQF	Res.	Res.	Res.	TFQPI[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	TFGI[1:0]		Res.	Res.	Res.	Res.	Res.	TFFL[2:0]		
	Reset value											0				0	0							0	0						0	1	1

Table 726. FDCAN register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00C8	FDCAN_TXBRP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRP2	TRP1	TRP0
	Reset value																														0	0	0
0x00CC	FDCAN_TXBAR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AR2	AR1	AR0
	Reset value																														0	0	0
0x00D0	FDCAN_TXBCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CR2	CR1	CR0
	Reset value																														0	0	0
0x00D4	FDCAN_TXBTO	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TO2	TO1	TO0
	Reset value																														0	0	0
0x00D8	FDCAN_TXBCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CF2	CF1	CF0
	Reset value																														0	0	0
0x00DC	FDCAN_TXBTIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIE2	TIE1	TIE0
	Reset value																														0	0	0
0x00E0	FDCAN_TXBCIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CFIE2	CFIE1	CFIE0
	Reset value																														0	0	0
0x00E4	FDCAN_TXEFS	Res.	Res.	Res.	Res.	Res.	Res.	TEFL	EFF	Res.	Res.	Res.	Res.	Res.	Res.	EFPI[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	EFG[1:0]		Res.	Res.	Res.	Res.	Res.	EFFL[2:0]		
	Reset value							0	0							0	0							0	0						0	0	0
0x00E8	FDCAN_TXEFA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EFAI[1:0]	
	Reset value																															0	0
0x0100	FDCAN_CKDIV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PDIV[3:0]			
	Reset value																													0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

66 USB on-the-go full-speed (OTG_FS)

66.1 OTG_FS introduction

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This section presents the architecture and the programming model of the OTG_FS controller.

The following acronyms are used throughout the section:

FS	Full-speed
LS	Low-speed
MAC	Media access controller
OTG	On-the-go
PFC	Packet FIFO controller
PHY	Physical layer
USB	Universal serial bus
UTMI	USB 2.0 Transceiver Macrocell interface (UTMI)
LPM	Link power management
BCD	Battery charging detector
HNP	Host negotiation protocol
SRP	Session request protocol

References are made to the following documents:

- USB On-The-Go Supplement, Revision 2.0
- Universal Serial Bus Revision 2.0 Specification
- USB 2.0 Link Power Management Addendum Engineering Change Notice to the USB 2.0 specification, July 16, 2007
- Errata for USB 2.0 ECN: Link Power Management (LPM) - 7/2007
- Battery Charging Specification, Revision 1.2

The USB OTG is a dual-role device (DRD) controller that supports both device and host functions and is fully compliant with the *On-The-Go Supplement to the USB 2.0 Specification*. It can also be configured as a host-only or device-only controller, fully compliant with the *USB 2.0 Specification.* OTG_FS supports the speeds defined in the *Table 727: OTG_FS speeds supported* below. The only external device required is a charge pump for V_{BUS} in OTG mode.

Table 727. OTG_FS speeds supported

-	HS (480 Mb/s)	FS (12 Mb/s)	LS (1.5 Mb/s)
Host mode	-	X	X
Device mode	-	X	-

66.2 OTG_FS main features

The main features can be divided into three categories: general, host-mode and device-mode features.

66.2.1 General features

The OTG_FS interface general features are the following:

- It is USB-IF certified to the Universal Serial Bus Specification Rev 2.0
- OTG_FS supports the following PHY interface:
  - An on-chip full-speed PHY
- It includes full support (PHY) for the optional On-The-Go (OTG) protocol detailed in the On-The-Go Supplement Rev 2.0 specification
  - It allows host to turn V_{BUS} off to conserve battery power in OTG applications
  - It supports dynamic host-peripheral switch of role
- It is software-configurable to operate as:
  - USB On-The-Go Full-Speed Dual Role device
- It supports FS SOF and LS Keep-alives with
  - SOF pulse PAD connectivity
  - SOF pulse internal connection to timer (TIMx)
  - Configurable framing period
  - Configurable end of frame interrupt
- It includes power saving features such as system stop during USB suspend, switch-off of clock domains internal to the digital core, PHY and DFIFO power management.
- It features a dedicated RAM of 1.25 Kbytes with advanced FIFO control:
  - Configurable partitioning of RAM space into different FIFOs for flexible and efficient use of RAM
  - Each FIFO can hold multiple packets
  - Dynamic memory allocation
  - Configurable FIFO sizes that are not powers of 2 to allow the use of contiguous memory locations
- It guarantees max USB bandwidth for up to one frame (1 ms) without system intervention.
- It supports charging port detection as described in Battery Charging Specification Revision 1.2.

66.2.2 Host-mode features

The OTG_FS interface main features and requirements in host-mode are the following:

- External charge pump for V_{BUS} voltage generation.
- Up to 12 host channels (pipes): each channel is dynamically reconfigurable to allocate any type of USB transfer.
- Built-in hardware scheduler holding:
  - Up to 12 interrupt plus isochronous transfer requests in the periodic hardware queue
  - Up to 12 control plus bulk transfer requests in the non-periodic hardware queue
- Management of a shared Rx FIFO, a periodic Tx FIFO and a nonperiodic Tx FIFO for efficient usage of the USB data RAM.

66.2.3 Peripheral-mode features

The OTG_FS interface main features in peripheral-mode are the following:

- 1 bidirectional control endpoint0
- 5 IN endpoints (EPs) configurable to support bulk, interrupt or isochronous transfers
- 5 OUT endpoints configurable to support bulk, interrupt or isochronous transfers
- Management of a shared Rx FIFO and a Tx-OUT FIFO for efficient usage of the USB data RAM
- Management of up to 6 dedicated Tx-IN FIFOs (one for each active IN EP) to put less load on the application
- Support for the soft disconnect feature.

66.3 OTG_FS implementation

Table 728. OTG_FS implementation(1)

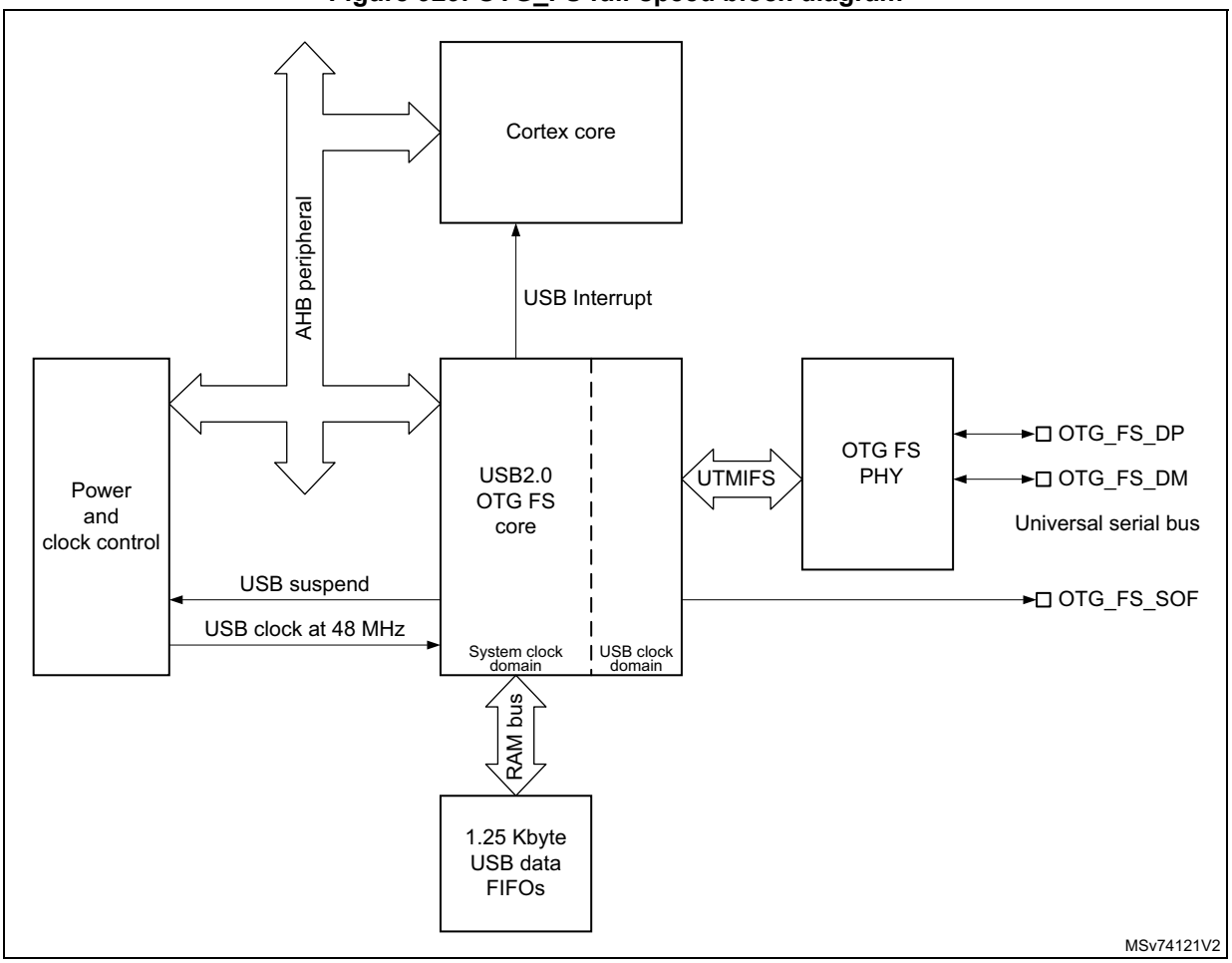
USB features	OTG_FS
Device bidirectional endpoints (including EP0)	6
Host mode channels	12
Size of dedicated SRAM	1.2 Kbytes
USB 2.0 link power management (LPM) support	X
OTG revision supported	2.0
Battery charging detection (BCD) support	X
Integrated PHY	FS

1. “X” = supported, “-” = not supported, “FS” = supported in FS mode, “HS” = supported in HS mode.

66.4 OTG_FS functional description

66.4.1 OTG_FS block diagram

Figure 929. OTG_FS full-speed block diagram



66.4.2 OTG_FS pin and internal signals

Table 729. OTG_FS input/output pins

Signal name	Signal type	Description
OTG_FS_DP	Digital input/output	USB OTG D+ line
OTG_FS_DM	Digital input/output	USB OTG D- line
OTG_FS_SOF	Digital output	USB OTG SOF

Table 730. OTG_FS input/output signals

Signal name	Signal type	Description
usb_sof	Digital output	USB OTG start-of-frame event for on chip peripherals
usb_wkup	Digital output	USB OTG wakeup event output
usb_gbl_it	Digital output	USB OTG global interrupt

66.4.3 OTG_FS core

The CPU reads and writes from/to the OTG core registers through the AHB peripheral bus. It is informed of USB events through the single USB OTG interrupt line described in *Section 66.13: OTG_FS interrupts*.

The CPU submits data over the USB by writing 32-bit words to dedicated OTG locations (push registers). The data are then automatically stored into Tx-data FIFOs configured within the USB data RAM. There is one Tx FIFO push register for each in-endpoint (peripheral mode) or out-channel (host mode).

The CPU receives the data from the USB by reading 32-bit words from dedicated OTG addresses (pop registers). The data are then automatically retrieved from a shared Rx FIFO configured within the 1.25-Kbyte USB data RAM. There is one Rx FIFO pop register for each out-endpoint or in-channel.

The USB protocol layer is driven by the serial interface engine (SIE) and serialized over the USB by the transceiver module within the on-chip physical layer (PHY).

Caution: To guarantee a correct operation for the USB OTG FS peripheral, the AHB frequency must be higher than 14.2 MHz.

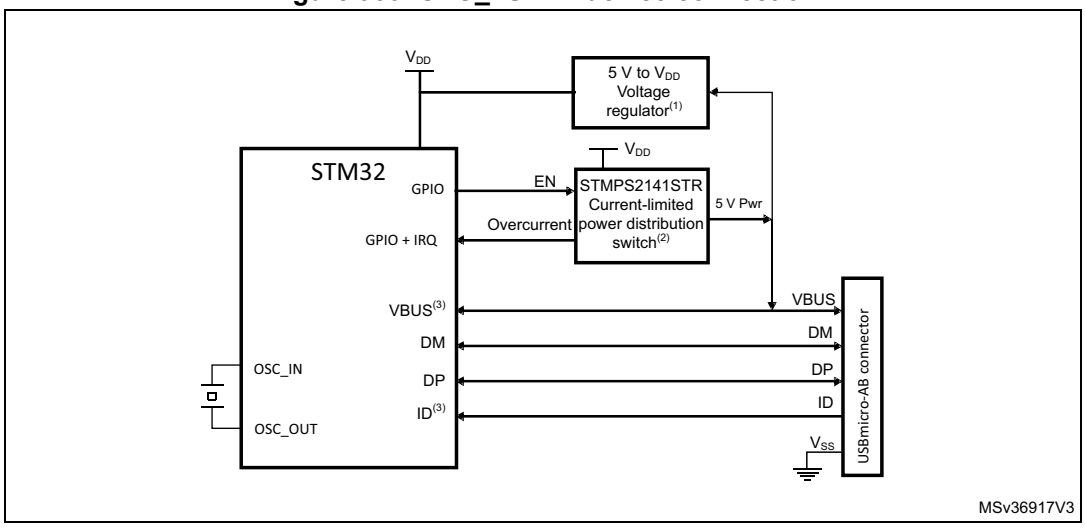
66.4.4 Embedded full-speed OTG PHY connected to OTG_FS

The embedded full-speed OTG PHY is controlled by the OTG FS core and conveys USB control & data signals through the full-speed subset of the UTMI+ Bus (UTMIFS). It provides the physical support to USB connectivity.
The full-speed OTG PHY includes the following components:

- FS/LS transceiver module used by both host and device. It directly drives transmission and reception on the single-ended USB lines.
- DP/DM integrated pull-up and pull-down resistors controlled by the OTG_FS core depending on the current role of the device. As a peripheral, it enables the DP pull-up resistor to signal full-speed peripheral connections as soon as V_{BUS} is sensed to be at a valid level (B-session valid). In host mode, pull-down resistors are enabled on both DP/DM. Pull-up and pull-down resistors are dynamically switched when the role of the device is changed via the host negotiation protocol (HNP).
- Pull-up/pull-down resistor ECN circuit. The DP pull-up consists of two resistors controlled separately from the OTG_FS as per the resistor Engineering Change Notice applied to USB Rev2.0. The dynamic trimming of the DP pull-up strength allows for better noise rejection and Tx/Rx signal quality.

66.5 OTG_FS dual role device (DRD)

Figure 930. OTG_FS A-B device connection



1. External voltage regulator only needed when building a VBUS powered device.
2. STMPS2141STR needed only if the application has to support a VBUS powered device. A basic power switch can be used if 5 V are available on the application board.
3. VBUS/ID pin(s) where implemented (see *Table 729: OTG_FS input/output pins*).

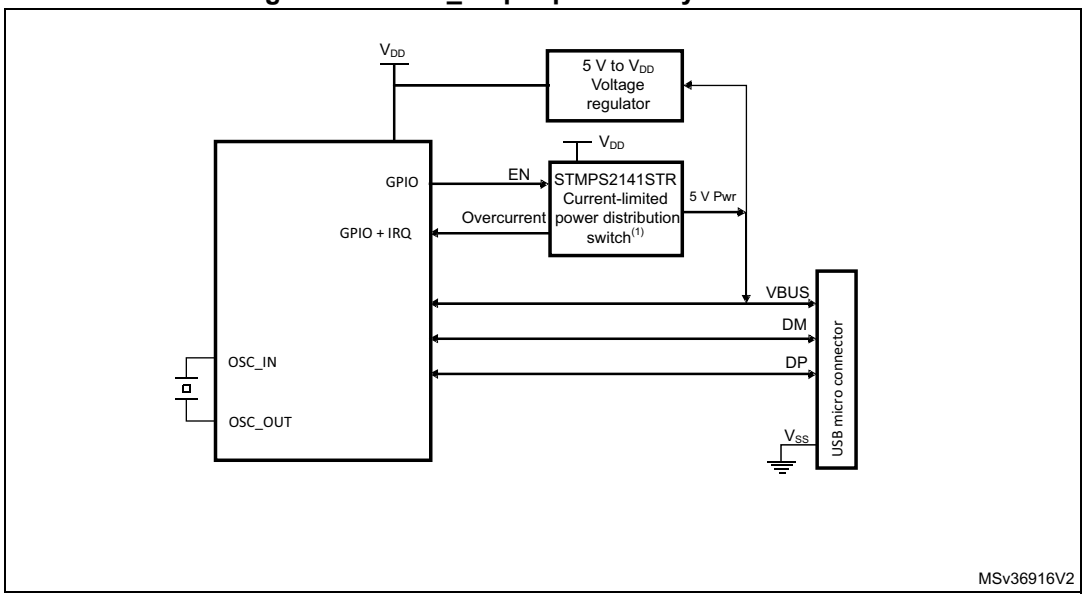
66.6 OTG_FS as a USB peripheral

This section gives the functional description of the OTG_FS in the USB peripheral mode. The OTG_FS works as an USB peripheral in the following circumstances:

- OTG B-Peripheral
  - OTG B-device default state if B-side of USB cable is plugged in
- B-device
  - If the ID line is present, functional and connected to the B-side of the USB cable.
- Peripheral only (see *Figure 931: OTG_FS peripheral-only connection*)
  - The force device mode bit (FDMOD) in the *Section 66.15.4: OTG USB configuration register (OTG_GUSBCFG)* is set to 1, forcing the OTG_FS core to work as an USB peripheral-only. In this case, the ID line is ignored even if it is present on the USB connector.

Note: To build a bus-powered device implementation in case of the B-device or peripheral-only configuration, an external regulator has to be added, that generates the necessary power-supply from V_{BUS}.

Figure 931. OTG_FS peripheral-only connection



1. Use a regulator to build a bus-powered device.

66.6.1 Peripheral states

Powered state

The V_{BUS} input detects the B-session valid voltage by which the USB peripheral is allowed to enter the powered state (see USB2.0 section 9.1). The OTG_FS then automatically connects the DP pull-up resistor to signal full-speed device connection to the host and generates the session request interrupt (SRQINT bit in OTG_GINTSTS) to notify the powered state.

The V_{BUS} input also ensures that valid V_{BUS} levels are supplied by the host during USB operations. If a drop in V_{BUS} below B-session valid happens to be detected (for instance because of a power disturbance or if the host port has been switched off), the OTG_FS automatically disconnects and the session end detected (SEDET bit in OTG_GOTGINT) interrupt is generated to notify that the OTG_FS has exited the powered state.

In the powered state, the OTG_FS expects to receive some reset signaling from the host. No other USB operation is possible. When a reset signaling is received the reset detected interrupt (USBRST in OTG_GINTSTS) is generated. When the reset signaling is complete, the enumeration done interrupt (ENUMDNE bit in OTG_GINTSTS) is generated and the OTG_FS enters the Default state.

Soft disconnect

The powered state can be exited by software with the soft disconnect feature. The DP pull-up resistor is removed by setting the soft disconnect bit in the device control register (SDIS bit in OTG_DCTL), causing a device disconnect detection interrupt on the host side even though the USB cable was not really removed from the host port.

Default state

In the Default state the OTG_FS expects to receive a SET_ADDRESS command from the host. No other USB operation is possible. When a valid SET_ADDRESS command is

decoded on the USB, the application writes the corresponding number into the device address field in the device configuration register (DAD bit in OTG_DCFG). The OTG_FS then enters the address state and is ready to answer host transactions at the configured USB address.

Suspended state

The OTG_FS peripheral constantly monitors the USB activity. After counting 3 ms of USB idleness, the early suspend interrupt (ESUSP bit in OTG_GINTSTS) is issued, and confirmed 3 ms later, if appropriate, by the suspend interrupt (USBSUSP bit in OTG_GINTSTS). The device suspend bit is then automatically set in the device status register (SUSPSTS bit in OTG_DSTS) and the OTG_FS enters the suspended state.

The suspended state may optionally be exited by the device itself. In this case the application sets the remote wakeup signaling bit in the device control register (RWUSIG bit in OTG_DCTL) and clears it after 1 to 15 ms.

When a resume signaling is detected from the host, the resume interrupt (WKUPINT bit in OTG_GINTSTS) is generated and the device suspend bit is automatically cleared.

66.6.2 Peripheral endpoints

The OTG_FS core instantiates the following USB endpoints:

- Control endpoint 0:
  - Bidirectional and handles control messages only
  - Separate set of registers to handle in and out transactions
  - Proper control (OTG_DIEPCTL0/OTG_DOEPCTL0), transfer configuration (OTG_DIEPTSIZ0/OTG_DOEPTSIZ0), and status-interrupt (OTG_DIEPINT0/)OTG_DOEPINT0) registers. The available set of bits inside the control and transfer size registers slightly differs from that of other endpoints
- 5 IN endpoints
  - Each of them can be configured to support the isochronous, bulk or interrupt transfer type
  - Each of them has proper control (OTG_DIEPCTL*x*), transfer configuration (OTG_DIEPTSIZ*x*), and status-interrupt (OTG_DIEPINT*x*) registers
  - The device IN endpoints common interrupt mask register (OTG_DIEPMSK) is available to enable/disable a single kind of endpoint interrupt source on all of the IN endpoints (EP0 included)
  - Support for incomplete isochronous IN transfer interrupt (IISOIXFR bit in OTG_GINTSTS), asserted when there is at least one isochronous IN endpoint on

which the transfer is not completed in the current frame. This interrupt is asserted along with the end of periodic frame interrupt (OTG_GINTSTS/EOPF).

- 5 OUT endpoints
  - Each of them can be configured to support the isochronous, bulk or interrupt transfer type
  - Each of them has a proper control (OTG_DOEPCTL*x*), transfer configuration (OTG_DOEPTSIZ*x*) and status-interrupt (OTG_DOEPINT*x*) register
  - Device OUT endpoints common interrupt mask register (OTG_DOEPMSK) is available to enable/disable a single kind of endpoint interrupt source on all of the OUT endpoints (EP0 included)
  - Support for incomplete isochronous OUT transfer interrupt (INCOMPISOOUT bit in OTG_GINTSTS), asserted when there is at least one isochronous OUT endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the end of periodic frame interrupt (OTG_GINTSTS/EOPF).

Endpoint control

- The following endpoint controls are available to the application through the device endpoint-*x* IN/OUT control register (OTG_DIEPCTL*x*/OTG_DOEPCTL*x*):
  - Endpoint enable/disable
  - Endpoint activate in current configuration
  - Program USB transfer type (isochronous, bulk, interrupt)
  - Program supported packet size
  - Program Tx FIFO number associated with the IN endpoint
  - Program the expected or transmitted data0/data1 PID (bulk/interrupt only)
  - Program the even/odd frame during which the transaction is received or transmitted (isochronous only)
  - Optionally program the NAK bit to always negative-acknowledge the host regardless of the FIFO status
  - Optionally program the STALL bit to always stall host tokens to that endpoint
  - Optionally program the SNOOP mode for OUT endpoint not to check the CRC field of received data

Endpoint transfer

The device endpoint-*x* transfer size registers (OTG_DIEPTSIZ*x*/OTG_DOEPTSIZ*x*) allow the application to program the transfer size parameters and read the transfer status. Programming must be done before setting the endpoint enable bit in the endpoint control register. Once the endpoint is enabled, these fields are read-only as the OTG_FS core updates them with the current transfer status.

The following transfer parameters can be programmed:

- Transfer size in bytes
- Number of packets that constitute the overall transfer size

Endpoint status/interrupt

The device endpoint-*x* interrupt registers (OTG_DIEPINT*x*/OTG_DOPEPINT*x)* indicate the status of an endpoint with respect to USB- and AHB-related events. The application must read these registers when the OUT endpoint interrupt bit or the IN endpoint interrupt bit in

the core interrupt register (OEPINT bit in OTG_GINTSTS or IEPINT bit in OTG_GINTSTS, respectively) is set. Before the application can read these registers, it must first read the device all endpoints interrupt (OTG_DAINT) register to get the exact endpoint number for the device endpoint-*x* interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_DAINT and OTG_GINTSTS registers

The peripheral core provides the following status checks and interrupt generation:

- Transfer completed interrupt, indicating that data transfer was completed on both the application (AHB) and USB sides
- Setup stage has been done (control-out only)
- Associated transmit FIFO is half or completely empty (in endpoints)
- NAK acknowledge has been transmitted to the host (isochronous-in only)
- IN token received when Tx FIFO was empty (bulk-in/interrupt-in only)
- Out token received when endpoint was not yet enabled
- Babble error condition has been detected
- Endpoint disable by application is effective
- Endpoint NAK by application is effective (isochronous-in only)
- More than 3 back-to-back setup packets were received (control-out only)
- Timeout condition detected (control-in only)
- Isochronous out packet has been dropped, without generating an interrupt

66.7 OTG_FS as a USB host

This section gives the functional description of the OTG_FS in the USB host mode. The OTG_FS works as a USB host in the following circumstances:

Automatic host mode direct from ID pin:

The ID pin is not always available, refer to product datasheet for available pins.

- Use case:
  - Micro connector: A-Device with a Micro-A plug inserted, and connector ID pin connected to the STM32 ID pin which is then detected in a low state.
- Note that the integrated pull-down resistors are automatically set on the DP/DM lines.

Manual forcing of host mode when not possible via ID pin:

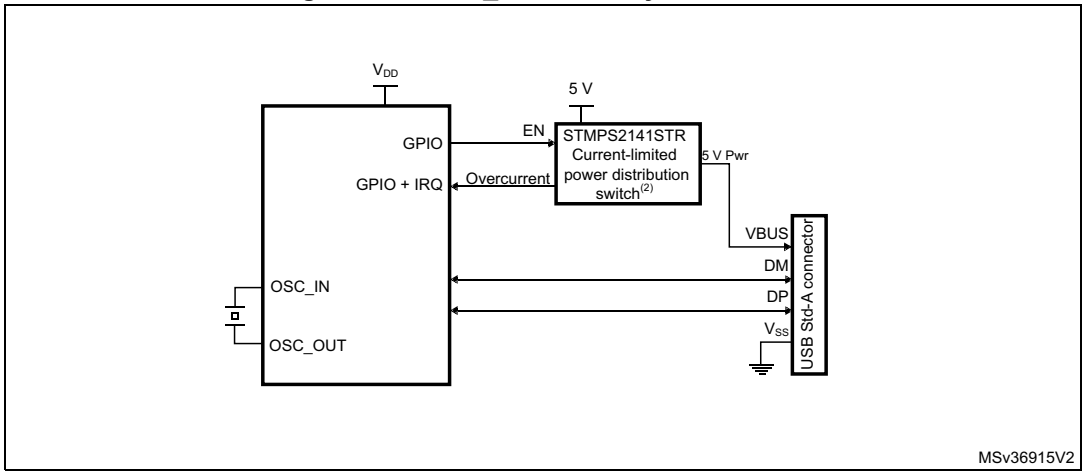
The force host mode bit (FHMOD) in the *OTG USB configuration register (OTG_GUSBCFG)* forces the OTG_FS core to work as a USB host-only when required.

- Use cases:
  - Standard-A connector which always implies Host mode.
  - Micro connector, so ID present on connector, but ID pin not available in pinout, at A-plug insertion (detected by another means, for example: GPIO).
  - A Type-C connector, when host functionality is determined at cable attachment or via power delivery messages.
- Note that the integrated pulldown resistors are automatically set on the DP/DM lines

Note: On-chip 5 V V_{BUS} generation is not supported. For this reason, a charge pump or, if 5 V are available on the application board, a basic power switch must be added externally to drive

the 5 V V_{BUS} line. The external charge pump can be driven by any GPIO output. This is required for the OTG A-host, A-device and host-only configurations.

Figure 932. OTG_FS host-only connection



1. V_{DD} range is between 2 V and 3.6 V.

66.7.1 USB host states

Host port power

On-chip 5 V V_{BUS} generation is not supported. For this reason, a charge pump or, if 5 V are available on the application board, a basic power switch, must be added externally to drive the 5 V V_{BUS} line. The external charge pump can be driven by any GPIO output or via an I^2C interface connected to an external PMIC (power management IC). When the application decides to power on V_{BUS}, it must also set the port power bit in the host port control and status register (PPWR bit in OTG_HPRT).

The charge pump overcurrent flag can also be used to prevent electrical damage. Connect the overcurrent flag output from the charge pump to any GPIO input and configure it to generate a port interrupt on the active level. The overcurrent ISR must promptly disable the V_{BUS} generation and clear the port power bit.

Host detection of a peripheral connection

USB peripherals or B-device are detected as soon as they are connected. The OTG_FS core issues a host port interrupt triggered by the device connected bit in the host port control and status (PCDET bit in OTG_HPRT).

Host detection of peripheral a disconnection

The peripheral disconnection event triggers the disconnect detected interrupt (DISCINT bit in OTG_GINTSTS).

Host enumeration

After detecting a peripheral connection the host must start the enumeration process by sending USB reset and configuration commands to the new peripheral.

The application drives a USB reset signaling (single-ended zero) over the USB by keeping the port reset bit set in the host port control and status register (PRST bit in OTG_HPRT) for

a minimum of 10 ms and a maximum of 20 ms. The application takes care of the timing count and then of clearing the port reset bit.

Once the USB reset sequence has completed, the host port interrupt is triggered by the port enable/disable change bit (PENCHNG bit in OTG_HPRT). This informs the application that the speed of the enumerated peripheral can be read from the port speed field in the host port control and status register (PSPD bit in OTG_HPRT) and that the host is starting to drive SOFs (FS) or Keep alives (LS). The host is now ready to complete the peripheral enumeration by sending peripheral configuration commands.

Host suspend

The application decides to suspend the USB activity by setting the port suspend bit in the host port control and status register (PSUSP bit in OTG_HPRT). The OTG_FS core stops sending SOFs and enters the suspended state.

The suspended state can be optionally exited on the remote device's initiative (remote wakeup). In this case the remote wakeup interrupt (WKUPINT bit in OTG_GINTSTS) is generated upon detection of a remote wakeup signaling, the port resume bit in the host port control and status register (PRES bit in OTG_HPRT) self-sets, and resume signaling is automatically driven over the USB. The application must time the resume window and then clear the port resume bit to exit the suspended state and restart the SOF.

If the suspended state is exited on the host initiative, the application must set the port resume bit to start resume signaling on the host port, time the resume window and finally clear the port resume bit.

66.7.2 Host channels

The OTG_FS core instantiates 12 host channels. Each host channel supports an USB host transfer (USB pipe). The host is not able to support more than 12 transfer requests at the same time. If more than 12 transfer requests are pending from the application, the host controller driver (HCD) must re-allocate channels when they become available from previous duty, that is, after receiving the transfer completed and channel halted interrupts.

Each host channel can be configured to support in/out and any type of periodic/nonperiodic transaction. Each host channel makes us of proper control (OTG_HCCHAR*x*), transfer configuration (OTG_HCTSIZ*x*) and status/interrupt (OTG_HCINT*x*) registers with associated mask (OTG_HCINTMSK*x*) registers.

Host channel control

- The following host channel controls are available to the application through the host channel-*x* characteristics register (OTG_HCCHAR*x*):
  - Channel enable/disable
  - Program the FS/LS speed of target USB peripheral
  - Program the address of target USB peripheral
  - Program the endpoint number of target USB peripheral
  - Program the transfer IN/OUT direction
  - Program the USB transfer type (control, bulk, interrupt, isochronous)
  - Program the maximum packet size (MPS)
  - Program the periodic transfer to be executed during odd/even frames

Host channel transfer

The host channel transfer size registers (OTG_HCTSIZ*x*) allow the application to program the transfer size parameters, and read the transfer status. Programming must be done before setting the channel enable bit in the host channel characteristics register. Once the endpoint is enabled the packet count field is read-only as the OTG_FS core updates it according to the current transfer status.

- The following transfer parameters can be programmed:
  - transfer size in bytes
  - number of packets making up the overall transfer size
  - initial data PID

Host channel status/interrupt

The host channel-*x* interrupt register (OTG_HCINT*x*) indicates the status of an endpoint with respect to USB- and AHB-related events. The application must read these register when the host channels interrupt bit in the core interrupt register (HCINT bit in OTG_GINTSTS) is set. Before the application can read these registers, it must first read the host all channels interrupt (OTG_HAINT) register to get the exact channel number for the host channel-x interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_HAINT and OTG_GINTSTS registers. The mask bits for each interrupt source of each channel are also available in the OTG_HCINTMSKx register.

- The host core provides the following status checks and interrupt generation:
  - Transfer completed interrupt, indicating that the data transfer is complete on both the application (AHB) and USB sides
  - Channel has stopped due to transfer completed, USB transaction error or disable command from the application
  - Associated transmit FIFO is half or completely empty (IN endpoints)
  - ACK response received
  - NAK response received
  - STALL response received
  - USB transaction error due to CRC failure, timeout, bit stuff error, false EOP
  - Babble error
  - frame overrun
  - data toggle error

66.7.3 Host scheduler

The host core features a built-in hardware scheduler which is able to autonomously re-order and manage the USB transaction requests posted by the application. At the beginning of each frame the host executes the periodic (isochronous and interrupt) transactions first, followed by the nonperiodic (control and bulk) transactions to achieve the higher level of priority granted to the isochronous and interrupt transfer types by the USB specification.

The host processes the USB transactions through request queues (one for periodic and one for nonperiodic). Each request queue can hold up to 8 entries. Each entry represents a pending transaction request from the application, and holds the IN or OUT channel number along with other information to perform a transaction on the USB. The order in which the

requests are written to the queue determines the sequence of the transactions on the USB interface.

At the beginning of each frame, the host processes the periodic request queue first, followed by the nonperiodic request queue. The host issues an incomplete periodic transfer interrupt (IPXFR bit in OTG_GINTSTS) if an isochronous or interrupt transaction scheduled for the current frame is still pending at the end of the current frame. The OTG_FS core is fully responsible for the management of the periodic and nonperiodic request queues.The periodic transmit FIFO and queue status register (OTG_HPTXSTS) and nonperiodic transmit FIFO and queue status register (OTG_HNPTXSTS) are read-only registers which can be used by the application to read the status of each request queue. They contain:

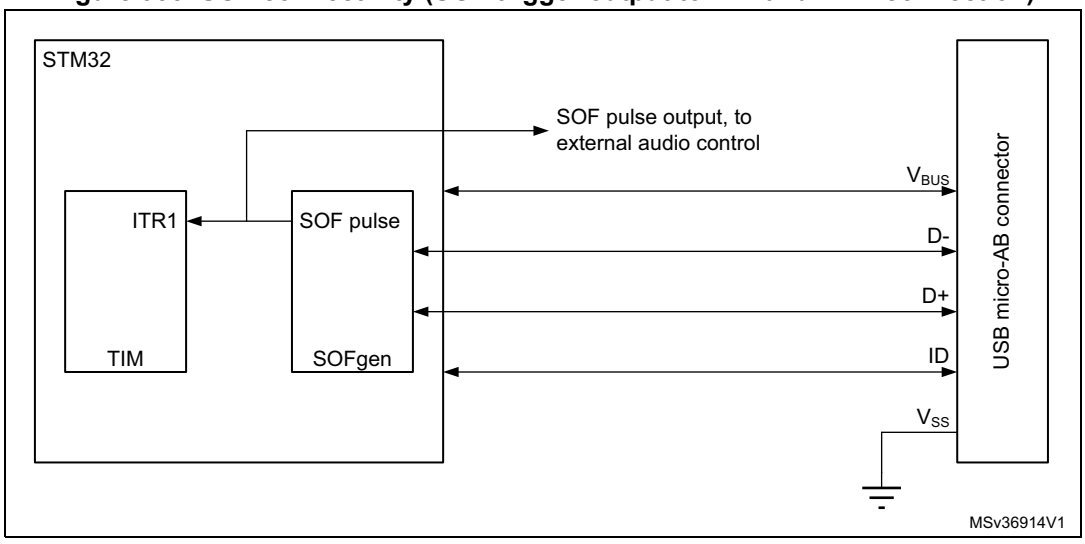
- The number of free entries currently available in the periodic (nonperiodic) request queue (8 max)
- Free space currently available in the periodic (nonperiodic) Tx FIFO (out-transactions)
- IN/OUT token, host channel number and other status information.

As request queues can hold a maximum of 8 entries each, the application can push to schedule host transactions in advance with respect to the moment they physically reach the SB for a maximum of 8 pending periodic transactions plus 8 pending non-periodic transactions.

To post a transaction request to the host scheduler (queue) the application must check that there is at least 1 entry available in the periodic (nonperiodic) request queue by reading the PTXQSAV bits in the OTG_HNPTXSTS register or NPTQXSAV bits in the OTG_HNPTXSTS register.

66.8 OTG_FS SOF trigger

Figure 933. SOF connectivity (SOF trigger output to TIM and ITR1 connection)



The OTG_FS core provides means to monitor, track and configure SOF framing in the host and peripheral, as well as an SOF pulse output connectivity feature.

Such utilities are especially useful for adaptive audio clock generation techniques, where the audio peripheral needs to synchronize to the isochronous stream provided by the PC, or the host needs to trim its framing rate according to the requirements of the audio peripheral.

66.8.1 Host SOFs

In host mode the number of PHY clocks occurring between the generation of two consecutive SOF (FS) or Keep-alive (LS) tokens is programmable in the host frame interval register (HFIR), thus providing application control over the SOF framing period. An interrupt is generated at any start of frame (SOF bit in OTG_GINTSTS). The current frame number and the time remaining until the next SOF are tracked in the host frame number register (HFNUM).

A SOF pulse signal, is generated at any SOF starting token and with a width of 20 HCLK cycles. The SOF pulse is also internally connected to the input trigger of the timer, so that the input capture feature, the output compare feature and the timer can be triggered by the SOF pulse.

66.8.2 Peripheral SOFs

In device mode, the start of frame interrupt is generated each time an SOF token is received on the USB (SOF bit in OTG_GINTSTS). The corresponding frame number can be read from the device status register (FNSOF bit in OTG_DSTS). A SOF pulse signal with a width of 20 HCLK cycles is also generated.The SOF pulse signal is also internally connected to the TIM input trigger, so that the input capture feature, the output compare feature and the timer can be triggered by the SOF pulse.

The end of periodic frame interrupt (OTG_GINTSTS/EOPF) is used to notify the application when 80%, 85%, 90% or 95% of the time frame interval elapsed depending on the periodic frame interval field in the device configuration register (PFIVL bit in OTG_DCFG). This feature can be used to determine if all of the isochronous traffic for that frame is complete.

66.9 OTG_FS low-power modes

Table 731 below defines the STM32 low power modes and their compatibility with the OTG.

Table 731. Compatibility of STM32 low power modes with the OTG

Mode	Description	USB compatibility
Run	MCU fully active	Required when USB not in suspend state.
Sleep	USB suspend exit causes the device to exit Sleep mode. Peripheral registers content is kept.	Available while USB is in suspend state.
Stop	USB suspend exit causes the device to exit Stop mode. Peripheral registers content is kept(1).	Available while USB is in suspend state.
Standby	Powered-down. The peripheral must be reinitialized after exiting Standby mode.	Not compatible with USB applications.

1. Within Stop mode there are different possible settings. Some restrictions may also exist, refer to *Section 10: Power control (PWR)* to understand which (if any) restrictions apply when using OTG.

The following bits and procedures reduce power consumption.

The power consumption of the OTG PHY is controlled by the following bit(s) in the general core configuration register, depending on OTG revision supported.

- PHY power down (OTG_GCCFG/PWRDWN)

  It switches on/off the full-speed transceiver module of the PHY. It must be preliminarily set to allow any USB operation

Power reduction techniques are available while in the USB suspended state, when the USB session is not yet valid or the device is disconnected.

- Stop PHY clock (STPPCLK bit in OTG_PCGCCTL)

  When setting the stop PHY clock bit in the clock gating control register, most of the 48 MHz clock domain internal to the OTG core is switched off by clock gating. The dynamic power consumption due to the USB clock switching activity is cut even if the 48 MHz clock input is kept running by the application

  Most of the transceiver is also disabled, and only the part in charge of detecting the asynchronous resume or remote wakeup event is kept alive.

- Gate HCLK (GATEHCLK bit in OTG_PCGCCTL)

  When setting the Gate HCLK bit in the clock gating control register, most of the system clock domain internal to the OTG_FS core is switched off by clock gating. Only the register read and write interface is kept alive. The dynamic power consumption due to the USB clock switching activity is cut even if the system clock is kept running by the application for other purposes.

- USB system stop

  When the OTG_FS is in the USB suspended state, the application may decide to drastically reduce the overall power consumption by a complete shut down of all the clock sources in the system. USB System Stop is activated by first setting the Stop PHY clock bit and then configuring the system deep sleep mode in the power control system module (PWR).

  The OTG_FS core automatically reactivates both system and USB clocks by asynchronous detection of remote wakeup (as an host) or resume (as a device) signaling on the USB.

To save dynamic power, the USB data FIFO is clocked only when accessed by the OTG_FS core.

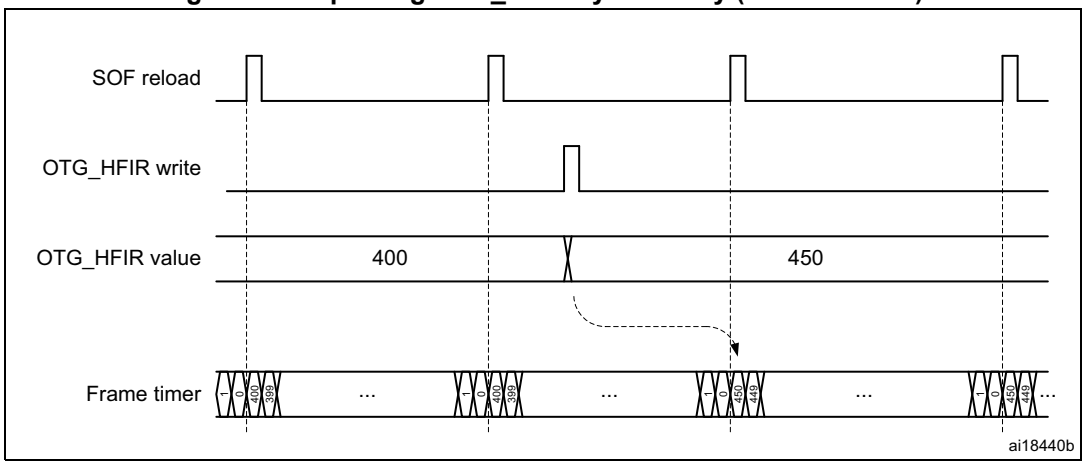
66.10 OTG_FS Dynamic update of the OTG_HFIR register

The USB core embeds a dynamic trimming capability of SOF framing period in host mode allowing to synchronize an external device with the SOF frames.

When the OTG_HFIR register is changed within a current SOF frame, the SOF period correction is applied in the next frame as described in *Figure 934*.

For a dynamic update, it is required to set RLDCTRL=1.

Figure 934. Updating OTG_HFIR dynamically (RLDCTRL = 1)

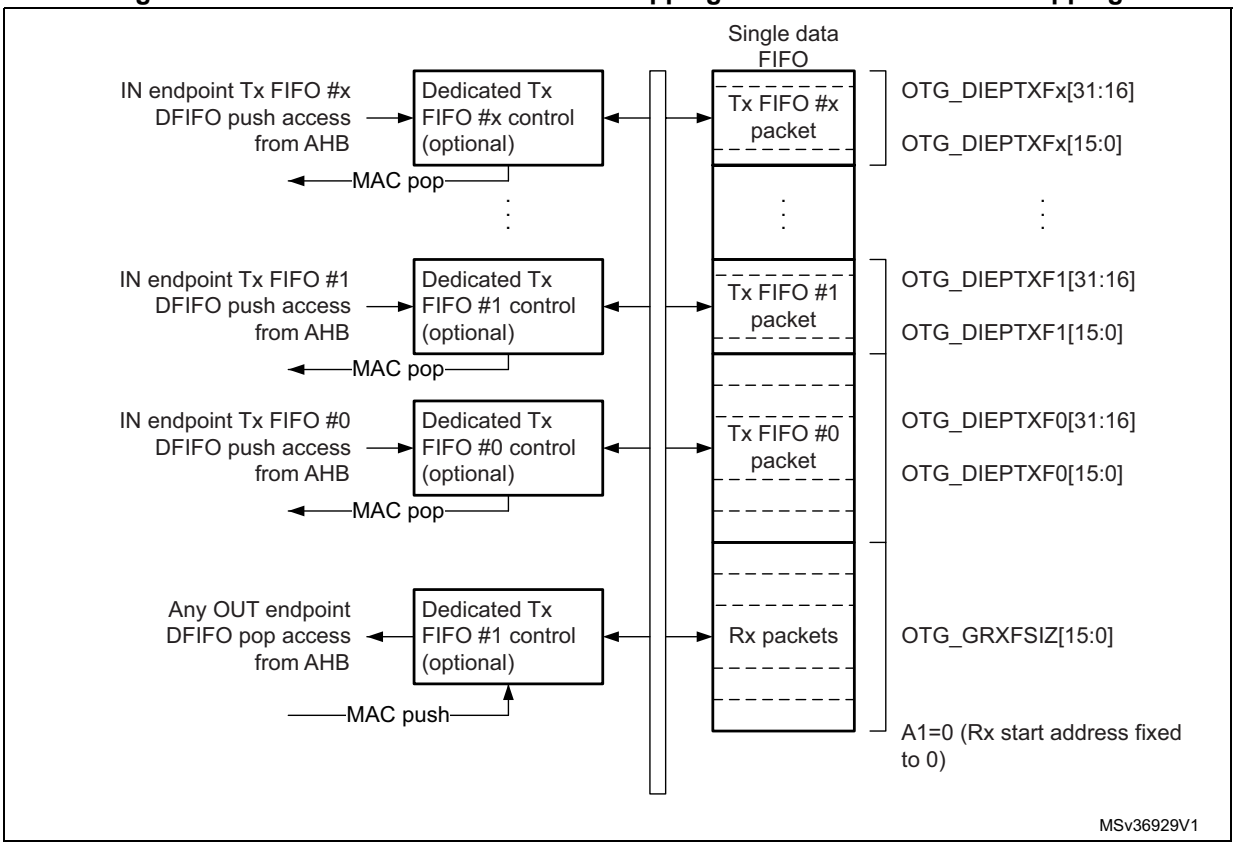


66.11 OTG_FS data FIFOs

The USB system features 1.25 Kbytes of dedicated RAM with a sophisticated FIFO control mechanism. The packet FIFO controller module in the OTG_FS core organizes RAM space into Tx FIFOs into which the application pushes the data to be temporarily stored before the USB transmission, and into a single Rx FIFO where the data received from the USB are temporarily stored before retrieval (popped) by the application. The number of instructed FIFOs and how these are organized inside the RAM depends on the device's role. In peripheral mode an additional Tx FIFO is instructed for each active IN endpoint. Any FIFO size is software configured to better meet the application requirements.

66.11.1 Peripheral FIFO architecture

Figure 935. Device-mode FIFO address mapping and AHB FIFO access mapping



Peripheral Rx FIFO

The OTG peripheral uses a single receive FIFO that receives the data directed to all OUT endpoints. Received packets are stacked back-to-back until free space is available in the Rx FIFO. The status of the received packet (which contains the OUT endpoint destination number, the byte count, the data PID and the validity of the received data) is also stored by the core on top of the data payload. When no more space is available, host transactions are NACKed and an interrupt is received on the addressed endpoint. The size of the receive FIFO is configured in the receive FIFO size register (OTG_GRXFSIZ).

The single receive FIFO architecture makes it more efficient for the USB peripheral to fill in the receive RAM buffer:

- All OUT endpoints share the same RAM buffer (shared FIFO)
- The OTG_FS core can fill in the receive FIFO up to the limit for any host sequence of OUT tokens

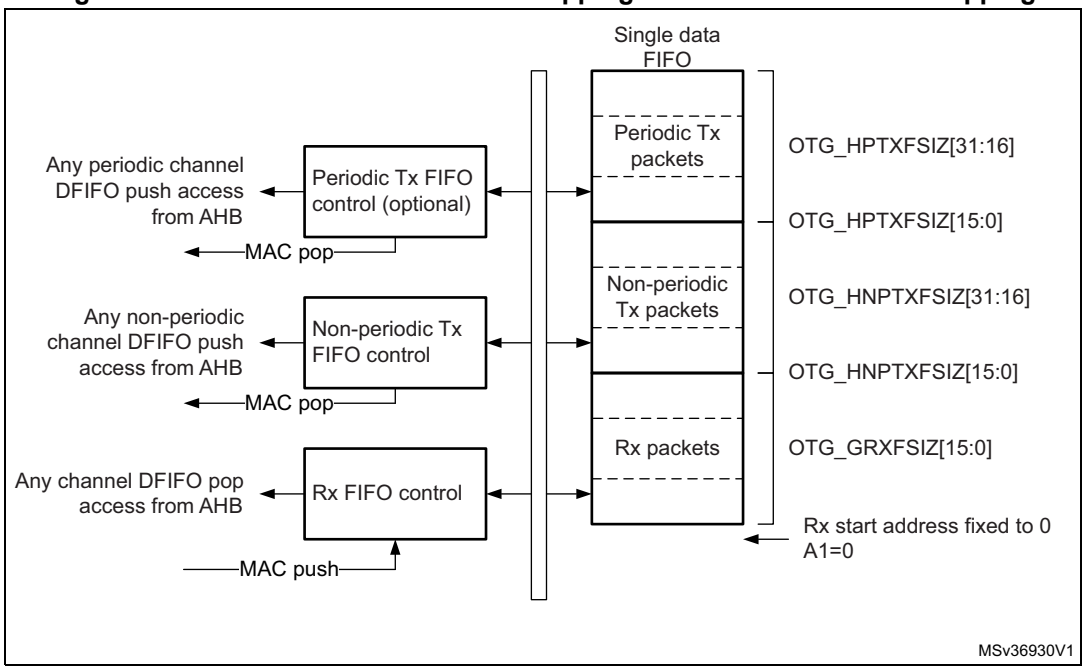
The application keeps receiving the Rx FIFO non-empty interrupt (RXFLVL bit in OTG_GINTSTS) as long as there is at least one packet available for download. It reads the packet information from the receive status read and pop register (OTG_GRXSTSP) and finally pops data off the receive FIFO by reading from the endpoint-related pop address.

Peripheral Tx FIFOs

The core has a dedicated FIFO for each IN endpoint. The application configures FIFO sizes by writing the endpoint 0 transmit FIFO size register (OTG_DIEPTXF0) for IN endpoint0 and the device IN endpoint transmit FIFOx registers (OTG_DIEPTXFx) for IN endpoint-x.

66.11.2 Host FIFO architecture

Figure 936. Host-mode FIFO address mapping and AHB FIFO access mapping



Host Rx FIFO

The host uses one receiver FIFO for all periodic and nonperiodic transactions. The FIFO is used as a receive buffer to hold the received data (payload of the received packet) from the USB until it is transferred to the system memory. Packets received from any remote IN endpoint are stacked back-to-back until free space is available. The status of each received packet with the host channel destination, byte count, data PID and validity of the received data are also stored into the FIFO. The size of the receive FIFO is configured in the receive FIFO size register (OTG_GRXFSIZ).

The single receive FIFO architecture makes it highly efficient for the USB host to fill in the receive data buffer:

- All IN configured host channels share the same RAM buffer (shared FIFO)
- The OTG_FS core can fill in the receive FIFO up to the limit for any sequence of IN tokens driven by the host software

The application receives the Rx FIFO not-empty interrupt as long as there is at least one packet available for download. It reads the packet information from the receive status read and pop register and finally pops the data off the receive FIFO.

Host Tx FIFOs

The host uses one transmit FIFO for all non-periodic (control and bulk) OUT transactions and one transmit FIFO for all periodic (isochronous and interrupt) OUT transactions. FIFOs are used as transmit buffers to hold the data (payload of the transmit packet) to be transmitted over the USB. The size of the periodic (nonperiodic) Tx FIFO is configured in the host periodic (nonperiodic) transmit FIFO size OTG_HPTXFSIZ / OTG_HNPTXFSIZ) register.

The two Tx FIFO implementation derives from the higher priority granted to the periodic type of traffic over the USB frame. At the beginning of each frame, the built-in host scheduler processes the periodic request queue first, followed by the nonperiodic request queue.

The two transmit FIFO architecture provides the USB host with separate optimization for periodic and nonperiodic transmit data buffer management:

- All host channels configured to support periodic (nonperiodic) transactions in the OUT direction share the same RAM buffer (shared FIFOs)
- The OTG_FS core can fill in the periodic (nonperiodic) transmit FIFO up to the limit for any sequence of OUT tokens driven by the host software

The OTG_FS core issues the periodic Tx FIFO empty interrupt (PTXFE bit in OTG_GINTSTS) as long as the periodic Tx FIFO is half or completely empty, depending on the value of the periodic Tx FIFO empty level bit in the AHB configuration register (PTXFELVL bit in OTG_GAHBCFG). The application can push the transmission data in advance as long as free space is available in both the periodic Tx FIFO and the periodic request queue. The host periodic transmit FIFO and queue status register (OTG_HPTXSTS) can be read to know how much space is available in both.

OTG_FS core issues the non periodic Tx FIFO empty interrupt (NPTXFE bit in OTG_GINTSTS) as long as the nonperiodic Tx FIFO is half or completely empty depending on the non periodic Tx FIFO empty level bit in the AHB configuration register (TXFELVL bit in OTG_GAHBCFG). The application can push the transmission data as long as free space is available in both the nonperiodic Tx FIFO and nonperiodic request queue. The host nonperiodic transmit FIFO and queue status register (OTG_HNPTXSTS) can be read to know how much space is available in both.

66.11.3 FIFO RAM allocation

Device mode

Receive FIFO RAM allocation: the application must allocate RAM for SETUP packets:

- 10 locations must be reserved in the receive FIFO to receive SETUP packets on control endpoint. The core does not use these locations, which are reserved for SETUP packets, to write any other data.
- One location is to be allocated for Global OUT NAK.
- Status information is written to the FIFO along with each received packet. Therefore, a minimum space of (largest packet size / 4) + 1 must be allocated to receive packets. If multiple isochronous endpoints are enabled, then at least two (largest packet size / 4) + 1 spaces must be allocated to receive back-to-back packets. Typically, two (largest packet size / 4) + 1 spaces are recommended so that when the previous packet is being transferred to the CPU, the USB can receive the subsequent packet.
- Along with the last packet for each endpoint, transfer complete status information is also pushed to the FIFO. One location for each OUT endpoint is recommended.

Device RxFIFO =

(5 * number of control endpoints + 8) + ((largest USB packet used / 4) + 1 for status information) + (2 * number of OUT endpoints) + 1 for Global NAK

Example: The MPS is 1,024 bytes for a periodic USB packet and 512 bytes for a non-periodic USB packet. There are three OUT endpoints, three IN endpoints, one control endpoint, and three host channels.

Device RxFIFO = (5 * 1 + 8) + ((1,024 / 4) +1) + (2 * 4) + 1 = 279

Transmit FIFO RAM allocation: the minimum RAM space required for each IN endpoint Transmit FIFO is the maximum packet size for that particular IN endpoint.

Note: More space allocated in the transmit IN endpoint FIFO results in better performance on the USB.

Host mode

Receive FIFO RAM allocation:

Status information is written to the FIFO along with each received packet. Therefore, a minimum space of (largest packet size / 4) + 1 must be allocated to receive packets. If multiple isochronous channels are enabled, then at least two (largest packet size / 4) + 1 spaces must be allocated to receive back-to-back packets. Typically, two (largest packet size / 4) + 1 spaces are recommended so that when the previous packet is being transferred to the CPU, the USB can receive the subsequent packet.

Along with the last packet in the host channel, transfer complete status information is also pushed to the FIFO. So one location must be allocated for this.

Host RxFIFO = (largest USB packet used / 4) + 1 for status information + 1 transfer complete

Example: Host RxFIFO = ((1,024 / 4) + 1) + 1 = 258

Transmit FIFO RAM allocation:

The minimum amount of RAM required for the host Non-periodic Transmit FIFO is the largest maximum packet size among all supported non-periodic OUT channels.

Typically, two largest packet sizes worth of space is recommended, so that when the current packet is under transfer to the USB, the CPU can get the next packet.

Non-Periodic TxFIFO = largest non-periodic USB packet used / 4

Example: Non-Periodic TxFIFO = (512 / 4) = 128

The minimum amount of RAM required for host periodic Transmit FIFO is the largest maximum packet size out of all the supported periodic OUT channels. If there is at least one isochronous OUT endpoint, then the space must be at least two times the maximum packet size of that channel.

Host Periodic TxFIFO = largest periodic USB packet used / 4

Example: Host Periodic TxFIFO = (1,024 / 4) = 256

Note: More space allocated in the Transmit Non-periodic FIFO results in better performance on the USB.

66.12 OTG_FS system performance

Best USB and system performance is achieved owing to the large RAM buffers, the highly configurable FIFO sizes, the quick 32-bit FIFO access through AHB push/pop registers and, especially, the advanced FIFO control mechanism. Indeed, this mechanism allows the OTG_FS to fill in the available RAM space at best regardless of the current USB sequence. With these features:

- The application gains good margins to calibrate its intervention in order to optimize the CPU bandwidth usage:
  - It can accumulate large amounts of transmission data in advance compared to when they are effectively sent over the USB
  - It benefits of a large time margin to download data from the single receive FIFO
- The USB core is able to maintain its full operating rate, that is to provide maximum full-speed bandwidth with a great margin of autonomy versus application intervention:
  - It has a large reserve of transmission data at its disposal to autonomously manage the sending of data over the USB
  - It has a lot of empty space available in the receive buffer to autonomously fill it in with the data coming from the USB

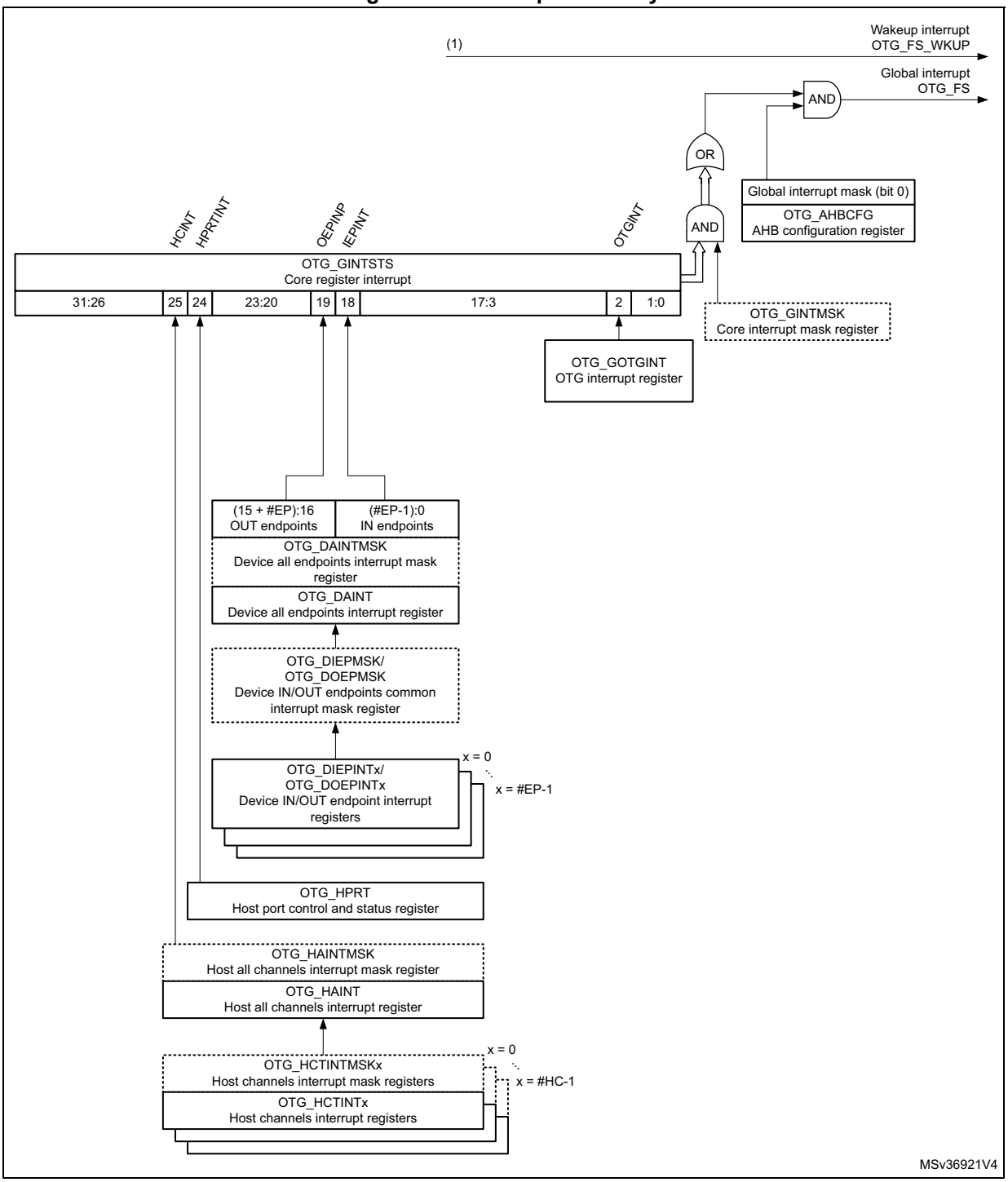
As the OTG_FS core is able to fill in the 1.25-Kbyte RAM buffer very efficiently, and as 1.25-Kbyte of transmit/receive data is more than enough to cover a full speed frame, the USB system is able to withstand the maximum full-speed data rate for up to one USB frame (1 ms) without any CPU intervention.

66.13 OTG_FS interrupts

When the OTG_FS controller is operating in one mode, either device or host, the application must not access registers from the other mode. If an illegal access occurs, a mode mismatch interrupt is generated and reflected in the core interrupt register (MMIS bit in the OTG_GINTSTS register). When the core switches from one mode to the other, the registers in the new mode of operation must be reprogrammed as they would be after a power-on reset.

Figure 937 shows the interrupt hierarchy.

Figure 937. Interrupt hierarchy



1. OTG_FS_WKUP becomes active (high state) when resume condition occurs during L1 SLEEP or L2 SUSPEND states.

66.14 OTG_FS control and status registers

By reading from and writing to the control and status registers (CSRs) through the AHB slave interface, the application controls the OTG_FS controller. These registers are 32 bits wide, and the addresses are 32-bit block aligned. The OTG_FS registers must be accessed by words (32 bits).

CSRs are classified as follows:

- Core global registers
- Host-mode registers
- Host global registers
- Host port CSRs
- Host channel-specific registers
- Device-mode registers
- Device global registers
- Device endpoint-specific registers
- Power and clock-gating registers
- Data FIFO (DFIFO) access registers

Only the core global, power and clock-gating, data FIFO access, and host port control and status registers can be accessed in both host and device modes. When the OTG_FS controller is operating in one mode, either device or host, the application must not access registers from the other mode. If an illegal access occurs, a mode mismatch interrupt is generated and reflected in the core interrupt register (MMIS bit in the OTG_GINTSTS register). When the core switches from one mode to the other, the registers in the new mode of operation must be reprogrammed as they would be after a power-on reset.

66.14.1 CSR memory map

The host and device mode registers occupy different addresses. All registers are implemented in the AHB clock domain.

Global CSR map

These registers are available in both host and device modes.

Table 732. Core global control and status registers (CSRs)

Acronym	Address offset	Register name
OTG_GOTGCTL	0x000	*Section 66.15.1: OTG control and status register (OTG_GOTGCTL)*
OTG_GOTGINT	0x004	*Section 66.15.2: OTG interrupt register (OTG_GOTGINT)*
OTG_GAHBCFG	0x008	*Section 66.15.3: OTG AHB configuration register (OTG_GAHBCFG)*
OTG_GUSBCFG	0x00C	*Section 66.15.4: OTG USB configuration register (OTG_GUSBCFG)*
OTG_GRSTCTL	0x010	*Section 66.15.5: OTG reset register (OTG_GRSTCTL)*
OTG_GINTSTS	0x014	*Section 66.15.6: OTG core interrupt register [alternate] (OTG_GINTSTS)* *Section 66.15.7: OTG core interrupt register [alternate] (OTG_GINTSTS)*

Table 732. Core global control and status registers (CSRs) (continued)

Acronym	Address offset	Register name
OTG_GINTMSK	0x018	*Section 66.15.8: OTG interrupt mask register [alternate] (OTG_GINTMSK)* *Section 66.15.9: OTG interrupt mask register [alternate] (OTG_GINTMSK)*
OTG_GRXSTSR	0x01C	*Section 66.15.10: OTG receive status debug read [alternate] (OTG_GRXSTSR)* *Section 66.15.11: OTG receive status debug read register [alternate] (OTG_GRXSTSR)*
OTG_GRXSTSP	0x020	*Section 66.15.12: OTG status read and pop registers [alternate] (OTG_GRXSTSP)* *Section 66.15.13: OTG status read and pop registers [alternate] (OTG_GRXSTSP)*
OTG_GRXFSIZ	0x024	*Section 66.15.14: OTG receive FIFO size register (OTG_GRXFSIZ)*
OTG_HNPTXFSIZ/ OTG_DIEPTXF0(1)	0x028	*Section 66.15.15: OTG host non-periodic transmit FIFO size register [alternate] (OTG_HNPTXFSIZ)* *Section 66.15.16: Endpoint 0 Transmit FIFO size [alternate] (OTG_DIEPTXF0)*
OTG_HNPTXSTS	0x02C	*Section 66.15.17: OTG non-periodic transmit FIFO/queue status register (OTG_HNPTXSTS)*
OTG_GCCFG	0x038	*Section 66.15.18: OTG general core configuration register (OTG_GCCFG)*
OTG_CID	0x03C	*Section 66.15.19: OTG core ID register (OTG_CID)*
OTG_GLPMCFG	0x54	*Section 66.15.20: OTG core LPM configuration register (OTG_GLPMCFG)*
OTG_HPTXFSIZ	0x100	*Section 66.15.21: OTG host periodic transmit FIFO size register (OTG_HPTXFSIZ)*
OTG_DIEPTXFx	0x104 0x108 ... 0x114	*Section 66.15.22: OTG device IN endpoint transmit FIFO x size register (OTG_DIEPTXFx)*

1. The general rule is to use OTG_HNPTXFSIZ for host mode and OTG_DIEPTXF0 for device mode.

Host-mode CSR map

These registers must be programmed every time the core changes to host mode.

Table 733. Host-mode control and status registers (CSRs)

Acronym	Offset address	Register name
OTG_HCFG	0x400	*Section 66.15.24: OTG host configuration register (OTG_HCFG)*
OTG_HFIR	0x404	*Section 66.15.25: OTG host frame interval register (OTG_HFIR)*
OTG_HFNUM	0x408	*Section 66.15.26: OTG host frame number/frame time remaining register (OTG_HFNUM)*

Table 733. Host-mode control and status registers (CSRs) (continued)

Acronym	Offset address	Register name
OTG_HPTXSTS	0x410	*Section 66.15.27: OTG_Host periodic transmit FIFO/queue status register (OTG_HPTXSTS)*
OTG_HAINT	0x414	*Section 66.15.28: OTG host all channels interrupt register (OTG_HAINT)*
OTG_HAINTMSK	0x418	*Section 66.15.29: OTG host all channels interrupt mask register (OTG_HAINTMSK)*
OTG_HPRT	0x440	*Section 66.15.30: OTG host port control and status register (OTG_HPRT)*
OTG_HCCHARx	0x500 0x520 ... 0x660	*Section 66.15.31: OTG host channel x characteristics register (OTG_HCCHARx)*
OTG_HCINTx	0x508 0x528 .... 0x668	*Section 66.15.32: OTG host channel x interrupt register (OTG_HCINTx)*
OTG_HCINTMSKx	0x50C 0x52C 0x66C	*Section 66.15.33: OTG host channel x interrupt mask register (OTG_HCINTMSKx)*
OTG_HCTSIZx	0x510 0x530 .... 0x670	*Section 66.15.34: OTG host channel x transfer size register (OTG_HCTSIZx)*

Device-mode CSR map

These registers must be programmed every time the core changes to device mode.

Table 734. Device-mode control and status registers

Acronym	Offset address	Register name
OTG_DCFG	0x800	*Section 66.15.36: OTG device configuration register (OTG_DCFG)*
OTG_DCTL	0x804	*Section 66.15.37: OTG device control register (OTG_DCTL)*
OTG_DSTS	0x808	*Section 66.15.38: OTG device status register (OTG_DSTS)*
OTG_DIEPMSK	0x810	*Section 66.15.39: OTG device IN endpoint common interrupt mask register (OTG_DIEPMSK)*
OTG_DOEPMSK	0x814	*Section 66.15.40: OTG device OUT endpoint common interrupt mask register (OTG_DOEPMSK)*
OTG_DAINT	0x818	*Section 66.15.41: OTG device all endpoints interrupt register (OTG_DAINT)*

Table 734. Device-mode control and status registers (continued)

Acronym	Offset address	Register name
OTG_DAINTMSK	0x81C	*Section 66.15.42: OTG all endpoints interrupt mask register (OTG_DAINTMSK)*
OTG_DIEPEMPMSK	0x834	*Section 66.15.43: OTG device IN endpoint FIFO empty interrupt mask register (OTG_DIEPEMPMSK)*
OTG_DEACHINT	0x838	*Section 66.15.44: OTG device each endpoint interrupt register (OTG_DEACHINT)*
OTG_DEACHINTMSK	0x83C	*Section 66.15.45: OTG device each endpoint interrupt mask register (OTG_DEACHINTMSK)*
OTG_DIEPEACHM	0x844	*Section 66.15.46: OTG device each IN endpoint-1 interrupt mask register (OTG_DIEPEACHM)*
OTG_DOEPEACHMSK1	0x884	*Section 66.15.47: OTG device each OUT endpoint-1 interrupt mask register (OTG_DOEPEACHMSK1)*
OTG_DIEPCTL0	0x900	*Section 66.15.48: OTG device control IN endpoint 0 control register (OTG_DIEPCTL0)*
OTG_DIEPCTLx	0x920 0x940 ... 0x9A0	*Section 66.15.49: OTG device IN endpoint x control register [alternate] (OTG_DIEPCTLx)* *Section 66.15.50: OTG device IN endpoint x control register [alternate] (OTG_DIEPCTLx)*
OTG_DIEPINTx	0x908 0x928 .... 0x988	*Section 66.15.51: OTG device IN endpoint x interrupt register (OTG_DIEPINTx)*
OTG_DIEPTSIZ0	0x910	*Section 66.15.52: OTG device IN endpoint 0 transfer size register (OTG_DIEPTSIZ0)*
OTG_DTXFSTSx	0x918 0x938 .... 0x998	*Section 66.15.53: OTG device IN endpoint transmit FIFO status register (OTG_DTXFSTSx)*
OTG_DIEPTSIZx	0x930 0x950 ... 0x9B0	*Section 66.15.54: OTG device IN endpoint x transfer size register (OTG_DIEPTSIZx)*
OTG_DOEPCTL0	0xB00	*Section 66.15.55: OTG device control OUT endpoint 0 control register (OTG_DOEPCTL0)*
OTG_DOEPINTx	0xB08 0xB28 ... 0xBA8	*Section 66.15.56: OTG device OUT endpoint x interrupt register (OTG_DOEPINTx)*

Table 734. Device-mode control and status registers (continued)

Acronym	Offset address	Register name
OTG_DOEPTSIZ0	0xB10	*Section 66.15.57: OTG device OUT endpoint 0 transfer size register (OTG_DOEPTSIZ0)*
OTG_DOEPCTLx	0xB20 0xB40 ... 0xBA0	*Section 66.15.58: OTG device OUT endpoint x control register [alternate] (OTG_DOEPCTLx)* *Section 66.15.59: OTG device OUT endpoint x control register [alternate] (OTG_DOEPCTLx)*
OTG_DOEPTSIZx	0xB30 0xB50 ... 0xBB0	*Section 66.15.60: OTG device OUT endpoint x transfer size register (OTG_DOEPTSIZx)*

Data FIFO (DFIFO) access register map

These registers, available in both host and device modes, are used to read or write the FIFO space for a specific endpoint or a channel, in a given direction. If a host channel is of type IN, the FIFO can only be read on the channel. Similarly, if a host channel is of type OUT, the FIFO can only be written on the channel.

Table 735. Data FIFO (DFIFO) access register map

FIFO access register section	Offset address	Access
Device IN endpoint 0/Host OUT Channel 0: DFIFO write access Device OUT endpoint 0/Host IN Channel 0: DFIFO read access	0x1000–0x1FFC	w r
Device IN endpoint 1/Host OUT Channel 1: DFIFO write access Device OUT endpoint 1/Host IN Channel 1: DFIFO read access	0x2000–0x2FFC	w r
...	...	...
Device IN endpoint x(1)/Host OUT Channel x(1): DFIFO write access Device OUT endpoint x(1)/Host IN Channel x(1): DFIFO read access	0xX000–0xXFFC	w r

1. Where x is 5in device mode and 11 in host mode.

Power and clock gating CSR map

There is a single register for power and clock gating. It is available in both host and device modes.

Table 736. Power and clock gating control and status registers

Acronym	Offset address	Register name
OTG_PCGCCTL	0xE00–0xE04	*Section 66.15.61: OTG power and clock gating control register (OTG_PCGCCTL)*

66.15 OTG_FS registers

These registers are available in both host and device modes, and do not need to be reprogrammed when switching between these modes.

Bit values in the register descriptions are expressed in binary unless otherwise specified.

66.15.1 OTG control and status register (OTG_GOTGCTL)

The OTG_GOTGCTL register controls the behavior and reflects the status of the OTG function of the core.

Address offset: 0x000

Reset value: 0x0001 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CUR MOD	OTG VER	BSVLD	ASVLD	DBCT	CID STS
										r	rw	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	EHEN	Res.	Res.	Res.	Res.	BVALO VAL	BVALO EN	AVALO VAL	AVALO EN	VBVAL OVAL	VBVAL OEN	Res.	Res.
			rw					rw	rw	rw	rw	rw	rw		

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **CURMOD:** Current mode of operation
Indicates the current mode (host or device).
0: Device mode
1: Host mode

Bit 20 **OTGVER:** OTG version
Selects the OTG revision.
0:OTG Version 1.3. OTG1.3 is obsolete for new product development.
1:OTG Version 2.0. In this version the core supports only data line pulsing for SRP.

Bit 19 **BSVLD:** B-session valid
Indicates the device mode transceiver status.
0: B-session is not valid.
1: B-session is valid.
In OTG mode, the user can use this bit to determine if the device is connected or disconnected.
Note: Only accessible in device mode.

Bit 18 **ASVLD:** A-session valid
Indicates the host mode transceiver status.
0: A-session is not valid
1: A-session is valid
Note: Only accessible in host mode.

Bit 17 **DBCT:** Long/short debounce time
Indicates the debounce time of a detected connection.
0: Long debounce time, used for physical connections (100 ms + 2.5 µs)
1: Short debounce time, used for soft connections (2.5 µs)
Note: Only accessible in host mode.

Bit 16 **CIDSTS:** Connector ID status
Indicates the connector ID status on a connect event.
0: The OTG_FS controller is in A-device mode
1: The OTG_FS controller is in B-device mode
Note: Accessible in both device and host modes.

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **EHEN:** Embedded host enable
It is used to select between OTG A device state machine and embedded host state machine.
0: OTG A device state machine is selected
1: Embedded host state machine is selected

Bits 11:8 Reserved, must be kept at reset value.

Bit 7 **BVALOVAL:** B-peripheral session valid override value.
This bit is used to set override value for Bvalid signal when BVALOEN bit is set.
0: Bvalid value is '0' when BVALOEN = 1
1: Bvalid value is '1' when BVALOEN = 1
Note: Only accessible in device mode.

Bit 6 **BVALOEN:** B-peripheral session valid override enable.
This bit is used to enable/disable the software to override the Bvalid signal using the BVALOVAL bit.
0: Override is disabled and Bvalid signal from the respective PHY selected is used internally by the core
1: Internally Bvalid received from the PHY is overridden with BVALOVAL bit value
Note: Only accessible in device mode.

Bit 5 **AVALOVAL:** A-peripheral session valid override value.
This bit is used to set override value for Avalid signal when AVALOEN bit is set.
0: Avalid value is '0' when AVALOEN = 1
1: Avalid value is '1' when AVALOEN = 1
Note: Only accessible in host mode.

Bit 4 **AVALOEN:** A-peripheral session valid override enable.
This bit is used to enable/disable the software to override the Avalid signal using the AVALOVAL bit.
0: Override is disabled and Avalid signal from the respective PHY selected is used internally by the core
1: Internally Avalid received from the PHY is overridden with AVALOVAL bit value
Note: Only accessible in host mode.

Bit 3 **VBVALOVAL:** V_{BUS} valid override value.

This bit is used to set override value for vbusvalid signal when VBVALOEN bit is set.

0: vbusvalid value is '0' when VBVALOEN = 1

1: vbusvalid value is '1' when VBVALOEN = 1

Note: Only accessible in host mode.

Bit 2 **VBVALOEN:** V_{BUS} valid override enable.

This bit is used to enable/disable the software to override the vbusvalid signal using the VBVALOVAL bit.

0: Override is disabled and vbusvalid signal from the respective PHY selected is used internally by the core

1: Internally vbusvalid received from the PHY is overridden with VBVALOVAL bit value

Note: Only accessible in host mode.

Bits 1:0 Reserved, must be kept at reset value.

66.15.2 OTG interrupt register (OTG_GOTGINT)

The application reads this register whenever there is an OTG interrupt and clears the bits in this register to clear the OTG interrupt.

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADTO CHG	Res.	Res.
													rc_w1		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEDET	Res.	Res.
													rc_w1		

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **ADTOCHG:** A-device timeout change

The core sets this bit to indicate that the A-device has timed out while waiting for the B-device to connect.

Note: Accessible in both device and host modes.

Bits 17:3 Reserved, must be kept at reset value.

Bit 2 **SEDET:** Session end detected

The core sets this bit to indicate that the level of the voltage on V_{BUS} is no longer valid for a B-Peripheral session when V_{BUS} < 0.8 V.

Note: Accessible in both device and host modes.

Bits 1:0 Reserved, must be kept at reset value.

66.15.3 OTG AHB configuration register (OTG_GAHBCFG)

This register can be used to configure the core after power-on or a change in mode. This register mainly contains AHB system-related configuration parameters. Do not change this register after the initial programming. The application must program this register before starting any transactions on either the AHB or the USB.

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	PTXFE LVL	TXFE LVL	Res.	Res.	Res.	Res.	Res.	Res.	GINT MSK
							rw	rw							rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **PTXFELVL:** Periodic Tx FIFO empty level

Indicates when the periodic Tx FIFO empty interrupt bit in the OTG_GINTSTS register (PTXFE bit in OTG_GINTSTS) is triggered.

0: PTXFE (in OTG_GINTSTS) interrupt indicates that the Periodic Tx FIFO is half empty

1: PTXFE (in OTG_GINTSTS) interrupt indicates that the Periodic Tx FIFO is completely empty

Note: Only accessible in host mode.

Bit 7 **TXFELVL:** Tx FIFO empty level

Condition: device mode. This bit indicates when IN endpoint Transmit FIFO empty interrupt (TXFE in OTG_DIEPINTx) is triggered:

0: The TXFE (in OTG_DIEPINTx) interrupt indicates that the IN endpoint Tx FIFO is half empty

1: The TXFE (in OTG_DIEPINTx) interrupt indicates that the IN endpoint Tx FIFO is completely empty

Condition: host mode. This bit indicates when the nonperiodic Tx FIFO empty interrupt (NPTXFE bit in OTG_GINTSTS) is triggered:

0: The NPTXFE (in OTG_GINTSTS) interrupt indicates that the nonperiodic Tx FIFO is half empty

1: The NPTXFE (in OTG_GINTSTS) interrupt indicates that the nonperiodic Tx FIFO is completely empty

Bits 6:1 Reserved, must be kept at reset value.

Bit 0 **GINTMSK:** Global interrupt mask

The application uses this bit to mask or unmask the interrupt line assertion to itself. Irrespective of this bit's setting, the interrupt status registers are updated by the core.

0: Mask the interrupt assertion to the application.

1: Unmask the interrupt assertion to the application.

Note: Accessible in both device and host modes.

66.15.4 OTG USB configuration register (OTG_GUSBCFG)

This register can be used to configure the core after power-on or a changing to host mode or device mode. It contains USB and USB-PHY related configuration parameters. The application must program this register before starting any transactions on either the AHB or the USB. Do not make changes to this register after the initial programming.

Address offset: 0x00C

Reset value: 0x0000 1440

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	FD MOD	FH MOD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw	rw													
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	TRDT[3:0]				Res.	Res.	Res.	PHY SEL	Res.	Res.	Res.	TOCAL[2:0]		
		rw	rw	rw	rw				r				rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **FDMOD:** Force device mode

Writing a 1 to this bit, forces the core to device mode irrespective of the OTG_ID input pin.
0: Normal mode
1: Force device mode
After setting the force bit, the application must wait at least 25 ms before the change takes effect.

Note: Accessible in both device and host modes.

Bit 29 **FHMOD:** Force host mode

Writing a 1 to this bit, forces the core to host mode irrespective of the OTG_ID input pin.
0: Normal mode
1: Force host mode
After setting the force bit, the application must wait at least 25 ms before the change takes effect.

Note: Accessible in both device and host modes.

Bits 28:14 Reserved, must be kept at reset value.

Bits 13:10 **TRDT[3:0]:** USB turnaround time

These bits allows to set the turnaround time in PHY clocks. They must be configured according to *Table 737: TRDT values*, depending on the application AHB frequency. Higher TRDT values allow stretching the USB response time to IN tokens in order to compensate for longer AHB read access latency to the data FIFO.

Note: Only accessible in device mode.

Bits 9:7 Reserved, must be kept at reset value.

Bit 6 **PHYSEL:** Full Speed serial transceiver mode select
This bit is always 1 with read-only access.

Bits 5:3 Reserved, must be kept at reset value.

Bits 2:0 **TOCAL[2:0]:** FS timeout calibration
The number of PHY clocks that the application programs in this field is added to the full-speed interpacket timeout duration in the core to account for any additional delays introduced by the PHY. This can be required, because the delay introduced by the PHY in generating the line state condition can vary from one PHY to another.
The USB standard timeout value for full-speed operation is 16 to 18 (inclusive) bit times. The application must program this field based on the speed of enumeration. The number of bit times added per PHY clock is 0.25 bit times.

Table 737. TRDT values

AHB frequency range (MHz)		TRDT minimum value
Min	Max	
14.2	15	0xF
15	16	0xE
16	17.2	0xD
17.2	18.5	0xC
18.5	20	0xB
20	21.8	0xA
21.8	24	0x9
24	27.5	0x8
27.5	32	0x7
32	-	0x6

66.15.5 OTG reset register (OTG_GRSTCTL)

The application uses this register to reset various hardware features inside the core.

Address offset: 0x010

Reset value: 0x8000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AHB IDL	Res.	CSRST DONE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r		rc_w1													

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	TXFNUM[4:0]					TXF FLSH	RXF FLSH	Res.	FCRST	PSRST	CSRST
					rw	rw	rw	rw	rw	rs	rs		rs	rs	rw

Bit 31 **AHBIDL:** AHB master idle

Indicates that the AHB master state machine is in the Idle condition.

Note: Accessible in both device and host modes.

Bit 30 Reserved, must be kept at reset value.

Bit 29 **CSRSTDONE**: Core soft reset done

The core sets this bit when all the necessary logic is reset in the core. This bit is cleared by the application along with CSRST.

0: Core reset not done

1: Core reset done

Bits 28:11 Reserved, must be kept at reset value.

Bits 10:6 **TXFNUM[4:0]:** Tx FIFO number

This is the FIFO number that must be flushed using the Tx FIFO Flush bit. This field must not be changed until the core clears the Tx FIFO Flush bit.

Condition: host mode

00000: Non-periodic Tx FIFO flush

00001: Periodic Tx FIFO flush

10000: Flush all the transmit FIFOs

Condition: device mode

00000: Tx FIFO 0 flush

00001: Tx FIFO 1 flush

00010: Tx FIFO 2 flush

...

01111: Tx FIFO 15 flush

10000: Flush all the transmit FIFOs

Note: Accessible in both device and host modes.

Bit 5 **TXFFLSH:** Tx FIFO flush

This bit selectively flushes a single or all transmit FIFOs, but cannot do so if the core is in the midst of a transaction.

The application must write this bit only after checking that the core is neither writing to the Tx FIFO nor reading from the Tx FIFO. Verify using these registers:

Read—NAK Effective interrupt ensures the core is not reading from the FIFO

Write—AHBIDL bit in OTG_GRSTCTL ensures the core is not writing anything to the FIFO.

Flushing is normally recommended when FIFOs are reconfigured. FIFO flushing is also recommended during device endpoint disable. The application must wait until the core clears this bit before performing any operations. This bit takes eight clocks to clear, using the slower clock of phy_clk or hclk.

Note: Accessible in both device and host modes.

Bit 4 **RXFFLSH:** Rx FIFO flush

The application can flush the entire Rx FIFO using this bit, but must first ensure that the core is not in the middle of a transaction.

The application must only write to this bit after checking that the core is neither reading from the Rx FIFO nor writing to the Rx FIFO.

The application must wait until the bit is cleared before performing any other operations. This bit requires 8 clocks (slowest of PHY or AHB clock) to clear.

Note: Accessible in both device and host modes.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **FCRST:** Host frame counter reset

The application writes this bit to reset the frame number counter inside the core. When the frame counter is reset, the subsequent SOF sent out by the core has a frame number of 0.

When application writes '1' to the bit, it might not be able to read back the value as it gets cleared by the core in a few clock cycles.

Note: Only accessible in host mode.

Bit 1 **PSRST:** Partial soft reset

Resets the internal state machines but keeps the enumeration info. Could be used to recover some specific PHY errors.

Note: Accessible in both device and host modes.

Bit 0 **CSRST:** Core soft reset

Resets the HCLK and PHY clock domains as follows:

Clears the interrupts and all the CSR register bits except for the following bits:

– GATEHCLK bit in OTG_PCGCCTL
– STPPCLK bit in OTG_PCGCCTL
– FSLSPCS bits in OTG_HCFG
– DSPD bit in OTG_DCFG
– SDIS bit in OTG_DCTL
– OTG_GCCFG register

All module state machines (except for the AHB slave unit) are reset to the Idle state, and all the transmit FIFOs and the receive FIFO are flushed.

Any transactions on the AHB Master are terminated as soon as possible, after completing the last data phase of an AHB transfer. Any transactions on the USB are terminated immediately.

The application can write to this bit any time it wants to reset the core. The application must clear this bit after checking CSRSTDONE (core soft reset done). The application must also check that AHBIDL = 1 (AHB master is IDLE) before starting any operation.

Typically, the software reset is used during software development and also when the PHY selection bits are dynamically changed in the USB configuration registers listed above. When the PHY is changed, the corresponding clock for the PHY is selected and used in the PHY domain. Once a new clock is selected, the PHY domain has to be reset for proper operation.

Note: Accessible in both device and host modes.

66.15.6 OTG core interrupt register [alternate] (OTG_GINTSTS)

Valid for Host mode, see next section for Device mode.

This register also indicates the current mode. To clear the interrupt status bits of the rc_w1 type, the application must write 1 into the bit.

This register interrupts the application for system-level events in the current mode (device mode or host mode).

The FIFO status interrupts are read-only; once software reads from or writes to the FIFO while servicing these interrupts, FIFO interrupt conditions are cleared automatically.

The application must clear the OTG_GINTSTS register at initialization before unmasking the interrupt bit to avoid any interrupts generated prior to initialization.

Address offset: 0x014

Reset value: 0x0400 0020

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WKUP INT	SRQ INT	DISC INT	CIDS CHG	LPM INT	PTXFE	HCINT	HPRT INT	RST DET	Res.	IPXFR	IISOI XFR	OEP INT	IEPINT	Res.	Res.
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	r	r	r	rc_w1		rc_w1	rc_w1	r	r		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EOPF	ISOO DRP	ENUM DNE	USB RST	USB SUSP	ESUSP	Res.	Res.	GO NAK EFF	GI NAK EFF	NPTXF E	RXF LVL	SOF	OTG INT	MMIS	CMOD
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1			r	r	r	r	rc_w1	r	rc_w1	r

Bit 31 **WKUPINT:** Resume/remote wakeup detected interrupt

Wakeup interrupt during suspend(L2) or LPM(L1) state.

– During suspend(L2):

In device mode, this interrupt is asserted when a resume is detected on the USB. In host mode, this interrupt is asserted when a remote wakeup is detected on the USB.

– During LPM(L1):

This interrupt is asserted for either host initiated resume or device initiated remote wakeup on USB.

Note: Accessible in both device and host modes.

Bit 30 **SRQINT:** Session request/new session detected interrupt

In host mode, this interrupt is asserted when a session request is detected from the device. In device mode, this interrupt is asserted when V_{BUS} is in the valid range for a B-peripheral device. Accessible in both device and host modes.

Bit 29 **DISCINT:** Disconnect detected interrupt

Asserted when a device disconnect is detected.

Note: Only accessible in host mode.

Bit 28 **CIDSCHG:** Connector ID status change

The core sets this bit when there is a change in connector ID status.

Note: Accessible in both device and host modes.

Bit 27 **LPMINT:** LPM interrupt

In device mode, this interrupt is asserted when the device receives an LPM transaction and responds with a non-ERRORed response.

In host mode, this interrupt is asserted when the device responds to an LPM transaction with a non-ERRORed response or when the host core has completed LPM transactions for the programmed number of times (RETRYCNT bit in OTG_GLPMCFG).

This field is valid only if the LPMEN bit in OTG_GLPMCFG is set to 1.

Bit 26 **PTXFE:** Periodic Tx FIFO empty

Asserted when the periodic transmit FIFO is either half or completely empty and there is space for at least one entry to be written in the periodic request queue. The half or completely empty status is determined by the periodic Tx FIFO empty level bit in the OTG_GAHBCFG register (PTXFELVL bit in OTG_GAHBCFG).

Note: Only accessible in host mode.

Bit 25 **HCINT:** Host channels interrupt

The core sets this bit to indicate that an interrupt is pending on one of the channels of the core (in host mode). The application must read the OTG_HAINT register to determine the exact number of the channel on which the interrupt occurred, and then read the corresponding OTG_HCINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the OTG_HCINTx register to clear this bit.

Note: Only accessible in host mode.

Bit 24 **HPRTINT:** Host port interrupt

The core sets this bit to indicate a change in port status of one of the OTG_FS controller ports in host mode. The application must read the OTG_HPRT register to determine the exact event that caused this interrupt. The application must clear the appropriate status bit in the OTG_HPRT register to clear this bit.

Note: Only accessible in host mode.

Bit 23 **RSTDET:** Reset detected interrupt

In device mode, this interrupt is asserted when a reset is detected on the USB in partial power-down mode when the device is in suspend.

Note: Only accessible in device mode.

Bit 22 Reserved, must be kept at reset value.

Bit 21 **IPXFR:** Incomplete periodic transfer

In host mode, the core sets this interrupt bit when there are incomplete periodic transactions still pending, which are scheduled for the current frame.

Bit 20 **IISOIXFR:** Incomplete isochronous IN transfer

The core sets this interrupt to indicate that there is at least one isochronous IN endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the End of periodic frame interrupt (EOPF) bit in this register.

Note: Only accessible in device mode.

Bit 19 **OEPINT:** OUT endpoint interrupt

The core sets this bit to indicate that an interrupt is pending on one of the OUT endpoints of the core (in device mode). The application must read the OTG_DAINT register to determine the exact number of the OUT endpoint on which the interrupt occurred, and then read the corresponding OTG_DOEPINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the corresponding OTG_DOEPINTx register to clear this bit.

Note: Only accessible in device mode.

Bit 18 **IEPINT:** IN endpoint interrupt

The core sets this bit to indicate that an interrupt is pending on one of the IN endpoints of the core (in device mode). The application must read the OTG_DAINT register to determine the exact number of the IN endpoint on which the interrupt occurred, and then read the corresponding OTG_DIEPINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the corresponding OTG_DIEPINTx register to clear this bit.

Note: Only accessible in device mode.

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 **EOPF:** End of periodic frame interrupt

Indicates that the period specified in the periodic frame interval field of the OTG_DCFG register (PFIVL bit in OTG_DCFG) has been reached in the current frame.

Note: Only accessible in device mode.

Bit 14 **ISOODRP:** Isochronous OUT packet dropped interrupt

The core sets this bit when it fails to write an isochronous OUT packet into the Rx FIFO because the Rx FIFO does not have enough space to accommodate a maximum size packet for the isochronous OUT endpoint.

Note: Only accessible in device mode.

Bit 13 **ENUMDNE:** Enumeration done

The core sets this bit to indicate that speed enumeration is complete. The application must read the OTG_DSTS register to obtain the enumerated speed.

Note: Only accessible in device mode.

Bit 12 **USBRST:** USB reset

The core sets this bit to indicate that a reset is detected on the USB.

Note: Only accessible in device mode.

Bit 11 **USBSUSP:** USB suspend

The core sets this bit to indicate that a suspend was detected on the USB. The core enters the suspended state when there is no activity on the data lines for an extended period of time.

Note: Only accessible in device mode.

Bit 10 **ESUSP:** Early suspend

The core sets this bit to indicate that an Idle state has been detected on the USB for 3 ms.

Note: Only accessible in device mode.

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 **GONAKEFF:** Global OUT NAK effective

Indicates that the Set global OUT NAK bit in the OTG_DCTL register (SGONAK bit in OTG_DCTL), set by the application, has taken effect in the core. This bit can be cleared by writing the Clear global OUT NAK bit in the OTG_DCTL register (CGONAK bit in OTG_DCTL).

Note: Only accessible in device mode.

Bit 6 **GINAKEFF:** Global IN non-periodic NAK effective

Indicates that the Set global non-periodic IN NAK bit in the OTG_DCTL register (SGINAK bit in OTG_DCTL), set by the application, has taken effect in the core. That is, the core has sampled the Global IN NAK bit set by the application. This bit can be cleared by clearing the Clear global non-periodic IN NAK bit in the OTG_DCTL register (CGINAK bit in OTG_DCTL).

This interrupt does not necessarily mean that a NAK handshake is sent out on the USB. The STALL bit takes precedence over the NAK bit.

Note: Only accessible in device mode.

Bit 5 **NPTXFE:** Non-periodic Tx FIFO empty

This interrupt is asserted when the non-periodic Tx FIFO is either half or completely empty, and there is space for at least one entry to be written to the non-periodic transmit request queue. The half or completely empty status is determined by the non-periodic Tx FIFO empty level bit in the OTG_GAHBCFG register (TXFELVL bit in OTG_GAHBCFG).

Note: Accessible in host mode only.

Bit 4 **RXFLVL:** Rx FIFO non-empty

Indicates that there is at least one packet pending to be read from the Rx FIFO.

Note: Accessible in both host and device modes.

Bit 3 **SOF:** Start of frame

In host mode, the core sets this bit to indicate that an SOF (FS), or Keep-Alive (LS) is transmitted on the USB. The application must write a 1 to this bit to clear the interrupt.

In device mode, in the core sets this bit to indicate that an SOF token has been received on the USB. The application can read the OTG_DSTS register to get the current frame number. This interrupt is seen only when the core is operating in FS.

Note: This register may return '1' if read immediately after power on reset. If the register bit reads '1' immediately after power on reset it does not indicate that an SOF has been sent (in case of host mode) or SOF has been received (in case of device mode). The read value of this interrupt is valid only after a valid connection between host and device is established. If the bit is set after power on reset the application can clear the bit.

Note: Accessible in both host and device modes.

Bit 2 **OTGINT:** OTG interrupt

The core sets this bit to indicate an OTG protocol event. The application must read the OTG interrupt status (OTG_GOTGINT) register to determine the exact event that caused this interrupt. The application must clear the appropriate status bit in the OTG_GOTGINT register to clear this bit.

Note: Accessible in both host and device modes.

Bit 1 **MMIS:** Mode mismatch interrupt

The core sets this bit when the application is trying to access:

– A host mode register, when the core is operating in device mode

– A device mode register, when the core is operating in host mode

The register access is completed on the AHB with an OKAY response, but is ignored by the core internally and does not affect the operation of the core.

Note: Accessible in both host and device modes.

Bit 0 **CMOD:** Current mode of operation

Indicates the current mode.

0: Device mode

1: Host mode

Note: Accessible in both host and device modes.

66.15.7 OTG core interrupt register [alternate] (OTG_GINTSTS)

Valid for Device mode, see previous section for Host mode.

This register also indicates the current mode. To clear the interrupt status bits of the rc_w1 type, the application must write 1 into the bit.

This register interrupts the application for system-level events in the current mode (device mode or host mode).

The FIFO status interrupts are read-only; once software reads from or writes to the FIFO while servicing these interrupts, FIFO interrupt conditions are cleared automatically.

The application must clear the OTG_GINTSTS register at initialization before unmasking the interrupt bit to avoid any interrupts generated prior to initialization.

Address offset: 0x014

Reset value: 0x0400 0020

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WKUP INT	SRQ INT	DISC INT	CIDS CHG	LPM INT	PTXFE	HCINT	HPRT INT	RST DET	Res.	IN COMP ISO OUT	IISOI XFR	OEP INT	IEPINT	Res.	Res.
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	r	r	r	rc_w1		rc_w1	rc_w1	r	r		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EOPF	ISOO DRP	ENUM DNE	USB RST	USB SUSP	ESUSP	Res.	Res.	GO NAK EFF	GI NAK EFF	NPTXF E	RXF LVL	SOF	OTG INT	MMIS	CMOD
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1			r	r	r	r	rc_w1	r	rc_w1	r

Bit 31 **WKUPINT:** Resume/remote wakeup detected interrupt

Wakeup interrupt during suspend(L2) or LPM(L1) state.

– During suspend(L2):

In device mode, this interrupt is asserted when a resume is detected on the USB. In host mode, this interrupt is asserted when a remote wakeup is detected on the USB.

– During LPM(L1):

This interrupt is asserted for either host initiated resume or device initiated remote wakeup on USB.

Note: Accessible in both device and host modes.

Bit 30 **SRQINT:** Session request/new session detected interrupt

In host mode, this interrupt is asserted when a session request is detected from the device. In device mode, this interrupt is asserted when V_{BUS} is in the valid range for a B-peripheral device. Accessible in both device and host modes.

Bit 29 **DISCINT:** Disconnect detected interrupt

Asserted when a device disconnect is detected.

Note: Only accessible in host mode.

Bit 28 **CIDSCHG:** Connector ID status change

The core sets this bit when there is a change in connector ID status.

Note: Accessible in both device and host modes.

Bit 27 **LPMINT:** LPM interrupt

In device mode, this interrupt is asserted when the device receives an LPM transaction and responds with a non-ERRORed response.

In host mode, this interrupt is asserted when the device responds to an LPM transaction with a non-ERRORed response or when the host core has completed LPM transactions for the programmed number of times (RETRYCNT bit in OTG_GLPMCFG).

This field is valid only if the LPMEN bit in OTG_GLPMCFG is set to 1.

Bit 26 **PTXFE:** Periodic Tx FIFO empty

Asserted when the periodic transmit FIFO is either half or completely empty and there is space for at least one entry to be written in the periodic request queue. The half or completely empty status is determined by the periodic Tx FIFO empty level bit in the OTG_GAHBCFG register (PTXFELVL bit in OTG_GAHBCFG).

Note: Only accessible in host mode.

Bit 25 **HCINT:** Host channels interrupt

The core sets this bit to indicate that an interrupt is pending on one of the channels of the core (in host mode). The application must read the OTG_HAINT register to determine the exact number of the channel on which the interrupt occurred, and then read the corresponding OTG_HCINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the OTG_HCINTx register to clear this bit.

Note: Only accessible in host mode.

Bit 24 **HPRTINT:** Host port interrupt

The core sets this bit to indicate a change in port status of one of the OTG_FS controller ports in host mode. The application must read the OTG_HPRT register to determine the exact event that caused this interrupt. The application must clear the appropriate status bit in the OTG_HPRT register to clear this bit.

Note: Only accessible in host mode.

Bit 23 **RSTDET:** Reset detected interrupt

In device mode, this interrupt is asserted when a reset is detected on the USB in partial power-down mode when the device is in suspend.

Note: Only accessible in device mode.

Bit 22 Reserved, must be kept at reset value.

Bit 21 **INCOMPISOOUT:** Incomplete isochronous OUT transfer

In device mode, the core sets this interrupt to indicate that there is at least one isochronous OUT endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the End of periodic frame interrupt (EOPF) bit in this register.

Bit 20 **IISOIXFR:** Incomplete isochronous IN transfer

The core sets this interrupt to indicate that there is at least one isochronous IN endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the End of periodic frame interrupt (EOPF) bit in this register.

Note: Only accessible in device mode.

Bit 19 **OEPINT:** OUT endpoint interrupt

The core sets this bit to indicate that an interrupt is pending on one of the OUT endpoints of the core (in device mode). The application must read the OTG_DAINT register to determine the exact number of the OUT endpoint on which the interrupt occurred, and then read the corresponding OTG_DOEPINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the corresponding OTG_DOEPINTx register to clear this bit.

Note: Only accessible in device mode.

Bit 18 **IEPINT:** IN endpoint interrupt

The core sets this bit to indicate that an interrupt is pending on one of the IN endpoints of the core (in device mode). The application must read the OTG_DAINT register to determine the exact number of the IN endpoint on which the interrupt occurred, and then read the corresponding OTG_DIEPINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the corresponding OTG_DIEPINTx register to clear this bit.

Note: Only accessible in device mode.

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 **EOPF:** End of periodic frame interrupt

Indicates that the period specified in the periodic frame interval field of the OTG_DCFG register (PFIVL bit in OTG_DCFG) has been reached in the current frame.

Note: Only accessible in device mode.

Bit 14 **ISOODRP:** Isochronous OUT packet dropped interrupt

The core sets this bit when it fails to write an isochronous OUT packet into the Rx FIFO because the Rx FIFO does not have enough space to accommodate a maximum size packet for the isochronous OUT endpoint.

Note: Only accessible in device mode.

Bit 13 **ENUMDNE:** Enumeration done

The core sets this bit to indicate that speed enumeration is complete. The application must read the OTG_DSTS register to obtain the enumerated speed.

Note: Only accessible in device mode.

Bit 12 **USBRST:** USB reset

The core sets this bit to indicate that a reset is detected on the USB.

Note: Only accessible in device mode.

Bit 11 **USBSUSP:** USB suspend

The core sets this bit to indicate that a suspend was detected on the USB. The core enters the suspended state when there is no activity on the data lines for an extended period of time.

Note: Only accessible in device mode.

Bit 10 **ESUSP:** Early suspend

The core sets this bit to indicate that an Idle state has been detected on the USB for 3 ms.

Note: Only accessible in device mode.

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 **GONAKEFF:** Global OUT NAK effective

Indicates that the Set global OUT NAK bit in the OTG_DCTL register (SGONAK bit in OTG_DCTL), set by the application, has taken effect in the core. This bit can be cleared by writing the Clear global OUT NAK bit in the OTG_DCTL register (CGONAK bit in OTG_DCTL).

Note: Only accessible in device mode.

Bit 6 **GINAKEFF:** Global IN non-periodic NAK effective

Indicates that the Set global non-periodic IN NAK bit in the OTG_DCTL register (SGINAK bit in OTG_DCTL), set by the application, has taken effect in the core. That is, the core has sampled the Global IN NAK bit set by the application. This bit can be cleared by clearing the Clear global non-periodic IN NAK bit in the OTG_DCTL register (CGINAK bit in OTG_DCTL).

This interrupt does not necessarily mean that a NAK handshake is sent out on the USB. The STALL bit takes precedence over the NAK bit.

Note: Only accessible in device mode.

Bit 5 **NPTXFE:** Non-periodic Tx FIFO empty

This interrupt is asserted when the non-periodic Tx FIFO is either half or completely empty, and there is space for at least one entry to be written to the non-periodic transmit request queue. The half or completely empty status is determined by the non-periodic Tx FIFO empty level bit in the OTG_GAHBCFG register (TXFELVL bit in OTG_GAHBCFG).

Note: Accessible in host mode only.

Bit 4 **RXFLVL:** Rx FIFO non-empty

Indicates that there is at least one packet pending to be read from the Rx FIFO.

Note: Accessible in both host and device modes.

Bit 3 **SOF:** Start of frame

In host mode, the core sets this bit to indicate that an SOF (FS), or Keep-Alive (LS) is transmitted on the USB. The application must write a 1 to this bit to clear the interrupt.

In device mode, in the core sets this bit to indicate that an SOF token has been received on the USB. The application can read the OTG_DSTS register to get the current frame number. This interrupt is seen only when the core is operating in FS.

Note: This register may return '1' if read immediately after power on reset. If the register bit reads '1' immediately after power on reset it does not indicate that an SOF has been sent (in case of host mode) or SOF has been received (in case of device mode). The read value of this interrupt is valid only after a valid connection between host and device is established. If the bit is set after power on reset the application can clear the bit.

Note: Accessible in both host and device modes.

Bit 2 **OTGINT:** OTG interrupt

The core sets this bit to indicate an OTG protocol event. The application must read the OTG interrupt status (OTG_GOTGINT) register to determine the exact event that caused this interrupt. The application must clear the appropriate status bit in the OTG_GOTGINT register to clear this bit.

Note: Accessible in both host and device modes.

Bit 1 **MMIS:** Mode mismatch interrupt

The core sets this bit when the application is trying to access:

– A host mode register, when the core is operating in device mode

– A device mode register, when the core is operating in host mode

The register access is completed on the AHB with an OKAY response, but is ignored by the core internally and does not affect the operation of the core.

Note: Accessible in both host and device modes.

Bit 0 **CMOD:** Current mode of operation

Indicates the current mode.

0: Device mode

1: Host mode

Note: Accessible in both host and device modes.

66.15.8 OTG interrupt mask register [alternate] (OTG_GINTMSK)

Valid for Host mode, see next section for Device mode.

This register works with the core interrupt register to interrupt the application. When an interrupt bit is masked, the interrupt associated with that bit is not generated. However, the core interrupt (OTG_GINTSTS) register bit corresponding to that interrupt is still set.

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WUIM	SRQIM	DISCINT	CIDSCHGM	LPMINTM	PTXFEM	HCIM	PRTIM	Res.	Res.	IPXFRM	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw			rc_w1					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NPTXFEM	RXFLVLM	SOFM	OTGINT	MMISM	Res.
										rw	rw	rw	rw	rw	

Bit 31 **WUIM:** Resume/remote wakeup detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 30 **SRQIM:** Session request/new session detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 29 **DISCINT:** Disconnect detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 28 **CIDSCHGM:** Connector ID status change mask
0: Masked interrupt
1: Unmasked interrupt

Bit 27 **LPMINTM:** LPM interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 26 **PTXFEM:** Periodic Tx FIFO empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 25 **HCIM:** Host channels interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 24 **PRTIM:** Host port interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **IPXFRM:** Incomplete periodic transfer mask
0: Masked interrupt
1: Unmasked interrupt

Bits 20:6 Reserved, must be kept at reset value.

Bit 5 **NPTXFEM:** Non-periodic Tx FIFO empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 4 **RXFLVLM:** Receive FIFO non-empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **SOFM:** Start of frame mask
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **OTGINT:** OTG interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **MMISM:** Mode mismatch interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 Reserved, must be kept at reset value.

66.15.9 OTG interrupt mask register [alternate] (OTG_GINTMSK)

Valid for Device mode, see previous section for Host mode.

This register works with the core interrupt register to interrupt the application. When an interrupt bit is masked, the interrupt associated with that bit is not generated. However, the core interrupt (OTG_GINTSTS) register bit corresponding to that interrupt is still set.

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WUIM	SRQIM	Res.	CIDSCHGM	LPMINTM	Res.	Res.	Res.	RSTDETM	Res.	IISOOXFRM	IISOIXFRM	OEPINT	IEPINT	Res.	Res.
rw	rw		rw	rw				rw		rw	rw	rw	rw		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EOPFM	ISOODRPM	ENUMDNEM	USBRST	USBSUSPM	ESUSPM	Res.	Res.	GONAKEFFM	GINAKEFFM	Res.	RXFLVLM	SOFM	OTGINT	MMISM	Res.
rw	rw	rw	rw	rw	rw			rw	rw		rw	rw	rw	rw	

Bit 31 **WUIM:** Resume/remote wakeup detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Accessible in both host and device modes.

Bit 30 **SRQIM:** Session request/new session detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Accessible in both host and device modes.

Bit 29 Reserved, must be kept at reset value.

Bit 28 **CIDSCHGM:** Connector ID status change mask
0: Masked interrupt
1: Unmasked interrupt
Note: Accessible in both host and device modes.

Bit 27 **LPMINTM:** LPM interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Accessible in both host and device modes.

Bits 26:24 Reserved, must be kept at reset value.

Bit 23 **RSTDETM:** Reset detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 22 Reserved, must be kept at reset value.

Bit 21 **IISOOXFRM:** Incomplete isochronous OUT transfer mask
0: Masked interrupt
1: Unmasked interrupt

Bit 20 **IISOIXFRM:** Incomplete isochronous IN transfer mask
0: Masked interrupt
1: Unmasked interrupt

Bit 19 **OEPINT:** OUT endpoints interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 18 **IEPINT:** IN endpoints interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 **EOPFM:** End of periodic frame interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 14 **ISOODRPM:** Isochronous OUT packet dropped interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 13 **ENUMDNEM:** Enumeration done mask
0: Masked interrupt
1: Unmasked interrupt

Bit 12 **USBRST:** USB reset mask
0: Masked interrupt
1: Unmasked interrupt

Bit 11 **USBSUSPM:** USB suspend mask
0: Masked interrupt
1: Unmasked interrupt

Bit 10 **ESUSPM:** Early suspend mask
0: Masked interrupt
1: Unmasked interrupt

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 **GONAKEFFM:** Global OUT NAK effective mask
0: Masked interrupt
1: Unmasked interrupt

Bit 6 **GINAKEFFM:** Global non-periodic IN NAK effective mask
0: Masked interrupt
1: Unmasked interrupt

Bit 5 Reserved, must be kept at reset value.

Bit 4 **RXFLVLM:** Receive FIFO non-empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **SOFM:** Start of frame mask
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **OTGINT:** OTG interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **MMISM:** Mode mismatch interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 Reserved, must be kept at reset value.

66.15.10 OTG receive status debug read [alternate] (OTG_GRXSTSR)

Valid for Host mode, see next section for Device mode.

A read to the receive status debug read register returns the contents of the top of the receive FIFO.

The core ignores the receive status read when the receive FIFO is empty and returns a value of 0x0000 0000.

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTSTS[3:0]				DPID
											r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DPID	BCNT[10:0]											CHNUM[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:17 **PKTSTS[3:0]:** Packet status
Indicates the status of the received packet
0010: IN data packet received
0011: IN transfer completed (triggers an interrupt)
0101: Data toggle error (triggers an interrupt)
0111: Channel halted (triggers an interrupt)
Others: Reserved

Bits 16:15 **DPID[1:0]:** Data PID
Indicates the data PID of the received packet
00: DATA0
10: DATA1

Bits 14:4 **BCNT[10:0]:** Byte count
Indicates the byte count of the received IN data packet.

Bits 3:0 **CHNUM[3:0]:** Channel number
Indicates the channel number to which the current received packet belongs.

66.15.11 OTG receive status debug read register [alternate] (OTG_GRXSTSR)

Valid for Device mode, see previous section for Host mode.

A read to the receive status debug read register returns the contents of the top of the receive FIFO.

The core ignores the receive status read when the receive FIFO is empty and returns a value of 0x0000 0000.

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	STSPHST	Res.	Res.	FRMNUM[3:0]				PKTSTS[3:0]				DPID[1]
				r			r	r	r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DPID[0]	BCNT[10:0]											EPNUM[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **STSPHST:** Status phase start
Indicates the start of the status phase for a control write transfer. This bit is set along with the OUT transfer completed PKTSTS pattern.

Bits 26:25 Reserved, must be kept at reset value.

Bits 24:21 **FRMNUM[3:0]:** Frame number
This is the least significant 4 bits of the frame number in which the packet is received on the USB. This field is supported only when isochronous OUT endpoints are supported.

Bits 20:17 **PKTSTS[3:0]:** Packet status
Indicates the status of the received packet
0001: Global OUT NAK (triggers an interrupt)
0010: OUT data packet received
0011: OUT transfer completed (triggers an interrupt)
0100: SETUP transaction completed (triggers an interrupt)
0110: SETUP data packet received
Others: Reserved

Bits 16:15 **DPID[1:0]:** Data PID
Indicates the data PID of the received OUT data packet
00: DATA0
10: DATA1

Bits 14:4 **BCNT[10:0]:** Byte count
Indicates the byte count of the received data packet.

Bits 3:0 **EPNUM[3:0]:** Endpoint number
Indicates the endpoint number to which the current received packet belongs.

66.15.12 OTG status read and pop registers [alternate] (OTG_GRXSTSP)

Valid for Host mode, see next section for Device mode.

Similarly to OTG_GRXSTSR (receive status debug read register) where a read returns the contents of the top of the receive FIFO, a read to OTG_GRXSTSP (receive status read and pop register) additionally pops the top data entry out of the Rx FIFO.

The core ignores the receive status pop/read when the receive FIFO is empty and returns a value of 0x0000 0000. The application must only pop the receive status FIFO when the receive FIFO non-empty bit of the core interrupt register (RXFLVL bit in OTG_GINTSTS) is asserted.

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTSTS[3:0]				DPID
											r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DPID	BCNT[10:0]											CHNUM[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:17 **PKTSTS[3:0]:** Packet status
Indicates the status of the received packet
0010: IN data packet received
0011: IN transfer completed (triggers an interrupt)
0101: Data toggle error (triggers an interrupt)
0111: Channel halted (triggers an interrupt)
Others: Reserved

Bits 16:15 **DPID[1:0]:** Data PID
Indicates the data PID of the received packet
00: DATA0
10: DATA1

Bits 14:4 **BCNT[10:0]:** Byte count
Indicates the byte count of the received IN data packet.

Bits 3:0 **CHNUM[3:0]:** Channel number
Indicates the channel number to which the current received packet belongs.

66.15.13 OTG status read and pop registers [alternate] (OTG_GRXSTSP)

Valid for Device mode, see previous section for Host mode.

This description is for register OTG_GRXSTSP in Device mode.

Similarly to OTG_GRXSTSR (receive status debug read register) where a read returns the contents of the top of the receive FIFO, a read to OTG_GRXSTSP (receive status read and pop register) additionally pops the top data entry out of the Rx FIFO.

The core ignores the receive status pop/read when the receive FIFO is empty and returns a value of 0x0000 0000. The application must only pop the receive status FIFO when the receive FIFO non-empty bit of the core interrupt register (RXFLVL bit in OTG_GINTSTS) is asserted.

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	STSPHST	Res.	Res.	FRMNUM[3:0]				PKTSTS[3:0]				DPID[1]
				r			r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DPID[0]	BCNT[10:0]											EPNUM[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **STSPHST:** Status phase start
Indicates the start of the status phase for a control write transfer. This bit is set along with the OUT transfer completed PKTSTS pattern.

Bits 26:25 Reserved, must be kept at reset value.

Bits 24:21 **FRMNUM[3:0]:** Frame number

This is the least significant 4 bits of the frame number in which the packet is received on the USB. This field is supported only when isochronous OUT endpoints are supported.

Bits 20:17 **PKTSTS[3:0]:** Packet status

Indicates the status of the received packet
0001: Global OUT NAK (triggers an interrupt)
0010: OUT data packet received
0011: OUT transfer completed (triggers an interrupt)
0100: SETUP transaction completed (triggers an interrupt)
0110: SETUP data packet received
Others: Reserved

Bits 16:15 **DPID[1:0]:** Data PID

Indicates the data PID of the received OUT data packet
00: DATA0
10: DATA1

Bits 14:4 **BCNT[10:0]:** Byte count

Indicates the byte count of the received data packet.

Bits 3:0 **EPNUM[3:0]:** Endpoint number

Indicates the endpoint number to which the current received packet belongs.

66.15.14 OTG receive FIFO size register (OTG_GRXFSIZ)

The application can program the RAM size that must be allocated to the Rx FIFO.

Address offset: 0x024

Reset value: 0x0000 0200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXFD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **RXFD[15:0]:** Rx FIFO depth

This value is in terms of 32-bit words.
Minimum value is 16
Programmed values must respect the available FIFO memory allocation and must not exceed the power-on value.

66.15.15 OTG host non-periodic transmit FIFO size register [alternate] (OTG_HNPTXFSIZ)

Valid for Host mode, see next section for Device mode.

Address offset: 0x028

Reset value: 0x0200 0200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NPTXFD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NPTXFSA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **NPTXFD[15:0]:** Non-periodic Tx FIFO depth
This value is in terms of 32-bit words.
Minimum value is 16
Programmed values must respect the available FIFO memory allocation and must not exceed the power-on value.

Bits 15:0 **NPTXFSA[15:0]:** Non-periodic transmit RAM start address
This field configures the memory start address for non-periodic transmit FIFO RAM.

66.15.16 Endpoint 0 Transmit FIFO size [alternate] (OTG_DIEPTXF0)

Valid for Device mode, see previous section for Host mode.

Address offset: 0x028

Reset value: 0x0200 0200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TX0FD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TX0FSA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **TX0FD[15:0]:** Endpoint 0 Tx FIFO depth
This value is in terms of 32-bit words.
Minimum value is 16
Programmed values must respect the available FIFO memory allocation and must not exceed the power-on value.

Bits 15:0 **TX0FSA[15:0]:** Endpoint 0 transmit RAM start address
This field configures the memory start address for the endpoint 0 transmit FIFO RAM.

66.15.17 OTG non-periodic transmit FIFO/queue status register (OTG_HNPTXSTS)

Host mode only, this register is not valid in Device mode.

This read-only register contains the free space information for the non-periodic Tx FIFO and the non-periodic transmit request queue.

Address offset: 0x02C

Reset value: 0x0008 0200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	NPTXQTOP[6:0]							NPTQXSAV[7:0]							
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NPTXFSAV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **NPTXQTOP[6:0]:** Top of the non-periodic transmit request queue
Entry in the non-periodic Tx request queue that is currently being processed by the MAC.
Bits 30:27: Channel/endpoint number
Bits 26:25:
XXXX00X: IN/OUT token
XXXX01X: Zero-length transmit packet (device IN/host OUT)
XXXX11X: Channel halt command
Bit 24: Terminate (last entry for selected channel/endpoint)

Bits 23:16 **NPTQXSAV[7:0]:** Non-periodic transmit request queue space available
Indicates the amount of free space available in the non-periodic transmit request queue. This queue holds both IN and OUT requests.
0: Non-periodic transmit request queue is full
1: 1 location available
2: locations available
n: n locations available (0 ≤ n ≤ 8)
Others: Reserved

Bits 15:0 **NPTXFSAV[15:0]:** Non-periodic Tx FIFO space available
Indicates the amount of free space available in the non-periodic Tx FIFO.
Values are in terms of 32-bit words.
0: Non-periodic Tx FIFO is full
1: 1 word available
2: 2 words available
n: n words available (where 0 ≤ n ≤ 512)
Others: Reserved

66.15.18 OTG general core configuration register (OTG_GCCFG)

Address offset: 0x038

Reset value: 0x0000 XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	FORCE HOST PD	COMP DIS	Res.	Res.	Res.	SDEN	PDEN	Res.	BCDEN	PWR DWN
						rw	rw				rw	rw		rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PS2 DET	SDET	PDET	Res.
												r	r	r	

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **FORCEHOSTPD:** Force host mode pull-downs

If the ID pin functions are enabled, the host mode pull-downs on DP and DM activate automatically. However, whenever that is not the case, yet host mode is required, this bit must be used to force the pull-downs active.

0: Do not force host mode pull-downs

1: Force host mode pull-downs

Bit 24 **COMPDIS:** Output resistance compensation disable

This bit is set and cleared by software.

0: R_{OUT} compensation enabled (default)

1: R_{OUT} compensation disabled

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 Reserved, must be kept at reset value.

Bit 20 **SDEN:** Secondary detection (SD) mode enable

This bit is set by the software to put the BCD into SD mode. Only one detection mode (PD, SD or OFF) must be selected to work correctly

Bit 19 **PDEN:** Primary detection (PD) mode enable

This bit is set by the software to put the BCD into PD mode. Only one detection mode (PD, SD or OFF) must be selected to work correctly.

Bit 18 Reserved, must be kept at reset value.

Bit 17 **BCDEN:** Battery charging detector (BCD) enable

This bit is set by the software to enable the BCD support within the USB device. When enabled, the USB PHY is fully controlled by BCD and cannot be used for normal communication. Once the BCD discovery is finished, the BCD must be placed in OFF mode by clearing this bit to ‘0’ in order to allow the normal USB operation.

Bit 16 **PWRDWN:** Power down control of FS PHY

Used to activate the FS PHY in transmission/reception. When reset, the PHY is kept in power-down. When set, the BCD function must be off (BCDEN=0).

0 = USB FS PHY disabled

1 = USB FS PHY enabled

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **PS2DET:** DM pull-up detection status

This bit is active only during PD and gives the result of comparison between DM voltage level and VLGC threshold. In normal situation, the DM level must be below this threshold. If it is above, it means that the DM is externally pulled high. This can be caused by connection to a PS2 port (which pulls-up both DP and DM lines) or to some proprietary charger not following the BCD specification.

0: Normal port detected (connected to SDP, CDP or DCP)

1: PS2 port or proprietary charger detected

Bit 2 **SDET:** Secondary detection (SD) status

This bit gives the result of SD.

0: CDP detected

1: DCP detected

Bit 1 **PDET:** Primary detection (PD) status

This bit gives the result of PD.

0: no BCD support detected (connected to SDP or proprietary device).

1: BCD support detected (connected to CDP or DCP).

Bit 0 Reserved, must be kept at reset value.

66.15.19 OTG core ID register (OTG_CID)

This is a register containing the Product ID as reset value.

Address offset: 0x03C

Reset value: 0x0000 5100

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRODUCT_ID[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRODUCT_ID[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PRODUCT_ID[31:0]:** Product ID field

Application-programmable ID field.

66.15.20 OTG core LPM configuration register (OTG_GLPMCFG)

Address offset: 0x054

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	EN BESL	LPMRCNTSTS[2:0]			SND LPM	LPMRCNT[2:0]			LPMCHIDX[3:0]				L1RSM OK
			rw	r	r	r	rs	rw	rw	rw	rw	rw	rw	rw	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SLP STS	LPMRSP[1:0]		L1DS EN	BESLTHRS[3:0]				L1SS EN	REM WAKE	BESL[3:0]				LPM ACK	LPM EN
r	r	r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **ENBESL:** Enable best effort service latency

This bit enables the BESL feature as defined in the LPM errata:

0: The core works as described in the following document:
USB 2.0 Link Power Management Addendum Engineering Change Notice to the USB 2.0 specification, July 16, 2007

1: The core works as described in the LPM Errata:
Errata for USB 2.0 ECN: Link Power Management (LPM) - 7/2007

Note: Only the updated behavior (described in LPM Errata) is considered in this document and so the ENBESL bit must be set to '1' by application SW.

Bits 27:25 **LPMRCNTSTS[2:0]:** LPM retry count status

Number of LPM host retries still remaining to be transmitted for the current LPM sequence.

Note: Accessible only in host mode.

Bit 24 **SNDLPM:** Send LPM transaction

When the application software sets this bit, an LPM transaction containing two tokens, EXT and LPM is sent. The hardware clears this bit once a valid response (STALL, NYET, or ACK) is received from the device or the core has finished transmitting the programmed number of LPM retries.

Note: This bit must be set only when the host is connected to a local port.

Note: Accessible only in host mode.

Bits 23:21 **LPMRCNT[2:0]:** LPM retry count

When the device gives an ERROR response, this is the number of additional LPM retries that the host performs until a valid device response (STALL, NYET, or ACK) is received.

Note: Accessible only in host mode.

Bits 20:17 **LPMCHIDX[3:0]:** LPM Channel Index

The channel number on which the LPM transaction has to be applied while sending an LPM transaction to the local device. Based on the LPM channel index, the core automatically inserts the device address and endpoint number programmed in the corresponding channel into the LPM transaction.

Note: Accessible only in host mode.

Bit 16 **L1RSMOK:** Sleep state resume OK

Indicates that the device or host can start resume from Sleep state. This bit is valid in LPM sleep (L1) state. It is set in sleep mode after a delay of 50 µs ($T_{L1Residency}$).
This bit is reset when SLPSTS is 0.

1: The application or host can start resume from Sleep state

0: The application or host cannot start resume from Sleep state

Bit 15 **SLPSTS:** Port sleep status

Device mode:

This bit is set as long as a Sleep condition is present on the USB bus. The core enters the Sleep state when an ACK response is sent to an LPM transaction and the $T_{L1TokenRetry}$ timer has expired. To stop the PHY clock, the application must set the STPPCLK bit in OTG_PCGCCTL, which asserts the PHY suspend input signal.

The application must rely on SLPSTS and not ACK in LPMRSP to confirm transition into sleep.

The core comes out of sleep:

– When there is any activity on the USB linestate

– When the application writes to the RWUSIG bit in OTG_DCTL or when the application resets or soft-disconnects the device.

Host mode:

The host transitions to Sleep (L1) state as a side-effect of a successful LPM transaction by the core to the local port with ACK response from the device. The read value of this bit reflects the current Sleep status of the port.

The core clears this bit after:

– The core detects a remote L1 wakeup signal,

– The application sets the PRST bit or the PRES bit in the OTG_HPRT register, or

– The application sets the L1Resume/ remote wakeup detected interrupt bit or disconnect detected interrupt bit in the core interrupt register (WKUPINT or DISCINT bit in OTG_GINTSTS, respectively).

0: Core not in L1

1: Core in L1

Bits 14:13 **LPMRSP[1:0]:** LPM response

Device mode:

The response of the core to LPM transaction received is reflected in these two bits.

Host mode:

Handshake response received from local device for LPM transaction

11: ACK

10: NYET

01: STALL

00: ERROR (No handshake response)

Bit 12 **L1DSEN:** L1 deep sleep enable

Enables suspending the PHY in L1 Sleep mode. For maximum power saving during L1 Sleep mode, this bit must be set to '1' by application SW in all the cases.

Bits 11:8 **BESLTHRS[3:0]:** BESL threshold

Device mode:

The core puts the PHY into deep low power mode in L1 when BESL value is greater than or equal to the value defined in this field BESL_Thres[3:0].

Host mode:

The core puts the PHY into deep low power mode in L1. BESLTHRS[3:0] specifies the time for which resume signaling is to be reflected by host ($T_{L1HubDrvResume2}$) on the USB bus when it detects device initiated resume.

BESLTHRS must not be programmed with a value greater than 1100b in host mode, because this exceeds maximum $T_{L1HubDrvResume2}$.

Thres[3:0] host mode resume signaling time (µs):

0000: 75

0001: 100

0010: 150

0011: 250

0100: 350

0101: 450

0110: 950

All other values: reserved

Bit 7 **L1SSEN:** L1 Shallow Sleep enable

Enables suspending the PHY in L1 Sleep mode. For maximum power saving during L1 Sleep mode, this bit must be set to '1' by application SW in all the cases.

Bit 6 **REMWAKE:** bRemoteWake value

Host mode:

The value of remote wake up to be sent in the wIndex field of LPM transaction.

Device mode (read-only):

This field is updated with the received LPM token bRemoteWake bmAttribute when an ACK, NYET, or STALL response is sent to an LPM transaction.

Bits 5:2 **BESL[3:0]:** Best effort service latency

Host mode:

The value of BESL to be sent in an LPM transaction. This value is also used to initiate resume for a duration $T_{L1HubDrvResume1}$ for host initiated resume.

Device mode (read-only):

This field is updated with the received LPM token BESL bmAttribute when an ACK, NYET, or STALL response is sent to an LPM transaction.

BESL[3:0]T_{BESL} (µs)

0000: 125
0001: 150
0010: 200
0011: 300
0100: 400
0101: 500
0110: 1000
0111: 2000
1000: 3000
1001: 4000
1010: 5000
1011: 6000
1100: 7000
1101: 8000
1110: 9000
1111: 10000

Bit 1 **LPMACK:** LPM token acknowledge enable

Handshake response to LPM token preprogrammed by device application software.

1: ACK

Even though ACK is preprogrammed, the core device responds with ACK only on successful LPM transaction. The LPM transaction is successful if:

– No PID/CRC5 errors in either EXT token or LPM token (else ERROR)
– Valid bLinkState = 0001B (L1) received in LPM transaction (else STALL)
– No data pending in transmit queue (else NYET).

0: NYET

The preprogrammed software bit is over-ridden for response to LPM token when:

– The received bLinkState is not L1 (STALL response), or
– An error is detected in either of the LPM token packets because of corruption (ERROR response).

Note: Accessible only in device mode.

Bit 0 **LPMEN:** LPM support enable

The application uses this bit to control the OTG_FS core LPM capabilities.

If the core operates as a non-LPM-capable host, it cannot request the connected device or hub to activate LPM mode.

If the core operates as a non-LPM-capable device, it cannot respond to any LPM transactions.

0: LPM capability is not enabled
1: LPM capability is enabled

66.15.21 OTG host periodic transmit FIFO size register (OTG_HPTXFSIZ)

Address offset: 0x100

Reset value: 0x0200 0400

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PTXFSIZ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PTXSA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **PTXFSIZ[15:0]:** Host periodic Tx FIFO depth
This value is in terms of 32-bit words.
Minimum value is 16

Bits 15:0 **PTXSA[15:0]:** Host periodic Tx FIFO start address
This field configures the memory start address for periodic transmit FIFO RAM.

66.15.22 OTG device IN endpoint transmit FIFO x size register (OTG_DIEPTXFx)

Address offset: 0x104 + 0x04 * (x - 1), (x = 1 to 5)

Reset value: 0x0200 0400, 0x0200 0600, 0x0200 0800, 0x0200 0A00, 0x0200 0C00

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
INEPTXFD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INEPTXSA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **INEPTXFD[15:0]:** IN endpoint Tx FIFO depth
This value is in terms of 32-bit words.
Minimum value is 16

Bits 15:0 **INEPTXSA[15:0]:** IN endpoint FIFOx transmit RAM start address
This field contains the memory start address for IN endpoint transmit FIFOx. The address must be aligned with a 32-bit memory location.

66.15.23 Host-mode registers

Bit values in the register descriptions are expressed in binary unless otherwise specified.

Host-mode registers affect the operation of the core in the host mode. Host mode registers must not be accessed in device mode, as the results are undefined. Host mode registers can be categorized as follows:

66.15.24 OTG host configuration register (OTG_HCFG)

This register configures the core after power-on. Do not make changes to this register after initializing the host.

Address offset: 0x400

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSLSS	FSLSPCS[1:0]	
													r	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **FSLSS:** FS- and LS-only support

The application uses this bit to control the core's enumeration speed. Using this bit, the application can make the core enumerate as an FS host, even if the connected device supports HS traffic. Do not make changes to this field after initial programming.
1: FS/LS-only, even if the connected device can support HS (read-only).

Bits 1:0 **FSLSPCS[1:0]:** FS/LS PHY clock select

Condition: FS Host mode
01: PHY clock is running at 48 MHz
Others: Reserved
Condition: LS Host mode
00: Reserved
01: Select 48 MHz PHY clock frequency
10: Select 6 MHz PHY clock frequency
11: Reserved

Note: The FSLSPCS must be set on a connection event according to the speed of the connected device (after changing this bit, a software reset must be performed).

66.15.25 OTG host frame interval register (OTG_HFIR)

This register stores the frame interval information for the current speed to which the OTG_FS controller has enumerated.

Address offset: 0x404

Reset value: 0x0000 EA60

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RLD CTRL
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FRIVL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **RLDCTRL:** Reload control

This bit allows dynamic reloading of the HFIR register during run time.

0: The HFIR cannot be reloaded dynamically

1: The HFIR can be dynamically reloaded during run time.

This bit needs to be programmed during initial configuration and its value must not be changed during run time.

Caution: RLDCTRL = 0 is not recommended.

Bits 15:0 **FRIVL[15:0]:** Frame interval

The value that the application programs to this field, specifies the interval between two consecutive SOFs (FS) or Keep-Alive tokens (LS). This field contains the number of PHY clocks that constitute the required frame interval. The application can write a value to this register only after the port enable bit of the host port control and status register (PENA bit in OTG_HPRT) has been set. If no value is programmed, the core calculates the value based on the PHY clock specified in the FS/LS PHY clock select field of the host configuration register (FSLSPCS in OTG_HCFG). Do not change the value of this field after the initial configuration, unless the RLDCTRL bit is set. In such case, the FRIVL is reloaded with each SOF event.

– Frame interval = 1 ms × (FRIVL - 1)

66.15.26 OTG host frame number/frame time remaining register (OTG_HFNUM)

This register indicates the current frame number. It also indicates the time remaining (in terms of the number of PHY clocks) in the current frame.

Address offset: 0x408

Reset value: 0x0000 3FFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FTREM[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FRNUM[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **FTREM[15:0]:** Frame time remaining

Indicates the amount of time remaining in the current frame, in terms of PHY clocks. This field decrements on each PHY clock. When it reaches zero, this field is reloaded with the value in the Frame interval register and a new SOF is transmitted on the USB.

Bits 15:0 **FRNUM[15:0]:** Frame number

This field increments when a new SOF is transmitted on the USB, and is cleared to 0 when it reaches 0x3FFF.

66.15.27 OTG_Host periodic transmit FIFO/queue status register (OTG_HPTXSTS)

This read-only register contains the free space information for the periodic Tx FIFO and the periodic transmit request queue.

Address offset: 0x410

Reset value: 0x0008 0100

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PTXQTOP[7:0]								PTXQSAV[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PTXFSAVL[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 **PTXQTOP[7:0]:** Top of the periodic transmit request queue

This indicates the entry in the periodic Tx request queue that is currently being processed by the MAC.
This register is used for debugging.
Bit 31: Odd/Even frame
0XXXXXXX: send in even frame
1XXXXXXX: send in odd frame
Bits 30:27: Channel/endpoint number
Bits 26:25: Type
XXXXX00X: IN/OUT
XXXXX01X: Zero-length packet
XXXXX11X: Disable channel command
Bit 24: Terminate (last entry for the selected channel/endpoint)

Bits 23:16 **PTXQSAV[7:0]:** Periodic transmit request queue space available

Indicates the number of free locations available to be written in the periodic transmit request queue. This queue holds both IN and OUT requests.
00: Periodic transmit request queue is full
01: 1 location available
10: 2 locations available
n: n locations available (0 ≤ n ≤ 8)
Others: Reserved

Bits 15:0 **PTXFSAVL[15:0]:** Periodic transmit data FIFO space available

Indicates the number of free locations available to be written to in the periodic Tx FIFO.
Values are in terms of 32-bit words
0000: Periodic Tx FIFO is full
0001: 1 word available
0010: 2 words available
n: n words available (where 0 ≤ n ≤ PTXFD)
Others: Reserved

66.15.28 OTG host all channels interrupt register (OTG_HAINT)

When a significant event occurs on a channel, the host all channels interrupt register interrupts the application using the host channels interrupt bit of the core interrupt register (HCINT bit in OTG_GINTSTS). This is shown in *Figure 937*. There is one interrupt bit per channel, up to a maximum of 16 bits. Bits in this register are set and cleared when the application sets and clears bits in the corresponding host channel-x interrupt register.

Address offset: 0x414

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HAINT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **HAINT[15:0]:** Channel interrupts
One bit per channel: Bit 0 for Channel 0, bit 15 for Channel 15

66.15.29 OTG host all channels interrupt mask register (OTG_HAINTMSK)

The host all channel interrupt mask register works with the host all channel interrupt register to interrupt the application when an event occurs on a channel. There is one interrupt mask bit per channel, up to a maximum of 16 bits.

Address offset: 0x418

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HAINTM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **HAINTM[15:0]:** Channel interrupt mask
0: Masked interrupt
1: Unmasked interrupt
One bit per channel: Bit 0 for channel 0, bit 15 for channel 15

66.15.30 OTG host port control and status register (OTG_HPRT)

This register is available only in host mode. Currently, the OTG host supports only one port.

A single register holds USB port-related information such as USB reset, enable, suspend, resume, connect status, and test mode for each port. It is shown in *Figure 937*. The rc_w1 bits in this register can trigger an interrupt to the application through the host port interrupt bit of the core interrupt register (HPRTINT bit in OTG_GINTSTS). On a port interrupt, the application must read this register and clear the bit that caused the interrupt. For the rc_w1 bits, the application must write a 1 to the bit to clear the interrupt.

Address offset: 0x440

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSPD[1:0]		PTCTL[3]
													r	r	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PTCTL[2:0]			PPWR	PLSTS[1:0]		Res.	PRST	PSUSP	PRES	POC CHNG	POCA	PEN CHNG	PENA	PCDET	PCSTS
rw	rw	rw	rw	r	r		rw	rs	rw	rc_w1	r	rc_w1	rc_w1	rc_w1	r

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:17 **PSPD[1:0]:** Port speed

Indicates the speed of the device attached to this port.
01: Full speed
10: Low speed
11: Reserved

Bits 16:13 **PTCTL[3:0]:** Port test control

The application writes a nonzero value to this field to put the port into a Test mode, and the corresponding pattern is signaled on the port.
0000: Test mode disabled
0001: Test_J mode
0010: Test_K mode
0011: Test_SE0_NAK mode
0100: Test_Packet mode
0101: Test_Force_Enable
Others: Reserved

Bit 12 **PPWR:** Port power

The application uses this field to control power to this port, and the core clears this bit on an overcurrent condition.
0: Power off
1: Power on

Bits 11:10 **PLSTS[1:0]:** Port line status

Indicates the current logic level USB data lines
Bit 10: Logic level of OTG_DP
Bit 11: Logic level of OTG_DM

Bit 9 Reserved, must be kept at reset value.

Bit 8 **PRST:** Port reset

When the application sets this bit, a reset sequence is started on this port. The application must time the reset period and clear this bit after the reset sequence is complete.

0: Port not in reset

1: Port in reset

The application must leave this bit set for a minimum duration of at least 10 ms to start a reset on the port. The application can leave it set for another 10 ms in addition to the required minimum duration, before clearing the bit, even though there is no maximum limit set by the USB standard.

High speed: 50 ms

Full speed/Low speed: 10 ms

Bit 7 **PSUSP:** Port suspend

The application sets this bit to put this port in suspend mode. The core only stops sending SOFs when this is set. To stop the PHY clock, the application must set the port clock stop bit, which asserts the suspend input pin of the PHY.

The read value of this bit reflects the current suspend status of the port. This bit is cleared by the core after a remote wakeup signal is detected or the application sets the port reset bit or port resume bit in this register or the resume/remote wakeup detected interrupt bit or disconnect detected interrupt bit in the core interrupt register (WKUPINT or DISCINT in OTG_GINTSTS, respectively).

0: Port not in suspend mode

1: Port in suspend mode

Bit 6 **PRES:** Port resume

The application sets this bit to drive resume signaling on the port. The core continues to drive the resume signal until the application clears this bit.

If the core detects a USB remote wakeup sequence, as indicated by the port resume/remote wakeup detected interrupt bit of the core interrupt register (WKUPINT bit in OTG_GINTSTS), the core starts driving resume signaling without application intervention and clears this bit when it detects a disconnect condition. The read value of this bit indicates whether the core is currently driving resume signaling.

0: No resume driven

1: Resume driven

When LPM is enabled and the core is in L1 state, the behavior of this bit is as follow:

1. The application sets this bit to drive resume signaling on the port.

2. The core continues to drive the resume signal until a predetermined time specified in BESLTHRS[3:0] field of OTG_GLPMCFG register.

3. If the core detects a USB remote wakeup sequence, as indicated by the port L1Resume/Remote L1Wakeup detected interrupt bit of the core interrupt register (WKUPINT in OTG_GINTSTS), the core starts driving resume signaling without application intervention and clears this bit at the end of resume.This bit can be set or cleared by both the core and the application. This bit is cleared by the core even if there is no device connected to the host.

Bit 5 **POCCHNG:** Port overcurrent change

The core sets this bit when the status of the port overcurrent active bit (bit 4) in this register changes.

Bit 4 **POCA:** Port overcurrent active

Indicates the overcurrent condition of the port.

0: No overcurrent condition

1: Overcurrent condition

Bit 3 **PENCHNG:** Port enable/disable change

The core sets this bit when the status of the port enable bit 2 in this register changes.

Bit 2 **PENA:** Port enable

A port is enabled only by the core after a reset sequence, and is disabled by an overcurrent condition, a disconnect condition, or by the application clearing this bit. The application cannot set this bit by a register write. It can only clear it to disable the port. This bit does not trigger any interrupt to the application.

0: Port disabled

1: Port enabled

Bit 1 **PCDET:** Port connect detected

The core sets this bit when a device connection is detected to trigger an interrupt to the application using the host port interrupt bit in the core interrupt register (HPRTINT bit in OTG_GINTSTS). The application must write a 1 to this bit to clear the interrupt.

Bit 0 **PCSTS:** Port connect status

0: No device is attached to the port

1: A device is attached to the port

66.15.31 OTG host channel x characteristics register (OTG_HCCHARx)

Address offset: 0x500 + 0x20 * x, (x = 0 to 11)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CHENA	CHDIS	ODD FRM	DAD[6:0]							MCNT[1:0]		EPTYP[1:0]		LSDEV	Res.
rs	rs	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EPDIR	EPNUM[3:0]				MPSIZ[10:0]										
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **CHENA:** Channel enable

This field is set by the application and cleared by the OTG host.

0: Channel disabled

1: Channel enabled

Bit 30 **CHDIS:** Channel disable

The application sets this bit to stop transmitting/receiving data on a channel, even before the transfer for that channel is complete. The application must wait for the Channel disabled interrupt before treating the channel as disabled.

Bit 29 **ODDFRM:** Odd frame

This field is set (reset) by the application to indicate that the OTG host must perform a transfer in an odd frame. This field is applicable for only periodic (isochronous and interrupt) transactions.

0: Even frame

1: Odd frame

Bits 28:22 **DAD[6:0]:** Device address

This field selects the specific device serving as the data source or sink.

Bits 21:20 **MCNT[1:0]:** Multicount

This field indicates to the host the number of transactions that must be executed per frame for this periodic endpoint. For non-periodic transfers, this field is not used

00: Reserved. This field yields undefined results

01: 1 transaction

10: 2 transactions per frame to be issued for this endpoint

11: 3 transactions per frame to be issued for this endpoint

Note: This field must be set to at least 01.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

Indicates the transfer type selected.

00: Control

01: Isochronous

10: Bulk

11: Interrupt

Bit 17 **LSDEV:** Low-speed device

This field is set by the application to indicate that this channel is communicating to a low-speed device.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **EPDIR:** Endpoint direction

Indicates whether the transaction is IN or OUT.

0: OUT

1: IN

Bits 14:11 **EPNUM[3:0]:** Endpoint number

Indicates the endpoint number on the device serving as the data source or sink.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size

Indicates the maximum packet size of the associated endpoint.

66.15.32 OTG host channel x interrupt register (OTG_HCINTx)

This register indicates the status of a channel with respect to USB- and AHB-related events. It is shown in *Figure 937*. The application must read this register when the host channels interrupt bit in the core interrupt register (HCINT bit in OTG_GINTSTS) is set. Before the application can read this register, it must first read the host all channels interrupt (OTG_HAINT) register to get the exact channel number for the host channel-x interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_HAINT and OTG_GINTSTS registers.

Address offset: 0x508 + 0x20 * x, (x = 0 to 11)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	DTERR	FRM OR	BBERR	TXERR	Res.	ACK	NAK	STALL	Res.	CHH	XFRC
					rc_w1	rc_w1	rc_w1	rc_w1		rc_w1	rc_w1	rc_w1		rc_w1	rc_w1

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **DTERR:** Data toggle error.

Bit 9 **FRMOR:** Frame overrun.

Bit 8 **BBERR:** Babble error.

Bit 7 **TXERR:** Transaction error.

Indicates one of the following errors occurred on the USB.
CRC check failure
Timeout
Bit stuff error
False EOP

Bit 6 Reserved, must be kept at reset value.

Bit 5 **ACK:** ACK response received/transmitted interrupt.

Bit 4 **NAK:** NAK response received interrupt.

Bit 3 **STALL:** STALL response received interrupt.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CHH:** Channel halted.

Indicates the transfer completed abnormally either because of any USB transaction error or in response to disable request by the application.

Bit 0 **XFRC:** Transfer completed.

Transfer completed normally without any errors.

66.15.33 OTG host channel x interrupt mask register (OTG_HCINTMSKx)

This register reflects the mask for each channel status described in the previous section.

Address offset: 0x50C + 0x20 * x, (x = 0 to 11)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	DTERRM	FRMORM	BBERRM	TXERRM	Res.	ACKM	NAKM	STALLM	Res.	CHHM	XFRCM
					rw	rw	rw	rw		rw	rw	rw		rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **DTERRM:** Data toggle error mask.

0: Masked interrupt
1: Unmasked interrupt

Bit 9 **FRMORM:** Frame overrun mask.

0: Masked interrupt
1: Unmasked interrupt

Bit 8 **BBERRM:** Babble error mask.
0: Masked interrupt
1: Unmasked interrupt

Bit 7 **TXERRM:** Transaction error mask.
0: Masked interrupt
1: Unmasked interrupt

Bit 6 Reserved, must be kept at reset value.

Bit 5 **ACKM:** ACK response received/transmitted interrupt mask.
0: Masked interrupt
1: Unmasked interrupt

Bit 4 **NAKM:** NAK response received interrupt mask.
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **STALLM:** STALL response received interrupt mask.
0: Masked interrupt
1: Unmasked interrupt

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CHHM:** Channel halted mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed mask
0: Masked interrupt
1: Unmasked interrupt

66.15.34 OTG host channel x transfer size register (OTG_HCTSIZx)

Address offset: 0x510 + 0x20 * x, (x = 0 to 11)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DO PNG	DPID[1:0]		PKTCNT[9:0]										XFRSIZ[18:16]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XFRSIZ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **DOPNG:** Do Ping

This bit is used only for OUT transfers. Setting this field to 1 directs the host to do PING protocol.

Note: Do not set this bit for IN transfers. If this bit is set for IN transfers, it disables the channel.

Bits 30:29 **DPID[1:0]:** Data PID

The application programs this field with the type of PID to use for the initial transaction. The host maintains this field for the rest of the transfer.

00: DATA0

10: DATA1

11: SETUP (control) / reserved (non-control)

Bits 28:19 **PKTCNT[9:0]:** Packet count

This field is programmed by the application with the expected number of packets to be transmitted (OUT) or received (IN).

The host decrements this count on every successful transmission or reception of an OUT/IN packet. Once this count reaches zero, the application is interrupted to indicate normal completion.

Bits 18:0 **XFRSIZ[18:0]:** Transfer size

For an OUT, this field is the number of data bytes the host sends during the transfer.

For an IN, this field is the buffer size that the application has reserved for the transfer. The application is expected to program this field as an integer multiple of the maximum packet size for IN transactions (periodic and non-periodic).

66.15.35 Device-mode registers

These registers must be programmed every time the core changes to device mode

66.15.36 OTG device configuration register (OTG_DCFG)

This register configures the core in device mode after power-on or after certain control commands or enumeration. Do not make changes to this register after initial programming.

Address offset: 0x800

Reset value: 0x0220 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ERRATIM	Res.	Res.	PFIVL[1:0]		DAD[6:0]							Res.	NZLSOHSK	DSPD[1:0]	
rw			rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **ERRATIM:** Erratic error interrupt mask

1: Mask early suspend interrupt on erratic error

0: Early suspend interrupt is generated on erratic error

Bit 14 Reserved, must be kept at reset value.

Bit 13 Reserved, must be kept at reset value.

Bits 12:11 **PFIVL[1:0]:** Periodic frame interval

Indicates the time within a frame at which the application must be notified using the end of periodic frame interrupt. This can be used to determine if all the isochronous traffic for that frame is complete.

00: 80% of the frame interval

01: 85% of the frame interval

10: 90% of the frame interval

11: 95% of the frame interval

Bits 10:4 **DAD[6:0]:** Device address

The application must program this field after every SetAddress control command.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **NZLSOHSK:** Non-zero-length status OUT handshake

The application can use this field to select the handshake the core sends on receiving a nonzero-length data packet during the OUT transaction of a control transfer's status stage.

1: Send a STALL handshake on a nonzero-length status OUT transaction and do not send the received OUT packet to the application.

0: Send the received OUT packet to the application (zero-length or nonzero-length) and send a handshake based on the NAK and STALL bits for the endpoint in the device endpoint control register.

Bits 1:0 **DSPD[1:0]:** Device speed

Indicates the speed at which the application requires the core to enumerate, or the maximum speed the application can support. However, the actual bus speed is determined only after the chirp sequence is completed, and is based on the speed of the USB host to which the core is connected.

00: Reserved

01: Reserved

10: Reserved

11: Full speed (USB 1.1 transceiver clock is 48 MHz)

66.15.37 OTG device control register (OTG_DCTL)

Address offset: 0x804

Reset value: 0x0000 0002

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DS BESL RJCT	Res.	Res.
													rw		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	PO PRG DNE	CGO NAK	SGO NAK	CGI NAK	SGI NAK	TCTL[2:0]			GON STS	GIN STS	SDIS	RWU SIG
				rw	w	w	w	w	rw	rw	rw	r	r	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **DSBESLRJCT:** Deep sleep BESL reject

Core rejects LPM request with BESL value greater than BESL threshold programmed. NYET response is sent for LPM tokens with BESL value greater than BESL threshold. By default, the deep sleep BESL reject feature is disabled.

Bits 17:12 Reserved, must be kept at reset value.

Bit 11 **POPRGDNE:** Power-on programming done

The application uses this bit to indicate that register programming is completed after a wakeup from power down mode.

Bit 10 **CGONAK:** Clear global OUT NAK

Writing 1 to this field clears the Global OUT NAK.

Bit 9 **SGONAK:** Set global OUT NAK

Writing 1 to this field sets the Global OUT NAK.
The application uses this bit to send a NAK handshake on all OUT endpoints.
The application must set the this bit only after making sure that the Global OUT NAK effective bit in the core interrupt register (GONAKEFF bit in OTG_GINTSTS) is cleared.

Bit 8 **CGINAK:** Clear global IN NAK

Writing 1 to this field clears the Global IN NAK.

Bit 7 **SGINAK:** Set global IN NAK

Writing 1 to this field sets the Global non-periodic IN NAK.The application uses this bit to send a NAK handshake on all non-periodic IN endpoints.
The application must set this bit only after making sure that the Global IN NAK effective bit in the core interrupt register (GINAKEFF bit in OTG_GINTSTS) is cleared.

Bits 6:4 **TCTL[2:0]:** Test control

000: Test mode disabled
001: Test_J mode
010: Test_K mode
011: Test_SE0_NAK mode
100: Test_Packet mode
101: Test_Force_Enable
Others: Reserved

Bit 3 **GONSTS:** Global OUT NAK status

0: A handshake is sent based on the FIFO status and the NAK and STALL bit settings.
1: No data is written to the Rx FIFO, irrespective of space availability. Sends a NAK handshake on all packets, except on SETUP transactions. All isochronous OUT packets are dropped.

Bit 2 **GINSTS:** Global IN NAK status

0: A handshake is sent out based on the data availability in the transmit FIFO.

1: A NAK handshake is sent out on all non-periodic IN endpoints, irrespective of the data availability in the transmit FIFO.

Bit 1 **SDIS:** Soft disconnect

The application uses this bit to signal the USB OTG core to perform a soft disconnect. As long as this bit is set, the host does not see that the device is connected, and the device does not receive signals on the USB. The core stays in the disconnected state until the application clears this bit.

0: Normal operation. When this bit is cleared after a soft disconnect, the core generates a device connect event to the USB host. When the device is reconnected, the USB host restarts device enumeration.

1: The core generates a device disconnect event to the USB host.

Bit 0 **RWUSIG:** Remote wakeup signaling

When the application sets this bit, the core initiates remote signaling to wake up the USB host. The application must set this bit to instruct the core to exit the suspend state. As specified in the USB 2.0 specification, the application must clear this bit 1 ms to 15 ms after setting it.

If LPM is enabled and the core is in the L1 (sleep) state, when the application sets this bit, the core initiates L1 remote signaling to wake up the USB host. The application must set this bit to instruct the core to exit the sleep state. As specified in the LPM specification, the hardware automatically clears this bit 50 µs ($T_{L1DevDrvResume}$) after being set by the application. The application must not set this bit when bRemoteWake from the previous LPM transaction is zero (refer to REMWAKE bit in GLPMCFG register).

Table 738 contains the minimum duration (according to device state) for which the Soft disconnect (SDIS) bit must be set for the USB host to detect a device disconnect. To accommodate clock jitter, it is recommended that the application add some extra delay to the specified minimum duration.

Table 738. Minimum duration for soft disconnect

Operating speed	Device state	Minimum duration
Full speed	Suspended	1 ms + 2.5 µs
Full speed	Idle	2.5 µs
Full speed	Not Idle or suspended (Performing transactions)	2.5 µs

66.15.38 OTG device status register (OTG_DSTS)

This register indicates the status of the core with respect to USB-related events. It must be read on interrupts from the device all interrupts (OTG_DAINT) register.

Address offset: 0x808

Reset value: 0x0000 0010

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEVLNSTS[1:0]		FNSOF[13:8]					
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FNSOF[7:0]								Res.	Res.	Res.	Res.	EERR	ENUMSPD[1:0]		SUSP STS
r	r	r	r	r	r	r	r					r	r	r	r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:22 **DEVLNSTS[1:0]:** Device line status

Indicates the current logic level USB data lines.
Bit [23]: Logic level of D+
Bit [22]: Logic level of D-

Bits 21:8 **FNSOF[13:0]:** Frame number of the received SOF

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **EERR:** Erratic error

The core sets this bit to report any erratic errors.
Due to erratic errors, the OTG_FS controller goes into suspended state and an interrupt is generated to the application with Early suspend bit of the OTG_GINTSTS register (ESUSP bit in OTG_GINTSTS). If the early suspend is asserted due to an erratic error, the application can only perform a soft disconnect recover.

Bits 2:1 **ENUMSPD[1:0]:** Enumerated speed

Indicates the speed at which the OTG_FS controller has come up after speed detection through a chirp sequence.
11: Full speed using embedded FS PHY
Others: reserved

Bit 0 **SUSPSTS:** Suspend status

In device mode, this bit is set as long as a suspend condition is detected on the USB. The core enters the suspended state when there is no activity on the USB data lines for a period of 3 ms. The core comes out of the suspend:

– When there is an activity on the USB data lines
– When the application writes to the remote wakeup signaling bit in the OTG_DCTL register (RWUSIG bit in OTG_DCTL).

66.15.39 OTG device IN endpoint common interrupt mask register (OTG_DIEPMSK)

This register works with each of the OTG_DIEPINTx registers for all endpoints to generate an interrupt per IN endpoint. The IN endpoint interrupt for a specific status in the OTG_DIEPINTx register can be masked by writing to the corresponding bit in this register. Status bits are masked by default.

Address offset: 0x810

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	NAKM	Res.	Res.	Res.	Res.	Res.	Res.	INEPNEM	INEPNMM	ITTXFEMSK	TOM	Res.	EPDM	XFRCM
		rw							rw	rw	rw	rw		rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **NAKM:** NAK interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 12:7 Reserved, must be kept at reset value.

Bit 6 **INEPNEM:** IN endpoint NAK effective mask
0: Masked interrupt
1: Unmasked interrupt

Bit 5 **INEPNMM:** IN token received with EP mismatch mask
0: Masked interrupt
1: Unmasked interrupt

Bit 4 **ITTXFEMSK:** IN token received when Tx FIFO empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **TOM:** Timeout condition mask (Non-isochronous endpoints)
0: Masked interrupt
1: Unmasked interrupt

Bit 2 Reserved, must be kept at reset value.

Bit 1 **EPDM:** Endpoint disabled interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed interrupt mask
0: Masked interrupt
1: Unmasked interrupt

66.15.40 OTG device OUT endpoint common interrupt mask register (OTG_DOEPMSK)

This register works with each of the OTG_DOEPINTx registers for all endpoints to generate an interrupt per OUT endpoint. The OUT endpoint interrupt for a specific status in the OTG_DOEPINTx register can be masked by writing into the corresponding bit in this register. Status bits are masked by default.

Address offset: 0x814

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	NAK MSK	BERR M	Res.	Res.	Res.	OUT PKT ERRM	Res.	Res.	STS PHSR XM	OTEPD M	STUPM	Res.	EPDM	XFRC M
		rw	rw				rw			rw	rw	rw		rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **NAKMSK:** NAK interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 12 **BERRM**: Babble error interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 Reserved, must be kept at reset value.

Bit 8 **OUTPKTERRM:** Out packet error mask
0: Masked interrupt
1: Unmasked interrupt

Bit 7 Reserved, must be kept at reset value.

Bit 6 Reserved, must be kept at reset value.

Bit 5 **STSPHSRXM**: Status phase received for control write mask
0: Masked interrupt
1: Unmasked interrupt

Bit 4 **OTEPDM:** OUT token received when endpoint disabled mask. Applies to control OUT endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **STUPM:** SETUP phase done mask. Applies to control endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 2 Reserved, must be kept at reset value.

Bit 1 **EPDM:** Endpoint disabled interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed interrupt mask
0: Masked interrupt
1: Unmasked interrupt

66.15.41 OTG device all endpoints interrupt register (OTG_DAINT)

When a significant event occurs on an endpoint, a OTG_DAINT register interrupts the application using the device OUT endpoints interrupt bit or device IN endpoints interrupt bit of the OTG_GINTSTS register (OEPINT or IEPINT in OTG_GINTSTS, respectively). There is one interrupt bit per endpoint, up to a maximum of 16 bits for OUT endpoints and 16 bits for IN endpoints. For a bidirectional endpoint, the corresponding IN and OUT interrupt bits are used. Bits in this register are set and cleared when the application sets and clears bits in the corresponding device endpoint-x interrupt register (OTG_DIEPINTx/OTG_DOEPINTx).

Address offset: 0x818

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OEPINT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IEPINT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **OEPINT[15:0]:** OUT endpoint interrupt bits
One bit per OUT endpoint:
Bit 16 for OUT endpoint 0, bit 19 for OUT endpoint 3.

Bits 15:0 **IEPINT[15:0]:** IN endpoint interrupt bits
One bit per IN endpoint:
Bit 0 for IN endpoint 0, bit 3 for endpoint 3.

66.15.42 OTG all endpoints interrupt mask register (OTG_DAINTMSK)

The OTG_DAINTMSK register works with the device endpoint interrupt register to interrupt the application when an event occurs on a device endpoint. However, the OTG_DAINT register bit corresponding to that interrupt is still set.

Address offset: 0x81C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OEPM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IEPM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **OEPM[15:0]:** OUT EP interrupt mask bits
One per OUT endpoint:
Bit 16 for OUT EP 0, bit 19 for OUT EP 3
0: Masked interrupt
1: Unmasked interrupt

Bits 15:0 **IEPM[15:0]:** IN EP interrupt mask bits
One bit per IN endpoint:
Bit 0 for IN EP 0, bit 3 for IN EP 3
0: Masked interrupt
1: Unmasked interrupt

66.15.43 OTG device IN endpoint FIFO empty interrupt mask register (OTG_DIEPEMPMSK)

This register is used to control the IN endpoint FIFO empty interrupt generation (TXFE_OTG_DIEPINTx).

Address offset: 0x834

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INEPTXFEM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **INEPTXFEM[15:0]:** IN EP Tx FIFO empty interrupt mask bits
These bits act as mask bits for OTG_DIEPINTx.
TXFE interrupt one bit per IN endpoint:
Bit 0 for IN endpoint 0, bit 3 for IN endpoint 3
0: Masked interrupt
1: Unmasked interrupt

66.15.44 OTG device each endpoint interrupt register (OTG_DEACHINT)

Address offset: 0x0838

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OEP1 INT	Res.
														r	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IEP1 INT	Res.
														r	

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **OEP1INT:** OUT endpoint 1 interrupt bit

Bits 16:2 Reserved, must be kept at reset value.

Bit 1 **IEP1INT:** IN endpoint 1interrupt bit

Bit 0 Reserved, must be kept at reset value.

66.15.45 OTG device each endpoint interrupt mask register (OTG_DEACHINTMSK)

There is one interrupt bit for endpoint 1 IN and one interrupt bit for endpoint 1 OUT.

Address offset: 0x083C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OEP1 INTM	Res.
														rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IEP1I NTM	Res.
														rw	

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **OEP1INTM:** OUT endpoint 1 interrupt mask bit

Bits 16:2 Reserved, must be kept at reset value.

Bit 1 **IEP1INTM:** IN endpoint 1 interrupt mask bit

Bit 0 Reserved, must be kept at reset value.

66.15.46 OTG device each IN endpoint-1 interrupt mask register (OTG_DIEPEACHM)

This register works with the OTG_DIEPINT1 register to generate a dedicated interrupt OTG_EP1_IN for endpoint #1. The IN endpoint interrupt for a specific status in the OTG_DOEPINT1 register can be masked by writing into the corresponding bit in this register. Status bits are masked by default.

Address offset: 0x844

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	NAKM	Res.	Res.	Res.	Res.	TXFURM	Res.	INEPNEM	Res.	ITTXFEMSK	TOM	AHBERRM	EPDM	XFRCM
		rw					rw		rw		rw	rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **NAKM:** NAK interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 12:10 Reserved, must be kept at reset value.

Bit 9 Reserved, must be kept at reset value.

Bit 8 **TXFURM:** FIFO underrun mask
0: Masked interrupt
1: Unmasked interrupt

Bit 7 Reserved, must be kept at reset value.

Bit 6 **INEPNEM:** IN endpoint NAK effective mask
0: Masked interrupt
1: Unmasked interrupt

Bit 5 Reserved, must be kept at reset value.

Bit 4 **ITTXFEMSK:** IN token received when Tx FIFO empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **TOM:** Timeout condition mask (Non-isochronous endpoints)
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **AHBERRM:** AHB error mask
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **EPDM:** Endpoint disabled interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed interrupt mask
0: Masked interrupt
1: Unmasked interrupt

66.15.47 OTG device each OUT endpoint-1 interrupt mask register (OTG_DOEPEACHMSK1)

This register works with the OTG_DOEPINT1 register to generate a dedicated interrupt OTG_EP1_OUT for endpoint #1. The OUT endpoint interrupt for a specific status in the OTG_DOEPINT1 register can be masked by writing into the corresponding bit in this register. Status bits are masked by default.

Address offset: 0x884

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	NYET MSK	NAK MSK	BERR M	Res.	Res.	Res.	OUT PKT ERRM	Res.	Res.	Res.	OTEPD M	STUPM	AHB ERRM	EPDM	XFRC M
	rw	rw	rw				rw				rw	rw	rw	rw	rw

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **NYETMSK:** NYET interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 13 **NAKMSK:** NAK interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 12 **BERRM**: Babble error interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 Reserved, must be kept at reset value.

Bit 8 **OUTPKTERRM:** Out packet error mask
0: Masked interrupt
1: Unmasked interrupt

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **OTEPDM:** OUT token received when endpoint disabled mask
Applies to control OUT endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **STUPM:** SETUP phase done mask
Applies to control endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **AHBERRM:** AHB error mask
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **EPDM:** Endpoint disabled interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed interrupt mask
0: Masked interrupt
1: Unmasked interrupt

66.15.48 OTG device control IN endpoint 0 control register (OTG_DIEPCTL0)

This section describes the OTG_DIEPCTL0 register for USB_OTG FS. Nonzero control endpoints use registers for endpoints 1–3.

Address offset: 0x900

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	Res.	Res.	SNAK	CNAK	TXFNUM[3:0]				STALL	Res.	EPTYP[1:0]		NAK STS	Res.
rs	rs			w	w	rw	rw	rw	rw	rs		r	r	r	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MPSIZ[1:0]	
r														rw	rw

Bit 31 **EPENA:** Endpoint enable
The application sets this bit to start transmitting data on the endpoint 0.
The core clears this bit before setting any of the following interrupts on this endpoint:
– Endpoint disabled
– Transfer completed

Bit 30 **EPDIS:** Endpoint disable
The application sets this bit to stop transmitting data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the endpoint disabled interrupt. The application must set this bit only if endpoint enable is already set for this endpoint.

Bits 29:28 Reserved, must be kept at reset value.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.

Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for an endpoint after a SETUP packet is received on that endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 **TXFNUM[3:0]:** Tx FIFO number

This value is set to the FIFO number that is assigned to IN endpoint 0.

Bit 21 **STALL:** STALL handshake

The application can only set this bit, and the core clears it when a SETUP token is received for this endpoint. If a NAK bit, a Global IN NAK or Global OUT NAK is set along with this bit, the STALL bit takes priority.

Bit 20 Reserved, must be kept at reset value.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

Hardcoded to ‘00’ for control.

Bit 17 **NAKSTS:** NAK status

Indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status

1: The core is transmitting NAK handshakes on this endpoint.

When this bit is set, either by the application or core, the core stops transmitting data, even if there are data available in the Tx FIFO. Irrespective of this bit’s setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **USBAEP:** USB active endpoint

This bit is always set to 1, indicating that control endpoint 0 is always active in all configurations and interfaces.

Bits 14:2 Reserved, must be kept at reset value.

Bits 1:0 **MPSIZ[1:0]:** Maximum packet size

The application must program this field with the maximum packet size for the current logical endpoint.

00: 64 bytes

01: 32 bytes

10: 16 bytes

11: 8 bytes

66.15.49 OTG device IN endpoint x control register [alternate] (OTG_DIEPCTLx)

Valid for INT/BULK endpoints, see next section for ISO endpoints.

The application uses this register to control the behavior of each logical endpoint other than endpoint 0.

Address offset: 0x900 + 0x20 * x, (x = 1 to 5)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	SD1 PID	SD0 PID	SNAK	CNAK	TXFNUM[3:0]				STALL	Res.	EPTYP[1:0]		NAK STS	DPID
rs	rs	w	w	w	w	rw	rw	rw	rw	rw		rw	rw	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	MPSIZ[10:0]										
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **EPENA:** Endpoint enable

The application sets this bit to start transmitting data on an endpoint.
The core clears this bit before setting any of the following interrupts on this endpoint:
– SETUP phase done
– Endpoint disabled
– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application sets this bit to stop transmitting/receiving data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the endpoint disabled interrupt. The application must set this bit only if endpoint enable is already set for this endpoint.

Bit 29 **SD1PID:** Set DATA1 PID

Writing to this field sets the endpoint data PID (DPID) field in this register to DATA1.

Bit 28 **SD0PID:** Set DATA0 PID

Applies to interrupt/bulk IN endpoints only.
Writing to this field sets the endpoint data PID (DPID) field in this register to DATA0.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.
Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for OUT endpoints on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 **TXFNUM[3:0]:** Tx FIFO number

These bits specify the FIFO number associated with this endpoint. Each active IN endpoint must be programmed to a separate FIFO number.
This field is valid only for IN endpoints.

Bit 21 **STALL:** STALL handshake

Applies to non-control, non-isochronous IN endpoints only (access type is rw).

The application sets this bit to stall all tokens from the USB host to this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Only the application can clear this bit, never the core.

Bit 20 Reserved, must be kept at reset value.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

This is the transfer type supported by this logical endpoint.

00: Control

01: Isochronous

10: Bulk

11: Interrupt

Bit 17 **NAKSTS:** NAK status

It indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status.

1: The core is transmitting NAK handshakes on this endpoint.

When either the application or the core sets this bit:

For non-isochronous IN endpoints: The core stops transmitting any data on an IN endpoint, even if there are data available in the Tx FIFO.

For isochronous IN endpoints: The core sends out a zero-length data packet, even if there are data available in the Tx FIFO.

Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 **DPID:** Endpoint data PID

Applies to interrupt/bulk IN endpoints only.

Contains the PID of the packet to be received or transmitted on this endpoint. The application must program the PID of the first packet to be received or transmitted on this endpoint, after the endpoint is activated. The application uses the SD0PID register field to program either DATA0 or DATA1 PID.

0: DATA0

1: DATA1

Bit 15 **USBAEP:** USB active endpoint

Indicates whether this endpoint is active in the current configuration and interface. The core clears this bit for all endpoints (other than EP 0) after detecting a USB reset. After receiving the SetConfiguration and SetInterface commands, the application must program endpoint registers accordingly and set this bit.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size

The application must program this field with the maximum packet size for the current logical endpoint. This value is in bytes.

66.15.50 OTG device IN endpoint x control register [alternate] (OTG_DIEPCTLx)

Valid for ISO endpoints, see previous section for INT/BULK endpoints.

The application uses this register to control the behavior of each logical endpoint other than endpoint 0.

Address offset: 0x900 + 0x20 * x, (x = 1 to 5)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	SODD FRM	SEVN FRM	SNAK	CNAK	TXFNUM[3:0]				STALL	Res.	EPTYP[1:0]		NAK STS	EO NUM
rs	rs	w	w	w	w	rw	rw	rw	rw	rw		rw	rw	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	MPSIZ[10:0]										
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **EPENA:** Endpoint enable

The application sets this bit to start transmitting data on an endpoint.
The core clears this bit before setting any of the following interrupts on this endpoint:
– SETUP phase done
– Endpoint disabled
– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application sets this bit to stop transmitting/receiving data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the endpoint disabled interrupt. The application must set this bit only if endpoint enable is already set for this endpoint.

Bit 29 **SODDFRM:** Set odd frame

Applies to isochronous IN and OUT endpoints only.
Writing to this field sets the Even/Odd frame (EONUM) field to odd frame.

Bit 28 **SEVNFRM:** Set even frame

Applies to isochronous IN endpoints only.
Writing to this field sets the Even/Odd frame (EONUM) field to even frame.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.
Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for OUT endpoints on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 **TXFNUM[3:0]:** Tx FIFO number

These bits specify the FIFO number associated with this endpoint. Each active IN endpoint must be programmed to a separate FIFO number.
This field is valid only for IN endpoints.

Bit 21 **STALL:** STALL handshake

Applies to non-control, non-isochronous IN endpoints only (access type is rw).

The application sets this bit to stall all tokens from the USB host to this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Only the application can clear this bit, never the core.

Bit 20 Reserved, must be kept at reset value.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

This is the transfer type supported by this logical endpoint.

00: Control

01: Isochronous

10: Bulk

11: Interrupt

Bit 17 **NAKSTS:** NAK status

It indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status.

1: The core is transmitting NAK handshakes on this endpoint.

When either the application or the core sets this bit:

For non-isochronous IN endpoints: The core stops transmitting any data on an IN endpoint, even if there are data available in the Tx FIFO.

For isochronous IN endpoints: The core sends out a zero-length data packet, even if there are data available in the Tx FIFO.

Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 **EONUM:** Even/odd frame

Applies to isochronous IN endpoints only.

Indicates the frame number in which the core transmits/receives isochronous data for this endpoint. The application must program the even/odd frame number in which it intends to transmit/receive isochronous data for this endpoint using the SEVNFRM and SODDFRM fields in this register.

0: Even frame

1: Odd frame

Bit 15 **USBAEP:** USB active endpoint

Indicates whether this endpoint is active in the current configuration and interface. The core clears this bit for all endpoints (other than EP 0) after detecting a USB reset. After receiving the SetConfiguration and SetInterface commands, the application must program endpoint registers accordingly and set this bit.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size

The application must program this field with the maximum packet size for the current logical endpoint. This value is in bytes.

66.15.51 OTG device IN endpoint x interrupt register (OTG_DIEPINTx)

This register indicates the status of an endpoint with respect to USB- and AHB-related events. It is shown in *Figure 937*. The application must read this register when the IN endpoints interrupt bit of the core interrupt register (IEPINT in OTG_GINTSTS) is set. Before the application can read this register, it must first read the device all endpoints interrupt (OTG_DAINT) register to get the exact endpoint number for the device endpoint-x interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_DAINT and OTG_GINTSTS registers.

Address offset: 0x908 + 0x20 * x, (x = 0 to 5)

Reset value: 0x0000 0080

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	NAK	Res.	PKTD RPSTS	Res.	Res.	Res.	TXFE	IN EPNE	IN EPNM	ITTXFE	TOC	Res.	EP DISD	XFRC
		rc_w1		rc_w1				r	rc_w1	rc_w1	rc_w1	rc_w1		rc_w1	rc_w1

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **NAK:** NAK input

The core generates this interrupt when a NAK is transmitted or received by the device. In case of isochronous IN endpoints the interrupt gets generated when a zero length packet is transmitted due to unavailability of data in the Tx FIFO.

Bit 12 Reserved, must be kept at reset value.

Bit 11 **PKTDRPSTS:** Packet dropped status

This bit indicates to the application that an ISOC OUT packet has been dropped. This bit does not have an associated mask bit and does not generate an interrupt.

Bits 10:8 Reserved, must be kept at reset value.

Bit 7 **TXFE:** Transmit FIFO empty

This interrupt is asserted when the Tx FIFO for this endpoint is either half or completely empty. The half or completely empty status is determined by the Tx FIFO Empty Level bit in the OTG_GAHBCFG register (TXFELVL bit in OTG_GAHBCFG).

Bit 6 **INEPNE:** IN endpoint NAK effective

This bit can be cleared when the application clears the IN endpoint NAK by writing to the CNAK bit in OTG_DIEPCTLx.

This interrupt indicates that the core has sampled the NAK bit set (either by the application or by the core). The interrupt indicates that the IN endpoint NAK bit set by the application has taken effect in the core.

This interrupt does not guarantee that a NAK handshake is sent on the USB. A STALL bit takes priority over a NAK bit.

Bit 5 **INEPNM**: IN token received with EP mismatch

Indicates that the data in the top of the non-periodic TxFIFO belongs to an endpoint other than the one for which the IN token was received. This interrupt is asserted on the endpoint for which the IN token was received.

Bit 4 **ITTXFE:** IN token received when Tx FIFO is empty
Indicates that an IN token was received when the associated Tx FIFO (periodic/non-periodic) was empty. This interrupt is asserted on the endpoint for which the IN token was received.

Bit 3 **TOC:** Timeout condition
Indicates that the core has detected a timeout condition on the USB for the last IN token on this endpoint.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **EPDISD:** Endpoint disabled interrupt
This bit indicates that the endpoint is disabled per the application's request.

Bit 0 **XFRC:** Transfer completed interrupt
This field indicates that the programmed transfer is complete on the AHB as well as on the USB, for this endpoint.

66.15.52 OTG device IN endpoint 0 transfer size register (OTG_DIEPTSIZ0)

The application must modify this register before enabling endpoint 0. Once endpoint 0 is enabled using the endpoint enable bit in the device control endpoint 0 control registers (EPENA in OTG_DIEPCTL0), the core modifies this register. The application can only read this register once the core has cleared the endpoint enable bit.

Nonzero endpoints use the registers for endpoints 1–3.

Address offset: 0x910

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTCNT[1:0]		Res.	Res.	Res.
											rw	rw			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XFRSIZ[6:0]						
									rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:19 **PKTCNT[1:0]:** Packet count
Indicates the total number of USB packets that constitute the transfer size amount of data for endpoint 0.
This field is decremented every time a packet (maximum size or short packet) is read from the Tx FIFO.

Bits 18:7 Reserved, must be kept at reset value.

Bits 6:0 **XFRSIZ[6:0]:** Transfer size
Indicates the transfer size in bytes for endpoint 0. The core interrupts the application only after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.
The core decrements this field every time a packet from the external memory is written to the Tx FIFO.

66.15.53 OTG device IN endpoint transmit FIFO status register (OTG_DTXFSTSx)

This read-only register contains the free space information for the device IN endpoint Tx FIFO.

Address offset: 0x918 + 0x20 * x, (x = 0 to 5)

Reset value: 0x0000 0200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INEPTFSAV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **INEPTFSAV[15:0]:** IN endpoint Tx FIFO space available
Indicates the amount of free space available in the endpoint Tx FIFO.
Values are in terms of 32-bit words:
0: Endpoint Tx FIFO is full
1: 1 word available
2: 2 words available
n: n words available
Others: Reserved

66.15.54 OTG device IN endpoint x transfer size register (OTG_DIEPTSIZx)

The application must modify this register before enabling the endpoint. Once the endpoint is enabled using the endpoint enable bit in the OTG_DIEPCTLx registers (EPENA bit in OTG_DIEPCTLx), the core modifies this register. The application can only read this register once the core has cleared the endpoint enable bit.

Address offset: 0x910 + 0x20 * x, (x = 1 to 5)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	MCNT[1:0]		PKTCNT[9:0]										XFRSIZ[18:16]		
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XFRSIZ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **MCNT[1:0]:** Multi count

For periodic IN endpoints, this field indicates the number of packets that must be transmitted per frame on the USB. The core uses this field to calculate the data PID for isochronous IN endpoints.

01: 1 packet

10: 2 packets

11: 3 packets

Bits 28:19 **PKTCNT[9:0]:** Packet count

Indicates the total number of USB packets that constitute the transfer size amount of data for this endpoint.

This field is decremented every time a packet (maximum size or short packet) is read from the Tx FIFO.

Bits 18:0 **XFRSIZ[18:0]:** Transfer size

This field contains the transfer size in bytes for the current endpoint. The core only interrupts the application after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.

The core decrements this field every time a packet from the external memory is written to the Tx FIFO.

66.15.55 OTG device control OUT endpoint 0 control register (OTG_DOEPCTL0)

This section describes the OTG_DOEPCTL0 register. Nonzero control endpoints use registers for endpoints 1–3.

Address offset: 0xB00

Reset value: 0x0000 8000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	Res.	Res.	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EPTYP[1:0]		NAK STS	Res.
w	r			w	w					rs	rw	r	r	r	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MPSIZ[1:0]	
r														r	r

Bit 31 **EPENA:** Endpoint enable

The application sets this bit to start transmitting data on endpoint 0.

The core clears this bit before setting any of the following interrupts on this endpoint:

– SETUP phase done

– Endpoint disabled

– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application cannot disable control OUT endpoint 0.

Bits 29:28 Reserved, must be kept at reset value.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.

Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **STALL:** STALL handshake

The application can only set this bit, and the core clears it, when a SETUP token is received for this endpoint. If a NAK bit or Global OUT NAK is set along with this bit, the STALL bit takes priority. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 20 **SNPM:** Snoop mode

This bit configures the endpoint to Snoop mode. In Snoop mode, the core does not check the correctness of OUT packets before transferring them to application memory.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

Hardcoded to 2'b00 for control.

Bit 17 **NAKSTS:** NAK status

Indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status.

1: The core is transmitting NAK handshakes on this endpoint.

When either the application or the core sets this bit, the core stops receiving data, even if there is space in the Rx FIFO to accommodate the incoming packet. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **USBAEP:** USB active endpoint

This bit is always set to 1, indicating that a control endpoint 0 is always active in all configurations and interfaces.

Bits 14:2 Reserved, must be kept at reset value.

Bits 1:0 **MPSIZ[1:0]:** Maximum packet size

The maximum packet size for control OUT endpoint 0 is the same as what is programmed in control IN endpoint 0.

00: 64 bytes

01: 32 bytes

10: 16 bytes

11: 8 bytes

66.15.56 OTG device OUT endpoint x interrupt register (OTG_DOEPINTx)

This register indicates the status of an endpoint with respect to USB- and AHB-related events. It is shown in *Figure 937*. The application must read this register when the OUT endpoints interrupt bit of the OTG_GINTSTS register (OEPINT bit in OTG_GINTSTS) is set. Before the application can read this register, it must first read the OTG_DAINT register to get the exact endpoint number for the OTG_DOEPINTx register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_DAINT and OTG_GINTSTS registers.

Address offset: 0xB08 + 0x20 * x, (x = 0 to 5)

Reset value: 0x0000 0080

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	NAK	BERR	Res.	Res.	Res.	Res.	Res.	Res.	STSPH SRX	OTEP DIS	STUP	Res.	EP DISD	XFRC
		rc_w1	rc_w1							rc_w1	rc_w1	rc_w1		rc_w1	rc_w1

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **NAK:** NAK input

The core generates this interrupt when a NAK is transmitted or received by the device. In case of isochronous IN endpoints the interrupt gets generated when a zero length packet is transmitted due to unavailability of data in the Tx FIFO.

Bit 12 **BERR:** Babble error interrupt

The core generates this interrupt when babble is received for the endpoint.

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 Reserved, must be kept at reset value.

Bit 8 Reserved, must be kept at reset value.

Bit 7 Reserved, must be kept at reset value.

Bit 6 Reserved, must be kept at reset value.

Bit 5 **STSPHSRX**: Status phase received for control write

This interrupt is valid only for control OUT endpoints. This interrupt is generated only after OTG_FS has transferred all the data that the host has sent during the data phase of a control write transfer, to the system memory buffer. The interrupt indicates to the application that the host has switched from data phase to the status phase of a control write transfer. The application can use this interrupt to ACK or STALL the status phase, after it has decoded the data phase.

Bit 4 **OTEPDIS:** OUT token received when endpoint disabled

Applies only to control OUT endpoints.

Indicates that an OUT token was received when the endpoint was not yet enabled. This interrupt is asserted on the endpoint for which the OUT token was received.

Bit 3 **STUP:** SETUP phase done

Applies to control OUT endpoint only.Indicates that the SETUP phase for the control endpoint is complete and no more back-to-back SETUP packets were received for the current control transfer. On this interrupt, the application can decode the received SETUP data packet.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **EPDISD:** Endpoint disabled interrupt

This bit indicates that the endpoint is disabled per the application's request.

Bit 0 **XFRC:** Transfer completed interrupt

This field indicates that the programmed transfer is complete on the AHB as well as on the USB, for this endpoint.

66.15.57 OTG device OUT endpoint 0 transfer size register (OTG_DOEPTSIZ0)

The application must modify this register before enabling endpoint 0. Once endpoint 0 is enabled using the endpoint enable bit in the OTG_DOEPCTL0 registers (EPENA bit in OTG_DOEPCTL0), the core modifies this register. The application can only read this register once the core has cleared the endpoint enable bit.

Nonzero endpoints use the registers for endpoints 1–5.

Address offset: 0xB10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	STUPCNT[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTCNT	Res.	Res.	Res.
	rw	rw										rw			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XFRSIZ[6:0]						
									rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **STUPCNT[1:0]:** SETUP packet count

This field specifies the number of back-to-back SETUP data packets the endpoint can receive.

01: 1 packet

10: 2 packets

11: 3 packets

Bits 28:20 Reserved, must be kept at reset value.

Bit 19 **PKTCNT:** Packet count

This field is decremented to zero after a packet is written into the Rx FIFO.

Bits 18:7 Reserved, must be kept at reset value.

Bits 6:0 **XFRSIZ[6:0]:** Transfer size

Indicates the transfer size in bytes for endpoint 0. The core interrupts the application only after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.

The core decrements this field every time a packet is read from the Rx FIFO and written to the external memory.

66.15.58 OTG device OUT endpoint x control register [alternate] (OTG_DOEPCTLx)

Valid for INT/BULK endpoints, see next section for ISO endpoints.

The application uses this register to control the behavior of each logical endpoint other than endpoint 0.

Address offset: 0xB00 + 0x20 * x, (x = 1 to 5)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	SD1 PID	SD0 PID	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EPTYP[1:0]		NAK STS	DPID
rs	rs	w	w	w	w					rw	rw	rw	rw	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	MPSIZ[10:0]										
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **EPENA:** Endpoint enable

Applies to IN and OUT endpoints.

The application sets this bit to start transmitting data on an endpoint.

The core clears this bit before setting any of the following interrupts on this endpoint:

– SETUP phase done

– Endpoint disabled

– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application sets this bit to stop transmitting/receiving data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the endpoint disabled interrupt. The application must set this bit only if endpoint enable is already set for this endpoint.

Bit 29 **SD1PID:** Set DATA1 PID

Applies to interrupt/bulk IN and OUT endpoints only. Writing to this field sets the endpoint data PID (DPID) field in this register to DATA1.

Bit 28 **SD0PID:** Set DATA0 PID

Applies to interrupt/bulk OUT endpoints only.

Writing to this field sets the endpoint data PID (DPID) field in this register to DATA0.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.

Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for OUT endpoints on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **STALL:** STALL handshake

Applies to non-control, non-isochronous OUT endpoints only (access type is rw).

The application sets this bit to stall all tokens from the USB host to this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Only the application can clear this bit, never the core.

Applies to control endpoints only (access type is rs).

The application can only set this bit, and the core clears it, when a SETUP token is received for this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 20 **SNPM:** Snoop mode

This bit configures the endpoint to Snoop mode. In Snoop mode, the core does not check the correctness of OUT packets before transferring them to application memory.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

This is the transfer type supported by this logical endpoint.

00: Control

01: Isochronous

10: Bulk

11: Interrupt

Bit 17 **NAKSTS:** NAK status

Indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status.

1: The core is transmitting NAK handshakes on this endpoint.

When either the application or the core sets this bit:

The core stops receiving any data on an OUT endpoint, even if there is space in the Rx FIFO to accommodate the incoming packet.

Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 **DPID:** Endpoint data PID

Applies to interrupt/bulk OUT endpoints only.

Contains the PID of the packet to be received or transmitted on this endpoint. The application must program the PID of the first packet to be received or transmitted on this endpoint, after the endpoint is activated. The application uses the SD0PID register field to program either DATA0 or DATA1 PID.

0: DATA0

1: DATA1

Bit 15 **USBAEP:** USB active endpoint

Indicates whether this endpoint is active in the current configuration and interface. The core clears this bit for all endpoints (other than EP 0) after detecting a USB reset. After receiving the SetConfiguration and SetInterface commands, the application must program endpoint registers accordingly and set this bit.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size

The application must program this field with the maximum packet size for the current logical endpoint. This value is in bytes.

66.15.59 OTG device OUT endpoint x control register [alternate] (OTG_DOEPCTLx)

Valid for ISO endpoints, see previous section for INT/BULK endpoints.

The application uses this register to control the behavior of each logical endpoint other than endpoint 0.

Address offset: 0xB00 + 0x20 * x, (x = 1 to 5)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	SODD FRM	SEVN FRM	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EPTYP[1:0]		NAK STS	EO NUM
rs	rs	w	w	w	w					rw	rw	rw	rw	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	MPSIZ[10:0]										
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **EPENA:** Endpoint enable

Applies to IN and OUT endpoints.

The application sets this bit to start transmitting data on an endpoint.

The core clears this bit before setting any of the following interrupts on this endpoint:

– SETUP phase done

– Endpoint disabled

– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application sets this bit to stop transmitting/receiving data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the endpoint disabled interrupt. The application must set this bit only if endpoint enable is already set for this endpoint.

Bit 29 **SODDFRM:** Set odd frame

Applies to isochronous IN and OUT endpoints only. Writing to this field sets the Even/Odd frame (EONUM) field to odd frame.

Bit 28 **SEVNFRM:** Set even frame

Applies to isochronous OUT endpoints only.

Writing to this field sets the Even/Odd frame (EONUM) field to even frame.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.

Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for OUT endpoints on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **STALL:** STALL handshake

Applies to non-control, non-isochronous OUT endpoints only (access type is rw).

The application sets this bit to stall all tokens from the USB host to this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Only the application can clear this bit, never the core.

Applies to control endpoints only (access type is rs).

The application can only set this bit, and the core clears it, when a SETUP token is received for this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 20 **SNPM:** Snoop mode

This bit configures the endpoint to Snoop mode. In Snoop mode, the core does not check the correctness of OUT packets before transferring them to application memory.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

This is the transfer type supported by this logical endpoint.

00: Control

01: Isochronous

10: Bulk

11: Interrupt

Bit 17 **NAKSTS:** NAK status

Indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status.

1: The core is transmitting NAK handshakes on this endpoint.

When either the application or the core sets this bit:

The core stops receiving any data on an OUT endpoint, even if there is space in the Rx FIFO to accommodate the incoming packet.

Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 **EONUM:** Even/odd frame

Applies to isochronous IN and OUT endpoints only.

Indicates the frame number in which the core transmits/receives isochronous data for this endpoint. The application must program the even/odd frame number in which it intends to transmit/receive isochronous data for this endpoint using the SEVNFRM and SODDFRM fields in this register.

0: Even frame

1: Odd frame

Bit 15 **USBAEP:** USB active endpoint

Indicates whether this endpoint is active in the current configuration and interface. The core clears this bit for all endpoints (other than EP 0) after detecting a USB reset. After receiving the SetConfiguration and SetInterface commands, the application must program endpoint registers accordingly and set this bit.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size

The application must program this field with the maximum packet size for the current logical endpoint. This value is in bytes.

66.15.60 OTG device OUT endpoint x transfer size register (OTG_DOEPTSIZx)

The application must modify this register before enabling the endpoint. Once the endpoint is enabled using endpoint enable bit of the OTG_DOEPCTLx registers (EPENA bit in OTG_DOEPCTLx), the core modifies this register. The application can only read this register once the core has cleared the endpoint enable bit.

Address offset: 0xB10 + 0x20 * x, (x = 1 to 5)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	RXDPID[1:0]		PKTCNT[9:0]										XFRSIZ[18:16]		
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XFRSIZ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **RXDPID[1:0]:**

Condition: isochronous OUT endpoints
Received data PID
This is the data PID received in the last packet for this endpoint.
00: DATA0
01: DATA2
10: DATA1
11: MDATA
Condition: control OUT endpoints
STUPCNT[1:0]: SETUP packet count
This field specifies the number of back-to-back SETUP data packets the endpoint can receive.
01: 1 packet
10: 2 packets
11: 3 packets

Bits 28:19 **PKTCNT[9:0]:** Packet count

Indicates the total number of USB packets that constitute the transfer size amount of data for this endpoint.
This field is decremented every time a packet (maximum size or short packet) is written to the Rx FIFO.

Bits 18:0 **XFRSIZ[18:0]:** Transfer size

This field contains the transfer size in bytes for the current endpoint. The core only interrupts the application after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.
The core decrements this field every time a packet is read from the Rx FIFO and written to the external memory.

66.15.61 OTG power and clock gating control register (OTG_PCGCCTL)

This register is available in host and device modes.

Address offset: 0xE00

Reset value: 0x200B 8000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUSP	PHY SLEEP	ENL1 GTG	PHY SUSP	Res.	Res.	GATE HCLK	STPP CLK
								r	r	rw	r			rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **SUSP:** Deep Sleep

This bit indicates that the PHY is in Deep Sleep when in L1 state.

Bit 6 **PHYSLEEP:** PHY in Sleep

This bit indicates that the PHY is in the Sleep state.

Bit 5 **ENL1GTG:** Enable sleep clock gating

When this bit is set, core internal clock gating is enabled in Sleep state if the core cannot assert utmi_l1_suspend_n. When this bit is not set, the PHY clock is not gated in Sleep state.

Bit 4 **PHYSUSP:** PHY suspended

Indicates that the PHY has been suspended. This bit is updated once the PHY is suspended after the application has set the STPPCLK bit.

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **GATEHCLK:** Gate HCLK

The application sets this bit to gate HCLK to modules other than the AHB Slave and Master and wakeup logic when the USB is suspended or the session is not valid. The application clears this bit when the USB is resumed or a new session starts.

Bit 0 **STPPCLK:** Stop PHY clock

The application sets this bit to stop the PHY clock when the USB is suspended, the session is not valid, or the device is disconnected. The application clears this bit when the USB is resumed or a new session starts.

66.15.62 OTG power and clock gating control register 1 (OTG_PCGCCTL1)

This register is available in host and device modes.

Address offset: 0xE04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RAM GATE EN	CNTGATECLK [1:0]		GATE EN
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **RAMGATEEN:** Enable RAM clock gating

Enable gating of the FIFO RAM.

Bits 2:1 **CNTGATECLK[1:0]:** Counter for clock gating

Indicates to the controller how many PHY clock cycles and AHB clock cycles of 'IDLE' (no activity) the controller waits for before gating the respective PHY and AHB clocks internal to the controller.

00: 64 clocks

01: 128 clocks

10: Reserved

11: Reserved

Bit 0 **GATEEN:** Enable active clock gating

The application programs GATEEN to enable active clock gating feature for the PHY and AHB clocks.

66.15.63 OTG_FS register map

The table below gives the USB OTG register map and reset values.

Table 739. OTG_FS register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	OTG_ GOTGCTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CURMOD	OTGVER	BSVLD	ASVLD	DBCT	CIDSTS	Res.	Res.	Res.	EHEN	Res.	Res.	Res.	Res.	BVALOVAL	BVALOEN	AVALOVAL	AVALOEN	VBVALOVA	VBVALOEN	Res.	Res.
	Reset value											0	0	0	0	0	1				0					0	0	0	0	0	0		
0x004	OTG_ GOTGINT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADTOCHG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEDET	Res.	Res.
	Reset value														0								-								0		
0x008	OTG_ GAHBCFG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PTXFELVL	TXFELVL	Res.	Res.	Res.	Res.	Res.	Res.	GINTMSK
	Reset value																								0	0							0
0x00C	OTG_ GUSBCFG	Res.	FDMOD	FHMOD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRDT				Res.	Res.	Res.	PHYSEL	Res.	Res.	Res.	TOCAL		
	Reset value		0	0																0	1	0	1				1				0	0	0
0x010	OTG_ GRSTCTL	AHBIDL	Res.	CSRSTDONE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXFNUM					TXFFLSH	RXFFLSH	Res.	FCRST	PSRST	CSRST
	Reset value	1		0																			0	0	0	0	0	0	0		0	0	0
0x014	OTG_ GINTSTS	WKUPINT	SRQINT	DISCINT	CIDSCHG	LPMINT	PTXFE	HCINT	HPRTINT	RSTDET	Res.	IPXFR/INCOMPISOOUT	IISOIXFR	OEPINT	IEPINT	Res.	Res.	EOPF	ISOODRP	ENUMDNE	USBRST	USBSUSP	ESUSP	Res.	Res.	GONAKEFF	GINAKEFF	NPTXFE	RXFLVL	SOF	OTGINT	MMIS	CMOD
	Reset value	0	0	0	0	0	1	0	0	0		0	0	0	0			0	0	0	0	0	0			0	0	1	0	0	0	0	0
0x018	OTG_ GINTMSK	WUIM	SRQIM	DISCINT	CIDSCHGM	LPMINTM	PTXFEM	HCIM	PRTIM	RSTDETM	Res.	IPXFRM/IISOOXFRM	IISOIXFRM	OEPINT	IEPINT	Res.	Res.	EOPFM	ISOODRPM	ENUMDNEM	USBRST	USBSUSPM	ESUSPM	Res.	Res.	GONAKEFFM	GINAKEFFM	NPTXFEM	RXFLVLM	SOFM	OTGINT	MMISM	Res.
	Reset value	0	0	0	0	0	0	0	0	0		0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0	0	

Table 739. OTG_FS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x01C	**OTG_ GRXSTSR (Device mode)**	Res.	Res.	Res.	Res.	STSPHST	Res.	Res.	FRMNUM				PKTSTS				DPID		BCNT											EPNUM			
	Reset value					0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OTG_ GRXSTSR (Host mode)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTSTS				DPID		BCNT											CHNUM			
	Reset value												0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	**OTG_ GRXSTSP (Device mode)**	Res.	Res.	Res.	Res	STSPHST	Res.	Res.	FRMNUM				PKTSTS				DPID		BCNT											EPNUM			
	Reset value					0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OTG_ GRXSTSP (Host mode)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTSTS				DPID		BCNT											CHNUM			
	Reset value												0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	**OTG_ GRXFSIZ**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXFD															
	Reset value																	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x028	**OTG_ HNPTXFSIZ/ OTG_ DIEPTXF0**	NPTXFD/TX0FD																NPTXFSA/TX0FSA															
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x02C	**OTG_ HNPTXSTS**	Res.	NPTXQTOP							NPTQXSAV								NPTXFSAV															
	Reset value		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x038	**OTG_ GCCFG**	Res.	Res.	Res.	Res.	Res.	Res.	FORCEHOSTPD	COMPDIS	Res.	Res.	Res.	SDEN	PDEN	Res.	BCDEN	PWRDWN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PS2DET	SDET	PDET	Res.
	Reset value							0	0				0	0		0	0													X	X	X	
0x03C	**OTG_CID**	PRODUCT_ID																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x054	**OTG_ GLPMCFG**	Res.	Res.	Res.	ENBESL	LPMR CNTSTS			SNDLPM	LPM RCNT			LPMCHIDX				L1RSMOK	SLPSTS	LPM RSP		L1DSEN	BESLTHRS				L1SSEN	REMWAKE	BESL			LPMACK	LPMEN
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x100	**OTG_ HPTXFSIZ**	PTXFSIZ																PTXSA															
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0x104	**OTG_ DIEPTXF1**	INEPTXFD																INEPTXSA															
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

Table 739. OTG_FS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
. . . .	. . . .	. . . .																															
0x114	**OTG_ DIEPTXF5**	INEPTXFD																INEPTXSA															
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
0x400	**OTG_ HCFG**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSLSS	FSLS PCS	
	Reset value																														0	0	0
0x404	**OTG_ HFIR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RLDCTRL	FRIVL															
	Reset value																0	1	1	1	0	1	0	1	0	0	1	1	0	0	0	0	0
0x408	**OTG_ HFNUM**	FTREM																FRNUM															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x410	**OTG_ HPTXSTS**	PTXQTOP								PTXQSAV								PTXFSAVL															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0x414	**OTG_ HAINT**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HAINT															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x418	**OTG_ HAINTMSK**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HAINTM															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x440	**OTG_ HPRT**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSPD	PTCTL			PPWR	PLSTS		PRST	PSUSP	PRES	POCCHNG	POCA	PENCHNG	PENA	PCDET	PCSTS			
	Reset value														0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0
0x500	**OTG_ HCCHAR0**	CHENA	CHDIS	ODDFRM	DAD							MCNT		EPTYP		LSDEV	Res.	EPDIR	EPNUM				MPSIZ											
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x508	**OTG_ HCINT0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERR	FRMOR	BBERR	TXERR	Res.	ACK	NAK	STALL	Res.	CHH	XFRC
	Reset value																						0	0	0	0		0	0	0		0	0
0x508	**OTG_ HCINT0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERR	FRMOR	BBERR	TXERR	NYET	ACK	NAK	STALL	AHBERR	CHH	XFRC
	Reset value																						0	0	0	0	0	0	0	0	0	0	0

Table 739. OTG_FS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x50C	**OTG_ HCINTMSK0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERRM	FRMORM	BBERRM	TXERRM		ACKM	NAKM	STALLM	Res.	CHHM	XFRCM
	Reset value																						0	0	0	0		0	0	0		0	0
0x510	**OTG_ HCTSIZ0**	DOPNG	DPID		PKTCNT										XFRSIZ																		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
. . . .	. . . .	. Iterating preceding block of registers starting at offset 0x500. .																															
0x660	**OTG_ HCCHAR11**	CHENA	CHDIS	ODDFRM	DAD							MCNT		EPTYP		LSDEV	Res.	EPDIR	EPNUM				MPSIZ											
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x668	**OTG_ HCINT11**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERR	FRMOR	BBERR	TXERR	Res.	ACK	NAK	STALL	Res.	CHH	XFRC
	Reset value																						0	0	0	0		0	0	0		0	0
0x66C	**OTG_ HCINTMSK11**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERRM	FRMORM	BBERRM	TXERRM		ACKM	NAKM	STALLM	Res.	CHHM	XFRCM
	Reset value																						0	0	0	0		0	0	0		0	0
0x670	**OTG_ HCTSIZ11**	DOPNG	DPID		PKTCNT										XFRSIZ																		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x800	**OTG_ DCFG**	Res.	Res.	Res	Res.	Res.	Res.	Res.	Res.	Res	Res.	Res.	Res.	Res	Res.	Res.	Res.	ERRATIM	XCVRDLY	Res.	PFIVL		DAD							Res.	NZLSOHSK	DSPD	
	Reset value																	0	0		0	0	0	0	0	0	0	0	0		0	0	0
0x804	**OTG_ DCTL**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DSBESLRJCT	Res.	Res.	Res.	Res.	Res.	Res.	POPRGDNE	CGONAK	SGONAK	CGINAK	SGINAK	TCTL			GONSTS	GINSTS	SDIS	RWUSIG
	Reset value														0							0	0	0	0	0	0	0	0	0	0	1	0
0x808	**OTG_ DSTS**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEV LN STS		FNSOF											Res.	Res.	Res.	Res.	EERR	ENUMSPD		SUSPSTS			
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0

Table 739. OTG_FS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x810	OTG_ DIEPMSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAKM	Res.	Res.	Res.	Res.	Res.	Res.	INEPNEM	INEPNMM	ITTXFEMSK	TOM	Res.	EPDM	XFRCM
	Reset value																			0							0	0	0	0		0	0
0x814	OTG_ DOEPMSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAKMSK	BERRM	Res.	Res.	Res.	OUTPKTERRM	Res.	Res.	Res.	OTEPDM	STUPM	Res.	EPDM	XFRCM
	Reset value																			0	0				0				0	0		0	0
0x818	OTG_ DAINT	OEPINT																IEPINT															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x81C	OTG_ DAINTMSK	OEPM																IEPM															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x834	OTG_DIE PEMPMSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INEPTXFEM															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x838	OTG_ DEACHINT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OEP1INT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IEP1INT	Res.
	Reset value															0																0	
0x83C	OTG_DEACHI NTMSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OEP1INTM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IEP1INTM	Res.
	Reset value															0																0	
0x844	OTG_ DIEPEACHM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAKM	Res.	Res.	Res.	Res.	TXFURM	Res.	INEPNEM	Res.	ITTXFEMSK	TOM	AHBERRM	EPDM	XFRCM
	Reset value																			0					0	-	0		0	0	0	0	0
0x884	OTG_ DOEPEACH MSK1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NYETMSK	NAKMSK	BERRM	Res.	Res.	Res.	OUTPKTERRM	Res.	Res.	Res.	OTEPDM	STUPM	AHBERRM	EPDM	XFRCM
	Reset value																		0	0	0				0				0	0	0	0	0
0x900	OTG_ DIEPCTL0	EPENA	EPDIS	Res.	Res.	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	Res.	USBAEP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MPSIZ	
	Reset value	0	0			0	0	0	0	0	0	0		0	0	0		1														0	0

Table 739. OTG_FS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x908	**OTG_ DIEPINT0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAK	Res.	PKTDRPSTS	Res.	Res.	Res.	TXFE	INEPNE	INEPNM	ITTXFE	TOC	Res.	EPDISD	XFRC
	Reset value																			0		0				1	0	0	0	0		0	0
0x910	**OTG_ DIEPTSIZ0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKT CNT		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XFRSIZ						
	Reset value												0	0													0	0	0	0	0	0	0
0x918	**OTG_ DTXFSTS0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INEPTFSAV															
	Reset value																	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x920	**OTG_ DIEPCTL1 (INT/BULK)**	EPENA	EPDIS	SD1PID	SD0PID	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
	OTG_ DIEPCTL1 (ISO)	EPENA	EPDIS	SODDFRM	SEVNFRM	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	EONUM	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
0x928	**OTG_ DIEPINT1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAK	Res.	PKTDRPSTS	Res.	Res.	Res.	TXFE	INEPNE	INEPNM	ITTXFE	TOC	Res.	EPDISD	XFRC
	Reset value																			0		0				1	0	0	0	0		0	0
0x930	**OTG_ DIEPTSIZ1**	Res.	MCNT		PKTCNT										XFRSIZ																		
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x938	**OTG_ DTXFSTS1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INEPTFSAV															
	Reset value																	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
. . . .	. . . .	. Iterating preceding block of registers starting at offset 0x920. .																															
0x9A0	**OTG_ DIEPCTL5 (INT/BULK)**	EPENA	EPDIS	SD1PID	SD0PID	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
	OTG_ DIEPCTL5 (ISO)	EPENA	EPDIS	SODDFRM	SEVNFRM	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	EONUM	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0

Table 739. OTG_FS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x9A8	**OTG_ DIEPINT5**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAK	Res.	PKTDRPSTS	Res.	Res.	Res.	TXFE	INEPNE	INEPNM	ITTXFE	TOC	Res.	EPDISD	XFRC
	Reset value																			0		0				1	0	0	0	0		0	0
0x9B8	**OTG_ DTXFSTS5**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INEPTFSAV															
	Reset value																	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x9B0	**OTG_ DIEPTSIZ5**	Res.	MCNT		PKTCNT										XFRSIZ																		
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xB00	**OTG_ DOEPCTL0**	EPENA	EPDIS	Res.	Res.	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EPTYP		NAKSTS	Res.	USBAEP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MPSIZ	
	Reset value	0	0			0	0					0	0	0	0	0		1														0	0
0xB08	**OTG_ DOEPINT0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAK	BERR	Res.	Res.	Res.	Res.	Res.	Res.	STSPHSRX	OTEPDIS	STUP	Res.	EPDISD	XFRC
	Reset value																			0	0							0	0	0		0	0
0xB10	**OTG_ DOEPTSIZ0**	Res.	STUP CNT		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTCNT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XFRSIZ						
	Reset value		0	0										0													0	0	0	0	0	0	0
0xB20	**OTG_ DOEPCTL1 (INT/BULK)**	EPENA	EPDIS	SD1PID	SD0PID	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EP TYP		NAKSTS	DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0					0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
	OTG_ DOEPCTL1 (ISO)	EPENA	EPDIS	SODDFRM	SEVNFRM	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EP TYP		NAKSTS	EONUM	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0					0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
0xB28	**OTG_ DOEPINT1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAK	BERR	Res.	Res.	Res.	Res.	Res.	Res.	STSPHSRX	OTEPDIS	STUP	Res.	EPDISD	XFRC
	Reset value																			0	0							0	0	0		0	0
0xB30	**OTG_ DOEPTSIZ1**	Res.	RXDPID/ STUPCNT		PKTCNT										XFRSIZ																		
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
. . . .	. . . .	Iterating preceding block of registers starting at offset 0xB20.																															

Table 739. OTG_FS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xBA0	**OTG_ DOEPCTL5 (INT/BULK)**	EPENA	EPDIS	SD1PID	SD0PID	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EP TYP		NAKSTS	DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0					0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
	OTG_ DOEPCTL5 (ISO)	EPENA	EPDIS	SODDFRM	SEVNFRM	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EP TYP		NAKSTS	EONUM	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0					0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
0xBA8	**OTG_ DOEPINT5**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAK	BERR	Res.	Res.	Res.	Res.	Res.	Res.	STSPHSRX	OTEPDIS	STUP	Res.	EPDISD	XFRC
	Reset value																			0	0					-		0	0	0		0	0
0xBB0	**OTG_ DOEPTSIZ5**	Res.	RXDPID/ STUPCNT		PKTCNT											XFRSIZ																	
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xE00	**OTG_ PCGCCTL**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUSP	PHYSLEEP	ENL1GTG	PHYSUSP	Res.	Res.	GATEHCLK	STPPCLK
	Reset value																									0	0	0	0			0	0
0xE04	**OTG_ PCGCCTL1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RAMGATEEN	CNTGATECLK		GATEEN
	Reset value																													0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

66.16 OTG_FS programming model

66.16.1 Core initialization

The application must perform the core initialization sequence. If the cable is connected during power-up, the current mode of operation bit in the OTG_GINTSTS (CMOD bit in OTG_GINTSTS) reflects the mode. The OTG_FS controller enters host mode when an “A” plug is connected or device mode when a “B” plug is connected.

This section explains the initialization of the OTG_FS controller after power-on. The application must follow the initialization sequence irrespective of host or device mode operation. All core global registers are initialized according to the core’s configuration:

1. Program the following fields in the OTG_GAHBCFG register:
   - Global interrupt mask bit GINTMSK = 1
   - Rx FIFO non-empty (RXFLVL bit in OTG_GINTSTS)
   - Periodic Tx FIFO empty level
2. Program the following fields in the OTG_GUSBCFG register:
   - OTG_FS timeout calibration field
   - USB turnaround time field
3. The software must unmask the following bits in the OTG_GINTMSK register:

   OTG interrupt mask

   Mode mismatch interrupt mask
4. The software can read the CMOD bit in OTG_GINTSTS to determine whether the OTG_FS controller is operating in host or device mode.

66.16.2 Host initialization

To initialize the core as host, the application must perform the following steps:

1. Program the HPRTINT in the OTG_GINTMSK register to unmask
2. Program the OTG_HCFG register to select full-speed host
3. Program the PPWR bit in OTG_HPRT to 1. This drives V_{BUS} on the USB.
4. Wait for the PCDET interrupt in OTG_HPRT0. This indicates that a device is connecting to the port.
5. Program the PRST bit in OTG_HPRT to 1. This starts the reset process.
6. Wait at least 10 ms for the reset process to complete.
7. Program the PRST bit in OTG_HPRT to 0.
8. Wait for the PENCHNG interrupt in OTG_HPRT.
9. Read the PSPD bit in OTG_HPRT to get the enumerated speed.
10. Program the HFIR register with a value corresponding to the selected PHY clock 1
11. Program the FSLSPCS field in the OTG_HCFG register following the speed of the device detected in step 9. If FSLSPCS has been changed a port reset must be performed.
12. Program the OTG_GRXFSIZ register to select the size of the receive FIFO.
13. Program the OTG_HNPTXFSIZ register to select the size and the start address of the Non-periodic transmit FIFO for non-periodic transactions.
14. Program the OTG_HPTXFSIZ register to select the size and start address of the periodic transmit FIFO for periodic transactions.

To communicate with devices, the system software must initialize and enable at least one channel.

66.16.3 Device initialization

The application must perform the following steps to initialize the core as a device on power-up or after a mode change from host to device.

1. Program the following fields in the OTG_DCFG register:
   - Device speed
   - Non-zero-length status OUT handshake
   - Periodic Frame Interval
2. Clear the DCTL.SDIS bit. The core issues a connect after this bit is cleared.
3. Program the OTG_GINTMSK register to unmask the following interrupts:
   - USB reset
   - Enumeration done
   - Early suspend
   - USB suspend
   - SOF
4. Wait for the USBRST interrupt in OTG_GINTSTS. It indicates that a reset has been detected on the USB that lasts for about 10 ms on receiving this interrupt.
5. Wait for the ENUMDNE interrupt in OTG_GINTSTS. This interrupt indicates the end of reset on the USB. On receiving this interrupt, the application must read the OTG_DSTS

register to determine the enumeration speed and perform the steps listed in *Endpoint initialization on enumeration completion on page 3245*.

At this point, the device is ready to accept SOF packets and perform control transfers on control endpoint 0.

66.16.4 Host programming model

Channel initialization

The application must initialize one or more channels before it can communicate with connected devices. To initialize and enable a channel, the application must perform the following steps:

1. Program the OTG_GINTMSK register to unmask the following:
2. Channel interrupt
   - Non-periodic transmit FIFO empty for OUT transactions (applicable when operating in pipelined transaction-level with the packet count field programmed with more than one).
   - Non-periodic transmit FIFO half-empty for OUT transactions (applicable when operating in pipelined transaction-level with the packet count field programmed with more than one).
3. Program the OTG_HAINTMSK register to unmask the selected channels' interrupts.
4. Program the OTG_HCINTMSK register to unmask the transaction-related interrupts of interest given in the host channel interrupt register.
5. Program the selected channel's OTG_HCTSIZx register with the total transfer size, in bytes, and the expected number of packets, including short packets. The application must program the PID field with the initial data PID (to be used on the first OUT transaction or to be expected from the first IN transaction).
6. Program the OTG_HCCHARx register of the selected channel with the device's endpoint characteristics, such as type, speed, direction, and so forth. (The channel can be enabled by setting the channel enable bit to 1 only when the application is ready to transmit or receive any packet).

Halting a channel

The application can disable any channel by programming the OTG_HCCHARx register with the CHDIS and CHENA bits set to 1. This enables the OTG_FS host to flush the posted requests (if any) and generates a channel halted interrupt. The application must wait for the CHH interrupt in OTG_HCINTx before reallocating the channel for other transactions. The OTG_FS host does not interrupt the transaction that has already been started on the USB.

Before disabling a channel, the application must ensure that there is at least one free space available in the non-periodic request queue (when disabling a non-periodic channel) or the periodic request queue (when disabling a periodic channel). The application can simply flush the posted requests when the request queue is full (before disabling the channel), by programming the OTG_HCCHARx register with the CHDIS bit set to 1 which automatically clears the CHENA bit to 0.

The application is expected to disable a channel on any of the following conditions:

1. When an STALL, TXERR, BBERR or DTERR interrupt in OTG_HCINTx is received for an IN or OUT channel. The application must be able to receive other interrupts (DTERR, Nak, data, TXERR) for the same channel before receiving the halt.
2. When a DISCINT (disconnect device) interrupt in OTG_GINTSTS is received. (The application is expected to disable all enabled channels).
3. When the application aborts a transfer before normal completion.

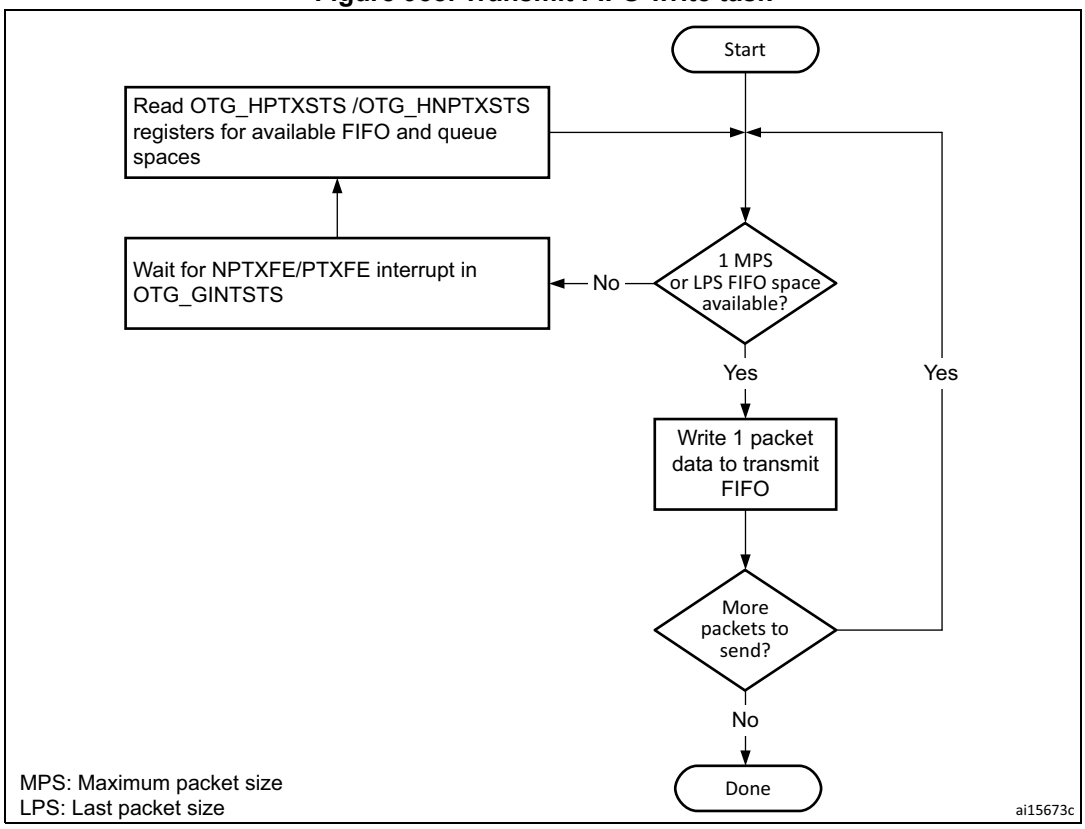
Operational model

The application must initialize a channel before communicating to the connected device. This section explains the sequence of operation to be performed for different types of USB transactions.

- **Writing the transmit FIFO**

  The OTG_FS host automatically writes an entry (OUT request) to the periodic/non-periodic request queue, along with the last 32-bit word write of a packet. The application must ensure that at least one free space is available in the periodic/non-periodic request queue before starting to write to the transmit FIFO. The application must always write to the transmit FIFO in 32-bit words. If the packet size is non-32-bit word aligned, the application must use padding. The OTG_FS host determines the actual packet size based on the programmed maximum packet size and transfer size.

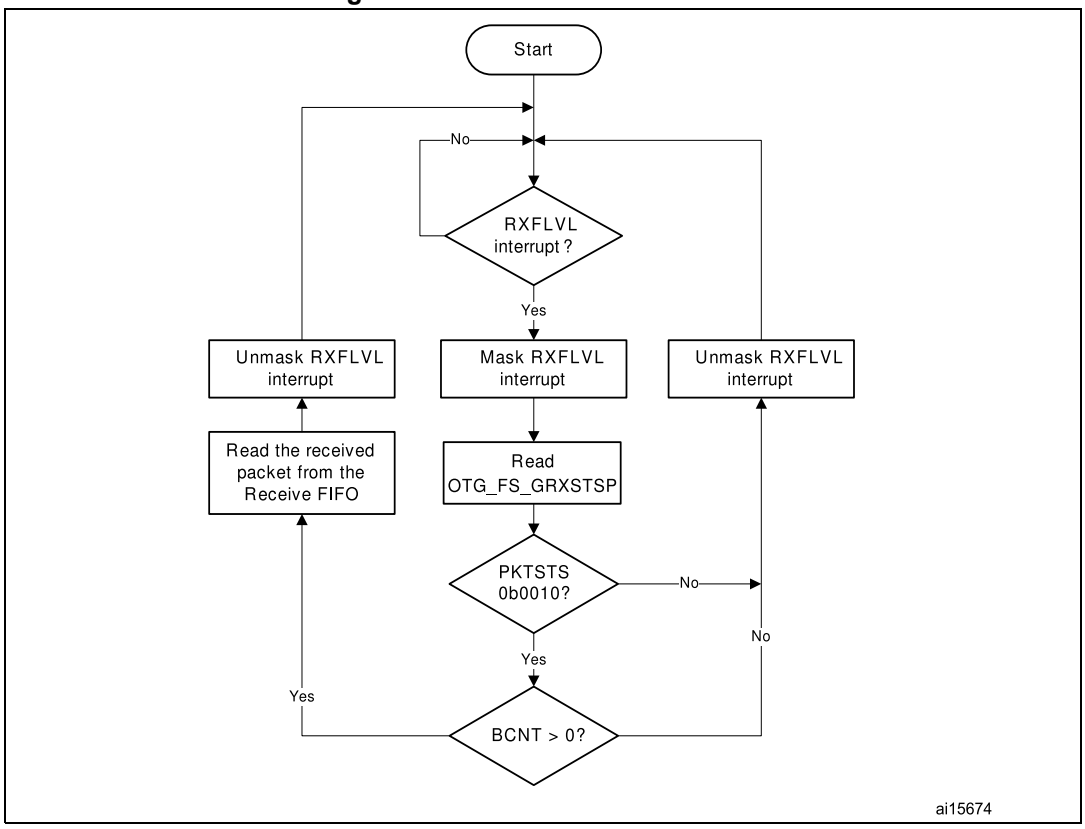
Figure 938. Transmit FIFO write task



- **Reading the receive FIFO**

  The application must ignore all packet statuses other than IN data packet (bx0010).

Figure 939. Receive FIFO read task



- **Bulk and control OUT/SETUP transactions**

  A typical bulk or control OUT/SETUP pipelined transaction-level operation is shown in *Figure 940*. See channel 1 (ch_1). Two bulk OUT packets are transmitted. A control SETUP transaction operates in the same way but has only one packet. The assumptions are:

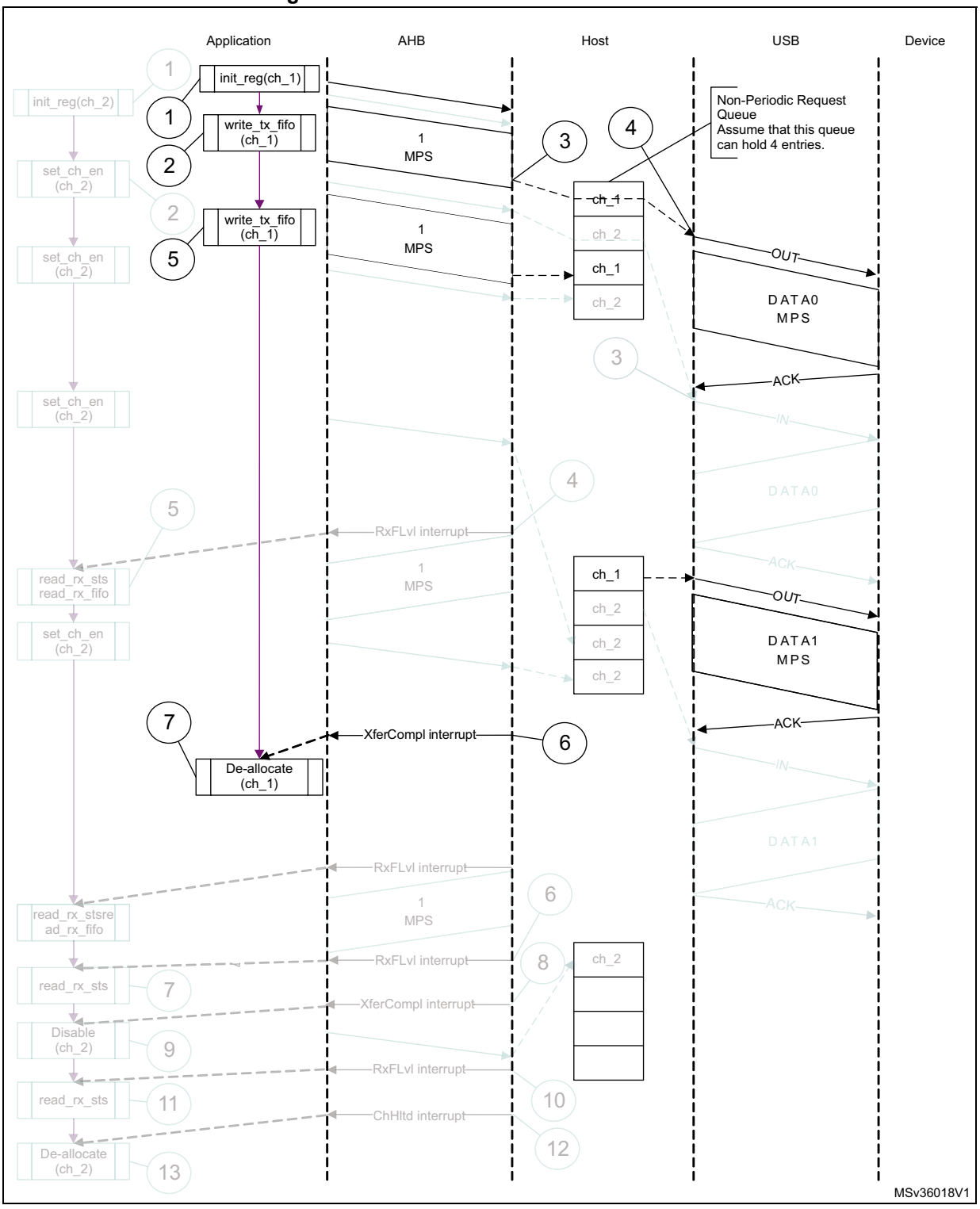
  – The application is attempting to send two maximum-packet-size packets (transfer size = 1, 024 bytes).
  – The non-periodic transmit FIFO can hold two packets (128 bytes for FS).
  – The non-periodic request queue depth = 4.

- **Normal bulk and control OUT/SETUP operations**

  The sequence of operations in (channel 1) is as follows:

1. Initialize channel 1
2. Write the first packet for channel 1
3. Along with the last word write, the core writes an entry to the non-periodic request queue
4. As soon as the non-periodic queue becomes non-empty, the core attempts to send an OUT token in the current frame
5. Write the second (last) packet for channel 1
6. The core generates the XFRC interrupt as soon as the last transaction is completed successfully
7. In response to the XFRC interrupt, de-allocate the channel for other transfers
8. Handling non-ACK responses

Figure 940. Normal bulk/control OUT/SETUP



1. The grayed elements are not relevant in the context of this figure.

The channel-specific interrupt service routine for bulk and control OUT/SETUP transactions is shown in the following code samples.

- **Interrupt service routine for bulk/control OUT/SETUP and bulk/control IN transactions**

  a) Bulk/control OUT/SETUP

```
Unmask (NAK/TXERR/STALL/XFRC)
if (XFRC)
   {
   Reset Error Count
   Mask ACK
   De-allocate Channel
   }
else if (STALL)
   {
   Transfer Done = 1
   Unmask CHH
   Disable Channel
   }
else if (NAK or TXERR )
   {
   Rewind Buffer Pointers
   Unmask CHH
   Disable Channel
   if (TXERR)
      {
      Increment Error Count
      Unmask ACK
      }
   else
      {
      Reset Error Count
      }
      }
else if (CHH)
   {
   Mask CHH
   if (Transfer Done or (Error_count == 3))
      {
      De-allocate Channel
      }
   else
      {
      Re-initialize Channel
      }
   }
```

```
   else if (ACK)
      {
      Reset Error Count
      Mask ACK
      }
```

The application is expected to write the data packets into the transmit FIFO when the space is available in the transmit FIFO and the request queue. The application can make use of the NPTXFE interrupt in OTG_GINTSTS to find the transmit FIFO space.

b) Bulk/control IN

```
Unmask (TXERR/XFRC/BBERR/STALL/DTERR)
if (XFRC)
   {
   Reset Error Count
   Unmask CHH
   Disable Channel
   Reset Error Count
   Mask ACK
   }
else if (TXERR or BBERR or STALL)
   {
   Unmask CHH
   Disable Channel
   if (TXERR)
      {
      Increment Error Count
      Unmask ACK
      }
   }
else if (CHH)
   {
   Mask CHH
   if (Transfer Done or (Error_count == 3))
      {
      De-allocate Channel
      }
   else
      {
      Re-initialize Channel
      }
   }
else if (ACK)
   {
   Reset Error Count
   Mask ACK
   }
```

```
else if (DTERR)
   {
   Reset Error Count
   }
```

The application is expected to write the requests as and when the request queue space is available and until the XFRC interrupt is received.

- **Bulk and control IN transactions**

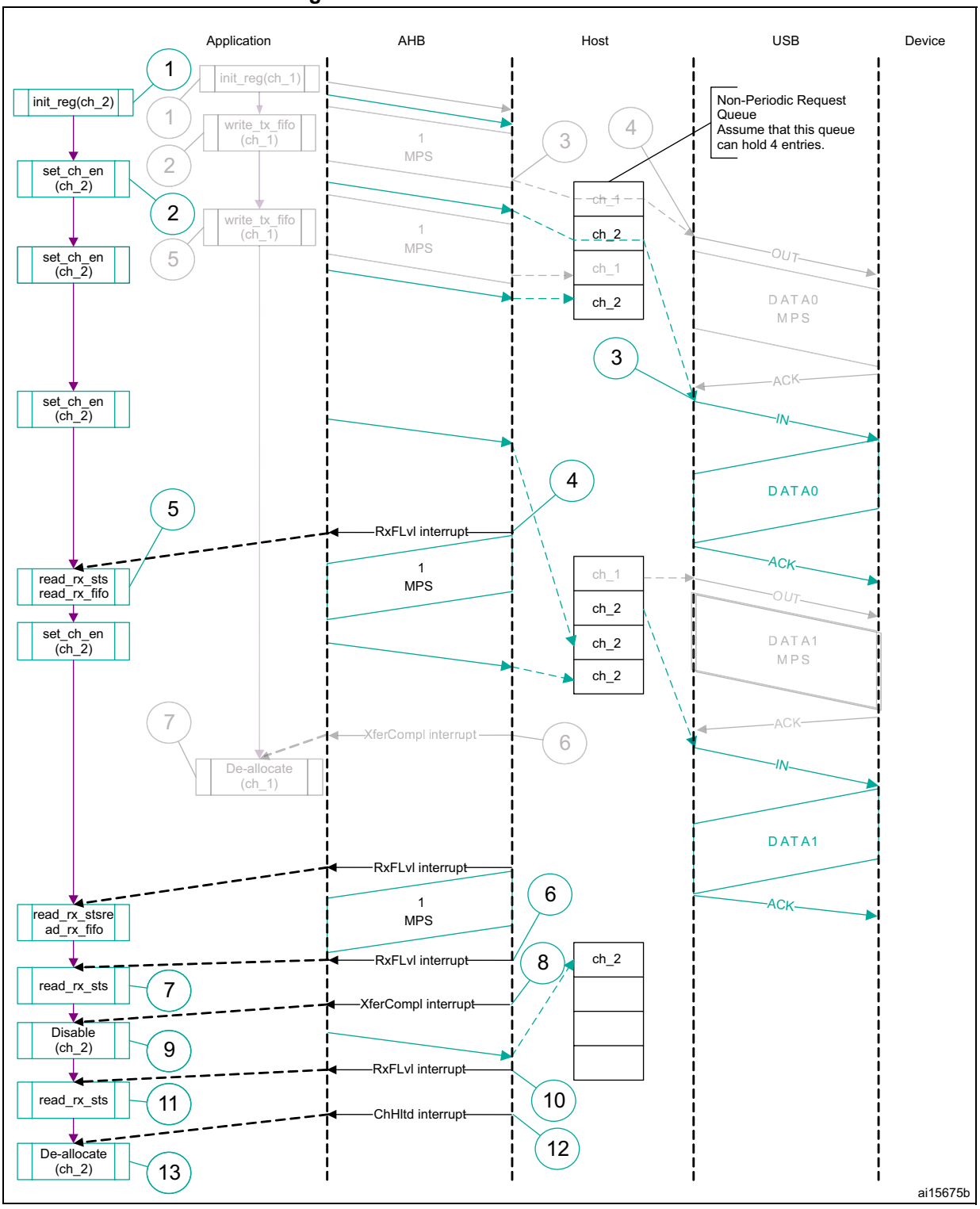
  A typical bulk or control IN pipelined transaction-level operation is shown in *Figure 941*. See channel 2 (ch_2). The assumptions are:

  – The application is attempting to receive two maximum-packet-size packets (transfer size = 1 024 bytes).

  – The receive FIFO can contain at least one maximum-packet-size packet and two status words per packet (72 bytes for FS).

  – The non-periodic request queue depth = 4.

Figure 941. Bulk/control IN transactions



1. The grayed elements are not relevant in the context of this figure.

The sequence of operations is as follows:

1. Initialize channel 2.
2. Set the CHENA bit in OTG_HCCHAR2 to write an IN request to the non-periodic request queue.
3. The core attempts to send an IN token after completing the current OUT transaction.
4. The core generates an RXFLVL interrupt as soon as the received packet is written to the receive FIFO.
5. In response to the RXFLVL interrupt, mask the RXFLVL interrupt and read the received packet status to determine the number of bytes received, then read the receive FIFO accordingly. Following this, unmask the RXFLVL interrupt.
6. The core generates the RXFLVL interrupt for the transfer completion status entry in the receive FIFO.
7. The application must read and ignore the receive packet status when the receive packet status is not an IN data packet (PKTSTS in OTG_GRXSTSR ≠ 0b0010).
8. The core generates the XFRC interrupt as soon as the receive packet status is read.
9. In response to the XFRC interrupt, disable the channel and stop writing the OTG_HCCHAR2 register for further requests. The core writes a channel disable request to the non-periodic request queue as soon as the OTG_HCCHAR2 register is written.
10. The core generates the RXFLVL interrupt as soon as the halt status is written to the receive FIFO.
11. Read and ignore the receive packet status.
12. The core generates a CHH interrupt as soon as the halt status is popped from the receive FIFO.
13. In response to the CHH interrupt, de-allocate the channel for other transfers.
14. Handling non-ACK responses

- **Control transactions**

  Setup, data, and status stages of a control transfer must be performed as three separate transfers. setup-, data- or status-stage OUT transactions are performed similarly to the bulk OUT transactions explained previously. Data- or status-stage IN transactions are performed similarly to the bulk IN transactions explained previously. For all three stages, the application is expected to set the EPTYP field in

OTG_HCCHAR1 to control. During the setup stage, the application is expected to set the PID field in OTG_HCTSIZ1 to SETUP.

- **Interrupt OUT transactions**

  A typical interrupt OUT operation is shown in *Figure 942*. The assumptions are:

  – The application is attempting to send one packet in every frame (up to 1 maximum packet size), starting with the odd frame (transfer size = 1 024 bytes)

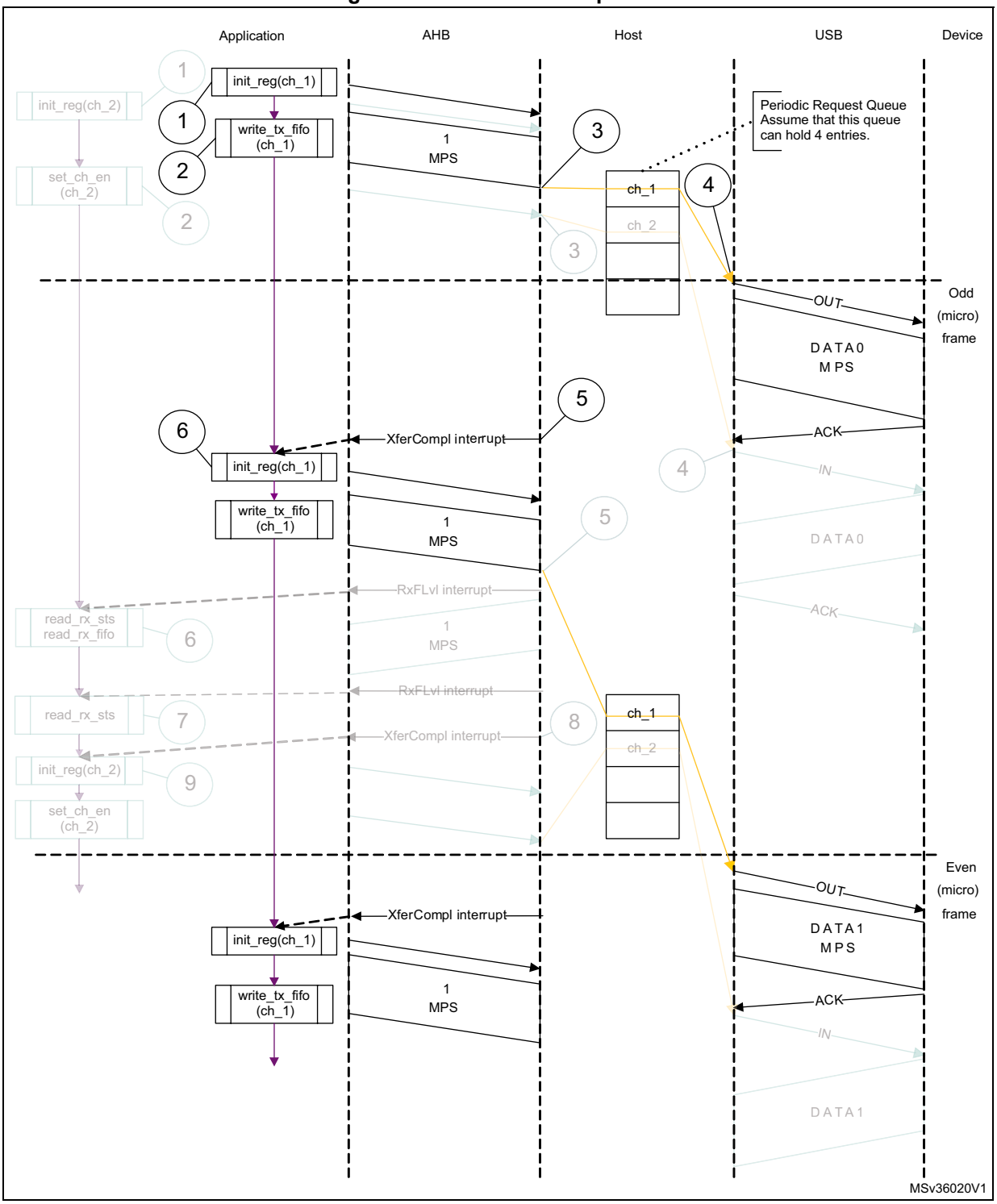
  – The periodic transmit FIFO can hold one packet (1 Kbyte)

  – Periodic request queue depth = 4

  The sequence of operations is as follows:

1. Initialize and enable channel 1. The application must set the ODDFRM bit in OTG_HCCHAR1.
2. Write the first packet for channel 1.
3. Along with the last word write of each packet, the OTG_FS host writes an entry to the periodic request queue.
4. The OTG_FS host attempts to send an OUT token in the next (odd) frame.
5. The OTG_FS host generates an XFRC interrupt as soon as the last packet is transmitted successfully.
6. In response to the XFRC interrupt, reinitialize the channel for the next transfer.

Figure 942. Normal interrupt OUT



1. The grayed elements are not relevant in the context of this figure.

- **Interrupt service routine for interrupt OUT/IN transactions**

  a) Interrupt OUT

`Unmask (NAK/TXERR/STALL/XFRC/FRMOR)`

```
if (XFRC)
   {
   Reset Error Count
   Mask ACK
   De-allocate Channel
   }
else
   if (STALL or FRMOR)
      {
      Mask ACK
      Unmask CHH
      Disable Channel
      if (STALL)
         {
         Transfer Done = 1
         }
      }
   else
      if (NAK or TXERR)
         {
         Rewind Buffer Pointers
         Reset Error Count
         Mask ACK
         Unmask CHH
         Disable Channel
         }
      else
         if (CHH)
         {
         Mask CHH
         if (Transfer Done or (Error_count == 3))
            {
            De-allocate Channel
            }
         else
            {
            Re-initialize Channel (in next b_interval - 1 Frame)
            }
         }
      else
         if (ACK)
         {
         Reset Error Count
         Mask ACK
         }
```

```
The application uses the NPTXFE interrupt in OTG_GINTSTS to find the
transmit FIFO space.
Interrupt IN
Unmask (NAK/TXERR/XFRC/BBERR/STALL/FRMOR/DTERR)
if (XFRC)
   {
   Reset Error Count
   Mask ACK
   if (OTG_HCTSIZx.PKTCNT == 0)
      {
      De-allocate Channel
      }
   else
      {
      Transfer Done = 1
      Unmask CHH
      Disable Channel
      }
   }
else
   if (STALL or FRMOR or NAK or DTERR or BBERR)
      {
      Mask ACK
      Unmask CHH
      Disable Channel
      if (STALL or BBERR)
         {
         Reset Error Count
         Transfer Done = 1
         }
      else
         if (!FRMOR)
         {
         Reset Error Count
         }
      }
else
   if (TXERR)
      {
      Increment Error Count
      Unmask ACK
      Unmask CHH
      Disable Channel
      }
else
```

```
   if (CHH)
      {
      Mask CHH
      if (Transfer Done or (Error_count == 3))
         {
         De-allocate Channel
         }
      else
         Re-initialize Channel (in next b_interval - 1 /Frame)
      }
   }
else
   if (ACK)
      {
      Reset Error Count
      Mask ACK
      }
```

- **Interrupt IN transactions**

  The assumptions are:

  – The application is attempting to receive one packet (up to 1 maximum packet size) in every frame, starting with odd (transfer size = 1 024 bytes).

  – The receive FIFO can hold at least one maximum-packet-size packet and two status words per packet (1 031 bytes).

  – Periodic request queue depth = 4.

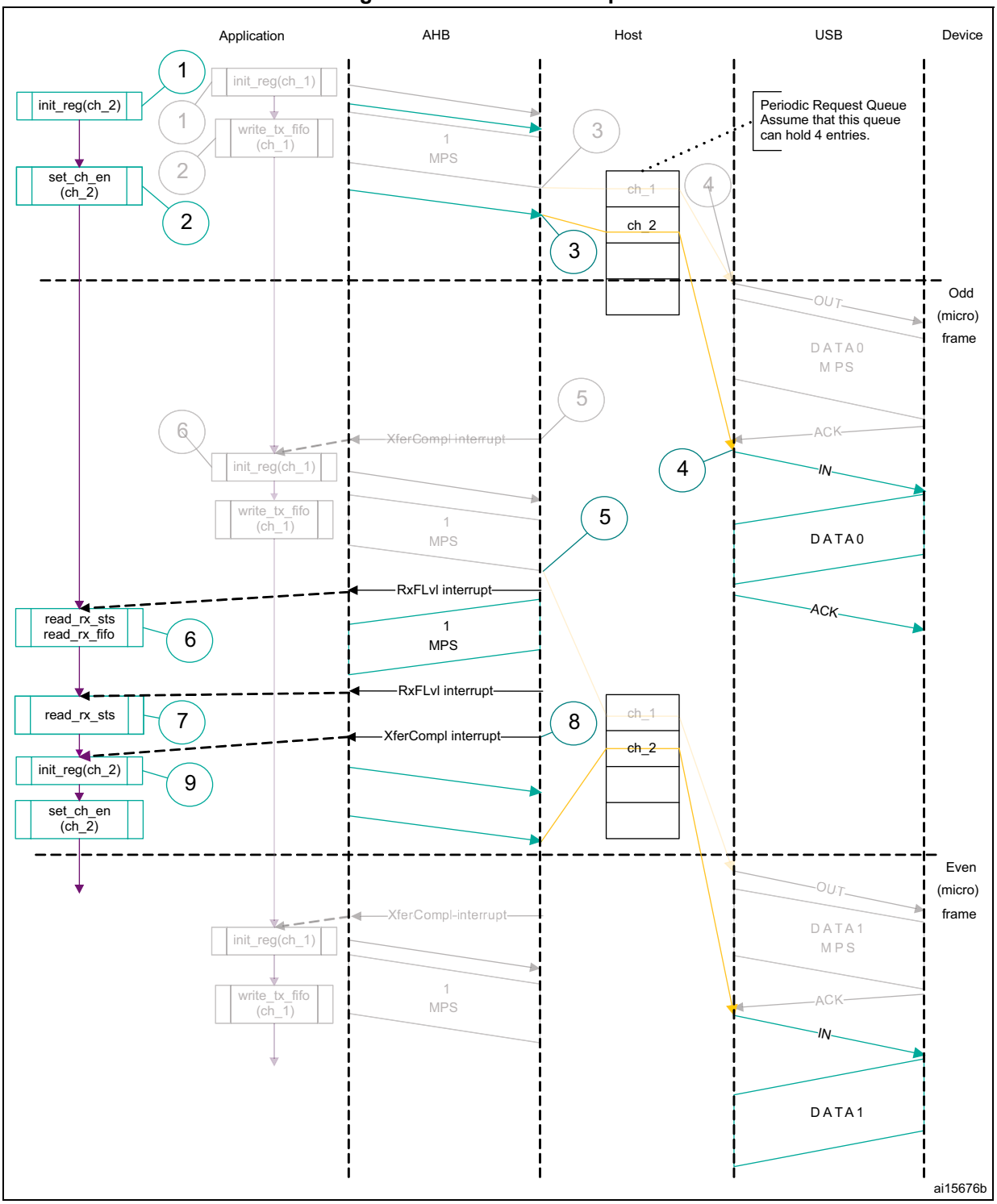
- **Normal interrupt IN operation**

  The sequence of operations is as follows:

1. Initialize channel 2. The application must set the ODDFRM bit in OTG_HCCHAR2.
2. Set the CHENA bit in OTG_HCCHAR2 to write an IN request to the periodic request queue.
3. The OTG_FS host writes an IN request to the periodic request queue for each OTG_HCCHAR2 register write with the CHENA bit set.
4. The OTG_FS host attempts to send an IN token in the next (odd) frame.
5. As soon as the IN packet is received and written to the receive FIFO, the OTG_FS host generates an RXFLVL interrupt.
6. In response to the RXFLVL interrupt, read the received packet status to determine the number of bytes received, then read the receive FIFO accordingly. The application must mask the RXFLVL interrupt before reading the receive FIFO, and unmask after reading the entire packet.
7. The core generates the RXFLVL interrupt for the transfer completion status entry in the receive FIFO. The application must read and ignore the receive packet status when the receive packet status is not an IN data packet (PKTSTS in GRXSTSR ≠ 0b0010).
8. The core generates an XFRC interrupt as soon as the receive packet status is read.
9. In response to the XFRC interrupt, read the PKTCNT field in OTG_HCTSIZ2. If the PKTCNT bit in OTG_HCTSIZ2 is not equal to 0, disable the channel before re-

initializing the channel for the next transfer, if any). If PKTCNT bit in OTG_HCTSIZ2 = 0, reinitialize the channel for the next transfer. This time, the application must reset the ODDFRM bit in OTG_HCCHAR2.

Figure 943. Normal interrupt IN



1. The grayed elements are not relevant in the context of this figure.

- **Isochronous OUT transactions**

  A typical isochronous OUT operation is shown in *Figure 944*. The assumptions are:

  – The application is attempting to send one packet every frame (up to 1 maximum

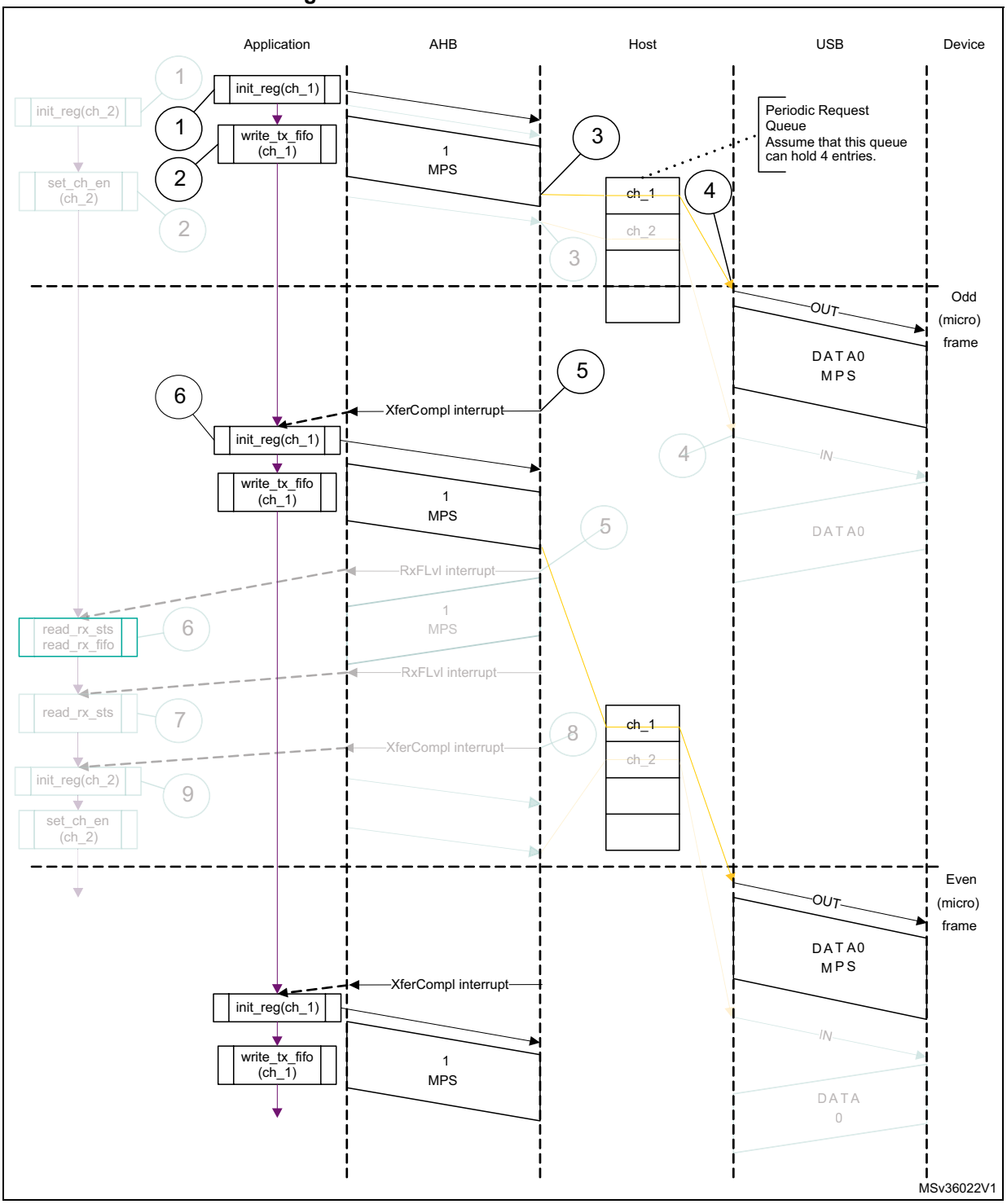
packet size), starting with an odd frame. (transfer size = 1 024 bytes).

– The periodic transmit FIFO can hold one packet (1 Kbyte).
– Periodic request queue depth = 4.

The sequence of operations is as follows:

1. Initialize and enable channel 1. The application must set the ODDFRM bit in OTG_HCCHAR1.
2. Write the first packet for channel 1.
3. Along with the last word write of each packet, the OTG_FS host writes an entry to the periodic request queue.
4. The OTG_FS host attempts to send the OUT token in the next frame (odd).
5. The OTG_FS host generates the XFRC interrupt as soon as the last packet is transmitted successfully.
6. In response to the XFRC interrupt, reinitialize the channel for the next transfer.
7. Handling non-ACK responses

Figure 944. Isochronous OUT transactions



1. The grayed elements are not relevant in the context of this figure.

- **Interrupt service routine for isochronous OUT/IN transactions**

  Code sample: isochronous OUT

```
Unmask (FRMOR/XFRC)
if (XFRC)
```

```
   {
   De-allocate Channel
   }
else
   if (FRMOR)
      {
      Unmask CHH
      Disable Channel
      }
   else
   if (CHH)
      {
      Mask CHH
      De-allocate Channel
      }
Code sample: Isochronous IN
Unmask (TXERR/XFRC/FRMOR/BBERR)
if (XFRC or FRMOR)
   {
   if (XFRC and (OTG_HCTSIZx.PKTCNT == 0))
      {
      Reset Error Count
      De-allocate Channel
      }
   else
      {
      Unmask CHH
      Disable Channel
      }
   }
   else
      if (TXERR or BBERR)
         {
         Increment Error Count
         Unmask CHH
         Disable Channel
         }
      else
         if (CHH)
            {
            Mask CHH
            if (Transfer Done or (Error_count == 3))
               {
               De-allocate Channel
               }
```

```
else
   {
   Re-initialize Channel
   }
}
```

- **Isochronous IN transactions**

  The assumptions are:

  – The application is attempting to receive one packet (up to 1 maximum packet size) in every frame starting with the next odd frame (transfer size = 1 024 bytes).

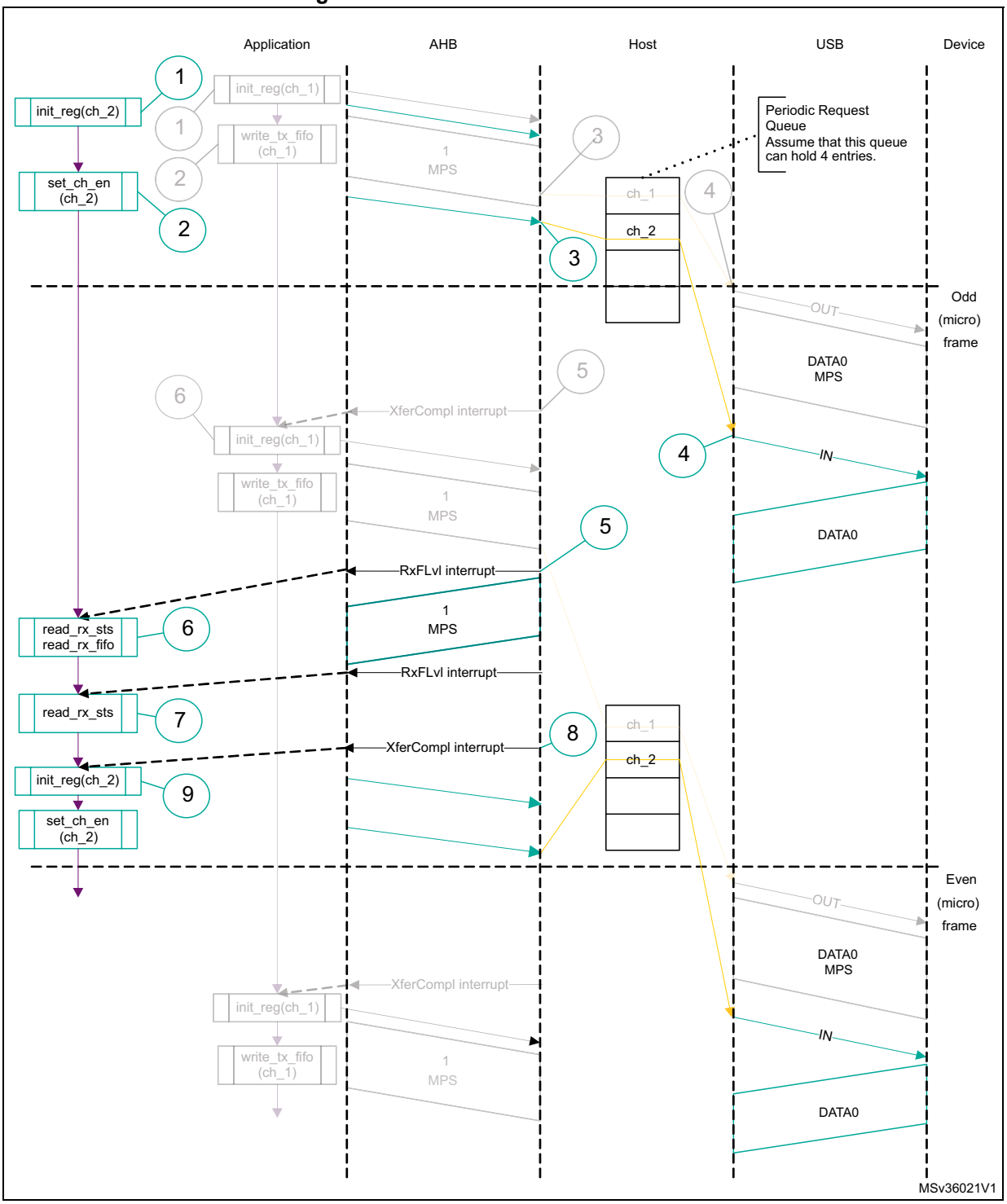
  – The receive FIFO can hold at least one maximum-packet-size packet and two status word per packet (1 031 bytes).

  – Periodic request queue depth = 4.

  The sequence of operations is as follows:

1. Initialize channel 2. The application must set the ODDFRM bit in OTG_HCCHAR2.
2. Set the CHENA bit in OTG_HCCHAR2 to write an IN request to the periodic request queue.
3. The OTG_FS host writes an IN request to the periodic request queue for each OTG_HCCHAR2 register write with the CHENA bit set.
4. The OTG_FS host attempts to send an IN token in the next odd frame.
5. As soon as the IN packet is received and written to the receive FIFO, the OTG_FS host generates an RXFLVL interrupt.
6. In response to the RXFLVL interrupt, read the received packet status to determine the number of bytes received, then read the receive FIFO accordingly. The application must mask the RXFLVL interrupt before reading the receive FIFO, and unmask it after reading the entire packet.
7. The core generates an RXFLVL interrupt for the transfer completion status entry in the receive FIFO. This time, the application must read and ignore the receive packet status when the receive packet status is not an IN data packet (PKTSTS bit in OTG_GRXSTSR ≠ 0b0010).
8. The core generates an XFRC interrupt as soon as the receive packet status is read.
9. In response to the XFRC interrupt, read the PKTCNT field in OTG_HCTSIZ2. If PKTCNT ≠ 0 in OTG_HCTSIZ2, disable the channel before re-initializing the channel for the next transfer, if any. If PKTCNT = 0 in OTG_HCTSIZ2, reinitialize the channel for the next transfer. This time, the application must reset the ODDFRM bit in OTG_HCCHAR2.

Figure 945. Isochronous IN transactions



1. The grayed elements are not relevant in the context of this figure.

- **Selecting the queue depth**

  Choose the periodic and non-periodic request queue depths carefully to match the number of periodic/non-periodic endpoints accessed.

  The non-periodic request queue depth affects the performance of non-periodic

transfers. The deeper the queue (along with sufficient FIFO size), the more often the core is able to pipeline non-periodic transfers. If the queue size is small, the core is able to put in new requests only when the queue space is freed up.

The core's periodic request queue depth is critical to perform periodic transfers as scheduled. Select the periodic queue depth, based on the number of periodic transfers scheduled in a microframe. If the periodic request queue depth is smaller than the periodic transfers scheduled in a microframe, a frame overrun condition occurs.

- **Handling babble conditions**

  OTG_FS controller handles two cases of babble: packet babble and port babble. Packet babble occurs if the device sends more data than the maximum packet size for the channel. Port babble occurs if the core continues to receive data from the device at EOF2 (the end of frame 2, which is very close to SOF).

  When OTG_FS controller detects a packet babble, it stops writing data into the Rx buffer and waits for the end of packet (EOP). When it detects an EOP, it flushes already written data in the Rx buffer and generates a Babble interrupt to the application.

  When OTG_FS controller detects a port babble, it flushes the Rx FIFO and disables the port. The core then generates a port disabled interrupt (HPRTINT in OTG_GINTSTS, PENCHNG in OTG_HPRT). On receiving this interrupt, the application must determine that this is not due to an overcurrent condition (another cause of the port disabled interrupt) by checking POCA in OTG_HPRT, then perform a soft reset. The core does not send any more tokens after it has detected a port babble condition.

66.16.5 Device programming model

Endpoint initialization on USB reset

1. Set the NAK bit for all OUT endpoints
   – SNAK = 1 in OTG_DOEPCTLx (for all OUT endpoints)
2. Unmask the following interrupt bits
   – INEP0 = 1 in OTG_DAINTMSK (control 0 IN endpoint)
   – OUTEP0 = 1 in OTG_DAINTMSK (control 0 OUT endpoint)
   – STUPM = 1 in OTG_DOEPMSK
   – XFRCM = 1 in OTG_DOEPMSK
   – XFRCM = 1 in OTG_DIEPMSK
   – TOM = 1 in OTG_DIEPMSK
3. Set up the data FIFO RAM for each of the FIFOs
   – Program the OTG_GRXFSIZ register, to be able to receive control OUT data and setup data. If thresholding is not enabled, at a minimum, this must be equal to 1 max packet size of control endpoint 0 + 2 words (for the status of the control OUT data packet) + 10 words (for setup packets).
   – Program the OTG_DIEPTXF0 register (depending on the FIFO number chosen) to be able to transmit control IN data. At a minimum, this must be equal to 1 max packet size of control endpoint 0.
4. Program the following fields in the endpoint-specific registers for control OUT endpoint 0 to receive a SETUP packet
   – STUPCNT = 3 in OTG_DOEPTSIZ0 (to receive up to 3 back-to-back SETUP packets)

At this point, all initialization required to receive SETUP packets is done.

Endpoint initialization on enumeration completion

1. On the Enumeration Done interrupt (ENUMDNE in OTG_GINTSTS), read the OTG_DSTS register to determine the enumeration speed.
2. Program the MPSIZ field in OTG_DIEPCTL0 to set the maximum packet size. This step configures control endpoint 0. The maximum packet size for a control endpoint depends on the enumeration speed.

At this point, the device is ready to receive SOF packets and is configured to perform control transfers on control endpoint 0.

Endpoint initialization on SetAddress command

This section describes what the application must do when it receives a SetAddress command in a SETUP packet.

1. Program the OTG_DCFG register with the device address received in the SetAddress command
2. Program the core to send out a status IN packet

Endpoint initialization on SetConfiguration/SetInterface command

This section describes what the application must do when it receives a SetConfiguration or SetInterface command in a SETUP packet.

1. When a SetConfiguration command is received, the application must program the endpoint registers to configure them with the characteristics of the valid endpoints in the new configuration.
2. When a SetInterface command is received, the application must program the endpoint registers of the endpoints affected by this command.
3. Some endpoints that were active in the prior configuration or alternate setting are not valid in the new configuration or alternate setting. These invalid endpoints must be deactivated.
4. Unmask the interrupt for each active endpoint and mask the interrupts for all inactive endpoints in the OTG_DAINTMSK register.
5. Set up the data FIFO RAM for each FIFO.
6. After all required endpoints are configured; the application must program the core to send a status IN packet.

At this point, the device core is configured to receive and transmit any type of data packet.

Endpoint activation

This section describes the steps required to activate a device endpoint or to configure an existing device endpoint to a new type.

1. Program the characteristics of the required endpoint into the following fields of the OTG_DIEPCTLx register (for IN or bidirectional endpoints) or the OTG_DOEPCTLx register (for OUT or bidirectional endpoints).
   – Maximum packet size
   – USB active endpoint = 1
   – Endpoint start data toggle (for interrupt and bulk endpoints)
   – Endpoint type
   – Tx FIFO number
2. Once the endpoint is activated, the core starts decoding the tokens addressed to that endpoint and sends out a valid handshake for each valid token received for the endpoint.

Endpoint deactivation

This section describes the steps required to deactivate an existing endpoint.

1. In the endpoint to be deactivated, clear the USB active endpoint bit in the OTG_DIEPCTLx register (for IN or bidirectional endpoints) or the OTG_DOEPCTLx register (for OUT or bidirectional endpoints).
2. Once the endpoint is deactivated, the core ignores tokens addressed to that endpoint, which results in a timeout on the USB.

Note: The application must meet the following conditions to set up the device core to handle traffic:
NPTXFEM and RXFLVLM in the OTG_GINTMSK register must be cleared.

Operational model

SETUP and OUT data transfers:

This section describes the internal data flow and application-level operations during data OUT transfers and SETUP transactions.

- **Packet read**

This section describes how to read packets (OUT data and SETUP packets) from the receive FIFO.

1. On catching an RXFLVL interrupt (OTG_GINTSTS register), the application must read the receive status pop register (OTG_GRXSTSP).
2. The application can mask the RXFLVL interrupt (in OTG_GINTSTS) by writing to RXFLVLM = 0 (in OTG_GINTMSK), until it has read the packet from the receive FIFO.
3. If the received packet's byte count is not 0, the byte count amount of data is popped from the receive data FIFO and stored in memory. If the received packet byte count is 0, no data is popped from the receive data FIFO.
4. The receive status readout of the packet of FIFO indicates one of the following:
   a) Global OUT NAK pattern:
   PKTSTS = Global OUT NAK, BCNT = 0x000, EPNUM = (0x0),
   DPID = (0b00).
   These data indicate that the global OUT NAK bit has taken effect.
   b) SETUP packet pattern:
   PKTSTS = SETUP, BCNT = 0x008, EPNUM = Control EP Num,

DPID = DATA0. These data indicate that a SETUP packet for the specified endpoint is now available for reading from the receive FIFO.

c) Setup stage done pattern:
PKTSTS = Setup Stage Done, BCNT = 0x0, EPNUM = Control EP Num, DPID = (0b00).
These data indicate that the setup stage for the specified endpoint has completed and the data stage has started. After this entry is popped from the receive FIFO, the core asserts a setup interrupt on the specified control OUT endpoint.

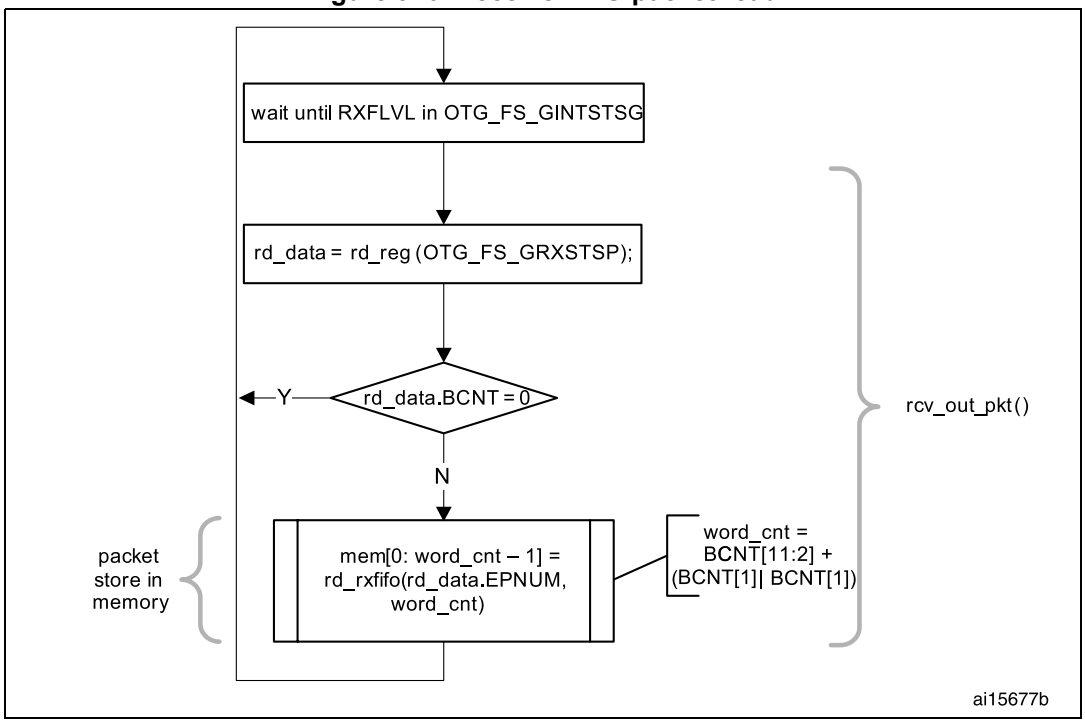
d) Data OUT packet pattern:
PKTSTS = DataOUT, BCNT = size of the received data OUT packet (0 ≤ BCNT ≤ 1 024), EPNUM = EPNUM on which the packet was received, DPID = Actual Data PID.

e) Data transfer completed pattern:
PKTSTS = Data OUT transfer done, BCNT = 0x0, EPNUM = OUT EP Num on which the data transfer is complete, DPID = (0b00).
These data indicate that an OUT data transfer for the specified OUT endpoint has completed. After this entry is popped from the receive FIFO, the core asserts a transfer completed interrupt on the specified OUT endpoint.

5. After the data payload is popped from the receive FIFO, the RXFLVL interrupt (OTG_GINTSTS) must be unmasked.
6. Steps 1–5 are repeated every time the application detects assertion of the interrupt line due to RXFLVL in OTG_GINTSTS. Reading an empty receive FIFO can result in undefined core behavior.

Figure 946 provides a flowchart of the above procedure.

Figure 946. Receive FIFO packet read



SETUP transactions

This section describes how the core handles SETUP packets and the application's sequence for handling SETUP transactions.

- **Application requirements**

1. To receive a SETUP packet, the STUPCNT field (OTG_DOEPTSIZx) in a control OUT endpoint must be programmed to a non-zero value. When the application programs the STUPCNT field to a non-zero value, the core receives SETUP packets and writes them to the receive FIFO, irrespective of the NAK status and EPENA bit setting in OTG_DOEPCTLx. The STUPCNT field is decremented every time the control endpoint receives a SETUP packet. If the STUPCNT field is not programmed to a proper value before receiving a SETUP packet, the core still receives the SETUP packet and decrements the STUPCNT field, but the application may not be able to determine the correct number of SETUP packets received in the setup stage of a control transfer.
   – STUPCNT = 3 in OTG_DOEPTSIZx
2. The application must always allocate some extra space in the receive data FIFO, to be able to receive up to three SETUP packets on a control endpoint.
   – The space to be reserved is 10 words. Three words are required for the first SETUP packet, 1 word is required for the setup stage done word and 6 words are required to store two extra SETUP packets among all control endpoints.
   – 3 words per SETUP packet are required to store 8 bytes of SETUP data and 4 bytes of SETUP status (setup packet pattern). The core reserves this space in the receive data FIFO to write SETUP data only, and never uses this space for data packets.
3. The application must read the 2 words of the SETUP packet from the receive FIFO.
4. The application must read and discard the setup stage done word from the receive FIFO.

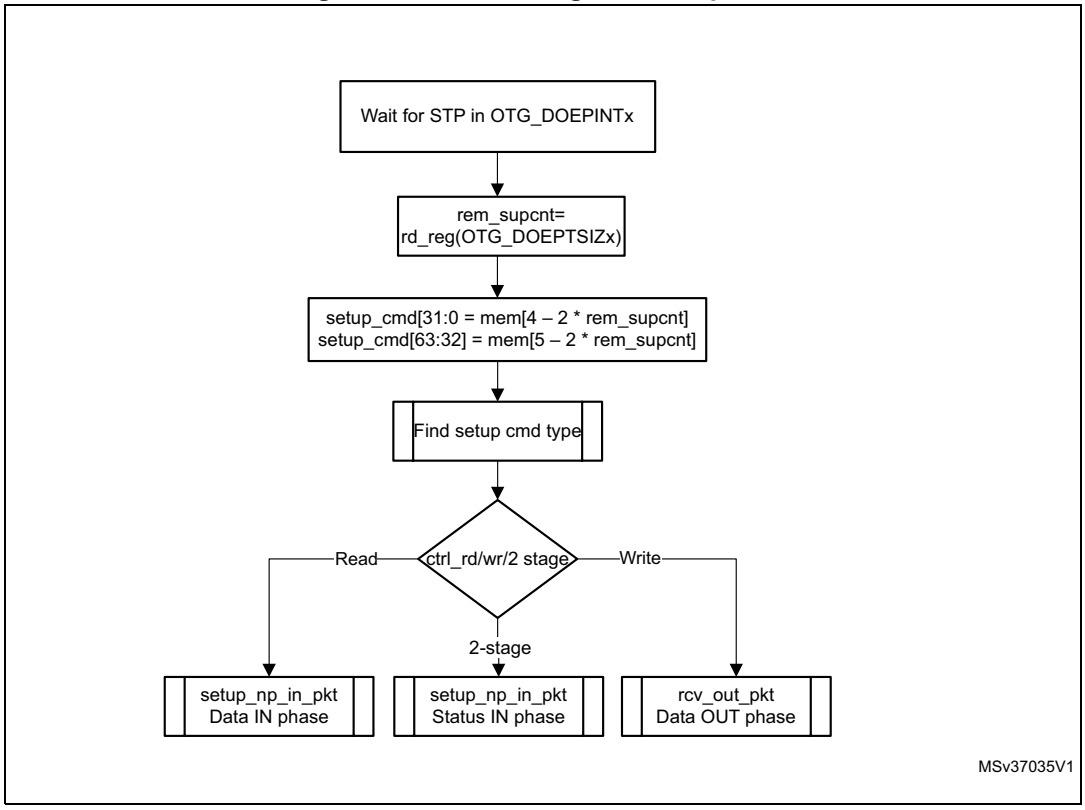
- **Internal data flow**

1. When a SETUP packet is received, the core writes the received data to the receive FIFO, without checking for available space in the receive FIFO and irrespective of the endpoint's NAK and STALL bit settings.
   – The core internally sets the IN NAK and OUT NAK bits for the control IN/OUT endpoints on which the SETUP packet was received.
2. For every SETUP packet received on the USB, 3 words of data are written to the receive FIFO, and the STUPCNT field is decremented by 1.
   – The first word contains control information used internally by the core
   – The second word contains the first 4 bytes of the SETUP command
   – The third word contains the last 4 bytes of the SETUP command
3. When the setup stage changes to a data IN/OUT stage, the core writes an entry (setup stage done word) to the receive FIFO, indicating the completion of the setup stage.
4. On the AHB side, SETUP packets are emptied by the application.
5. When the application pops the setup stage done word from the receive FIFO, the core interrupts the application with an STUP interrupt (OTG_DOEPINTx), indicating it can process the received SETUP packet.
6. The core clears the endpoint enable bit for control OUT endpoints.

- **Application programming sequence**

1. Program the OTG_DOEPTSIZx register.
   – STUPCNT = 3
2. Wait for the RXFLVL interrupt (OTG_GINTSTS) and empty the data packets from the receive FIFO.
3. Assertion of the STUP interrupt (OTG_DOEPINTx) marks a successful completion of the SETUP data transfer.
   – On this interrupt, the application must read the OTG_DOEPTSIZx register to determine the number of SETUP packets received and process the last received SETUP packet.

Figure 947. Processing a SETUP packet



- **Setting the global OUT NAK**

Internal data flow:

1. When the application sets the Global OUT NAK (SGONAK bit in OTG_DCTL), the core stops writing data, except SETUP packets, to the receive FIFO. Irrespective of the

space availability in the receive FIFO, non-isochronous OUT tokens receive a NAK handshake response, and the core ignores isochronous OUT data packets

2. The core writes the Global OUT NAK pattern to the receive FIFO. The application must reserve enough receive FIFO space to write this data pattern.
3. When the application pops the Global OUT NAK pattern word from the receive FIFO, the core sets the GONAKEFF interrupt (OTG_GINTSTS).
4. Once the application detects this interrupt, it can assume that the core is in Global OUT NAK mode. The application can clear this interrupt by clearing the SGONAK bit in OTG_DCTL.

Application programming sequence:

1. To stop receiving any kind of data in the receive FIFO, the application must set the Global OUT NAK bit by programming the following field:
   – SGONAK = 1 in OTG_DCTL
2. Wait for the assertion of the GONAKEFF interrupt in OTG_GINTSTS. When asserted, this interrupt indicates that the core has stopped receiving any type of data except SETUP packets.
3. The application can receive valid OUT packets after it has set SGONAK in OTG_DCTL and before the core asserts the GONAKEFF interrupt (OTG_GINTSTS).
4. The application can temporarily mask this interrupt by writing to the GONAKEFFM bit in the OTG_GINTMSK register.
   – GONAKEFFM = 0 in the OTG_GINTMSK register
5. Whenever the application is ready to exit the Global OUT NAK mode, it must clear the SGONAK bit in OTG_DCTL. This also clears the GONAKEFF interrupt (OTG_GINTSTS).
   – CGONAK = 1 in OTG_DCTL
6. If the application has masked this interrupt earlier, it must be unmasked as follows:
   – GONAKEFFM = 1 in OTG_GINTMSK

- **Disabling an OUT endpoint**

The application must use this sequence to disable an OUT endpoint that it has enabled.

Application programming sequence:

1. Before disabling any OUT endpoint, the application must enable Global OUT NAK mode in the core.
   – SGONAK = 1 in OTG_DCTL
2. Wait for the GONAKEFF interrupt (OTG_GINTSTS)
3. Disable the required OUT endpoint by programming the following fields:
   – EPDIS = 1 in OTG_DOEPCTLx
   – SNAK = 1 in OTG_DOEPCTLx
4. Wait for the EPDISD interrupt (OTG_DOEPINTx), which indicates that the OUT endpoint is completely disabled. When the EPDISD interrupt is asserted, the core also clears the following bits:
   – EPDIS = 0 in OTG_DOEPCTLx
   – EPENA = 0 in OTG_DOEPCTLx
5. The application must clear the Global OUT NAK bit to start receiving data from other non-disabled OUT endpoints.
   – SGONAK = 0 in OTG_DCTL

- **Transfer Stop Programming for OUT endpoints**

The application must use the following programing sequence to stop any transfers (because of an interrupt from the host, typically a reset).

Sequence of operations:

1. Enable all OUT endpoints by setting
   – EPENA = 1 in all OTG_DOEPCTLx registers.
2. Flush the RxFIFO as follows
   – Poll OTG_GRSTCTL.AHBIDL until it is 1. This indicates that AHB master is idle.
   – Perform read modify write operation on OTG_GRSTCTL.RXFFLSH =1
   – Poll OTG_GRSTCTL.RXFFLSH until it is 0, but also using a timeout of less than 10 milli-seconds (corresponds to minimum reset signaling duration). If 0 is seen before the timeout, then the RxFIFO flush is successful. If at the moment the timeout occurs, there is still a 1, (this may be due to a packet on EP0 coming from the host) then go back (once only) to the previous step (“Perform read modify write operation”).
3. Before disabling any OUT endpoint, the application must enable Global OUT NAK mode in the core, according to the instructions in “*Setting the global OUT NAK on page 3249*”. This ensures that data in the RxFIFO is sent to the application successfully. Set SGONAK = 1 in OTG_DCTL
4. Wait for the GONAKEFF interrupt (OTG_GINTSTS)
5. Disable all active OUT endpoints by programming the following register bits:
   – EPDIS = 1 in registers OTG_DOEPCTLx
   – SNAK = 1 in registers OTG_DOEPCTLx
6. Wait for the EPDIS interrupt in OTG_DOEPINTx for each OUT endpoint programmed in the previous step. The EPDIS interrupt in OTG_DOEPINTx indicates that the

corresponding OUT endpoint is completely disabled. When the EPDIS interrupt is asserted, the following bits are cleared:

– EPENA = 0 in registers OTG_DOEPCTLx
– EPDIS = 0 in registers OTG_DOEPCTLx
– SNAK = 0 in registers OTG_DOEPCTLx

- **Generic non-isochronous OUT data transfers**

This section describes a regular non-isochronous OUT data transfer (control, bulk, or interrupt).

Application requirements:

1. Before setting up an OUT transfer, the application must allocate a buffer in the memory to accommodate all data to be received as part of the OUT transfer.
2. For OUT transfers, the transfer size field in the endpoint's transfer size register must be a multiple of the maximum packet size of the endpoint, adjusted to the word boundary.
   – transfer size[EPNUM] = *n* × (MPSIZ[EPNUM] + 4 – (MPSIZ[EPNUM] mod 4))
   – packet count[EPNUM] = *n*
   – *n* > 0
3. On any OUT endpoint interrupt, the application must read the endpoint's transfer size register to calculate the size of the payload in the memory. The received payload size can be less than the programmed transfer size.
   – Payload size in memory = application programmed initial transfer size – core updated final transfer size
   – Number of USB packets in which this payload was received = application programmed initial packet count – core updated final packet count

Internal data flow:

1. The application must set the transfer size and packet count fields in the endpoint-specific registers, clear the NAK bit, and enable the endpoint to receive the data.
2. Once the NAK bit is cleared, the core starts receiving data and writes it to the receive FIFO, as long as there is space in the receive FIFO. For every data packet received on the USB, the data packet and its status are written to the receive FIFO. Every packet (maximum packet size or short packet) written to the receive FIFO decrements the packet count field for that endpoint by 1.
   – OUT data packets received with bad data CRC are flushed from the receive FIFO automatically.
   – After sending an ACK for the packet on the USB, the core discards non-isochronous OUT data packets that the host, which cannot detect the ACK, re-sends. The application does not detect multiple back-to-back data OUT packets on the same endpoint with the same data PID. In this case the packet count is not decremented.
   – If there is no space in the receive FIFO, isochronous or non-isochronous data packets are ignored and not written to the receive FIFO. Additionally, non-isochronous OUT tokens receive a NAK handshake reply.
   – In all the above three cases, the packet count is not decremented because no data are written to the receive FIFO.

3. When the packet count becomes 0 or when a short packet is received on the endpoint, the NAK bit for that endpoint is set. Once the NAK bit is set, the isochronous or non-isochronous data packets are ignored and not written to the receive FIFO, and non-isochronous OUT tokens receive a NAK handshake reply.
4. After the data are written to the receive FIFO, the application reads the data from the receive FIFO and writes it to external memory, one packet at a time per endpoint.
5. At the end of every packet write on the AHB to external memory, the transfer size for the endpoint is decremented by the size of the written packet.
6. The OUT data transfer completed pattern for an OUT endpoint is written to the receive FIFO on one of the following conditions:
   – The transfer size is 0 and the packet count is 0
   – The last OUT data packet written to the receive FIFO is a short packet (0 ≤ packet size < maximum packet size)
7. When either the application pops this entry (OUT data transfer completed), a transfer completed interrupt is generated for the endpoint and the endpoint enable is cleared.

Application programming sequence:

1. Program the OTG_DOEPTSIZx register for the transfer size and the corresponding packet count.
2. Program the OTG_DOEPCTLx register with the endpoint characteristics, and set the EPENA and CNAK bits.
   – EPENA = 1 in OTG_DOEPCTLx
   – CNAK = 1 in OTG_DOEPCTLx
3. Wait for the RXFLVL interrupt (in OTG_GINTSTS) and empty the data packets from the receive FIFO.
   – This step can be repeated many times, depending on the transfer size.
4. Asserting the XFRC interrupt (OTG_DOEPINTx) marks a successful completion of the non-isochronous OUT data transfer.
5. Read the OTG_DOEPTSIZx register to determine the size of the received data payload.

- **Generic isochronous OUT data transfer**

This section describes a regular isochronous OUT data transfer.

Application requirements:

1. All the application requirements for non-isochronous OUT data transfers also apply to isochronous OUT data transfers.
2. For isochronous OUT data transfers, the transfer size and packet count fields must always be set to the number of maximum-packet-size packets that can be received in a single frame and no more. Isochronous OUT data transfers cannot span more than 1 frame.
3. The application must read all isochronous OUT data packets from the receive FIFO (data and status) before the end of the periodic frame (EOPF interrupt in OTG_GINTSTS).
4. To receive data in the following frame, an isochronous OUT endpoint must be enabled after the EOPF (OTG_GINTSTS) and before the SOF (OTG_GINTSTS).

Internal data flow:

1. The internal data flow for isochronous OUT endpoints is the same as that for non-isochronous OUT endpoints, but for a few differences.
2. When an isochronous OUT endpoint is enabled by setting the endpoint enable and clearing the NAK bits, the Even/Odd frame bit must also be set appropriately. The core receives data on an isochronous OUT endpoint in a particular frame only if the following condition is met:
   – EONUM (in OTG_DOEPCTLx) = FNSOF[0] (in OTG_DSTS)
3. When the application completely reads an isochronous OUT data packet (data and status) from the receive FIFO, the core updates the RXDPID field in OTG_DOEPTSIZx with the data PID of the last isochronous OUT data packet read from the receive FIFO.

Application programming sequence:

1. Program the OTG_DOEPTSIZx register for the transfer size and the corresponding packet count
2. Program the OTG_DOEPCTLx register with the endpoint characteristics and set the endpoint enable, ClearNAK, and Even/Odd frame bits.
   – EPENA = 1
   – CNAK = 1
   – EONUM = (0: Even/1: Odd)
3. Wait for the RXFLVL interrupt (in OTG_GINTSTS) and empty the data packets from the receive FIFO
   – This step can be repeated many times, depending on the transfer size.
4. The assertion of the XFRC interrupt (in OTG_DOEPINTx) marks the completion of the isochronous OUT data transfer. This interrupt does not necessarily mean that the data in memory are good.
5. This interrupt cannot always be detected for isochronous OUT transfers. Instead, the application can detect the INCOMPISOOUT interrupt in OTG_GINTSTS.
6. Read the OTG_DOEPTSIZx register to determine the size of the received transfer and to determine the validity of the data received in the frame. The application must treat the data received in memory as valid only if one of the following conditions is met:
   – RXDPID = DATA0 (in OTG_DOEPTSIZx) and the number of USB packets in which this payload was received = 1
   – RXDPID = DATA1 (in OTG_DOEPTSIZx) and the number of USB packets in which this payload was received = 2

   The number of USB packets in which this payload was received = Application programmed initial packet count – core updated final packet count

   The application can discard invalid data packets.

- **Incomplete isochronous OUT data transfers**

This section describes the application programming sequence when isochronous OUT data packets are dropped inside the core.

Internal data flow:

1. For isochronous OUT endpoints, the XFRC interrupt (in OTG_DOEPINTx) may not always be asserted. If the core drops isochronous OUT data packets, the application

could fail to detect the XFRC interrupt (OTG_DOEPINTx) under the following circumstances:

- When the receive FIFO cannot accommodate the complete ISO OUT data packet, the core drops the received ISO OUT data
- When the isochronous OUT data packet is received with CRC errors
- When the isochronous OUT token received by the core is corrupted
- When the application is very slow in reading the data from the receive FIFO

2. When the core detects an end of periodic frame before transfer completion to all isochronous OUT endpoints, it asserts the incomplete isochronous OUT data interrupt (INCOMPISOOUT in OTG_GINTSTS), indicating that an XFRC interrupt (in OTG_DOEPINTx) is not asserted on at least one of the isochronous OUT endpoints. At this point, the endpoint with the incomplete transfer remains enabled, but no active transfers remain in progress on this endpoint on the USB.

Application programming sequence:

1. Asserting the INCOMPISOOUT interrupt (OTG_GINTSTS) indicates that in the current frame, at least one isochronous OUT endpoint has an incomplete transfer.
2. If this occurs because isochronous OUT data is not completely emptied from the endpoint, the application must ensure that the application empties all isochronous OUT data (data and status) from the receive FIFO before proceeding.
   - When all data are emptied from the receive FIFO, the application can detect the XFRC interrupt (OTG_DOEPINTx). In this case, the application must re-enable the endpoint to receive isochronous OUT data in the next frame.
3. When it receives an INCOMPISOOUT interrupt (in OTG_GINTSTS), the application must read the control registers of all isochronous OUT endpoints (OTG_DOEPCTLx) to determine which endpoints had an incomplete transfer in the current microframe. An endpoint transfer is incomplete if both the following conditions are met:
   - EONUM bit (in OTG_DOEPCTLx) = FNSOF[0] (in OTG_DSTS)
   - EPENA = 1 (in OTG_DOEPCTLx)
4. The previous step must be performed before the SOF interrupt (in OTG_GINTSTS) is detected, to ensure that the current frame number is not changed.
5. For isochronous OUT endpoints with incomplete transfers, the application must discard the data in the memory and disable the endpoint by setting the EPDIS bit in OTG_DOEPCTLx.
6. Wait for the EPDISD interrupt (in OTG_DOEPINTx) and enable the endpoint to receive new data in the next frame.
   - Because the core can take some time to disable the endpoint, the application may not be able to receive the data in the next frame after receiving bad isochronous data.

- **Stalling a non-isochronous OUT endpoint**

This section describes how the application can stall a non-isochronous endpoint.

1. Put the core in the Global OUT NAK mode.
2. Disable the required endpoint
   – When disabling the endpoint, instead of setting the SNAK bit in OTG_DOEPCTL, set STALL = 1 (in OTG_DOEPCTL).

     The STALL bit always takes precedence over the NAK bit.
3. When the application is ready to end the STALL handshake for the endpoint, the STALL bit (in OTG_DOEPCTLx) must be cleared.
4. If the application is setting or clearing a STALL for an endpoint due to a SetFeature.Endpoint Halt or ClearFeature.Endpoint Halt command, the STALL bit must be set or cleared before the application sets up the status stage transfer on the control endpoint.

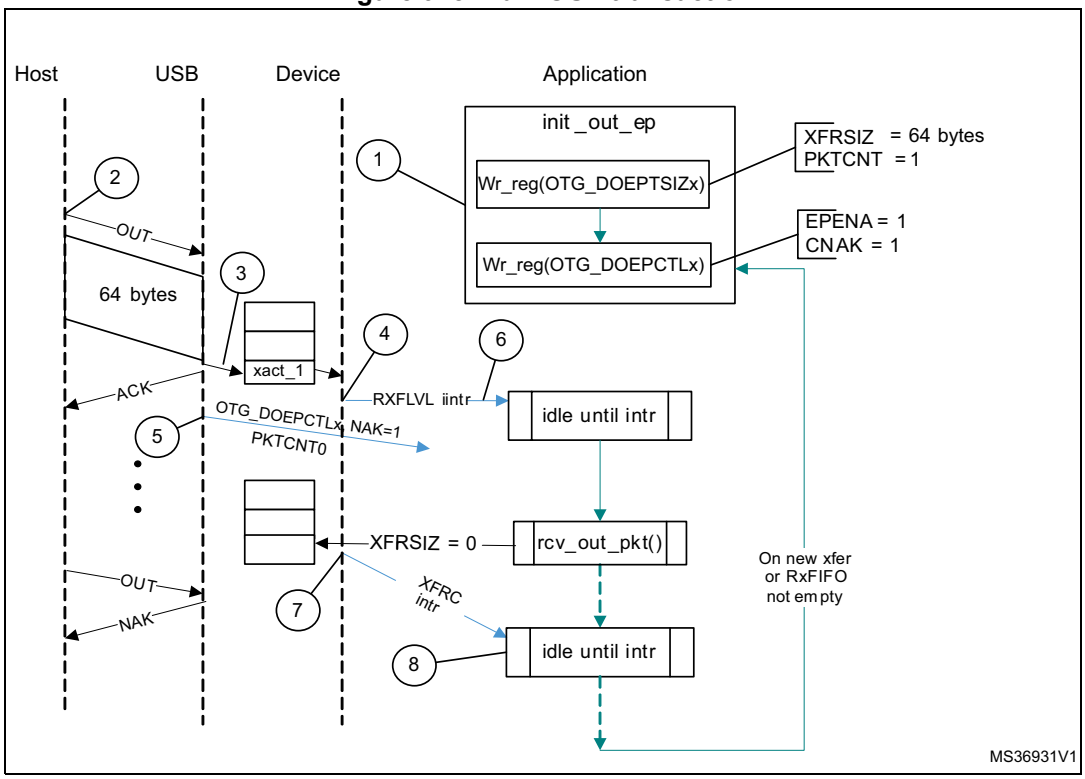
Examples

This section describes and depicts some fundamental transfer types and scenarios.

- Bulk OUT transaction

Figure 948 depicts the reception of a single Bulk OUT data packet from the USB to the AHB and describes the events involved in the process.

Figure 948. Bulk OUT transaction



After a SetConfiguration/SetInterface command, the application initializes all OUT endpoints by setting CNAK = 1 and EPENA = 1 (in OTG_DOEPCTLx), and setting a suitable XFRSIZ and PKTCNT in the OTG_DOEPTSIZx register.

1. host attempts to send data (OUT token) to an endpoint.
2. When the core receives the OUT token on the USB, it stores the packet in the Rx FIFO because space is available there.
3. After writing the complete packet in the Rx FIFO, the core then asserts the RXFLVL interrupt (in OTG_GINTSTS).
4. On receiving the PKTCNT number of USB packets, the core internally sets the NAK bit for this endpoint to prevent it from receiving any more packets.
5. The application processes the interrupt and reads the data from the Rx FIFO.
6. When the application has read all the data (equivalent to XFRSIZ), the core generates an XFRC interrupt (in OTG_DOEPINTx).
7. The application processes the interrupt and uses the setting of the XFRC interrupt bit (in OTG_DOEPINTx) to determine that the intended transfer is complete.

IN data transfers

- **Packet write**

This section describes how the application writes data packets to the endpoint FIFO when dedicated transmit FIFOs are enabled.

1. The application can either choose the polling or the interrupt mode.
   - In polling mode, the application monitors the status of the endpoint transmit data FIFO by reading the OTG_DTXFSTSx register, to determine if there is enough space in the data FIFO.
   - In interrupt mode, the application waits for the TXFE interrupt (in OTG_DIEPINTx) and then reads the OTG_DTXFSTSx register, to determine if there is enough space in the data FIFO.
   - To write a single non-zero length data packet, there must be space to write the entire packet in the data FIFO.
   - To write zero length packet, the application must not look at the FIFO space.
2. Using one of the above mentioned methods, when the application determines that there is enough space to write a transmit packet, the application must first write into the endpoint control register, before writing the data into the data FIFO. Typically, the application, must do a read modify write on the OTG_DIEPCTLx register to avoid modifying the contents of the register, except for setting the endpoint enable bit.

The application can write multiple packets for the same endpoint into the transmit FIFO, if space is available. For periodic IN endpoints, the application must write packets only for one microframe. It can write packets for the next periodic transaction only after getting transfer complete for the previous transaction.

- **Setting IN endpoint NAK**

Internal data flow:

1. When the application sets the IN NAK for a particular endpoint, the core stops transmitting data on the endpoint, irrespective of data availability in the endpoint's transmit FIFO.
2. Non-isochronous IN tokens receive a NAK handshake reply
   – Isochronous IN tokens receive a zero-data-length packet reply
3. The core asserts the INEPNE (IN endpoint NAK effective) interrupt in OTG_DIEPINTx in response to the SNAK bit in OTG_DIEPCTLx.
4. Once this interrupt is seen by the application, the application can assume that the endpoint is in IN NAK mode. This interrupt can be cleared by the application by setting the CNAK bit in OTG_DIEPCTLx.

Application programming sequence:

1. To stop transmitting any data on a particular IN endpoint, the application must set the IN NAK bit. To set this bit, the following field must be programmed.
   – SNAK = 1 in OTG_DIEPCTLx
2. Wait for assertion of the INEPNE interrupt in OTG_DIEPINTx. This interrupt indicates that the core has stopped transmitting data on the endpoint.
3. The core can transmit valid IN data on the endpoint after the application has set the NAK bit, but before the assertion of the NAK Effective interrupt.
4. The application can mask this interrupt temporarily by writing to the INEPNEM bit in OTG_DIEPMSK.
   – INEPNEM = 0 in OTG_DIEPMSK
5. To exit endpoint NAK mode, the application must clear the NAK status bit (NAKSTS) in OTG_DIEPCTLx. This also clears the INEPNE interrupt (in OTG_DIEPINTx).
   – CNAK = 1 in OTG_DIEPCTLx
6. If the application masked this interrupt earlier, it must be unmasked as follows:
   – INEPNEM = 1 in OTG_DIEPMSK

- **IN endpoint disable**

Use the following sequence to disable a specific IN endpoint that has been previously enabled.

Application programming sequence:

1. The application must stop writing data on the AHB for the IN endpoint to be disabled.
2. The application must set the endpoint in NAK mode.
   – SNAK = 1 in OTG_DIEPCTLx
3. Wait for the INEPNE interrupt in OTG_DIEPINTx.
4. Set the following bits in the OTG_DIEPCTLx register for the endpoint that must be disabled.
   – EPDIS = 1 in OTG_DIEPCTLx
   – SNAK = 1 in OTG_DIEPCTLx
5. Assertion of the EPDISD interrupt in OTG_DIEPINTx indicates that the core has completely disabled the specified endpoint. Along with the assertion of the interrupt, the core also clears the following bits:
   – EPENA = 0 in OTG_DIEPCTLx
   – EPDIS = 0 in OTG_DIEPCTLx
6. The application must read the OTG_DIEPTSIZx register for the periodic IN EP, to calculate how much data on the endpoint were transmitted on the USB.
7. The application must flush the data in the endpoint transmit FIFO, by setting the following fields in the OTG_GRSTCTL register:
   – TXFNUM (in OTG_GRSTCTL) = Endpoint transmit FIFO number
   – TXFFLSH in (OTG_GRSTCTL) = 1

The application must poll the OTG_GRSTCTL register, until the TXFFLSH bit is cleared by the core, which indicates the end of flush operation. To transmit new data on this endpoint, the application can re-enable the endpoint at a later point.

- **Transfer Stop Programming for IN endpoints**

The application must use the following programing sequence to stop any transfers (because of an interrupt from the host, typically a reset).

Sequence of operations:

1. Disable the IN endpoint by setting:
   – EPDIS = 1 in all OTG_DIEPCTLx registers
2. Wait for the EPDIS interrupt in OTG_DIEPINTx, which indicates that the IN endpoint is completely disabled. When the EPDIS interrupt is asserted the following bits are cleared:
   – EPDIS = 0 in OTG_DIEPCTLx
   – EPENA = 0 in OTG_DIEPCTLx
3. Flush the TxFIFO by programming the following bits:
   – TXFFLSH = 1 in OTG_GRSTCTL
   – TXFNUM = “FIFO number specific to endpoint” in OTG_GRSTCTL
4. The application can start polling till TXFFLSH in OTG_GRSTCTL is cleared. When this bit is cleared, it ensures that there is no data left in the Tx FIFO.

- **Generic non-periodic IN data transfers**

Application requirements:

1. Before setting up an IN transfer, the application must ensure that all data to be transmitted as part of the IN transfer are part of a single buffer.
2. For IN transfers, the transfer size field in the endpoint transfer size register denotes a payload that constitutes multiple maximum-packet-size packets and a single short packet. This short packet is transmitted at the end of the transfer.
   – To transmit a few maximum-packet-size packets and a short packet at the end of the transfer:

     Transfer size[EPNUM] = *x* × MPSIZ[EPNUM] + sp

     If (sp > 0), then packet count[EPNUM] = x + 1.
     Otherwise, packet count[EPNUM] = *x*
   – To transmit a single zero-length data packet:

     Transfer size[EPNUM] = 0

     Packet count[EPNUM] = 1
   – To transmit a few maximum-packet-size packets and a zero-length data packet at the end of the transfer, the application must split the transfer into two parts. The first sends maximum-packet-size data packets and the second sends the zero-length data packet alone.

     First transfer: transfer size[EPNUM] = *x* × MPSIZ[epnum]; packet count = *n*;

     Second transfer: transfer size[EPNUM] = 0; packet count = 1;
3. Once an endpoint is enabled for data transfers, the core updates the transfer size register. At the end of the IN transfer, the application must read the transfer size register to determine how much data posted in the transmit FIFO have already been sent on the USB.
4. Data fetched into transmit FIFO = Application-programmed initial transfer size – core-updated final transfer size
   – Data transmitted on USB = (application-programmed initial packet count – core updated final packet count) × MPSIZ[EPNUM]
   – Data yet to be transmitted on USB = (Application-programmed initial transfer size – data transmitted on USB)

Internal data flow:

1. The application must set the transfer size and packet count fields in the endpoint-specific registers and enable the endpoint to transmit the data.
2. The application must also write the required data to the transmit FIFO for the endpoint.
3. Every time a packet is written into the transmit FIFO by the application, the transfer size for that endpoint is decremented by the packet size. The data is fetched from the memory by the application, until the transfer size for the endpoint becomes 0. After writing the data into the FIFO, the “number of packets in FIFO” count is incremented (this is a 3-bit count, internally maintained by the core for each IN endpoint transmit FIFO. The maximum number of packets maintained by the core at any time in an IN endpoint FIFO is eight). For zero-length packets, a separate flag is set for each FIFO, without any data in the FIFO.
4. Once the data are written to the transmit FIFO, the core reads them out upon receiving an IN token. For every non-isochronous IN data packet transmitted with an ACK

handshake, the packet count for the endpoint is decremented by one, until the packet count is zero. The packet count is not decremented on a timeout.

5. For zero length packets (indicated by an internal zero length flag), the core sends out a zero-length packet for the IN token and decrements the packet count field.
6. If there are no data in the FIFO for a received IN token and the packet count field for that endpoint is zero, the core generates an “IN token received when Tx FIFO is empty” (ITTXFE) interrupt for the endpoint, provided that the endpoint NAK bit is not set. The core responds with a NAK handshake for non-isochronous endpoints on the USB.
7. The core internally rewinds the FIFO pointers and no timeout interrupt is generated.
8. When the transfer size is 0 and the packet count is 0, the transfer complete (XFRC) interrupt for the endpoint is generated and the endpoint enable is cleared.

Application programming sequence:

1. Program the OTG_DIEPTSIZx register with the transfer size and corresponding packet count.
2. Program the OTG_DIEPCTLx register with the endpoint characteristics and set the CNAK and EPENA (endpoint enable) bits.
3. When transmitting non-zero length data packet, the application must poll the OTG_DTXFSTSx register (where x is the FIFO number associated with that endpoint) to determine whether there is enough space in the data FIFO. The application can optionally use TXFE (in OTG_DIEPINTx) before writing the data.

- **Generic periodic IN data transfers**

This section describes a typical periodic IN data transfer.

Application requirements:

1. Application requirements 1, 2, 3, and 4 of *Generic non-periodic IN data transfers on page 3259* also apply to periodic IN data transfers, except for a slight modification of requirement 2.
   – The application can only transmit multiples of maximum-packet-size data packets or multiples of maximum-packet-size packets, plus a short packet at the end. To

transmit a few maximum-packet-size packets and a short packet at the end of the transfer, the following conditions must be met:

transfer size[EPNUM] = x × MPSIZ[EPNUM] + sp
(where *x* is an integer ≥ 0, and 0 ≤ sp < MPSIZ[EPNUM])

If (sp > 0), packet count[EPNUM] = *x* + 1
Otherwise, packet count[EPNUM] = *x*;

MCNT[EPNUM] = packet count[EPNUM]

– The application cannot transmit a zero-length data packet at the end of a transfer. It can transmit a single zero-length data packet by itself. To transmit a single zero-length data packet:
– transfer size[EPNUM] = 0

packet count[EPNUM] = 1

MCNT[EPNUM] = packet count[EPNUM]

2. The application can only schedule data transfers one frame at a time.
   – (MCNT – 1) × MPSIZ ≤ XFERSIZ ≤ MCNT × MPSIZ
   – PKTCNT = MCNT (in OTG_DIEPTSIZx)
   – If XFERSIZ < MCNT × MPSIZ, the last data packet of the transfer is a short packet.
   – Note that: MCNT is in OTG_DIEPTSIZx, MPSIZ is in OTG_DIEPCTLx, PKTCNT is in OTG_DIEPTSIZx and XFERSIZ is in OTG_DIEPTSIZx
3. The complete data to be transmitted in the frame must be written into the transmit FIFO by the application, before the IN token is received. Even when 1 word of the data to be transmitted per frame is missing in the transmit FIFO when the IN token is received, the core behaves as when the FIFO is empty. When the transmit FIFO is empty:
   – A zero data length packet would be transmitted on the USB for isochronous IN endpoints
   – A NAK handshake would be transmitted on the USB for interrupt IN endpoints

Internal data flow:

1. The application must set the transfer size and packet count fields in the endpoint-specific registers and enable the endpoint to transmit the data.
2. The application must also write the required data to the associated transmit FIFO for the endpoint.
3. Every time the application writes a packet to the transmit FIFO, the transfer size for that endpoint is decremented by the packet size. The data are fetched from application memory until the transfer size for the endpoint becomes 0.
4. When an IN token is received for a periodic endpoint, the core transmits the data in the FIFO, if available. If the complete data payload (complete packet, in dedicated FIFO

mode) for the frame is not present in the FIFO, then the core generates an IN token received when Tx FIFO empty interrupt for the endpoint.
   – A zero-length data packet is transmitted on the USB for isochronous IN endpoints
   – A NAK handshake is transmitted on the USB for interrupt IN endpoints
5. The packet count for the endpoint is decremented by 1 under the following conditions:
   – For isochronous endpoints, when a zero- or non-zero-length data packet is transmitted
   – For interrupt endpoints, when an ACK handshake is transmitted
   – When the transfer size and packet count are both 0, the transfer completed interrupt for the endpoint is generated and the endpoint enable is cleared.
6. At the “Periodic frame Interval” (controlled by PFIVL in OTG_DCFG), when the core finds non-empty any of the isochronous IN endpoint FIFOs scheduled for the current frame non-empty, the core generates an IISOIXFR interrupt in OTG_GINTSTS.

Application programming sequence:

1. Program the OTG_DIEPCTLx register with the endpoint characteristics and set the CNAK and EPENA bits.
2. Write the data to be transmitted in the next frame to the transmit FIFO.
3. Asserting the ITTXFE interrupt (in OTG_DIEPINTx) indicates that the application has not yet written all data to be transmitted to the transmit FIFO.
4. If the interrupt endpoint is already enabled when this interrupt is detected, ignore the interrupt. If it is not enabled, enable the endpoint so that the data can be transmitted on the next IN token attempt.
5. Asserting the XFRC interrupt (in OTG_DIEPINTx) with no ITTXFE interrupt in OTG_DIEPINTx indicates the successful completion of an isochronous IN transfer. A read to the OTG_DIEPTSIZx register must give transfer size = 0 and packet count = 0, indicating all data were transmitted on the USB.
6. Asserting the XFRC interrupt (in OTG_DIEPINTx), with or without the ITTXFE interrupt (in OTG_DIEPINTx), indicates the successful completion of an interrupt IN transfer. A read to the OTG_DIEPTSIZx register must give transfer size = 0 and packet count = 0, indicating all data were transmitted on the USB.
7. Asserting the incomplete isochronous IN transfer (IISOIXFR) interrupt in OTG_GINTSTS with none of the aforementioned interrupts indicates the core did not receive at least 1 periodic IN token in the current frame.

- **Incomplete isochronous IN data transfers**

This section describes what the application must do on an incomplete isochronous IN data transfer.

Internal data flow:

1. An isochronous IN transfer is treated as incomplete in one of the following conditions:
   a) The core receives a corrupted isochronous IN token on at least one isochronous IN endpoint. In this case, the application detects an incomplete isochronous IN transfer interrupt (IISOIXFR in OTG_GINTSTS).
   b) The application is slow to write the complete data payload to the transmit FIFO and an IN token is received before the complete data payload is written to the FIFO. In this case, the application detects an IN token received when Tx FIFO empty interrupt in OTG_DIEPINTx. The application can ignore this interrupt, as it

eventually results in an incomplete isochronous IN transfer interrupt (IISOIXFR in OTG_GINTSTS) at the end of periodic frame.

The core transmits a zero-length data packet on the USB in response to the received IN token.

2. The application must stop writing the data payload to the transmit FIFO as soon as possible.
3. The application must set the NAK bit and the disable bit for the endpoint.
4. The core disables the endpoint, clears the disable bit, and asserts the endpoint disable interrupt for the endpoint.

Application programming sequence:

1. The application can ignore the IN token received when Tx FIFO empty interrupt in OTG_DIEPINTx on any isochronous IN endpoint, as it eventually results in an incomplete isochronous IN transfer interrupt (in OTG_GINTSTS).
2. Assertion of the incomplete isochronous IN transfer interrupt (in OTG_GINTSTS) indicates an incomplete isochronous IN transfer on at least one of the isochronous IN endpoints.
3. The application must read the endpoint control register for all isochronous IN endpoints to detect endpoints with incomplete IN data transfers.
4. The application must stop writing data to the Periodic Transmit FIFOs associated with these endpoints on the AHB.
5. Program the following fields in the OTG_DIEPCTLx register to disable the endpoint:
   – SNAK = 1 in OTG_DIEPCTLx
   – EPDIS = 1 in OTG_DIEPCTLx
6. The assertion of the endpoint disabled interrupt in OTG_DIEPINTx indicates that the core has disabled the endpoint.
   – At this point, the application must flush the data in the associated transmit FIFO or overwrite the existing data in the FIFO by enabling the endpoint for a new transfer in the next microframe. To flush the data, the application must use the OTG_GRSTCTL register.

- **Stalling non-isochronous IN endpoints**

This section describes how the application can stall a non-isochronous endpoint.

Application programming sequence:

1. Disable the IN endpoint to be stalled. Set the STALL bit as well.
2. EPDIS = 1 in OTG_DIEPCTLx, when the endpoint is already enabled
   – STALL = 1 in OTG_DIEPCTLx
   – The STALL bit always takes precedence over the NAK bit
3. Assertion of the endpoint disabled interrupt (in OTG_DIEPINTx) indicates to the application that the core has disabled the specified endpoint.
4. The application must flush the non-periodic or periodic transmit FIFO, depending on the endpoint type. In case of a non-periodic endpoint, the application must re-enable the other non-periodic endpoints that do not need to be stalled, to transmit data.
5. Whenever the application is ready to end the STALL handshake for the endpoint, the STALL bit must be cleared in OTG_DIEPCTLx.
6. If the application sets or clears a STALL bit for an endpoint due to a SetFeature.Endpoint Halt command or ClearFeature.Endpoint Halt command, the STALL bit must be set or cleared before the application sets up the status stage transfer on the control endpoint.

Special case: stalling the control OUT endpoint

The core must stall IN/OUT tokens if, during the data stage of a control transfer, the host sends more IN/OUT tokens than are specified in the SETUP packet. In this case, the application must enable the ITTXFE interrupt in OTG_DIEPINTx and the OTEPDIS interrupt in OTG_DOEPINTx during the data stage of the control transfer, after the core has transferred the amount of data specified in the SETUP packet. Then, when the application receives this interrupt, it must set the STALL bit in the corresponding endpoint control register, and clear this interrupt.

66.16.6 Worst case response time

When the OTG_FS controller acts as a device, there is a worst case response time for any tokens that follow an isochronous OUT. This worst case response time depends on the AHB clock frequency.

The core registers are in the AHB domain, and the core does not accept another token before updating these register values. The worst case is for any token following an isochronous OUT, because for an isochronous transaction, there is no handshake and the next token could come sooner. This worst case value is 7 PHY clocks when the AHB clock is the same as the PHY clock. When the AHB clock is faster, this value is smaller.

If this worst case condition occurs, the core responds to bulk/interrupt tokens with a NAK and drops isochronous and SETUP tokens. The host interprets this as a timeout condition for SETUP and retries the SETUP packet. For isochronous transfers, the Incomplete isochronous IN transfer interrupt (IISOIXFR) and Incomplete isochronous OUT transfer interrupt (IISOOXFR) inform the application that isochronous IN/OUT packets were dropped.

Choosing the value of TRDT in OTG_GUSBCFG

The value in TRDT (OTG_GUSBCFG) is the time it takes for the MAC, in terms of PHY clocks after it has received an IN token, to get the FIFO status, and thus the first data from the PFC block. This time involves the synchronization delay between the PHY and AHB clocks. The worst case delay for this is when the AHB clock is the same as the PHY clock. In this case, the delay is 5 clocks.

Once the MAC receives an IN token, this information (token received) is synchronized to the AHB clock by the PFC (the PFC runs on the AHB clock). The PFC then reads the data from the SPRAM and writes them into the dual clock source buffer. The MAC then reads the data out of the source buffer (4 deep).

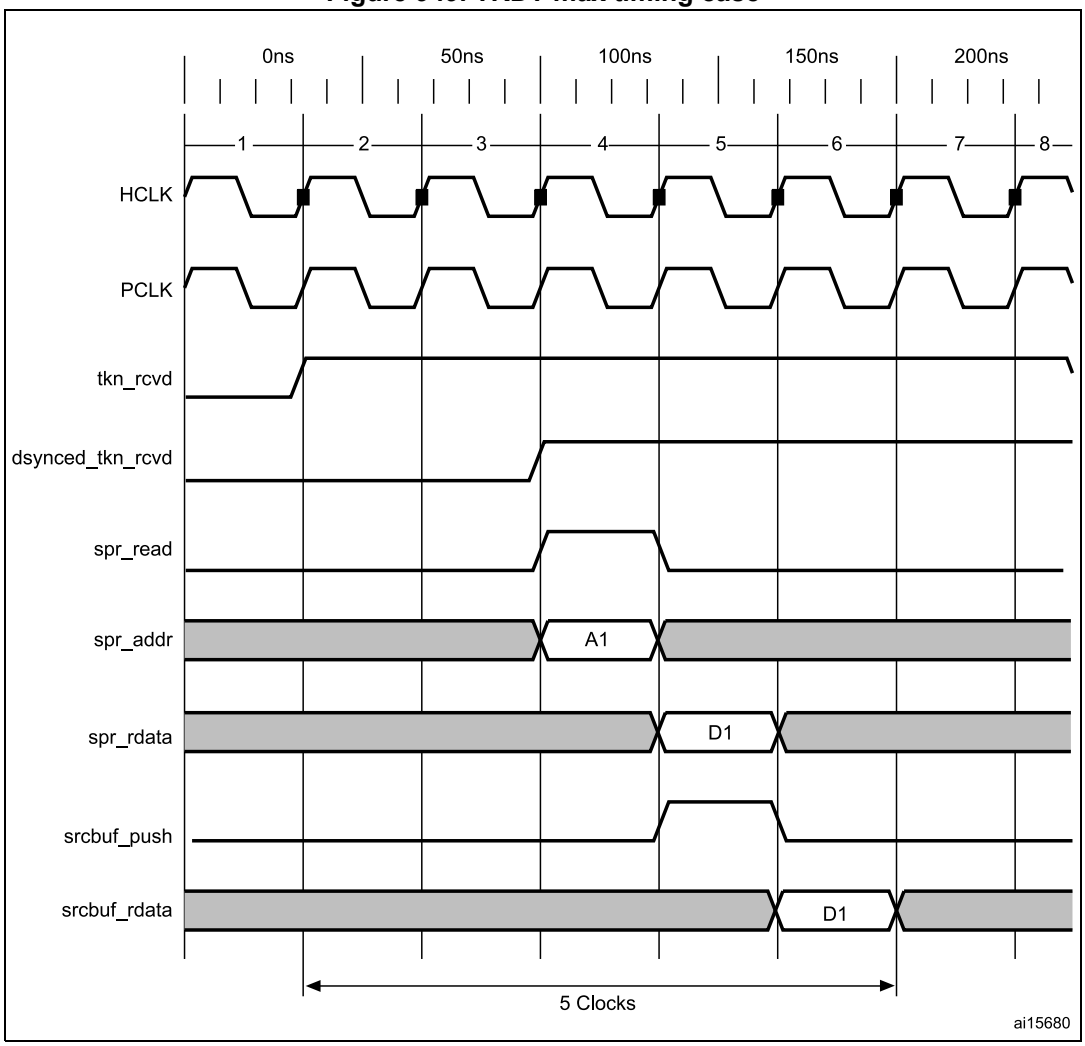
If the AHB is running at a higher frequency than the PHY, the application can use a smaller value for TRDT (in OTG_GUSBCFG).

Figure 949 has the following signals:

- tkn_rcvd: Token received information from MAC to PFC
- dynced_tkn_rcvd: Doubled sync tkn_rcvd, from PCLK to HCLK domain
- spr_read: Read to SPRAM
- spr_addr: Address to SPRAM
- spr_rdata: Read data from SPRAM
- srcbuf_push: Push to the source buffer
- srcbuf_rdata: Read data from the source buffer. Data seen by MAC

To calculate the value of TRDT, refer to *Table 737: TRDT values*.

Figure 949. TRDT max timing case



66.16.7 OTG programming model

The OTG_FS controller is an OTG device. When the core is connected to an “A” plug, it is referred to as an A-device. When the core is connected to a “B” plug it is referred to as a B-device.

67 USB on-the-go high-speed (OTG_HS)

67.1 OTG_HS introduction

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This section presents the architecture and the programming model of the OTG_HS controller.

The following acronyms are used throughout the section:

FS	Full-speed
LS	Low-speed
HS	High-speed
MAC	Media access controller
OTG	On-the-go
PFC	Packet FIFO controller
PHY	Physical layer
USB	Universal serial bus
UTMI	USB 2.0 Transceiver Macrocell interface (UTMI)
LPM	Link power management
BCD	Battery charging detector
HNP	Host negotiation protocol
SRP	Session request protocol

References are made to the following documents:

- USB On-The-Go Supplement, Revision 2.0
- Universal Serial Bus Revision 2.0 Specification
- USB 2.0 Link Power Management Addendum Engineering Change Notice to the USB 2.0 specification, July 16, 2007
- Errata for USB 2.0 ECN: Link Power Management (LPM) - 7/2007
- Battery Charging Specification, Revision 1.2

The USB OTG is a dual-role device (DRD) controller that supports both device and host functions and is fully compliant with the *On-The-Go Supplement to the USB 2.0 Specification*. It can also be configured as a host-only or device-only controller, fully compliant with the *USB 2.0 Specification*. OTG_HS supports the speeds defined in the *Table 740: OTG_HS speeds supported* below. The only external device required is a charge pump for V_{BUS} in OTG mode.

Table 740. OTG_HS speeds supported

-	HS (480 Mbit/s)	FS (12 Mbit/s)	LS (1.5 Mbit/s)
Host mode	X	X	X
Device mode	X	X	-

67.2 OTG_HS main features

The main features can be divided into three categories: general, host-mode, and device-mode features.

67.2.1 General features

The OTG_HS interface general features are the following:

- It is USB-IF certified to the Universal Serial Bus Specification Rev 2.0.
- OTG_HS supports the following PHY interfaces:
  - A UTMI interface for internal HS PHY
- It includes support (PHY) for the optional On-The-Go (OTG) protocol detailed in the On-The-Go Supplement Rev 2.0 specification
  - It allows host to turn V_{BUS} off to conserve battery power in OTG applications.
- It is software-configurable to operate as:
  - USB On-The-Go Full-Speed Dual Role device
- It supports HS SOF and LS Keep-alives with
  - SOF pulse PAD connectivity
  - SOF pulse internal connection to timer (TIMx)
  - Configurable framing period
  - Configurable end of frame interrupt
- OTG_HS embeds an internal DMA with thresholding support and software selectable AHB burst type in DMA mode.
- It includes power saving features such as system stop during USB suspend, switch-off of clock domains internal to the digital core, PHY and DFIFO power management.
- It features a dedicated RAM of 4 Kbytes with advanced FIFO control:
  - Configurable partitioning of RAM space into different FIFOs for flexible and efficient use of RAM
  - Each FIFO can hold multiple packets.
  - Dynamic memory allocation
  - Configurable FIFO sizes that are not powers of 2 to allow the use of contiguous memory locations
- It guarantees max USB bandwidth for up to one frame (1 ms) without system intervention.
- It supports charging port detection as described in Battery Charging Specification Revision 1.2.

67.2.2 Host-mode features

The OTG_HS interface main features and requirements in host-mode are the following:

- External charge pump for V_{BUS} voltage generation
- Up to 16 host channels (pipes): each channel is dynamically reconfigurable to allocate any type of USB transfer.
- Built-in hardware scheduler holding:
  - Up to 16 interrupt plus isochronous transfer requests in the periodic hardware queue
  - Up to 16 control plus bulk transfer requests in the non-periodic hardware queue
- Management of a shared Rx FIFO, a periodic Tx FIFO and a nonperiodic Tx FIFO for efficient usage of the USB data RAM.

67.2.3 Peripheral-mode features

The OTG_HS interface main features in peripheral-mode are the following:

- 1 bidirectional control endpoint0
- 8 IN endpoints (EPs) configurable to support bulk, interrupt or isochronous transfers
- 8 OUT endpoints configurable to support bulk, interrupt or isochronous transfers
- Management of a shared Rx FIFO and a Tx-OUT FIFO for efficient usage of the USB data RAM
- Management of up to 9 dedicated Tx-IN FIFOs (one for each active IN EP) to put less load on the application
- Support for the soft disconnect feature.

67.3 OTG_HS implementation

Table 741. OTG_HS implementation(1)

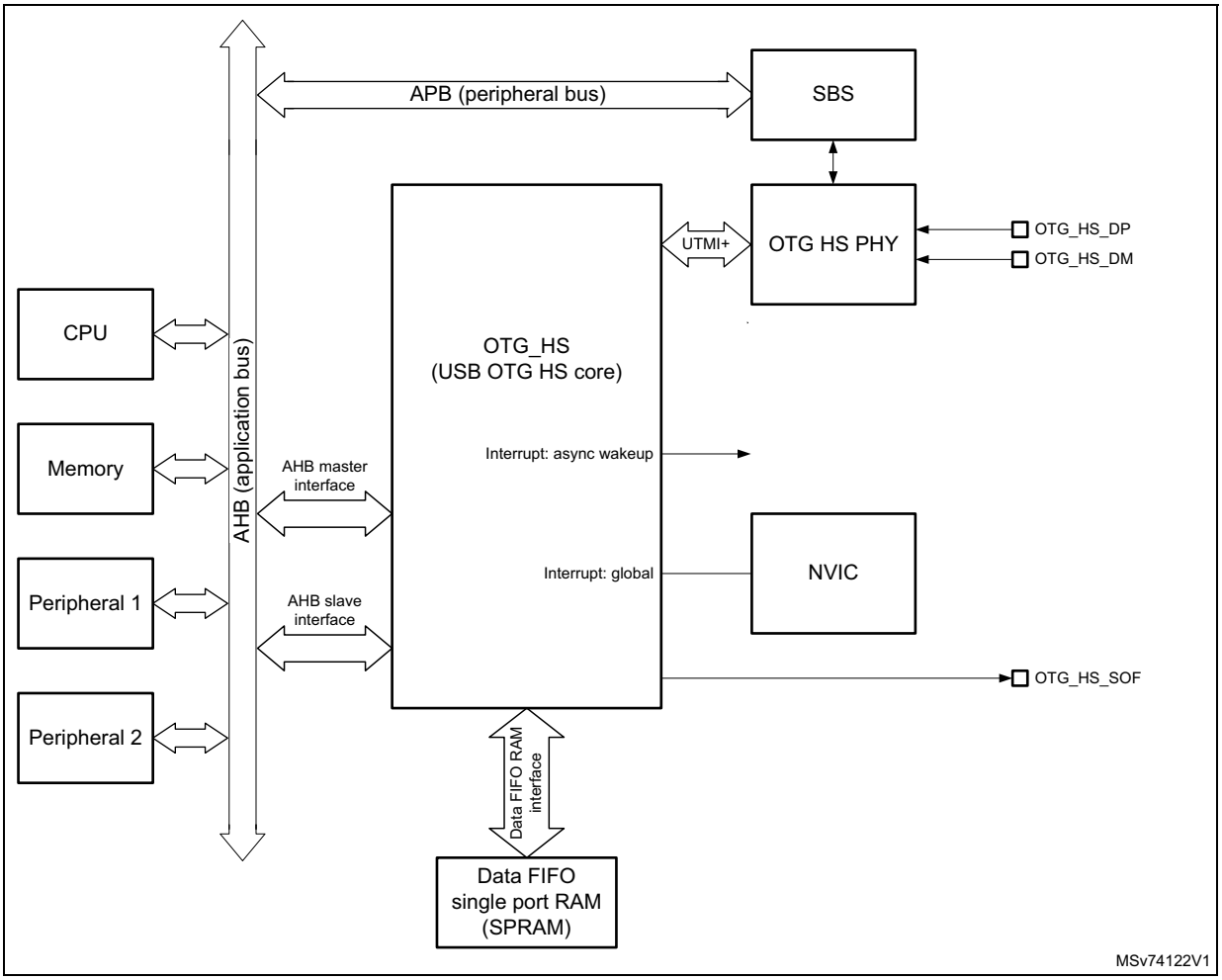
USB features	OTG_HS
Device bidirectional endpoints (including EP0)	9
Host mode channels	16
Size of dedicated SRAM	4 Kbytes
USB 2.0 link power management (LPM) support	X
OTG revision supported	2.0
Battery charging detection (BCD) support	X
Integrated PHY	HS

1. “X” = supported, “-” = not supported, “FS” = supported in FS mode, “HS” = supported in HS mode.

67.4 OTG_HS functional description

67.4.1 OTG_HS block diagram

Figure 950. OTG_HS high-speed block diagram



67.4.2 OTG_HS pin and internal signals

Table 742. OTG_HS input/output pins

Signal name	Signal type	Description
OTG_HS_DP	Digital input/output	USB OTG D+ line
OTG_HS_DM	Digital input/output	USB OTG D- line
OTG_HS_SOF	Digital output	USB OTG Start Of Frame (visibility)

Table 743. OTG_HS input/output signals

Signal name	Signal type	Description
usb_sof	Digital output	USB OTG start-of-frame event for on chip peripherals
usb_wkup	Digital output	USB OTG wake-up event output
usb_gbl_it	Digital output	USB OTG global interrupt

67.4.3 OTG_HS core

The OTG_HS receives the 60 MHz clock from the reset and clock controller (RCC). This is typically generated in the PLL associated with the HS PHY and enabled in the RCC. This clock is used for driving the 60 MHz domain at high-speed (480 Mbit/s) and must be enabled prior to configuring the OTG core.

The CPU reads and writes from/to the OTG core registers through the AHB peripheral bus. It is informed of USB events through the single USB OTG interrupt line described in *Section 67.12: OTG_HS interrupts*.

The CPU submits data over the USB by writing 32-bit words to dedicated OTG locations (push registers). The data are then automatically stored into Tx-data FIFOs configured within the USB data RAM. There is one Tx FIFO push register for each in-endpoint (peripheral mode) or out-channel (host mode).

The CPU receives the data from the USB by reading 32-bit words from dedicated OTG addresses (pop registers). The data are then automatically retrieved from a shared Rx FIFO configured within the 4-Kbyte USB data RAM. There is one Rx FIFO pop register for each out-endpoint or in-channel.

The USB protocol layer is driven by the serial interface engine (SIE) and serialized over the USB by the transceiver module within the on-chip physical layer (PHY).

Caution: To guarantee a correct operation for the USB OTG_HS peripheral, the AHB frequency must be higher than 30 MHz.

67.4.4 High-speed OTG PHY connected to OTG_HS

Note: Refer to implementation table to determine if an HS PHY is embedded.

The USB OTG core includes an internal UTMI interface which is connected to the embedded HS PHY (see *Section 67.4.1: OTG_HS block diagram*).

67.4.5 Battery charging detection

Support is available for the USB battery charging specification (v1.2).

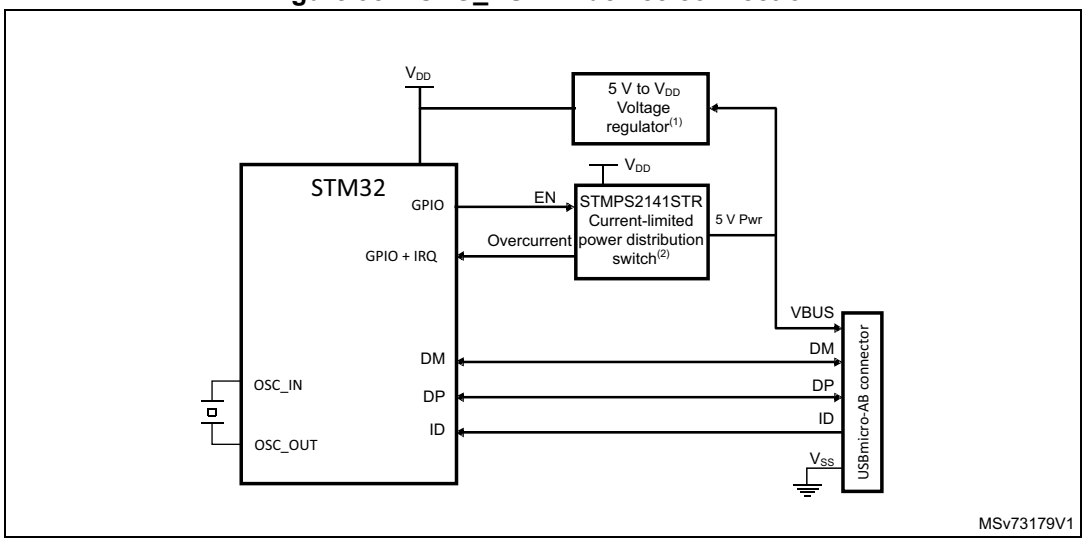
The OTG_HS includes the necessary circuits to enable battery charging detection (portable device).

There is also a possibility to behave as a charging data port (the port advertises 1.5 A available on it's VBUS pin).

Various fields control this functions and are implemented in register OTG_GCCFG.

67.5 OTG_HS dual role device (DRD)

Figure 951. OTG_HS A-B device connection



1. External voltage regulator only needed when building a VBUS powered device.
2. STMPS2141STR needed only if the application has to support a VBUS powered device. A basic power switch can be used if 5 V are available on the application board.

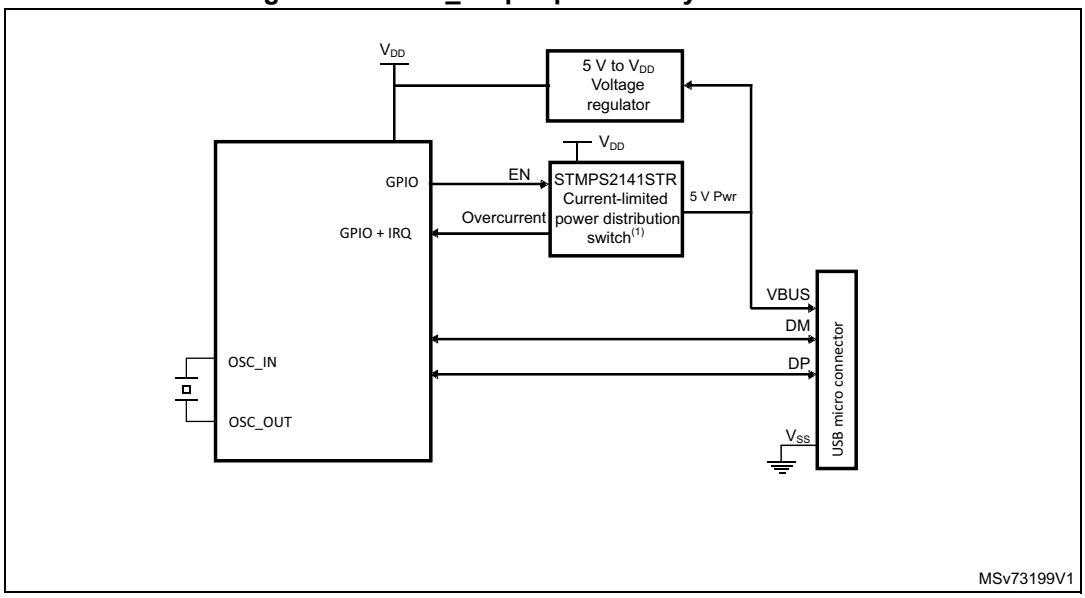
67.6 OTG_HS as a USB peripheral

This section gives the functional description of the OTG_HS in the USB peripheral mode. The OTG_HS works as an USB peripheral in the following circumstances:

- OTG B-Peripheral
  - OTG B-device default state if B-side of USB cable is plugged in
- B-device
  - If the ID line is present, functional and connected to the B-side of the USB cable.
- Peripheral only
  - The force device mode bit (FDMOD) in the *Section 67.14.4: OTG USB configuration register (OTG_GUSBCFG)* is set to 1, forcing the OTG_HS core to work as an USB peripheral-only. In this case, the ID line is ignored even if it is present on the USB connector.

Note: To build a bus-powered device implementation in case of the B-device or peripheral-only configuration, an external regulator has to be added, that generates the necessary power-supply from V_{BUS}.

Figure 952. OTG_HS peripheral-only connection



1. Use a regulator to build a bus-powered device.

67.6.1 Peripheral states

Powered state

External circuitry should be used to detect presence of a voltage on the VBUS connector pin. Refer to AN4879 "Introduction to USB hardware and PCB guidelines using STM32 MCUs" for recommended components. The B-peripheral V_{BUS} detection should be overridden with OTG_GOTGCTL.BVALOEN = 1. The result of this detection should be maintained by writing the current value to OTG_GOTGCTL.BVALOVAL.

In the powered state, the OTG_HS expects to receive some reset signaling from the host. No other USB operation is possible. When a reset signaling is received the reset detected interrupt (USBRST in OTG_GINTSTS) is generated. When the reset signaling is complete, the enumeration done interrupt (ENUMDNE bit in OTG_GINTSTS) is generated and the OTG_HS enters the Default state.

Soft disconnect

The powered state can be exited by software with the soft disconnect feature. The DP pull-up resistor is removed by setting the soft disconnect bit in the device control register (SDIS bit in OTG_DCTL), causing a device disconnect detection interrupt on the host side even though the USB cable was not really removed from the host port.

Default state

In the Default state the OTG_HS expects to receive a SET_ADDRESS command from the host. No other USB operation is possible. When a valid SET_ADDRESS command is decoded on the USB, the application writes the corresponding number into the device address field in the device configuration register (DAD bit in OTG_DCFG). The OTG_HS then enters the address state and is ready to answer host transactions at the configured USB address.

Suspended state

The OTG_HS peripheral constantly monitors the USB activity. After counting 3 ms of USB idleness, the early suspend interrupt (ESUSP bit in OTG_GINTSTS) is issued, and confirmed 3 ms later, if appropriate, by the suspend interrupt (USBSUSP bit in OTG_GINTSTS). The device suspend bit is then automatically set in the device status register (SUSPSTS bit in OTG_DSTS) and the OTG_HS enters the suspended state.

The suspended state may optionally be exited by the device itself. In this case the application sets the remote wake-up signaling bit in the device control register (RWUSIG bit in OTG_DCTL) and clears it after 1 to 15 ms.

When a resume signaling is detected from the host, the resume interrupt (WKUPINT bit in OTG_GINTSTS) is generated and the device suspend bit is automatically cleared.

67.6.2 Peripheral endpoints

The OTG_HS core instantiates the following USB endpoints:

- Control endpoint 0:
  - Bidirectional and handles control messages only
  - Separate set of registers to handle in and out transactions
  - Dedicated control (OTG_DIEPCTL0/OTG_DOEPCTL0), transfer configuration (OTG_DIEPTSIZ0/OTG_DOEPTSIZ0), and status-interrupt (OTG_DIEPINT0/)OTG_DOEPINT0) registers. The available set of bits inside the control and transfer size registers slightly differs from that of other endpoints
- eight IN endpoints
  - Each of them can be configured to support the isochronous, bulk or interrupt transfer type
  - Each of them has dedicated control (OTG_DIEPCTL*x*), transfer configuration (OTG_DIEPTSIZ*x*), and status-interrupt (OTG_DIEPINT*x*) registers
  - The device IN endpoints common interrupt mask register (OTG_DIEPMSK) is available to enable/disable a single kind of endpoint interrupt source on all of the IN endpoints (EP0 included)
  - Support for incomplete isochronous IN transfer interrupt (IISOIXFR bit in OTG_GINTSTS), asserted when there is at least one isochronous IN endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the end of periodic frame interrupt (OTG_GINTSTS/EOPF).
- eight OUT endpoints
  - Each of them can be configured to support the isochronous, bulk or interrupt transfer type
  - Each of them has a dedicated control (OTG_DOEPCTL*x*), transfer configuration (OTG_DOEPTSIZ*x*) and status-interrupt (OTG_DOEPINT*x*) register
  - Device OUT endpoints common interrupt mask register (OTG_DOEPMSK) is available to enable/disable a single kind of endpoint interrupt source on all of the OUT endpoints (EP0 included)
  - Support for incomplete isochronous OUT transfer interrupt (INCOMPISOOUT bit in OTG_GINTSTS), asserted when there is at least one isochronous OUT endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the end of periodic frame interrupt (OTG_GINTSTS/EOPF).

Endpoint control

- The following endpoint controls are available to the application through the device endpoint-*x* IN/OUT control register (OTG_DIEPCTL*x*/OTG_DOEPCTL*x*):
  - endpoint enable/disable
  - endpoint activate in current configuration
  - program USB transfer type (isochronous, bulk, interrupt)
  - program supported packet size
  - program Tx FIFO number associated with the IN endpoint
  - program the expected or transmitted data0/data1 PID (bulk/interrupt only)
  - program the even/odd frame during which the transaction is received or transmitted (isochronous only)
  - optionally program the NAK bit to always negative-acknowledge the host regardless of the FIFO status
  - optionally program the STALL bit to always stall host tokens to that endpoint
  - optionally program the SNOOP mode for OUT endpoint not to check the CRC field of received data

Endpoint transfer

The device endpoint-*x* transfer size registers (OTG_DIEPTSIZ*x*/OTG_DOEPTSIZ*x*) allow the application to program the transfer size parameters and read the transfer status. Programming must be done before setting the endpoint enable bit in the endpoint control register. Once the endpoint is enabled, these fields are read-only as the OTG_HS core updates them with the current transfer status.

The following transfer parameters can be programmed:

- transfer size in bytes
- number of packets that constitute the overall transfer size

Endpoint status/interrupt

The device endpoint-*x* interrupt registers (OTG_DIEPINT*x*/OTG_DOPEPINT*x)* indicate the status of an endpoint with respect to USB- and AHB-related events. The application must read these registers when the OUT endpoint interrupt bit or the IN endpoint interrupt bit in the core interrupt register (OEPINT bit in OTG_GINTSTS or IEPINT bit in OTG_GINTSTS, respectively) is set. Before the application can read these registers, it must first read the device all endpoints interrupt (OTG_DAINT) register to get the exact endpoint number for the device endpoint-*x* interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_DAINT and OTG_GINTSTS registers

The peripheral core provides the following status checks and interrupt generation:

- transfer completed interrupt, indicating that data transfer was completed on both the application (AHB) and USB sides
- setup stage has been done (control-out only)
- associated transmit FIFO is half or completely empty (in endpoints)
- NAK acknowledge has been transmitted to the host (isochronous-in only)
- IN token received when Tx FIFO was empty (bulk-in/interrupt-in only)
- Out token received when endpoint was not yet enabled
- babble error condition has been detected
- endpoint disable by application is effective
- endpoint NAK by application is effective (isochronous-in only)
- more than 3 back-to-back setup packets were received (control-out only)
- timeout condition detected (control-in only)
- isochronous out packet has been dropped, without generating an interrupt

67.7 OTG_HS as a USB host

This section gives the functional description of the OTG_HS in the USB host mode. The OTG_HS works as a USB host in the following circumstances:

Automatic host mode direct from ID pin:

The ID pin is not always available, refer to product datasheet for available pins.

- Use cases:
  - Micro connector: A-Device with a Micro-A plug inserted, and connector ID pin connected to the STM32 ID pin which is then detected in a low state.
- Note that the integrated pull-down resistors are automatically set on the DP/DM lines.

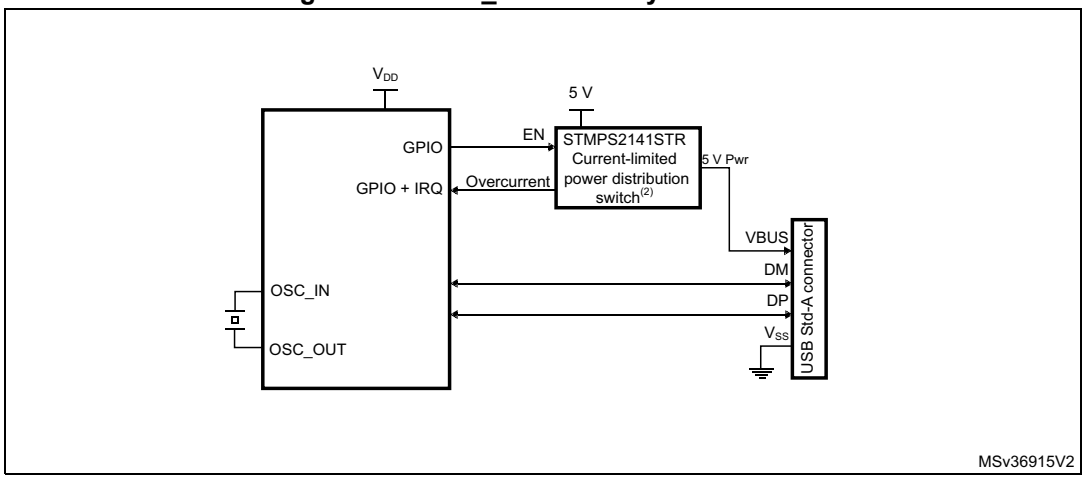
Manual forcing of host mode when not possible via ID pin:

The force host mode bit (FHMOD) in the *OTG USB configuration register (OTG_GUSBCFG)* forces the OTG_HS core to work as a USB host-only when required.

- Use cases:
  - Standard-A connector which always implies Host mode.
  - Micro connector, so ID present on connector, but ID pin not available in pinout, at A-plug insertion (detected by another means, for example: GPIO).
  - A Type-C connector, when host functionality is determined at cable attachment or via power delivery messages.
- Note that the integrated pull-down resistors are set on the DP/DM lines by setting bit FORCEHOSTPD.

Note: On-chip 5 V V_{BUS} generation is not supported. For this reason, a charge pump or, if 5 V are available on the application board, a basic power switch must be added externally to drive the 5 V V_{BUS} line. The external charge pump can be driven by any GPIO output. This is required for the OTG A-host, A-device and host-only configurations.

Figure 953. OTG_HS host-only connection



1. V_{DD} range is between 2 V and 3.6 V.

67.7.1 USB host states

Host port power

On-chip 5 V V_{BUS} generation is not supported. For this reason, a charge pump or, if 5 V are available on the application board, a basic power switch, must be added externally to drive the 5 V V_{BUS} line. The external charge pump can be driven by any GPIO output or via an I^2C interface connected to an external PMIC (power management IC). When the application decides to power on V_{BUS}, it must also set the port power bit in the host port control and status register (PPWR bit in OTG_HPRT).

The charge pump overcurrent flag can also be used to prevent electrical damage. Connect the overcurrent flag output from the charge pump to any GPIO input and configure it to generate a port interrupt on the active level. The overcurrent ISR must promptly disable the V_{BUS} generation and clear the port power bit.

Host detection of a peripheral connection

USB peripherals or B-device are detected as soon as they are connected. The OTG_HS core issues a host port interrupt triggered by the device connected bit in the host port control and status (PCDET bit in OTG_HPRT).

Host detection of peripheral a disconnection

The peripheral disconnection event triggers the disconnect detected interrupt (DISCINT bit in OTG_GINTSTS).

Host enumeration

After detecting a peripheral connection the host must start the enumeration process by sending USB reset and configuration commands to the new peripheral.

The application drives a USB reset signaling (single-ended zero) over the USB by keeping the port reset bit set in the host port control and status register (PRST bit in OTG_HPRT) for a minimum of 10 ms and a maximum of 20 ms. The application takes care of the timing count and then of clearing the port reset bit.

Once the USB reset sequence has completed, the host port interrupt is triggered by the port enable/disable change bit (PENCHNG bit in OTG_HPRT). This informs the application that the speed of the enumerated peripheral can be read from the port speed field in the host port control and status register (PSPD bit in OTG_HPRT) and that the host is starting to drive SOFs (FS) or Keep alives (LS). The host is now ready to complete the peripheral enumeration by sending peripheral configuration commands.

Host suspend

The application decides to suspend the USB activity by setting the port suspend bit in the host port control and status register (PSUSP bit in OTG_HPRT). The OTG_HS core stops sending SOFs and enters the suspended state.

The suspended state can be optionally exited on the remote device's initiative (remote wake-up). In this case the remote wake-up interrupt (WKUPINT bit in OTG_GINTSTS) is generated upon detection of a remote wake-up signaling, the port resume bit in the host port control and status register (PRES bit in OTG_HPRT) self-sets, and resume signaling is automatically driven over the USB. The application must time the resume window and then clear the port resume bit to exit the suspended state and restart the SOF.

If the suspended state is exited on the host initiative, the application must set the port resume bit to start resume signaling on the host port, time the resume window and finally clear the port resume bit.

67.7.2 Host channels

The OTG_HS core instantiates 16 host channels. Each host channel supports an USB host transfer (USB pipe). The host is not able to support more than 16 transfer requests at the same time. If more than 16 transfer requests are pending from the application, the host controller driver (HCD) must re-allocate channels when they become available from previous duty, that is, after receiving the transfer completed and channel halted interrupts.

Each host channel can be configured to support in/out and any type of periodic/nonperiodic transaction. Each host channel makes us of dedicated control (OTG_HCCHAR*x*), transfer configuration (OTG_HCTSIZ*x*) and status/interrupt (OTG_HCINT*x*) registers with associated mask (OTG_HCINTMSK*x*) registers.

Host channel control

- The following host channel controls are available to the application through the host channel-*x* characteristics register (OTG_HCCHAR*x*):
  - Channel enable/disable
  - Program the HS/FS/LS speed of target USB peripheral
  - Program the address of target USB peripheral
  - Program the endpoint number of target USB peripheral
  - Program the transfer IN/OUT direction
  - Program the USB transfer type (control, bulk, interrupt, isochronous)
  - Program the maximum packet size (MPS)
  - Program the periodic transfer to be executed during odd/even frames

Host channel transfer

The host channel transfer size registers (OTG_HCTSIZ*x*) allow the application to program the transfer size parameters, and read the transfer status. Programming must be done before setting the channel enable bit in the host channel characteristics register. Once the endpoint is enabled the packet count field is read-only as the OTG_HS core updates it according to the current transfer status.

- The following transfer parameters can be programmed:
  - transfer size in bytes
  - number of packets making up the overall transfer size
  - initial data PID

Host channel status/interrupt

The host channel-*x* interrupt register (OTG_HCINT*x*) indicates the status of an endpoint with respect to USB- and AHB-related events. The application must read these register when the host channels interrupt bit in the core interrupt register (HCINT bit in OTG_GINTSTS) is set. Before the application can read these registers, it must first read the host all channels interrupt (OTG_HAINT) register to get the exact channel number for the host channel-x interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_HAINT and OTG_GINTSTS registers. The mask bits for each interrupt source of each channel are also available in the OTG_HCINTMSKx register.

- The host core provides the following status checks and interrupt generation:
  - Transfer completed interrupt, indicating that the data transfer is complete on both the application (AHB) and USB sides
  - Channel has stopped due to transfer completed, USB transaction error or disable command from the application
  - Associated transmit FIFO is half or completely empty (IN endpoints)
  - ACK response received
  - NAK response received
  - STALL response received
  - USB transaction error due to CRC failure, timeout, bit stuff error, false EOP
  - Babble error
  - frame overrun
  - data toggle error

67.7.3 Host scheduler

The host core features a built-in hardware scheduler which is able to autonomously re-order and manage the USB transaction requests posted by the application. At the beginning of each frame the host executes the periodic (isochronous and interrupt) transactions first, followed by the nonperiodic (control and bulk) transactions to achieve the higher level of priority granted to the isochronous and interrupt transfer types by the USB specification.

The host processes the USB transactions through request queues (one for periodic and one for nonperiodic). Each request queue can hold up to 8 entries. Each entry represents a pending transaction request from the application, and holds the IN or OUT channel number along with other information to perform a transaction on the USB. The order in which the

requests are written to the queue determines the sequence of the transactions on the USB interface.

At the beginning of each frame, the host processes the periodic request queue first, followed by the nonperiodic request queue. The host issues an incomplete periodic transfer interrupt (IPXFR bit in OTG_GINTSTS) if an isochronous or interrupt transaction scheduled for the current frame is still pending at the end of the current frame. The OTG_HS core is fully responsible for the management of the periodic and nonperiodic request queues.The periodic transmit FIFO and queue status register (OTG_HPTXSTS) and nonperiodic transmit FIFO and queue status register (OTG_HNPTXSTS) are read-only registers which can be used by the application to read the status of each request queue. They contain:

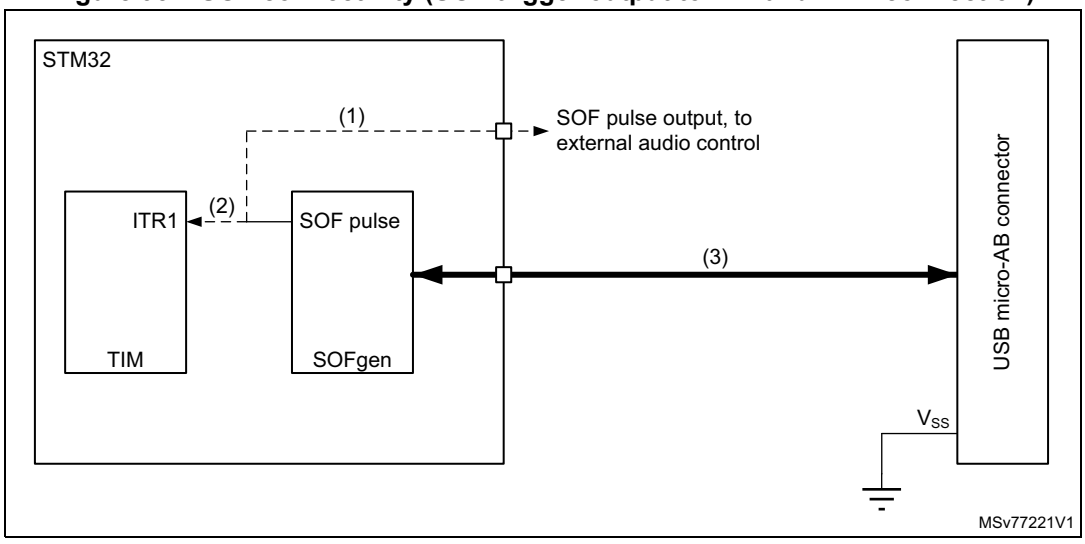
- The number of free entries currently available in the periodic (nonperiodic) request queue (8 max)
- Free space currently available in the periodic (nonperiodic) Tx FIFO (out-transactions)
- IN/OUT token, host channel number and other status information.

As request queues can hold a maximum of eight entries each, the application can push to schedule host transactions in advance with respect to the moment they physically reach the SB for a maximum of eight pending periodic transactions plus 8 pending non-periodic transactions.

To post a transaction request to the host scheduler (queue) the application must check that there is at least 1 entry available in the periodic (nonperiodic) request queue by reading the PTXQSAV bits in the OTG_HNPTXSTS register or NPTQXSAV bits in the OTG_HNPTXSTS register.

67.8 OTG_HS SOF trigger

Figure 954. SOF connectivity (SOF trigger output to TIM and ITR1 connection)



1. SOF pulse output is available on this product.
2. SOF timer connection is available on this product.
3. See *Table 742: OTG_HS input/output pins* for full pin list.

The OTG_HS core provides means to monitor, track and configure SOF framing in the host and peripheral, as well as an SOF pulse output connectivity feature.

Such utilities are especially useful for adaptive audio clock generation techniques, where the audio peripheral needs to synchronize to the isochronous stream provided by the PC, or the host needs to trim its framing rate according to the requirements of the audio peripheral.

67.8.1 Host SOFs

In host mode the number of PHY clocks occurring between the generation of two consecutive SOF (HS/FS) or Keep-alive (LS) tokens is programmable in the host frame interval register (HFIR), thus providing application control over the SOF framing period. An interrupt is generated at any start of frame (SOF bit in OTG_GINTSTS). The current frame number and the time remaining until the next SOF are tracked in the host frame number register (HFNUM).

A SOF pulse signal, is generated at any SOF starting token and with a width of 20 HCLK cycles. The SOF pulse is also internally connected to the input trigger of the timer, so that the input capture feature, the output compare feature and the timer can be triggered by the SOF pulse.

67.8.2 Peripheral SOFs

In device mode, the start of frame interrupt is generated each time an SOF token is received on the USB (SOF bit in OTG_GINTSTS). The corresponding frame number can be read from the device status register (FNSOF bit in OTG_DSTS). A SOF pulse signal with a width of 20 HCLK cycles is also generated. The SOF pulse signal is also internally connected to the TIM input trigger, so that the input capture feature, the output compare feature and the timer can be triggered by the SOF pulse.

The end of periodic frame interrupt (OTG_GINTSTS/EOPF) is used to notify the application when 80%, 85%, 90% or 95% of the time frame interval elapsed depending on the periodic frame interval field in the device configuration register (PFIVL bit in OTG_DCFG). This feature can be used to determine if all of the isochronous traffic for that frame is complete.

67.9 OTG_HS low-power modes

Table 744 below defines the STM32 low power modes and their compatibility with the OTG.

Table 744. Compatibility of STM32 low power modes with the OTG

Mode	Description	USB compatibility
Run	MCU fully active	Required when USB not in suspend state.
Sleep	USB suspend exit causes the device to exit Sleep mode. Peripheral registers content is kept.	Available while USB is in suspend state.
Stop	USB suspend exit causes the device to exit Stop mode. Peripheral registers content is kept(1).	Available while USB is in suspend state.
Standby	Powered-down. The peripheral must be reinitialized after exiting Standby mode.	Not compatible with USB applications.

1. Within Stop mode there are different possible settings. Some restrictions may also exist, refer to *TBD Section 6: Power control (PWR)* to understand which (if any) restrictions apply when using OTG.

The following bits and procedures reduce power consumption.

Power reduction techniques are available while in the USB suspended state, when the USB session is not yet valid or the device is disconnected.

- Stop PHY clock (STPPCLK bit in OTG_PCGCCTL)

  When setting the stop PHY clock bit in the clock gating control register, most of the transceiver is disabled, and only the part in charge of detecting the asynchronous resume or remote wake-up event is kept alive.

- Gate HCLK (GATEHCLK bit in OTG_PCGCCTL)

  When setting the Gate HCLK bit in the clock gating control register, most of the system clock domain internal to the OTG_HS core is switched off by clock gating. Only the register read and write interface is kept alive. The dynamic power consumption due to the USB clock switching activity is cut even if the system clock is kept running by the application for other purposes.

- USB system stop

  When the OTG_HS is in the USB suspended state, the application may decide to drastically reduce the overall power consumption by a complete shut down of all the clock sources in the system. USB System Stop is activated by first setting the Stop PHY clock bit and then configuring the system deep sleep mode in the power control system module (PWR).

  The OTG_HS core automatically reactivates both system and USB clocks by asynchronous detection of remote wake-up (as an host) or resume (as a device) signaling on the USB.

To save dynamic power, the USB data FIFO is clocked only when accessed by the OTG_HS core.

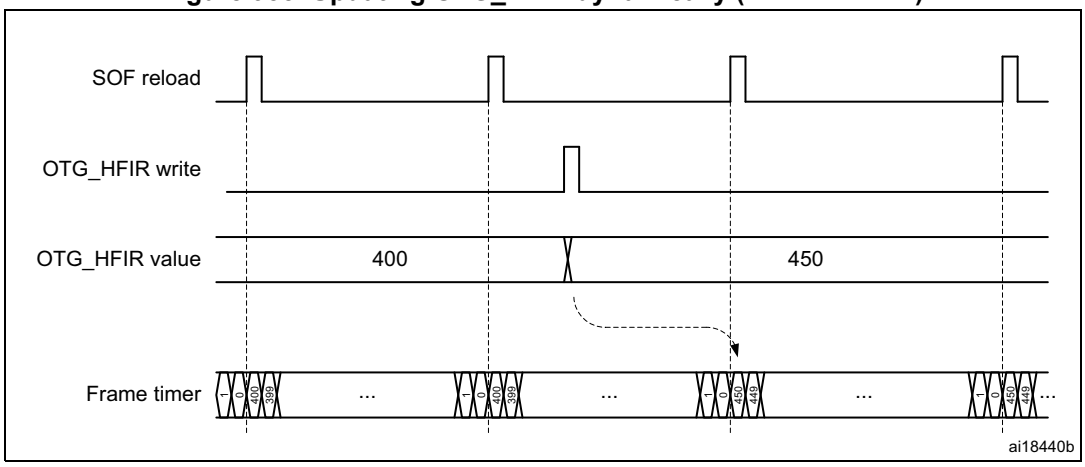
67.10 OTG_HS Dynamic update of the OTG_HFIR register

The USB core embeds a dynamic trimming capability of micro-SOF framing period in host mode allowing to synchronize an external device with the micro-SOF frames.

When the OTG_HFIR register is changed within a current micro-SOF frame, the SOF period correction is applied in the next frame as described in *Figure 955*.

For a dynamic update, it is required to set RLDCTRL=1.

Figure 955. Updating OTG_HFIR dynamically (RLDCTRL = 1)

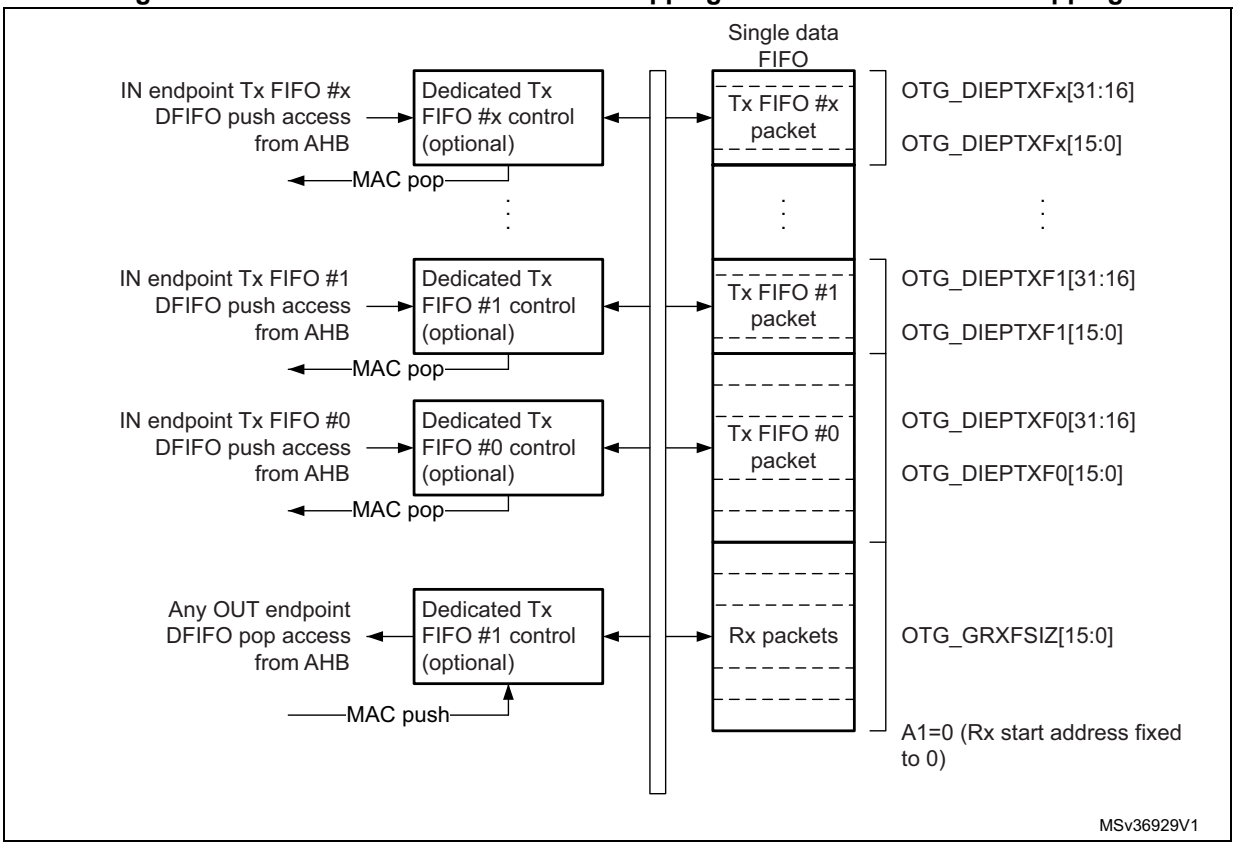


67.11 OTG_HS data FIFOs

The USB system features 4 Kbytes of dedicated RAM with a sophisticated FIFO control mechanism. The packet FIFO controller module in the OTG_HS core organizes RAM space into Tx FIFOs into which the application pushes the data to be temporarily stored before the USB transmission, and into a single Rx FIFO where the data received from the USB are temporarily stored before retrieval (popped) by the application. The number of instructed FIFOs and how these are organized inside the RAM depends on the device's role. In peripheral mode an additional Tx FIFO is instructed for each active IN endpoint. Any FIFO size is software configured to better meet the application requirements.

67.11.1 Peripheral FIFO architecture

Figure 956. Device-mode FIFO address mapping and AHB FIFO access mapping



Peripheral Rx FIFO

The OTG peripheral uses a single receive FIFO that receives the data directed to all OUT endpoints. Received packets are stacked back-to-back until free space is available in the Rx FIFO. The status of the received packet (which contains the OUT endpoint destination number, the byte count, the data PID and the validity of the received data) is also stored by the core on top of the data payload. When no more space is available, host transactions are NACKed and an interrupt is received on the addressed endpoint. The size of the receive FIFO is configured in the receive FIFO size register (OTG_GRXFSIZ).

The single receive FIFO architecture makes it more efficient for the USB peripheral to fill in the receive RAM buffer:

- All OUT endpoints share the same RAM buffer (shared FIFO)
- The OTG_HS core can fill in the receive FIFO up to the limit for any host sequence of OUT tokens

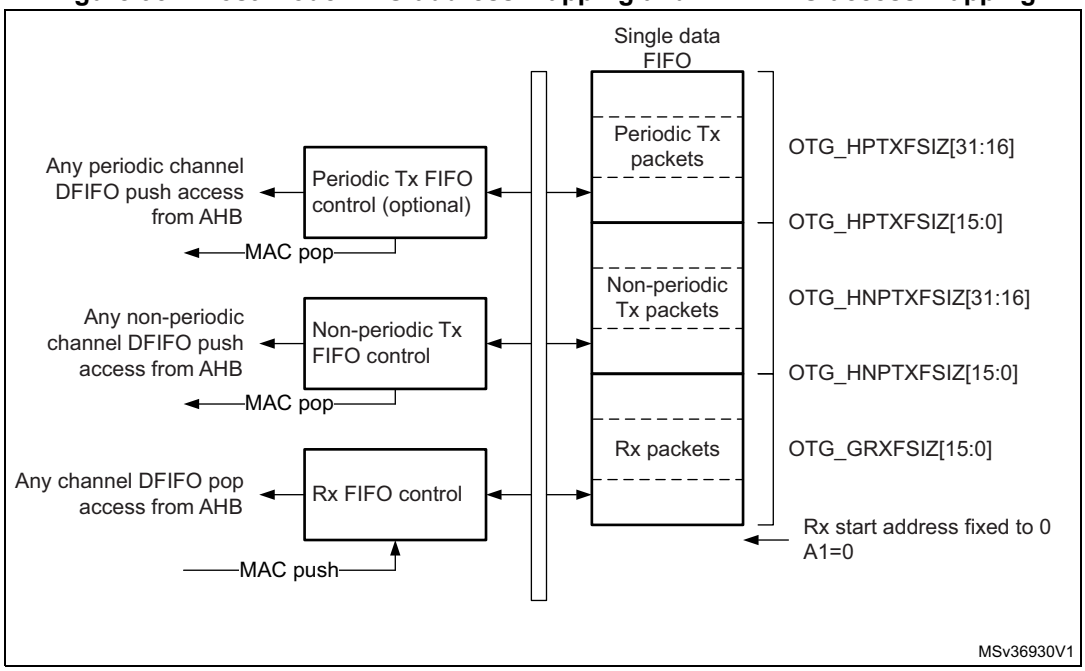
The application keeps receiving the Rx FIFO non-empty interrupt (RXFLVL bit in OTG_GINTSTS) as long as there is at least one packet available for download. It reads the packet information from the receive status read and pop register (OTG_GRXSTSP) and finally pops data off the receive FIFO by reading from the endpoint-related pop address.

Peripheral Tx FIFOs

The core has a dedicated FIFO for each IN endpoint. The application configures FIFO sizes by writing the endpoint 0 transmit FIFO size register (OTG_DIEPTXF0) for IN endpoint0 and the device IN endpoint transmit FIFOx registers (OTG_DIEPTXFx) for IN endpoint-x.

67.11.2 Host FIFO architecture

Figure 957. Host-mode FIFO address mapping and AHB FIFO access mapping



Host Rx FIFO

The host uses one receiver FIFO for all periodic and nonperiodic transactions. The FIFO is used as a receive buffer to hold the received data (payload of the received packet) from the USB until it is transferred to the system memory. Packets received from any remote IN endpoint are stacked back-to-back until free space is available. The status of each received packet with the host channel destination, byte count, data PID and validity of the received data are also stored into the FIFO. The size of the receive FIFO is configured in the receive FIFO size register (OTG_GRXFSIZ).

The single receive FIFO architecture makes it highly efficient for the USB host to fill in the receive data buffer:

- All IN configured host channels share the same RAM buffer (shared FIFO)
- The OTG_HS core can fill in the receive FIFO up to the limit for any sequence of IN tokens driven by the host software

The application receives the Rx FIFO not-empty interrupt as long as there is at least one packet available for download. It reads the packet information from the receive status read and pop register and finally pops the data off the receive FIFO.

Host Tx FIFOs

The host uses one transmit FIFO for all non-periodic (control and bulk) OUT transactions and one transmit FIFO for all periodic (isochronous and interrupt) OUT transactions. FIFOs are used as transmit buffers to hold the data (payload of the transmit packet) to be transmitted over the USB. The size of the periodic (nonperiodic) Tx FIFO is configured in the host periodic (nonperiodic) transmit FIFO size OTG_HPTXFSIZ / OTG_HNPTXFSIZ) register.

The two Tx FIFO implementation derives from the higher priority granted to the periodic type of traffic over the USB frame. At the beginning of each frame, the built-in host scheduler processes the periodic request queue first, followed by the nonperiodic request queue.

The two transmit FIFO architecture provides the USB host with separate optimization for periodic and nonperiodic transmit data buffer management:

- All host channels configured to support periodic (nonperiodic) transactions in the OUT direction share the same RAM buffer (shared FIFOs)
- The OTG_HS core can fill in the periodic (nonperiodic) transmit FIFO up to the limit for any sequence of OUT tokens driven by the host software

The OTG_HS core issues the periodic Tx FIFO empty interrupt (PTXFE bit in OTG_GINTSTS) as long as the periodic Tx FIFO is half or completely empty, depending on the value of the periodic Tx FIFO empty level bit in the AHB configuration register (PTXFELVL bit in OTG_GAHBCFG). The application can push the transmission data in advance as long as free space is available in both the periodic Tx FIFO and the periodic request queue. The host periodic transmit FIFO and queue status register (OTG_HPTXSTS) can be read to know how much space is available in both.

OTG_HS core issues the non periodic Tx FIFO empty interrupt (NPTXFE bit in OTG_GINTSTS) as long as the nonperiodic Tx FIFO is half or completely empty depending on the non periodic Tx FIFO empty level bit in the AHB configuration register (TXFELVL bit in OTG_GAHBCFG). The application can push the transmission data as long as free space is available in both the nonperiodic Tx FIFO and nonperiodic request queue. The host nonperiodic transmit FIFO and queue status register (OTG_HNPTXSTS) can be read to know how much space is available in both.

67.11.3 FIFO RAM allocation

Device mode

Receive FIFO RAM allocation: the application must allocate RAM for SETUP packets:

- 10 locations must be reserved in the receive FIFO to receive SETUP packets on control endpoint. The core does not use these locations, which are reserved for SETUP packets, to write any other data.
- One location is to be allocated for Global OUT NAK.
- Status information is written to the FIFO along with each received packet. Therefore, a minimum space of (largest packet size / 4) + 1 must be allocated to receive packets. If multiple isochronous endpoints are enabled, then at least two (largest packet size / 4) + 1 spaces must be allocated to receive back-to-back packets. Typically, two (largest packet size / 4) + 1 spaces are recommended so that when the previous packet is being transferred to the CPU, the USB can receive the subsequent packet.
- Along with the last packet for each endpoint, transfer complete status information is also pushed to the FIFO. One location for each OUT endpoint is recommended.

Device RxFIFO =

(5 * number of control endpoints + 8) + ((largest USB packet used / 4) + 1 for status information) + (2 * number of OUT endpoints) + 1 for Global NAK

Example: The MPS is 1,024 bytes for a periodic USB packet and 512 bytes for a non-periodic USB packet. There are three OUT endpoints, three IN endpoints, one control endpoint, and three host channels.

Device RxFIFO = (5 * 1 + 8) + ((1,024 / 4) +1) + (2 * 4) + 1 = 279

Transmit FIFO RAM allocation: the minimum RAM space required for each IN endpoint Transmit FIFO is the maximum packet size for that particular IN endpoint.

Note: More space allocated in the transmit IN endpoint FIFO results in better performance on the USB.

Host mode

Receive FIFO RAM allocation:

Status information is written to the FIFO along with each received packet. Therefore, a minimum space of (largest packet size / 4) + 1 must be allocated to receive packets. If multiple isochronous channels are enabled, then at least two (largest packet size / 4) + 1 spaces must be allocated to receive back-to-back packets. Typically, two (largest packet size / 4) + 1 spaces are recommended so that when the previous packet is being transferred to the CPU, the USB can receive the subsequent packet.

Along with the last packet in the host channel, transfer complete status information is also pushed to the FIFO. So one location must be allocated for this.

Host RxFIFO = (largest USB packet used / 4) + 1 for status information + 1 transfer complete

Example: Host RxFIFO = ((1,024 / 4) + 1) + 1 = 258

Transmit FIFO RAM allocation:

The minimum amount of RAM required for the host Non-periodic Transmit FIFO is the largest maximum packet size among all supported non-periodic OUT channels.

Typically, two largest packet sizes worth of space is recommended, so that when the current packet is under transfer to the USB, the CPU can get the next packet.

Non-Periodic TxFIFO = largest non-periodic USB packet used / 4

Example: Non-Periodic TxFIFO = (512 / 4) = 128

The minimum amount of RAM required for host periodic Transmit FIFO is the largest maximum packet size out of all the supported periodic OUT channels. If there is at least one isochronous OUT endpoint, then the space must be at least two times the maximum packet size of that channel.

Host Periodic TxFIFO = largest periodic USB packet used / 4

Example: Host Periodic TxFIFO = (1,024 / 4) = 256

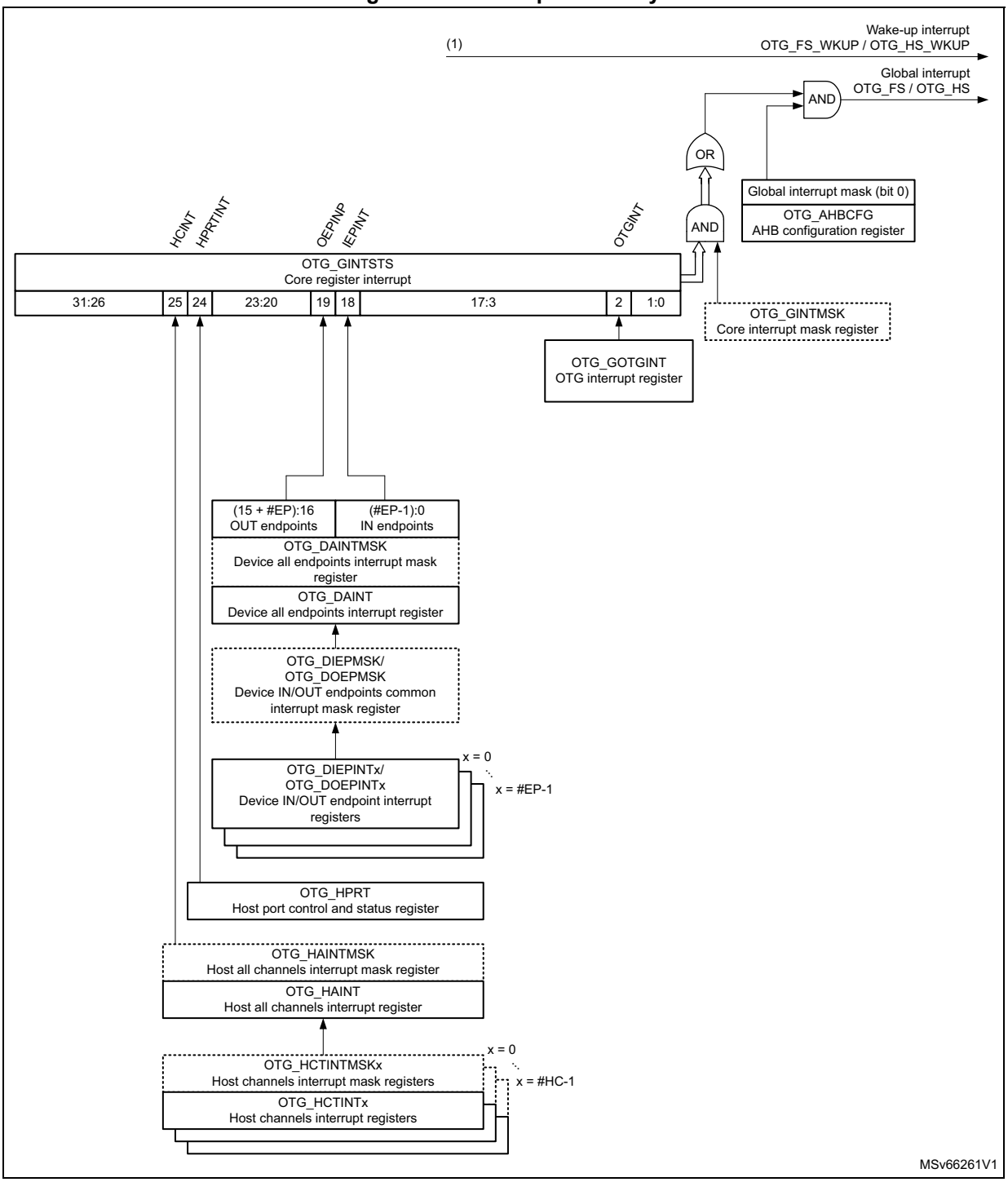
Note: More space allocated in the Transmit Non-periodic FIFO results in better performance on the USB.

67.12 OTG_HS interrupts

When the OTG_HS controller is operating in one mode, either device or host, the application must not access registers from the other mode. If an illegal access occurs, a mode mismatch interrupt is generated and reflected in the core interrupt register (MMIS bit in the OTG_GINTSTS register). When the core switches from one mode to the other, the registers in the new mode of operation must be reprogrammed as they would be after a power-on reset.

Figure 958 shows the interrupt hierarchy.

Figure 958. Interrupt hierarchy



1. OTG_HS_WKUP becomes active (high state) when resume condition occurs during L1 SLEEP or L2 SUSPEND states.

67.13 OTG_HS control and status registers

By reading from and writing to the control and status registers (CSRs) through the AHB slave interface, the application controls the OTG_HS controller. These registers are 32 bits wide, and the addresses are 32-bit block aligned. The OTG_HS registers must be accessed by words (32 bits).

CSRs are classified as follows:

- Core global registers
- Host-mode registers
- Host global registers
- Host port CSRs
- Host channel-specific registers
- Device-mode registers
- Device global registers
- Device endpoint-specific registers
- Power and clock-gating registers
- Data FIFO (DFIFO) access registers

Only the core global, power and clock-gating, data FIFO access, and host port control and status registers can be accessed in both host and device modes. When the OTG_HS controller is operating in one mode, either device or host, the application must not access registers from the other mode. If an illegal access occurs, a mode mismatch interrupt is generated and reflected in the core interrupt register (MMIS bit in the OTG_GINTSTS register). When the core switches from one mode to the other, the registers in the new mode of operation must be reprogrammed as they would be after a power-on reset.

67.13.1 CSR memory map

The host and device mode registers occupy different addresses. All registers are implemented in the AHB clock domain.

Global CSR map

These registers are available in both host and device modes.

Table 745. Core global control and status registers (CSRs)

Acronym	Address offset	Register name
OTG_GOTGCTL	0x000	*Section 67.14.1: OTG control and status register (OTG_GOTGCTL)*
OTG_GOTGINT	0x004	*Section 67.14.2: OTG interrupt register (OTG_GOTGINT)*
OTG_GAHBCFG	0x008	*Section 67.14.3: OTG AHB configuration register (OTG_GAHBCFG)*
OTG_GUSBCFG	0x00C	*Section 67.14.4: OTG USB configuration register (OTG_GUSBCFG)*
OTG_GRSTCTL	0x010	*Section 67.14.5: OTG reset register (OTG_GRSTCTL)*
OTG_GINTSTS	0x014	*Section 67.14.6: OTG core interrupt register [alternate] (OTG_GINTSTS)* *Section 67.14.7: OTG core interrupt register [alternate] (OTG_GINTSTS)*

Table 745. Core global control and status registers (CSRs) (continued)

Acronym	Address offset	Register name
OTG_GINTMSK	0x018	*Section 67.14.8: OTG interrupt mask register [alternate] (OTG_GINTMSK)* *Section 67.14.9: OTG interrupt mask register [alternate] (OTG_GINTMSK)*
OTG_GRXSTSR	0x01C	*Section 67.14.10: OTG receive status debug read register [alternate] (OTG_GRXSTSR)* *Section 67.14.11: OTG receive status debug read register [alternate] (OTG_GRXSTSR)*
OTG_GRXSTSP	0x020	*Section 67.14.12: OTG status read and pop registers (OTG_GRXSTSP)* *Section 67.14.13: OTG status read and pop registers [alternate] (OTG_GRXSTSP)*
OTG_GRXFSIZ	0x024	*Section 67.14.14: OTG receive FIFO size register (OTG_GRXFSIZ)*
OTG_HNPTXFSIZ/ OTG_DIEPTXF0(1)	0x028	*Section 67.14.15: OTG host non-periodic transmit FIFO size register [alternate] (OTG_HNPTXFSIZ)* *Section 67.14.16: Endpoint 0 transmit FIFO size [alternate] (OTG_DIEPTXF0)*
OTG_HNPTXSTS	0x02C	*Section 67.14.17: OTG non-periodic transmit FIFO/queue status register (OTG_HNPTXSTS)*
OTG_GCCFG	0x038	*Section 67.14.18: OTG general core configuration register (OTG_GCCFG)*
OTG_CID	0x03C	*Section 67.14.19: OTG core ID register (OTG_CID)*
OTG_GLPMCFG	0x54	*Section 67.14.20: OTG core LPM configuration register (OTG_GLPMCFG)*
OTG_HPTXFSIZ	0x100	*Section 67.14.21: OTG host periodic transmit FIFO size register (OTG_HPTXFSIZ)*
OTG_DIEPTXFx	0x104 0x108 ... 0x120	*Section 67.14.22: OTG device IN endpoint transmit FIFO x size register (OTG_DIEPTXFx)*

1. The general rule is to use OTG_HNPTXFSIZ for host mode and OTG_DIEPTXF0 for device mode.

Host-mode CSR map

These registers must be programmed every time the core changes to host mode.

Table 746. Host-mode control and status registers (CSRs)

Acronym	Offset address	Register name
OTG_HCFG	0x400	*Section 67.14.24: OTG host configuration register (OTG_HCFG)*
OTG_HFIR	0x404	*Section 67.14.25: OTG host frame interval register (OTG_HFIR)*
OTG_HFNUM	0x408	*Section 67.14.26: OTG host frame number/frame time remaining register (OTG_HFNUM)*
OTG_HPTXSTS	0x410	*Section 67.14.27: OTG_Host periodic transmit FIFO/queue status register (OTG_HPTXSTS)*

Table 746. Host-mode control and status registers (CSRs) (continued)

Acronym	Offset address	Register name
OTG_HAINT	0x414	*Section 67.14.28: OTG host all channels interrupt register (OTG_HAINT)*
OTG_HAINTMSK	0x418	*Section 67.14.29: OTG host all channels interrupt mask register (OTG_HAINTMSK)*
OTG_HPRT	0x440	*Section 67.14.30: OTG host port control and status register (OTG_HPRT)*
OTG_HCCHARx	0x500 0x520 ... 0x6E0	*Section 67.14.31: OTG host channel x characteristics register (OTG_HCCHARx)*
OTG_HCSPLTx	0x504 0x524 .... 0x6E4	*Section 67.14.32: OTG host channel x split control register (OTG_HCSPLTx)*
OTG_HCINTx	0x508 0x528 .... 0x6E8	*Section 67.14.33: OTG host channel x interrupt register (OTG_HCINTx)*
OTG_HCINTMSKx	0x50C 0x52C 0x6EC	*Section 67.14.34: OTG host channel x interrupt mask register (OTG_HCINTMSKx)*
OTG_HCTSIZx	0x510 0x530 .... 0x6F0	*Section 67.14.35: OTG host channel x transfer size register (OTG_HCTSIZx)*
OTG_HCDMAx	0x514 0x534 .... 0x6F4	*Section 67.14.36: OTG host channel x DMA address register(OTG_HCDMAx)*

Device-mode CSR map

These registers must be programmed every time the core changes to device mode.

Table 747. Device-mode control and status registers

Acronym	Offset address	Register name
OTG_DCFG	0x800	*Section 67.14.38: OTG device configuration register (OTG_DCFG)*
OTG_DCTL	0x804	*Section 67.14.39: OTG device control register (OTG_DCTL)*
OTG_DSTS	0x808	*Section 67.14.40: OTG device status register (OTG_DSTS)*

Table 747. Device-mode control and status registers (continued)

Acronym	Offset address	Register name
OTG_DIEPMSK	0x810	*Section 67.14.41: OTG device IN endpoint common interrupt mask register (OTG_DIEPMSK)*
OTG_DOEPMSK	0x814	*Section 67.14.42: OTG device OUT endpoint common interrupt mask register (OTG_DOEPMSK)*
OTG_DAINT	0x818	*Section 67.14.43: OTG device all endpoints interrupt register (OTG_DAINT)*
OTG_DAINTMSK	0x81C	*Section 67.14.44: OTG all endpoints interrupt mask register (OTG_DAINTMSK)*
OTG_DTHRCTL	0x830	*Section 67.14.45: OTG device threshold control register (OTG_DTHRCTL)*
OTG_DIEPEMPMSK	0x834	*Section 67.14.46: OTG device IN endpoint FIFO empty interrupt mask register (OTG_DIEPEMPMSK)*
OTG_DIEPCTLx	0x900 0x920 ... 0xA00	*Section 67.14.47: OTG device IN endpoint x control register [alternate] (OTG_DIEPCTLx)* *Section 67.14.48: OTG device IN endpoint x control register [alternate] (OTG_DIEPCTLx)*
OTG_DIEPINTx	0x908 0x928 ... 0x9E8	*Section 67.14.49: OTG device IN endpoint x interrupt register (OTG_DIEPINTx)*
OTG_DIEPTSIZ0	0x910	*Section 67.14.50: OTG device IN endpoint 0 transfer size register (OTG_DIEPTSIZ0)*
OTG_DIEPDMAx	0x914 0x934 ... 0x9F4	*Section 67.14.51: OTG device IN endpoint x DMA address register (OTG_DIEPDMAx)*
OTG_DTXFSTSx	0x918 0x938 ..... 0x9F8	*Section 67.14.52: OTG device IN endpoint transmit FIFO status register (OTG_DTXFSTSx)*
OTG_DIEPTSIZx	0x930 0x950 ... 0x9F0	*Section 67.14.53: OTG device IN endpoint x transfer size register (OTG_DIEPTSIZx)*
OTG_DOEPCTL0	0xB00	*Section 67.14.54: OTG device control OUT endpoint 0 control register (OTG_DOEPCTL0)*
OTG_DOEPINTx	0xB08 0XB28 ... 0xC08	*Section 67.14.55: OTG device OUT endpoint x interrupt register (OTG_DOEPINTx)*

Table 747. Device-mode control and status registers (continued)

Acronym	Offset address	Register name
OTG_DOEPTSIZ0	0xB10	*Section 67.14.56: OTG device OUT endpoint 0 transfer size register (OTG_DOEPTSIZ0)*
OTG_DOEPDMAx	0xB14 0xB34 ... 0xC14	*Section 67.14.57: OTG device OUT endpoint x DMA address register (OTG_DOEPDMAx)*
OTG_DOEPCTLx	0xB20 0xB40 ... 0xC00	*Section 67.14.58: OTG device OUT endpoint x control register [alternate] (OTG_DOEPCTLx)* *Section 67.14.59: OTG device OUT endpoint x control register [alternate] (OTG_DOEPCTLx)*
OTG_DOEPTSIZx	0xB30 0xB50 .. 0xBF0	*Section 67.14.60: OTG device OUT endpoint x transfer size register (OTG_DOEPTSIZx)*

Data FIFO (DFIFO) access register map

These registers, available in both host and device modes, are used to read or write the FIFO space for a specific endpoint or a channel, in a given direction. If a host channel is of type IN, the FIFO can only be read on the channel. Similarly, if a host channel is of type OUT, the FIFO can only be written on the channel.

Table 748. Data FIFO (DFIFO) access register map

FIFO access register section	Offset address	Access
Device IN endpoint 0/Host OUT Channel 0: DFIFO write access Device OUT endpoint 0/Host IN Channel 0: DFIFO read access	0x1000–0x1FFC	w r
Device IN endpoint 1/Host OUT Channel 1: DFIFO write access Device OUT endpoint 1/Host IN Channel 1: DFIFO read access	0x2000–0x2FFC	w r
...	...	...
Device IN endpoint x(1)/Host OUT Channel x(1): DFIFO write access Device OUT endpoint x(1)/Host IN Channel x(1): DFIFO read access	0xX000–0xXFFC	w r

1. Where x is 8 in device mode and 15 in host mode.

Power and clock gating CSR map

There is a single register for power and clock gating. It is available in both host and device modes.

Table 749. Power and clock gating control and status registers

Acronym	Offset address	Register name
OTG_PCGCCTL	0xE00–0xE04	*Section 67.14.61: OTG power and clock gating control register (OTG_PCGCCTL)*

67.14 OTG_HS registers

These registers are available in both host and device modes, and do not need to be reprogrammed when switching between these modes.

Bit values in the register descriptions are expressed in binary unless otherwise specified.

67.14.1 OTG control and status register (OTG_GOTGCTL)

The OTG_GOTGCTL register controls the behavior and reflects the status of the OTG function of the core.

Address offset: 0x000

Reset value: 0x0001 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CUR MOD	OTG VER	BSVLD	ASVLD	DBCT	CID STS
										r	rw	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	EHEN	Res.	Res.	Res.	Res.	BVALO VAL	BVALO EN	AVALO VAL	AVALO EN	VBVAL OVAL	VBVAL OEN	Res.	Res.
			rw					rw	rw	rw	rw	rw	rw		

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **CURMOD:** Current mode of operation

Indicates the current mode (host or device).

0: Device mode

1: Host mode

Bit 20 **OTGVER:** OTG version

Selects the OTG revision.

0:OTG Version 1.3. OTG1.3 is obsolete for new product development.

1:OTG Version 2.0. In this version the core supports only data line pulsing for SRP.

Bit 19 **BSVLD:** B-session valid

Indicates the device mode transceiver status.

0: B-session is not valid.

1: B-session is valid.

In OTG mode, the user can use this bit to determine if the device is connected or disconnected.

Note: Only accessible in device mode.

Bit 18 **ASVLD:** A-session valid
Indicates the host mode transceiver status.
0: A-session is not valid
1: A-session is valid
Note: Only accessible in host mode.

Bit 17 **DBCT:** Long/short debounce time
Indicates the debounce time of a detected connection.
0: Long debounce time, used for physical connections (100 ms + 2.5 µs)
1: Short debounce time, used for soft connections (2.5 µs)
Note: Only accessible in host mode.

Bit 16 **CIDSTS:** Connector ID status
Indicates the connector ID status on a connect event.
0: The OTG_HS controller is in A-device mode
1: The OTG_HS controller is in B-device mode
Note: Accessible in both device and host modes.

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **EHEN:** Embedded host enable
It is used to select between OTG A device state machine and embedded host state machine.
0: OTG A device state machine is selected
1: Embedded host state machine is selected

Bits 11:8 Reserved, must be kept at reset value.

Bit 7 **BVALOVAL:** B-peripheral session valid override value
This bit is used to set override value for Bvalid signal when BVALOEN bit is set.
0: Bvalid value is '0' when BVALOEN = 1
1: Bvalid value is '1' when BVALOEN = 1
Note: Only accessible in device mode.

Bit 6 **BVALOEN:** B-peripheral session valid override enable
This bit is used to enable/disable the software to override the Bvalid signal using the BVALOVAL bit.
0: B-peripheral session valid is '0'
1: Use bit BVALOVAL to indicate B-peripheral session valid
Note: Only accessible in device mode.

Bit 5 **AVALOVAL:** A-peripheral session valid override value
This bit is used to set override value for Avalid signal when AVALOEN bit is set.
0: Avalid value is '0' when AVALOEN = 1
1: Avalid value is '1' when AVALOEN = 1
Note: Only accessible in host mode.

Bit 4 **AVALOEN:** A-peripheral session valid override enable
This bit is used to enable/disable the software to override the Avalid signal using the AVALOVAL bit.
0: A-peripheral session valid is '0'
1: Use bit AVALOVAL to indicate A-peripheral session valid
Note: Only accessible in host mode.

Bit 3 **VBVALOVAL:** V_{BUS} valid override value
This bit is used to set override value for vbusvalid signal when VBVALOEN bit is set.
0: vbusvalid value is '0' when VBVALOEN = 1
1: vbusvalid value is '1' when VBVALOEN = 1
Note: Only accessible in host mode.

Bit 2 **VBVALOEN:** V_{BUS} valid override enable
This bit is used to enable/disable the software to override the vbusvalid signal using the VBVALOVAL bit.
0: VBUS valid is '0'
1: Use bit VBVALOVAL to indicate A-peripheral session valid
Note: Only accessible in host mode.

Bits 1:0 Reserved, must be kept at reset value.

67.14.2 OTG interrupt register (OTG_GOTGINT)

The application reads this register whenever there is an OTG interrupt and clears the bits in this register to clear the OTG interrupt.

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADTO CHG	Res.	Res.
													rc_w1		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEDET	Res.	Res.
													rc_w1		

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **ADTOCHG:** A-device timeout change
The core sets this bit to indicate that the A-device has timed out while waiting for the B-device to connect.
Note: Accessible in both device and host modes.

Bits 17:3 Reserved, must be kept at reset value.

Bit 2 **SEDET:** Session end detected
The core sets this bit to indicate that the level of the voltage on V_{BUS} is no longer valid for a B-Peripheral session when V_{BUS} < 0.8 V.
Note: Accessible in both device and host modes.

Bits 1:0 Reserved, must be kept at reset value.

67.14.3 OTG AHB configuration register (OTG_GAHBCFG)

This register can be used to configure the core after power-on or a change in mode. This register mainly contains AHB system-related configuration parameters. Do not change this register after the initial programming. The application must program this register before starting any transactions on either the AHB or the USB.

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	PTXFE LVL	TXFE LVL	Res.	DMAE N	HBSTLEN[3:0]				GINT MSK
							rw	rw		rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **PTXFELVL:** Periodic Tx FIFO empty level

Indicates when the periodic Tx FIFO empty interrupt bit in the OTG_GINTSTS register (PTXFE bit in OTG_GINTSTS) is triggered.

0: PTXFE (in OTG_GINTSTS) interrupt indicates that the Periodic Tx FIFO is half empty

1: PTXFE (in OTG_GINTSTS) interrupt indicates that the Periodic Tx FIFO is completely empty

Note: Only accessible in host mode.

Bit 7 **TXFELVL:** Tx FIFO empty level

Condition: device mode

This bit indicates when IN endpoint Transmit FIFO empty interrupt (TXFE in OTG_DIEPINTx) is triggered:

0: The TXFE (in OTG_DIEPINTx) interrupt indicates that the IN endpoint Tx FIFO is half empty

1: The TXFE (in OTG_DIEPINTx) interrupt indicates that the IN endpoint Tx FIFO is completely empty

Condition: host mode

This bit indicates when the nonperiodic Tx FIFO empty interrupt (NPTXFE bit in OTG_GINTSTS) is triggered:

0: The NPTXFE (in OTG_GINTSTS) interrupt indicates that the nonperiodic Tx FIFO is half empty

1: The NPTXFE (in OTG_GINTSTS) interrupt indicates that the nonperiodic Tx FIFO is completely empty

Bit 6 Reserved, must be kept at reset value.

Bit 5 **DMAEN:** DMA enabled

0: The core operates in slave mode

1: The core operates in DMA mode

Bits 4:1 **HBSTLEN[3:0]:** Burst length/type

0000 Single: Bus transactions use single 32 bit accesses (not recommended)

0001 INCR: Bus transactions use unspecified length accesses (not recommended, uses the INCR AHB bus command)

0011 INCR4: Bus transactions target 4x 32 bit accesses

0101 INCR8: Bus transactions target 8x 32 bit accesses

0111 INCR16: Bus transactions based on 16x 32 bit accesses

Others: Reserved

Bit 0 **GINTMSK:** Global interrupt mask

The application uses this bit to mask or unmask the interrupt line assertion to itself. Irrespective of this bit setting, the interrupt status registers are updated by the core.

0: Mask the interrupt assertion to the application.

1: Unmask the interrupt assertion to the application.

Note: Accessible in both device and host modes.

67.14.4 OTG USB configuration register (OTG_GUSBCFG)

This register can be used to configure the core after power-on or a changing to host mode or device mode. It contains USB and USB-PHY related configuration parameters. The application must program this register before starting any transactions on either the AHB or the USB. Do not make changes to this register after the initial programming.

Address offset: 0x00C

Reset value: 0x0000 1400

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	FD MOD	FH MOD	Res.	Res.	Res.	Res.	Res.	Res.	TSDPS	Res.	Res.	Res.	Res.	Res.	Res.
	rw	rw							rw						
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PHYL PC	Res.	TRDT[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	TOCAL[2:0]		
rw		rw	rw	rw	rw								rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **FDMOD:** Force device mode

Writing a 1 to this bit, forces the core to device mode irrespective of the OTG_ID input pin.
0: Normal mode
1: Force device mode
After setting the force bit, the application must wait at least 25 ms before the change takes effect.

Note: Accessible in both device and host modes.

Bit 29 **FHMOD:** Force host mode

Writing a 1 to this bit, forces the core to host mode irrespective of the OTG_ID input pin.
0: Normal mode
1: Force host mode
After setting the force bit, the application must wait at least 25 ms before the change takes effect.

Note: Accessible in both device and host modes.

Bits 28:26 Reserved, must be kept at reset value.

Bits 25:23 Reserved, must be kept at reset value.

Bit 22 **TSDPS**: TermSel DLine pulsing selection

This bit selects utmi_termselect to drive the data line pulse during SRP (session request protocol).
0: Data line pulsing using utmi_txvalid (default)
1: Data line pulsing using utmi_termsel

Bits 21:16 Reserved, must be kept at reset value.

Bit 15 **PHYLPC:** PHY Low-power clock select

This bit selects either 480 MHz or 48 MHz (low-power) PHY mode. In FS and LS modes, the PHY can usually operate on a 48 MHz clock to save power.
0: 480 MHz internal PLL clock
1: 48 MHz external clock
In 480 MHz mode, the UTMI interface operates at either 60 or 30 MHz, depending on whether the 8- or 16-bit data width is selected. In 48 MHz mode, the UTMI interface operates at 48 MHz in FS and LS modes.

Bit 14 Reserved, must be kept at reset value.

Bits 13:10 **TRDT[3:0]:** USB turnaround time

These bits allows to set the turnaround time in PHY clocks. They must be configured according to *Table 750: TRDT values*, depending on the application AHB frequency. Higher TRDT values allow stretching the USB response time to IN tokens in order to compensate for longer AHB read access latency to the data FIFO.

Note: Only accessible in device mode.

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 Reserved, must be kept at reset value.

Bit 6 Reserved, must be kept at reset value.

Bit 5 Reserved, must be kept at reset value.

Bit 4 Reserved, must be kept at reset value.

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **TOCAL[2:0]:** FS timeout calibration

The number of PHY clocks that the application programs in this field is added to the full-speed interpacket timeout duration in the core to account for any additional delays introduced by the PHY. This can be required, because the delay introduced by the PHY in generating the line state condition can vary from one PHY to another.

The USB standard timeout value for full-speed operation is 16 to 18 (inclusive) bit times. The application must program this field based on the speed of enumeration. The number of bit times added per PHY clock is 0.25 bit times.

Table 750. TRDT values

AHB frequency range (MHz)		TRDT minimum value
Min	Max	
30	-	0x9

67.14.5 OTG reset register (OTG_GRSTCTL)

The application uses this register to reset various hardware features inside the core.

Address offset: 0x010

Reset value: 0x8000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AHB IDL	DMAREQ	CSRSTDONE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	rc_w1													
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	TXFNUM[4:0]					TXFFLSH	RXFFLSH	Res.	FCRST	PSRST	CSRST
					rw	rw	rw	rw	rw	rs	rs		rs	rs	rw

Bit 31 **AHBIDL:** AHB master idle

Indicates that the AHB master state machine is in the Idle condition.

Note: Accessible in both device and host modes.

Bit 30 **DMAREQ:** DMA request signal enabled

This bit indicates that the DMA request is in progress. Used for debug.

Bit 29 **CSRSTDONE**: Core soft reset done

The core sets this bit when all the necessary logic is reset in the core. This bit is cleared by the application along with CSRST.

0: Core reset not done

1: Core reset done

Bits 28:11 Reserved, must be kept at reset value.

Bits 10:6 **TXFNUM[4:0]:** Tx FIFO number

This is the FIFO number that must be flushed using the Tx FIFO Flush bit. This field must not be changed until the core clears the Tx FIFO Flush bit.

Condition: host mode

00000: Non-periodic Tx FIFO flush

00001: Periodic Tx FIFO flush

10000: Flush all the transmit FIFOs

Condition: device mode

00000: Tx FIFO 0 flush

00001: Tx FIFO 1 flush

00010: Tx FIFO 2 flush

...

01111: Tx FIFO 15 flush

10000: Flush all the transmit FIFOs

Note: Accessible in both device and host modes.

Bit 5 **TXFFLSH:** Tx FIFO flush

This bit selectively flushes a single or all transmit FIFOs, but cannot do so if the core is in the midst of a transaction.

The application must write this bit only after checking that the core is neither writing to the Tx FIFO nor reading from the Tx FIFO. Verify using these registers:

Read—NAK Effective interrupt ensures the core is not reading from the FIFO

Write—AHBIDL bit in OTG_GRSTCTL ensures the core is not writing anything to the FIFO.

Flushing is normally recommended when FIFOs are reconfigured. FIFO flushing is also recommended during device endpoint disable. The application must wait until the core clears this bit before performing any operations. This bit takes eight clocks to clear, using the slower clock of phy_clk or hclk.

Note: Accessible in both device and host modes.

Bit 4 **RXFFLSH:** Rx FIFO flush

The application can flush the entire Rx FIFO using this bit, but must first ensure that the core is not in the middle of a transaction.

The application must only write to this bit after checking that the core is neither reading from the Rx FIFO nor writing to the Rx FIFO.

The application must wait until the bit is cleared before performing any other operations. This bit requires 8 clocks (slowest of PHY or AHB clock) to clear.

Note: Accessible in both device and host modes.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **FCRST:** Host frame counter reset

The application writes this bit to reset the (micro-)frame number counter inside the core. When the (micro-)frame counter is reset, the subsequent SOF sent out by the core has a frame number of 0.

When application writes '1' to the bit, it might not be able to read back the value as it gets cleared by the core in a few clock cycles.

Note: Only accessible in host mode.

Bit 1 **PSRST:** Partial soft reset

Resets the internal state machines but keeps the enumeration info. Can be used to recover some specific PHY errors.

Note: Accessible in both device and host modes.

Bit 0 **CSRST:** Core soft reset

Resets the HCLK and PHY clock domains as follows:

Clears the interrupts and all the CSR register bits except for the following bits:

- GATEHCLK bit in OTG_PCGCCTL
- STPPCLK bit in OTG_PCGCCTL
- FSLSPCS bits in OTG_HCFG
- DSPD bit in OTG_DCFG
- SDIS bit in OTG_DCTL
- OTG_GCCFG register
- PHYLPC bit in OTG_GUSBCFG
- TSDPS bit in OTG_GUSBCFG

All module state machines (except for the AHB slave unit) are reset to the Idle state, and all the transmit FIFOs and the receive FIFO are flushed.

Any transactions on the AHB Master are terminated as soon as possible, after completing the last data phase of an AHB transfer. Any transactions on the USB are terminated immediately.

The application can write to this bit any time it wants to reset the core. The application must clear this bit after checking CSRSTDONE (core soft reset done). The application must also check that AHBIDL = 1 (AHB master is IDLE) before starting any operation.

Typically, the software reset is used during software development and also when the PHY selection bits are dynamically changed in the USB configuration registers listed above. When the PHY is changed, the corresponding clock for the PHY is selected and used in the PHY domain. Once a new clock is selected, the PHY domain has to be reset for proper operation.

Note: Accessible in both device and host modes.

67.14.6 OTG core interrupt register [alternate] (OTG_GINTSTS)

Valid for Host mode, see next section for Device mode.

This register also indicates the current mode. To clear the interrupt status bits of the rc_w1 type, the application must write 1 into the bit.

This register interrupts the application for system-level events in the current mode (device mode or host mode).

The FIFO status interrupts are read-only; once software reads from or writes to the FIFO while servicing these interrupts, FIFO interrupt conditions are cleared automatically.

The application must clear the OTG_GINTSTS register at initialization before unmasking the interrupt bit to avoid any interrupts generated prior to initialization.

Address offset: 0x014

Reset value: 0x0400 0020

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WKUP INT	SRQ INT	DISC INT	CIDS CHG	LPM INT	PTXFE	HCINT	HPRT INT	RST DET	DATAF SUSP	IPXFR	IISOI XFR	OEP INT	IEPINT	Res.	Res.
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	r	r	r	rc_w1	rc_w1	rc_w1	rc_w1	r	r		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EOPF	ISOO DRP	ENUM DNE	USB RST	USB SUSP	ESUSP	Res.	Res.	GO NAK EFF	GI NAK EFF	NPTXF E	RXF LVL	SOF	OTG INT	MMIS	CMOD
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1			r	r	r	r	rc_w1	r	rc_w1	r

Bit 31 **WKUPINT:** Resume/remote wake-up detected interrupt

Wake-up interrupt during suspend(L2) or LPM(L1) state.

– During suspend(L2):

In device mode, this interrupt is asserted when a resume is detected on the USB. In host mode, this interrupt is asserted when a remote wake-up is detected on the USB.

– During LPM(L1):

This interrupt is asserted for either host initiated resume or device initiated remote wake-up on USB.

Note: Accessible in both device and host modes.

Bit 30 **SRQINT:** Session request/new session detected interrupt

In host mode, this interrupt is asserted when a session request is detected from the device. In device mode, this interrupt is asserted when V_{BUS} is in the valid range for a B-peripheral device. Accessible in both device and host modes.

Bit 29 **DISCINT:** Disconnect detected interrupt

Asserted when a device disconnect is detected.

Note: Only accessible in host mode.

Bit 28 **CIDSCHG:** Connector ID status change

The core sets this bit when there is a change in connector ID status.

Note: Accessible in both device and host modes.

Bit 27 **LPMINT:** LPM interrupt

In device mode, this interrupt is asserted when the device receives an LPM transaction and responds with a non-ERRORed response.

In host mode, this interrupt is asserted when the device responds to an LPM transaction with a non-ERRORed response or when the host core has completed LPM transactions for the programmed number of times (RETRYCNT bit in OTG_GLPMCFG).

This field is valid only if the LPMEN bit in OTG_GLPMCFG is set to 1.

Bit 26 **PTXFE:** Periodic Tx FIFO empty

Asserted when the periodic transmit FIFO is either half or completely empty and there is space for at least one entry to be written in the periodic request queue. The half or completely empty status is determined by the periodic Tx FIFO empty level bit in the OTG_GAHBCFG register (PTXFELVL bit in OTG_GAHBCFG).

Note: Only accessible in host mode.

Bit 25 **HCINT:** Host channels interrupt

The core sets this bit to indicate that an interrupt is pending on one of the channels of the core (in host mode). The application must read the OTG_HAINT register to determine the exact number of the channel on which the interrupt occurred, and then read the corresponding OTG_HCINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the OTG_HCINTx register to clear this bit.

Note: Only accessible in host mode.

Bit 24 **HPRTINT:** Host port interrupt

The core sets this bit to indicate a change in port status of one of the OTG_HS controller ports in host mode. The application must read the OTG_HPRT register to determine the exact event that caused this interrupt. The application must clear the appropriate status bit in the OTG_HPRT register to clear this bit.

Note: Only accessible in host mode.

Bit 23 **RSTDET:** Reset detected interrupt

In device mode, this interrupt is asserted when a reset is detected on the USB in partial power-down mode when the device is in suspend.

Note: Only accessible in device mode.

Bit 22 **DATAFSUSP:** Data fetch suspended

This interrupt is valid only in DMA mode. This interrupt indicates that the core has stopped fetching data for IN endpoints due to the unavailability of TxFIFO space or request queue space. This interrupt is used by the application for an endpoint mismatch algorithm. For example, after detecting an endpoint mismatch, the application:

- Sets a global nonperiodic IN NAK handshake
- Disables IN endpoints
- Flushes the FIFO
- Determines the token sequence from the IN token sequence learning queue
- Re-enables the endpoints

Clears the global nonperiodic IN NAK handshake If the global nonperiodic IN NAK is cleared, the core has not yet fetched data for the IN endpoint, and the IN token is received: the core generates an “IN token received when FIFO empty” interrupt. The OTG then sends a NAK response to the host. To avoid this scenario, the application can check the FetSusp interrupt in OTG_GINTSTS, which ensures that the FIFO is full before clearing a global NAK handshake. Alternatively, the application can mask the “IN token received when FIFO empty” interrupt when clearing a global IN NAK handshake.

Bit 21 **IPXFR:** Incomplete periodic transfer

In host mode, the core sets this interrupt bit when there are incomplete periodic transactions still pending, which are scheduled for the current frame.

Bit 20 **IISOIXFR:** Incomplete isochronous IN transfer

The core sets this interrupt to indicate that there is at least one isochronous IN endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the End of periodic frame interrupt (EOPF) bit in this register.

Note: Only accessible in device mode.

Bit 19 **OEPINT:** OUT endpoint interrupt

The core sets this bit to indicate that an interrupt is pending on one of the OUT endpoints of the core (in device mode). The application must read the OTG_DAINT register to determine the exact number of the OUT endpoint on which the interrupt occurred, and then read the corresponding OTG_DOEPINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the corresponding OTG_DOEPINTx register to clear this bit.

Note: Only accessible in device mode.

Bit 18 **IEPINT:** IN endpoint interrupt

The core sets this bit to indicate that an interrupt is pending on one of the IN endpoints of the core (in device mode). The application must read the OTG_DAINT register to determine the exact number of the IN endpoint on which the interrupt occurred, and then read the corresponding OTG_DIEPINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the corresponding OTG_DIEPINTx register to clear this bit.

Note: Only accessible in device mode.

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 **EOPF:** End of periodic frame interrupt

Indicates that the period specified in the periodic frame interval field of the OTG_DCFG register (PFIVL bit in OTG_DCFG) has been reached in the current frame.

Note: Only accessible in device mode.

Bit 14 **ISOODRP:** Isochronous OUT packet dropped interrupt

The core sets this bit when it fails to write an isochronous OUT packet into the Rx FIFO because the Rx FIFO does not have enough space to accommodate a maximum size packet for the isochronous OUT endpoint.

Note: Only accessible in device mode.

Bit 13 **ENUMDNE:** Enumeration done

The core sets this bit to indicate that speed enumeration is complete. The application must read the OTG_DSTS register to obtain the enumerated speed.

Note: Only accessible in device mode.

Bit 12 **USBRST:** USB reset

The core sets this bit to indicate that a reset is detected on the USB.

Note: Only accessible in device mode.

Bit 11 **USBSUSP:** USB suspend

The core sets this bit to indicate that a suspend was detected on the USB. The core enters the suspended state when there is no activity on the data lines for an extended period of time.

Note: Only accessible in device mode.

Bit 10 **ESUSP:** Early suspend

The core sets this bit to indicate that an Idle state has been detected on the USB for 3 ms.

Note: Only accessible in device mode.

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 **GONAKEFF:** Global OUT NAK effective

Indicates that the Set global OUT NAK bit in the OTG_DCTL register (SGONAK bit in OTG_DCTL), set by the application, has taken effect in the core. This bit can be cleared by writing the Clear global OUT NAK bit in the OTG_DCTL register (CGONAK bit in OTG_DCTL).

Note: Only accessible in device mode.

Bit 6 **GINAKEFF:** Global IN non-periodic NAK effective

Indicates that the Set global non-periodic IN NAK bit in the OTG_DCTL register (SGINAK bit in OTG_DCTL), set by the application, has taken effect in the core. That is, the core has sampled the Global IN NAK bit set by the application. This bit can be cleared by clearing the Clear global non-periodic IN NAK bit in the OTG_DCTL register (CGINAK bit in OTG_DCTL). This interrupt does not necessarily mean that a NAK handshake is sent out on the USB. The STALL bit takes precedence over the NAK bit.

Note: Only accessible in device mode.

Bit 5 **NPTXFE:** Non-periodic Tx FIFO empty

This interrupt is asserted when the non-periodic Tx FIFO is either half or completely empty, and there is space for at least one entry to be written to the non-periodic transmit request queue. The half or completely empty status is determined by the non-periodic Tx FIFO empty level bit in the OTG_GAHBCFG register (TXFELVL bit in OTG_GAHBCFG).

Note: Accessible in host mode only.

Bit 4 **RXFLVL:** Rx FIFO non-empty

Indicates that there is at least one packet pending to be read from the Rx FIFO.

Note: Accessible in both host and device modes.

Bit 3 **SOF:** Start of frame

In host mode, the core sets this bit to indicate that an SOF (FS), or Keep-Alive (LS) is transmitted on the USB. The application must write a 1 to this bit to clear the interrupt.

In device mode, in the core sets this bit to indicate that an SOF token has been received on the USB. The application can read the OTG_DSTS register to get the current frame number. This interrupt is seen only when the core is operating in FS.

Note: This register may return '1' if read immediately after power on reset. If the register bit reads '1' immediately after power on reset it does not indicate that an SOF has been sent (in case of host mode) or SOF has been received (in case of device mode). The read value of this interrupt is valid only after a valid connection between host and device is established. If the bit is set after power on reset the application can clear the bit.

Note: Accessible in both host and device modes.

Bit 2 **OTGINT:** OTG interrupt

The core sets this bit to indicate an OTG protocol event. The application must read the OTG interrupt status (OTG_GOTGINT) register to determine the exact event that caused this interrupt. The application must clear the appropriate status bit in the OTG_GOTGINT register to clear this bit.

Note: Accessible in both host and device modes.

Bit 1 **MMIS:** Mode mismatch interrupt

The core sets this bit when the application is trying to access:

– A host mode register, when the core is operating in device mode

– A device mode register, when the core is operating in host mode

The register access is completed on the AHB with an OKAY response, but is ignored by the core internally and does not affect the operation of the core.

Note: Accessible in both host and device modes.

Bit 0 **CMOD:** Current mode of operation

Indicates the current mode.

0: Device mode

1: Host mode

Note: Accessible in both host and device modes.

67.14.7 OTG core interrupt register [alternate] (OTG_GINTSTS)

Valid for Device mode, see previous section for Host mode.

This register also indicates the current mode. To clear the interrupt status bits of the rc_w1 type, the application must write 1 into the bit.

This register interrupts the application for system-level events in the current mode (device mode or host mode).

The FIFO status interrupts are read-only; once software reads from or writes to the FIFO while servicing these interrupts, FIFO interrupt conditions are cleared automatically.

The application must clear the OTG_GINTSTS register at initialization before unmasking the interrupt bit to avoid any interrupts generated prior to initialization.

Address offset: 0x014

Reset value: 0x0400 0020

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WKUP INT	SRQ INT	DISC INT	CIDS CHG	LPM INT	PTXFE	HCINT	HPRT INT	RST DET	DATAF SUSP	IN COMP ISO OUT	IISOI XFR	OEP INT	IEPINT	Res.	Res.
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	r	r	r	rc_w1	rc_w1	rc_w1	rc_w1	r	r		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EOPF	ISOO DRP	ENUM DNE	USB RST	USB SUSP	ESUSP	Res.	Res.	GO NAK EFF	GI NAK EFF	NPTXF E	RXF LVL	SOF	OTG INT	MMIS	CMOD
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1			r	r	r	r	rc_w1	r	rc_w1	r

Bit 31 **WKUPINT:** Resume/remote wake-up detected interrupt

Wake-up interrupt during suspend(L2) or LPM(L1) state.

– During suspend(L2):

In device mode, this interrupt is asserted when a resume is detected on the USB. In host mode, this interrupt is asserted when a remote wake-up is detected on the USB.

– During LPM(L1):

This interrupt is asserted for either host initiated resume or device initiated remote wake-up on USB.

Note: Accessible in both device and host modes.

Bit 30 **SRQINT:** Session request/new session detected interrupt

In host mode, this interrupt is asserted when a session request is detected from the device. In device mode, this interrupt is asserted when V_{BUS} is in the valid range for a B-peripheral device. Accessible in both device and host modes.

Bit 29 **DISCINT:** Disconnect detected interrupt

Asserted when a device disconnect is detected.

Note: Only accessible in host mode.

Bit 28 **CIDSCHG:** Connector ID status change

The core sets this bit when there is a change in connector ID status.

Note: Accessible in both device and host modes.

Bit 27 **LPMINT:** LPM interrupt

In device mode, this interrupt is asserted when the device receives an LPM transaction and responds with a non-ERRORed response.

In host mode, this interrupt is asserted when the device responds to an LPM transaction with a non-ERRORed response or when the host core has completed LPM transactions for the programmed number of times (RETRYCNT bit in OTG_GLPMCFG).

This field is valid only if the LPMEN bit in OTG_GLPMCFG is set to 1.

Bit 26 **PTXFE:** Periodic Tx FIFO empty

Asserted when the periodic transmit FIFO is either half or completely empty and there is space for at least one entry to be written in the periodic request queue. The half or completely empty status is determined by the periodic Tx FIFO empty level bit in the OTG_GAHBCFG register (PTXFELVL bit in OTG_GAHBCFG).

Note: Only accessible in host mode.

Bit 25 **HCINT:** Host channels interrupt

The core sets this bit to indicate that an interrupt is pending on one of the channels of the core (in host mode). The application must read the OTG_HAINT register to determine the exact number of the channel on which the interrupt occurred, and then read the corresponding OTG_HCINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the OTG_HCINTx register to clear this bit.

Note: Only accessible in host mode.

Bit 24 **HPRTINT:** Host port interrupt

The core sets this bit to indicate a change in port status of one of the OTG_HS controller ports in host mode. The application must read the OTG_HPRT register to determine the exact event that caused this interrupt. The application must clear the appropriate status bit in the OTG_HPRT register to clear this bit.

Note: Only accessible in host mode.

Bit 23 **RSTDET:** Reset detected interrupt

In device mode, this interrupt is asserted when a reset is detected on the USB in partial power-down mode when the device is in suspend.

Note: Only accessible in device mode.

Bit 22 **DATAFSUSP:** Data fetch suspended

This interrupt is valid only in DMA mode. This interrupt indicates that the core has stopped fetching data for IN endpoints due to the unavailability of TxFIFO space or request queue space. This interrupt is used by the application for an endpoint mismatch algorithm. For example, after detecting an endpoint mismatch, the application:

- Sets a global nonperiodic IN NAK handshake
- Disables IN endpoints
- Flushes the FIFO
- Determines the token sequence from the IN token sequence learning queue
- Re-enables the endpoints

Clears the global nonperiodic IN NAK handshake If the global nonperiodic IN NAK is cleared, the core has not yet fetched data for the IN endpoint, and the IN token is received: the core generates an “IN token received when FIFO empty” interrupt. The OTG then sends a NAK response to the host. To avoid this scenario, the application can check the FetSusp interrupt in OTG_GINTSTS, which ensures that the FIFO is full before clearing a global NAK handshake. Alternatively, the application can mask the “IN token received when FIFO empty” interrupt when clearing a global IN NAK handshake.

Bit 21 **INCOMPISOOUT:** Incomplete isochronous OUT transfer

In device mode, the core sets this interrupt to indicate that there is at least one isochronous OUT endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the End of periodic frame interrupt (EOPF) bit in this register.

Bit 20 **IISOIXFR:** Incomplete isochronous IN transfer

The core sets this interrupt to indicate that there is at least one isochronous IN endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the End of periodic frame interrupt (EOPF) bit in this register.

Note: Only accessible in device mode.

Bit 19 **OEPINT:** OUT endpoint interrupt

The core sets this bit to indicate that an interrupt is pending on one of the OUT endpoints of the core (in device mode). The application must read the OTG_DAINT register to determine the exact number of the OUT endpoint on which the interrupt occurred, and then read the corresponding OTG_DOEPINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the corresponding OTG_DOEPINTx register to clear this bit.

Note: Only accessible in device mode.

Bit 18 **IEPINT:** IN endpoint interrupt

The core sets this bit to indicate that an interrupt is pending on one of the IN endpoints of the core (in device mode). The application must read the OTG_DAINT register to determine the exact number of the IN endpoint on which the interrupt occurred, and then read the corresponding OTG_DIEPINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the corresponding OTG_DIEPINTx register to clear this bit.

Note: Only accessible in device mode.

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 **EOPF:** End of periodic frame interrupt

Indicates that the period specified in the periodic frame interval field of the OTG_DCFG register (PFIVL bit in OTG_DCFG) has been reached in the current frame.

Note: Only accessible in device mode.

Bit 14 **ISOODRP:** Isochronous OUT packet dropped interrupt

The core sets this bit when it fails to write an isochronous OUT packet into the Rx FIFO because the Rx FIFO does not have enough space to accommodate a maximum size packet for the isochronous OUT endpoint.

Note: Only accessible in device mode.

Bit 13 **ENUMDNE:** Enumeration done

The core sets this bit to indicate that speed enumeration is complete. The application must read the OTG_DSTS register to obtain the enumerated speed.

Note: Only accessible in device mode.

Bit 12 **USBRST:** USB reset

The core sets this bit to indicate that a reset is detected on the USB.

Note: Only accessible in device mode.

Bit 11 **USBSUSP:** USB suspend

The core sets this bit to indicate that a suspend was detected on the USB. The core enters the suspended state when there is no activity on the data lines for an extended period of time.

Note: Only accessible in device mode.

Bit 10 **ESUSP:** Early suspend

The core sets this bit to indicate that an Idle state has been detected on the USB for 3 ms.

Note: Only accessible in device mode.

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 **GONAKEFF:** Global OUT NAK effective

Indicates that the Set global OUT NAK bit in the OTG_DCTL register (SGONAK bit in OTG_DCTL), set by the application, has taken effect in the core. This bit can be cleared by writing the Clear global OUT NAK bit in the OTG_DCTL register (CGONAK bit in OTG_DCTL).

Note: Only accessible in device mode.

Bit 6 **GINAKEFF:** Global IN non-periodic NAK effective

Indicates that the Set global non-periodic IN NAK bit in the OTG_DCTL register (SGINAK bit in OTG_DCTL), set by the application, has taken effect in the core. That is, the core has sampled the Global IN NAK bit set by the application. This bit can be cleared by clearing the Clear global non-periodic IN NAK bit in the OTG_DCTL register (CGINAK bit in OTG_DCTL). This interrupt does not necessarily mean that a NAK handshake is sent out on the USB. The STALL bit takes precedence over the NAK bit.

Note: Only accessible in device mode.

Bit 5 **NPTXFE:** Non-periodic Tx FIFO empty

This interrupt is asserted when the non-periodic Tx FIFO is either half or completely empty, and there is space for at least one entry to be written to the non-periodic transmit request queue. The half or completely empty status is determined by the non-periodic Tx FIFO empty level bit in the OTG_GAHBCFG register (TXFELVL bit in OTG_GAHBCFG).

Note: Accessible in host mode only.

Bit 4 **RXFLVL:** Rx FIFO non-empty

Indicates that there is at least one packet pending to be read from the Rx FIFO.

Note: Accessible in both host and device modes.

Bit 3 **SOF:** Start of frame

In host mode, the core sets this bit to indicate that an SOF (FS), or Keep-Alive (LS) is transmitted on the USB. The application must write a 1 to this bit to clear the interrupt.

In device mode, in the core sets this bit to indicate that an SOF token has been received on the USB. The application can read the OTG_DSTS register to get the current frame number. This interrupt is seen only when the core is operating in FS.

Note: This register may return '1' if read immediately after power on reset. If the register bit reads '1' immediately after power on reset it does not indicate that an SOF has been sent (in case of host mode) or SOF has been received (in case of device mode). The read value of this interrupt is valid only after a valid connection between host and device is established. If the bit is set after power on reset the application can clear the bit.

Note: Accessible in both host and device modes.

Bit 2 **OTGINT:** OTG interrupt

The core sets this bit to indicate an OTG protocol event. The application must read the OTG interrupt status (OTG_GOTGINT) register to determine the exact event that caused this interrupt. The application must clear the appropriate status bit in the OTG_GOTGINT register to clear this bit.

Note: Accessible in both host and device modes.

Bit 1 **MMIS:** Mode mismatch interrupt

The core sets this bit when the application is trying to access:

– A host mode register, when the core is operating in device mode

– A device mode register, when the core is operating in host mode

The register access is completed on the AHB with an OKAY response, but is ignored by the core internally and does not affect the operation of the core.

Note: Accessible in both host and device modes.

Bit 0 **CMOD:** Current mode of operation

Indicates the current mode.

0: Device mode

1: Host mode

Note: Accessible in both host and device modes.

67.14.8 OTG interrupt mask register [alternate] (OTG_GINTMSK)

Valid for Host mode, see next section for Device mode.

This register works with the core interrupt register to interrupt the application. When an interrupt bit is masked, the interrupt associated with that bit is not generated. However, the core interrupt (OTG_GINTSTS) register bit corresponding to that interrupt is still set.

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WUIM	SRQIM	DISCINT	CIDSCHGM	LPMINTM	PTXFEM	HCIM	PRTIM	Res.	Res.	IPXFRM	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	r			rw					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NPTXFEM	RXFLVLM	SOFM	OTGINT	MMISM	Res.
										rw	rw	rw	rw	rw	

Bit 31 **WUIM:** Resume/remote wake-up detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 30 **SRQIM:** Session request/new session detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 29 **DISCINT:** Disconnect detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 28 **CIDSCHGM:** Connector ID status change mask
0: Masked interrupt
1: Unmasked interrupt

Bit 27 **LPMINTM:** LPM interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 26 **PTXFEM:** Periodic Tx FIFO empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 25 **HCIM:** Host channels interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 24 **PRTIM:** Host port interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **IPXFRM:** Incomplete periodic transfer mask
0: Masked interrupt
1: Unmasked interrupt

Bits 20:6 Reserved, must be kept at reset value.

Bit 5 **NPTXFEM:** Non-periodic Tx FIFO empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 4 **RXFLVLM:** Receive FIFO non-empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **SOFM:** Start of frame mask
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **OTGINT:** OTG interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **MMISM:** Mode mismatch interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 Reserved, must be kept at reset value.

67.14.9 OTG interrupt mask register [alternate] (OTG_GINTMSK)

Valid for Device mode, see previous section for Host mode.

This register works with the core interrupt register to interrupt the application. When an interrupt bit is masked, the interrupt associated with that bit is not generated. However, the core interrupt (OTG_GINTSTS) register bit corresponding to that interrupt is still set.

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WUIM	SRQIM	Res.	CIDSCHGM	LPMINTM	Res.	Res.	Res.	RSTDETM	FSUSPM	IISOOXFRM	IISOIXFRM	OEPINT	IEPINT	Res.	Res.
rw	rw		rw	rw				rw	rw	rw	rw	rw	rw		

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EOPFM	ISOODRPM	ENUMDNEM	USBRST	USBSUSPM	ESUSPM	Res.	Res.	GONAKEFFM	GINAKEFFM	Res.	RXFLVLM	SOFM	OTGINT	MMISM	Res.
rw	rw	rw	rw	rw	rw			rw	rw		rw	rw	rw	rw	

Bit 31 **WUIM:** Resume/remote wake-up detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 30 **SRQIM:** Session request/new session detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 29 Reserved, must be kept at reset value.

Bit 28 **CIDSCHGM:** Connector ID status change mask
0: Masked interrupt
1: Unmasked interrupt

Bit 27 **LPMINTM:** LPM interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 26:24 Reserved, must be kept at reset value.

Bit 23 **RSTDETM:** Reset detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 22 **FSUSPM:** Data fetch suspended mask
0: Masked interrupt
1: Unmasked interrupt

Bit 21 **IISOOXFRM:** Incomplete isochronous OUT transfer mask
0: Masked interrupt
1: Unmasked interrupt

Bit 20 **IISOIXFRM:** Incomplete isochronous IN transfer mask
0: Masked interrupt
1: Unmasked interrupt

Bit 19 **OEPINT:** OUT endpoints interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 18 **IEPINT:** IN endpoints interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 **EOPFM:** End of periodic frame interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 14 **ISOODRPM:** Isochronous OUT packet dropped interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 13 **ENUMDNEM:** Enumeration done mask
0: Masked interrupt
1: Unmasked interrupt

Bit 12 **USBRST:** USB reset mask
0: Masked interrupt
1: Unmasked interrupt

Bit 11 **USBSUSPM:** USB suspend mask
0: Masked interrupt
1: Unmasked interrupt

Bit 10 **ESUSPM:** Early suspend mask
0: Masked interrupt
1: Unmasked interrupt

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 **GONAKEFFM:** Global OUT NAK effective mask
0: Masked interrupt
1: Unmasked interrupt

Bit 6 **GINAKEFFM:** Global non-periodic IN NAK effective mask
0: Masked interrupt
1: Unmasked interrupt

Bit 5 Reserved, must be kept at reset value.

Bit 4 **RXFLVLM:** Receive FIFO non-empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **SOFM:** Start of frame mask
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **OTGINT:** OTG interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **MMISM:** Mode mismatch interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 Reserved, must be kept at reset value.

67.14.10 OTG receive status debug read register [alternate] (OTG_GRXSTSR)

This description is for register OTG_GRXSTSR in Device mode.

A read to the receive status debug read register returns the contents of the top of the receive FIFO.

The core ignores the receive status read when the receive FIFO is empty and returns a value of 0x0000 0000.

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	STSPHST	Res.	Res.	FRMNUM[3:0]				PKTSTS[3:0]				DPID[1]
				r			r	r	r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DPID[0]	BCNT[10:0]											EPNUM[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **STSPHST:** Status phase start
Indicates the start of the status phase for a control write transfer. This bit is set along with the OUT transfer completed PKTSTS pattern.

Bits 26:25 Reserved, must be kept at reset value.

Bits 24:21 **FRMNUM[3:0]:** Frame number

This is the least significant 4 bits of the frame number in which the packet is received on the USB. This field is supported only when isochronous OUT endpoints are supported.

Bits 20:17 **PKTSTS[3:0]:** Packet status

Indicates the status of the received packet
0001: Global OUT NAK (triggers an interrupt)
0010: OUT data packet received
0011: OUT transfer completed (triggers an interrupt)
0100: SETUP transaction completed (triggers an interrupt)
0110: SETUP data packet received
Others: Reserved

Bits 16:15 **DPID[1:0]:** Data PID

Indicates the data PID of the received OUT data packet
00: DATA0
10: DATA1
01: DATA2
11: MDATA

Bits 14:4 **BCNT[10:0]:** Byte count

Indicates the byte count of the received data packet.

Bits 3:0 **EPNUM[3:0]:** Endpoint number

Indicates the endpoint number to which the current received packet belongs.

67.14.11 OTG receive status debug read register [alternate] (OTG_GRXSTSR)

This description is for register OTG_GRXSTSR in Host mode.

A read to the receive status debug read register returns the contents of the top of the receive FIFO.

The core ignores the receive status read when the receive FIFO is empty and returns a value of 0x0000 0000.

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTSTS[3:0]				DPID
											r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DPID	BCNT[10:0]											CHNUM[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:17 **PKTSTS[3:0]:** Packet status
Indicates the status of the received packet
0010: IN data packet received
0011: IN transfer completed (triggers an interrupt)
0101: Data toggle error (triggers an interrupt)
0111: Channel halted (triggers an interrupt)
Others: Reserved

Bits 16:15 **DPID[1:0]:** Data PID
Indicates the data PID of the received packet
00: DATA0
10: DATA1
01: DATA2
11: MDATA

Bits 14:4 **BCNT[10:0]:** Byte count
Indicates the byte count of the received IN data packet.

Bits 3:0 **CHNUM[3:0]:** Channel number
Indicates the channel number to which the current received packet belongs.

67.14.12 OTG status read and pop registers (OTG_GRXSTSP)

This description is for register OTG_GRXSTSP in Device mode.

Similarly to OTG_GRXSTSR (receive status debug read register) where a read returns the contents of the top of the receive FIFO, a read to OTG_GRXSTSP (receive status read and pop register) additionally pops the top data entry out of the Rx FIFO.

The core ignores the receive status pop/read when the receive FIFO is empty and returns a value of 0x0000 0000. The application must only pop the receive status FIFO when the receive FIFO non-empty bit of the core interrupt register (RXFLVL bit in OTG_GINTSTS) is asserted.

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	STSPHST	Res.	Res.	FRMNUM[3:0]				PKTSTS[3:0]				DPID[1]
				r			r	r	r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DPID[0]	BCNT[10:0]											EPNUM[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **STSPHST:** Status phase start
Indicates the start of the status phase for a control write transfer. This bit is set along with the OUT transfer completed PKTSTS pattern.

Bits 26:25 Reserved, must be kept at reset value.

Bits 24:21 **FRMNUM[3:0]:** Frame number

This is the least significant 4 bits of the frame number in which the packet is received on the USB. This field is supported only when isochronous OUT endpoints are supported.

Bits 20:17 **PKTSTS[3:0]:** Packet status

Indicates the status of the received packet
0001: Global OUT NAK (triggers an interrupt)
0010: OUT data packet received
0011: OUT transfer completed (triggers an interrupt)
0100: SETUP transaction completed (triggers an interrupt)
0110: SETUP data packet received
Others: Reserved

Bits 16:15 **DPID[1:0]:** Data PID

Indicates the data PID of the received OUT data packet
00: DATA0
10: DATA1
01: DATA2
11: MDATA

Bits 14:4 **BCNT[10:0]:** Byte count

Indicates the byte count of the received data packet.

Bits 3:0 **EPNUM[3:0]:** Endpoint number

Indicates the endpoint number to which the current received packet belongs.

67.14.13 OTG status read and pop registers [alternate] (OTG_GRXSTSP)

This description is for register OTG_GRXSTSP in Host mode.

Similarly to OTG_GRXSTSR (receive status debug read register) where a read returns the contents of the top of the receive FIFO, a read to OTG_GRXSTSP (receive status read and pop register) additionally pops the top data entry out of the Rx FIFO.

The core ignores the receive status pop/read when the receive FIFO is empty and returns a value of 0x0000 0000. The application must only pop the receive status FIFO when the receive FIFO non-empty bit of the core interrupt register (RXFLVL bit in OTG_GINTSTS) is asserted.

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTSTS[3:0]				DPID
											r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DPID	BCNT[10:0]											CHNUM[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:17 **PKTSTS[3:0]:** Packet status
Indicates the status of the received packet
0010: IN data packet received
0011: IN transfer completed (triggers an interrupt)
0101: Data toggle error (triggers an interrupt)
0111: Channel halted (triggers an interrupt)
Others: Reserved

Bits 16:15 **DPID[1:0]:** Data PID
Indicates the data PID of the received packet
00: DATA0
10: DATA1
01: DATA2
11: MDATA

Bits 14:4 **BCNT[10:0]:** Byte count
Indicates the byte count of the received IN data packet.

Bits 3:0 **CHNUM[3:0]:** Channel number
Indicates the channel number to which the current received packet belongs.

67.14.14 OTG receive FIFO size register (OTG_GRXFSIZ)

The application can program the RAM size that must be allocated to the Rx FIFO.

Address offset: 0x024

Reset value: 0x0000 0400

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXFD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **RXFD[15:0]:** Rx FIFO depth
This value is in terms of 32-bit words.
Maximum value is 1024
Programmed values must respect the available FIFO memory allocation and must not exceed the power-on value.

67.14.15 OTG host non-periodic transmit FIFO size register [alternate] (OTG_HNPTXFSIZ)

Valid for Host mode, see next section for Device mode.

Address offset: 0x028

Reset value: 0x0200 0200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NPTXFD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NPTXFSA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **NPTXFD[15:0]:** Non-periodic Tx FIFO depth
This value is in terms of 32-bit words.
Minimum value is 16
Programmed values must respect the available FIFO memory allocation and must not exceed the power-on value.

Bits 15:0 **NPTXFSA[15:0]:** Non-periodic transmit RAM start address
This field configures the memory start address for non-periodic transmit FIFO RAM.

67.14.16 Endpoint 0 transmit FIFO size [alternate] (OTG_DIEPTXF0)

Valid for Device mode, see previous section for Host mode.

Address offset: 0x028

Reset value: 0x0200 0200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TX0FD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TX0FSA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **TX0FD[15:0]:** Endpoint 0 Tx FIFO depth
This value is in terms of 32-bit words.
Minimum value is 16
Programmed values must respect the available FIFO memory allocation and must not exceed the power-on value.

Bits 15:0 **TX0FSA[15:0]:** Endpoint 0 transmit RAM start address
This field configures the memory start address for the endpoint 0 transmit FIFO RAM.

67.14.17 OTG non-periodic transmit FIFO/queue status register (OTG_HNPTXSTS)

Note: In device mode, this register is not valid.

This read-only register contains the free space information for the non-periodic Tx FIFO and the non-periodic transmit request queue.

Address offset: 0x02C

Reset value: 0x0008 0400

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	NPTXQTOP[6:0]							NPTQXSAV[7:0]							
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NPTXFSAV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **NPTXQTOP[6:0]:** Top of the non-periodic transmit request queue
Entry in the non-periodic Tx request queue that is currently being processed by the MAC.
Bits 30:27: Channel/endpoint number
Bits 26:25:
XXXX00X: IN/OUT token
XXXX01X: Zero-length transmit packet (device IN/host OUT)
XXXX11X: Channel halt command
Bit 24: Terminate (last entry for selected channel/endpoint)

Bits 23:16 **NPTQXSAV[7:0]:** Non-periodic transmit request queue space available
Indicates the amount of free space available in the non-periodic transmit request queue. This queue holds both IN and OUT requests.
0: Non-periodic transmit request queue is full
1: 1 location available
2: locations available
n: n locations available (0 ≤ n ≤ 8)
Others: Reserved

Bits 15:0 **NPTXFSAV[15:0]:** Non-periodic Tx FIFO space available
Indicates the amount of free space available in the non-periodic Tx FIFO.
Values are in terms of 32-bit words.
0: Non-periodic Tx FIFO is full
1: 1 word available
2: 2 words available
n: n words available (where 0 ≤ n ≤ 512)
Others: Reserved

67.14.18 OTG general core configuration register (OTG_GCCFG)

This register is available in host and device modes.

Address offset: 0x038

Reset value: 0x0000 XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	BCDEN	FORCEHOSTPD	VBVALOVEN	VBVALOVAL	SDEN	Res.	PDEN	DCDEN	HVDMSRCEN	HCDPDETEN	HCDPEN
					rw	rw	rw	rw	rw		rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSVMINUS	FSVPLUS	CHGDET
													r	r	r

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 Reserved, must be kept at reset value.

Bit 27 Reserved, must be kept at reset value.

Bit 26 **BCDEN:** Force Battery charging (BC) mode

This bit is set by the software to force the Battery charging mode. When enabled, the USB PHY is fully controlled by Battery Charging controls and cannot be used for normal communication.

0: Normal USB mode

1: Battery Charging mode

Bit 25 **FORCEHOSTPD:** Force host mode pull-downs

If the ID pin functions are enabled, the host mode pull-downs on DP and DM activate automatically. However, whenever that is not the case, yet host mode is required, this bit must be used to force the pull-downs active.

0: Do not force host mode pull-downs

1: Force host mode pull-downs

Bit 24 **VBVALOVEN:** Enables a software override of the VBUS B-session detection.

0: Use hardware

1: Use VBVALOVAL to indicate B-session active

Bit 23 **VBVALOVAL:** Software override value of the VBUS B-session detection

0: B-session inactive

1: B-session active

Bit 22 **SDEN:** Battery charging specification – secondary detection enable

0: Secondary detection disabled

1: Secondary detection enabled

Bit 21 Reserved, must be kept at reset value.

Bit 20 **PDEN:** Battery charging specification – primary detection enable

0: Primary detection disabled

1: Primary detection enabled

Bit 19 **DCDEN:** Battery charging specification – data contact detection enable

0: Data Contact Detection disabled

1: Data Contact Detection enabled

Bit 18 **HVDMSRCEN:** Battery charging specification – host CDP port voltage source enable on DM
0: DM voltage source disabled
1: DM Voltage source enabled

Bit 17 **HCDPDETEN:** Battery charging specification – host CDP port voltage detector enable on DP
0: DP voltage detection disabled
1: DP voltage detection enabled

Bit 16 **HCDPEN:** Battery charging specification – host CDP behavior enable
0: Disable CDP behavior
1: Enable CDP behavior

Bits 15:5 Reserved, must be kept at reset value.

Bit 4 Reserved, must be kept at reset value.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **FSVMINUS:** Battery charging specification – single-ended DM indicator
This bit gives the voltage level on DM (also result of the comparison with V_{LGC} threshold as defined in BC v1.2 standard).
0: DM voltage at low level
1: DM voltage at high level

Bit 1 **FSVPLUS:** Battery charging specification – single-ended DP indicator
This bit gives the voltage level on DP (also result of the comparison with V_{LGC} threshold as defined in BC v1.2 standard).
0: DM voltage at low level
1: DM voltage at high level

Bit 0 **CHGDET:** Battery charging specification – charger detection, result of the current mode (primary or secondary).
0: Low value on pin
1: High value on pin

67.14.19 OTG core ID register (OTG_CID)

This is a register containing the Product ID as reset value.

Address offset: 0x03C

Reset value: 0x0000 6200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRODUCT_ID[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRODUCT_ID[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PRODUCT_ID[31:0]:** Product ID field
Application-programmable ID field.

67.14.20 OTG core LPM configuration register (OTG_GLPMCFG)

Address offset: 0x054

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	EN BESL	LPMRCNTSTS[2:0]			SND LPM	LPMRCNT[2:0]			LPMCHIDX[3:0]				L1RSM OK
			rw	r	r	r	rs	rw	rw	rw	rw	rw	rw	rw	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SLP STS	LPMRSP[1:0]		L1DS EN	BESLTHRS[3:0]				L1SS EN	REM WAKE	BESL[3:0]				LPM ACK	LPM EN
r	r	r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **ENBESL:** Enable best effort service latency

This bit enables the BESL feature as defined in the LPM errata:

0: The core works as described in the following document:
USB 2.0 Link Power Management Addendum Engineering Change Notice to the USB 2.0 specification, July 16, 2007

1: The core works as described in the LPM Errata:
Errata for USB 2.0 ECN: Link Power Management (LPM) - 7/2007

Note: Only the updated behavior (described in LPM Errata) is considered in this document and so the ENBESL bit must be set to '1' by application SW.

Bits 27:25 **LPMRCNTSTS[2:0]:** LPM retry count status

Number of LPM host retries still remaining to be transmitted for the current LPM sequence.

Note: Accessible only in host mode.

Bit 24 **SNDLPM:** Send LPM transaction

When the application software sets this bit, an LPM transaction containing two tokens, EXT and LPM is sent. The hardware clears this bit once a valid response (STALL, NYET, or ACK) is received from the device or the core has finished transmitting the programmed number of LPM retries.

Note: This bit must be set only when the host is connected to a local port.

Note: Accessible only in host mode.

Bits 23:21 **LPMRCNT[2:0]:** LPM retry count

When the device gives an ERROR response, this is the number of additional LPM retries that the host performs until a valid device response (STALL, NYET, or ACK) is received.

Note: Accessible only in host mode.

Bits 20:17 **LPMCHIDX[3:0]:** LPM Channel Index

The channel number on which the LPM transaction has to be applied while sending an LPM transaction to the local device. Based on the LPM channel index, the core automatically inserts the device address and endpoint number programmed in the corresponding channel into the LPM transaction.

Note: Accessible only in host mode.

Bit 16 **L1RSMOK:** Sleep state resume OK

Indicates that the device or host can start resume from Sleep state. This bit is valid in LPM sleep (L1) state. It is set in sleep mode after a delay of 50 µs ($T_{L1Residency}$).
This bit is reset when SLPSTS is 0.
1: The application or host can start resume from Sleep state
0: The application or host cannot start resume from Sleep state

Bit 15 **SLPSTS:** Port sleep status

Device mode:
This bit is set as long as a Sleep condition is present on the USB bus. The core enters the Sleep state when an ACK response is sent to an LPM transaction and the $T_{L1TokenRetry}$ timer has expired. To stop the PHY clock, the application must set the STPPCLK bit in OTG_PCGCCTL, which asserts the PHY suspend input signal.
The application must rely on SLPSTS and not ACK in LPMRSP to confirm transition into sleep.
The core comes out of sleep:
– When there is any activity on the USB linestate
– When the application writes to the RWUSIG bit in OTG_DCTL or when the application resets or soft-disconnects the device.

Host mode:
The host transitions to Sleep (L1) state as a side-effect of a successful LPM transaction by the core to the local port with ACK response from the device. The read value of this bit reflects the current Sleep status of the port.
The core clears this bit after:
– The core detects a remote L1 wake-up signal,
– The application sets the PRST bit or the PRES bit in the OTG_HPRT register, or
– The application sets the L1Resume/ remote wake-up detected interrupt bit or disconnect detected interrupt bit in the core interrupt register (WKUPINT or DISCINT bit in OTG_GINTSTS, respectively).
0: Core not in L1
1: Core in L1

Bits 14:13 **LPMRSP[1:0]:** LPM response

Device mode:
The response of the core to LPM transaction received is reflected in these two bits.
Host mode:
Handshake response received from local device for LPM transaction
11: ACK
10: NYET
01: STALL
00: ERROR (No handshake response)

Bit 12 **L1DSEN:** L1 deep sleep enable

Enables suspending the PHY in L1 Sleep mode. For maximum power saving during L1 Sleep mode, this bit must be set to '1' by application SW in all the cases.

Bits 11:8 **BESLTHRS[3:0]:** BESL threshold

Device mode:

The core puts the PHY into deep low power mode in L1 when BESL value is greater than or equal to the value defined in this field BESL_Thres[3:0].

Host mode:

The core puts the PHY into deep low power mode in L1. BESLTHRS[3:0] specifies the time for which resume signaling is to be reflected by host ($T_{L1HubDrvResume2}$) on the USB bus when it detects device initiated resume.

BESLTHRS must not be programmed with a value greater than 1100b in host mode, because this exceeds maximum $T_{L1HubDrvResume2}$.

Thres[3:0] host mode resume signaling time (µs):

0000: 75

0001: 100

0010: 150

0011: 250

0100: 350

0101: 450

0110: 950

All other values: reserved

Bit 7 **L1SSEN:** L1 Shallow Sleep enable

Enables suspending the PHY in L1 Sleep mode. For maximum power saving during L1 Sleep mode, this bit must be set to '1' by application SW in all the cases.

Bit 6 **REMWAKE:** bRemoteWake value

Host mode:

The value of remote wake up to be sent in the wIndex field of LPM transaction.

Device mode (read-only):

This field is updated with the received LPM token bRemoteWake bmAttribute when an ACK, NYET, or STALL response is sent to an LPM transaction.

Bits 5:2 **BESL[3:0]:** Best effort service latency

Host mode:

The value of BESL to be sent in an LPM transaction. This value is also used to initiate resume for a duration $T_{L1HubDrvResume1}$ for host initiated resume.

Device mode (read-only):

This field is updated with the received LPM token BESL bmAttribute when an ACK, NYET, or STALL response is sent to an LPM transaction.

BESL[3:0]T_{BESL} (µs)

0000: 125
0001: 150
0010: 200
0011: 300
0100: 400
0101: 500
0110: 1000
0111: 2000
1000: 3000
1001: 4000
1010: 5000
1011: 6000
1100: 7000
1101: 8000
1110: 9000
1111: 10000

Bit 1 **LPMACK:** LPM token acknowledge enable

Handshake response to LPM token preprogrammed by device application software.

1: ACK

Even though ACK is preprogrammed, the core device responds with ACK only on successful LPM transaction. The LPM transaction is successful if:

– No PID/CRC5 errors in either EXT token or LPM token (else ERROR)
– Valid bLinkState = 0001B (L1) received in LPM transaction (else STALL)
– No data pending in transmit queue (else NYET).

0: NYET

The preprogrammed software bit is over-ridden for response to LPM token when:

– The received bLinkState is not L1 (STALL response), or
– An error is detected in either of the LPM token packets because of corruption (ERROR response).

Note: Accessible only in device mode.

Bit 0 **LPMEN:** LPM support enable

The application uses this bit to control the OTG_HS core LPM capabilities.

If the core operates as a non-LPM-capable host, it cannot request the connected device or hub to activate LPM mode.

If the core operates as a non-LPM-capable device, it cannot respond to any LPM transactions.

0: LPM capability is not enabled
1: LPM capability is enabled

67.14.21 OTG host periodic transmit FIFO size register (OTG_HPTXFSIZ)

Address offset: 0x100

Reset value: 0x0400 0800

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PTXFSIZ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PTXSA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **PTXFSIZ[15:0]:** Host periodic Tx FIFO depth
This value is in terms of 32-bit words.
Minimum value is 16

Bits 15:0 **PTXSA[15:0]:** Host periodic Tx FIFO start address
This field configures the memory start address for periodic transmit FIFO RAM.

67.14.22 OTG device IN endpoint transmit FIFO x size register (OTG_DIEPTXFx)

Address offset: 0x104 + 0x04 * (x - 1), (x = 1 to 8)

Reset value: 0x0200 0400, 0x0200 0600, 0x0200 0800, 0x0200 0A00, 0x0200 0C00, 0x0200 0E00, 0x0200 1000, 0x0200 1200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
INEPTXFD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INEPTXSA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **INEPTXFD[15:0]:** IN endpoint Tx FIFO depth
This value is in terms of 32-bit words.
Minimum value is 16

Bits 15:0 **INEPTXSA[15:0]:** IN endpoint FIFOx transmit RAM start address
This field contains the memory start address for IN endpoint transmit FIFOx. The address must be aligned with a 32-bit memory location.

67.14.23 Host-mode registers

Bit values in the register descriptions are expressed in binary unless otherwise specified.

Host-mode registers affect the operation of the core in the host mode. Host mode registers must not be accessed in device mode, as the results are undefined. Host mode registers can be categorized as follows:

67.14.24 OTG host configuration register (OTG_HCFG)

This register configures the core after power-on. Do not make changes to this register after initializing the host.

Address offset: 0x400

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSLSS	FSLSPCS[1:0]	
													r	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **FSLSS:** FS- and LS-only support

The application uses this bit to control the core enumeration speed. Using this bit, the application can make the core enumerate as an FS host, even if the connected device supports HS traffic. Do not make changes to this field after initial programming.

Bits 1:0 **FSLSPCS[1:0]:** FS/LS PHY clock select

Condition: FS host mode
01: PHY clock is running at 48 MHz
Others: Reserved
Condition: LS host mode
00: Reserved
01: Select 48 MHz PHY clock frequency
10: Select 6 MHz PHY clock frequency
11: Reserved

Note: The FSLSPCS must be set on a connection event according to the speed of the connected device (after changing this bit, a software reset must be performed).

67.14.25 OTG host frame interval register (OTG_HFIR)

This register stores the frame interval information for the current speed to which the OTG_HS controller has enumerated.

Address offset: 0x404

Reset value: 0x0000 EA60

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RLD CTRL
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FRIVL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **RLDCTRL:** Reload control

This bit allows dynamic reloading of the HFIR register during run time.

0: The HFIR cannot be reloaded dynamically

1: The HFIR can be dynamically reloaded during run time.

This bit needs to be programmed during initial configuration and its value must not be changed during run time.

Caution: RLDCTRL = 0 is not recommended.

Bits 15:0 **FRIVL[15:0]:** Frame interval

The value that the application programs to this field, specifies the interval between two consecutive micro-SOFs (HS) or Keep-Alive tokens (LS). This field contains the number of PHY clocks that constitute the required frame interval. The application can write a value to this register only after the port enable bit of the host port control and status register (PENA bit in OTG_HPRT) has been set. If no value is programmed, the core calculates the value based on the PHY clock specified in the FS/LS PHY clock select field of the host configuration register (FSLSPCS in OTG_HCFG). Do not change the value of this field after the initial configuration, unless the RLDCTRL bit is set. In such case, the FRIVL is reloaded with each SOF event.

– Frame interval = 125 µs × (FRIVL - 1) in high speed operation

– Frame interval = 1 ms × (FRIVL - 1) in low/full speed operation

67.14.26 OTG host frame number/frame time remaining register (OTG_HFNUM)

This register indicates the current frame number. It also indicates the time remaining (in terms of the number of PHY clocks) in the current frame.

Address offset: 0x408

Reset value: 0x0000 3FFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FTREM[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FRNUM[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **FTREM[15:0]:** Frame time remaining

Indicates the amount of time remaining in the current frame, in terms of PHY clocks. This field decrements on each PHY clock. When it reaches zero, this field is reloaded with the value in the Frame interval register and a new SOF is transmitted on the USB.

Bits 15:0 **FRNUM[15:0]:** Frame number

This field increments when a new SOF is transmitted on the USB, and is cleared to 0 when it reaches 0x3FFF.

67.14.27 OTG_Host periodic transmit FIFO/queue status register (OTG_HPTXSTS)

This read-only register contains the free space information for the periodic Tx FIFO and the periodic transmit request queue.

Address offset: 0x410

Reset value: 0x0008 0100

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PTXQTOP[7:0]								PTXQSAV[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PTXFSAVL[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 **PTXQTOP[7:0]:** Top of the periodic transmit request queue

This indicates the entry in the periodic Tx request queue that is currently being processed by the MAC.

This register is used for debugging.

Bit 31: Odd/Even frame

0XXXXXXX: send in even frame

1XXXXXXX: send in odd frame

Bits 30:27: Channel/endpoint number

Bits 26:25: Type

XXXXX00X: IN/OUT

XXXXX01X: Zero-length packet

XXXXX11X: Disable channel command

Bit 24: Terminate (last entry for the selected channel/endpoint)

Bits 23:16 **PTXQSAV[7:0]:** Periodic transmit request queue space available

Indicates the number of free locations available to be written in the periodic transmit request queue. This queue holds both IN and OUT requests.

0: Periodic transmit request queue is full

1: 1 location available

2: 2 locations available

n: n locations available (0 ≤ n ≤ 8)

Others: Reserved

Bits 15:0 **PTXFSAVL[15:0]:** Periodic transmit data FIFO space available

Indicates the number of free locations available to be written to in the periodic Tx FIFO.

Values are in terms of 32-bit words

0: Periodic Tx FIFO is full

1: 1 word available

2: 2 words available

n: n words available (where 0 ≤ n ≤ PTXFD)

Others: Reserved

67.14.28 OTG host all channels interrupt register (OTG_HAINT)

When a significant event occurs on a channel, the host all channels interrupt register interrupts the application using the host channels interrupt bit of the core interrupt register (HCINT bit in OTG_GINTSTS). This is shown in *Figure 958*. There is one interrupt bit per channel, up to a maximum of 16 bits. Bits in this register are set and cleared when the application sets and clears bits in the corresponding host channel-x interrupt register.

Address offset: 0x414

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HAINT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **HAINT[15:0]:** Channel interrupts
One bit per channel: Bit 0 for Channel 0, bit 15 for Channel 15

67.14.29 OTG host all channels interrupt mask register (OTG_HAINTMSK)

The host all channel interrupt mask register works with the host all channel interrupt register to interrupt the application when an event occurs on a channel. There is one interrupt mask bit per channel, up to a maximum of 16 bits.

Address offset: 0x418

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HAINTM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **HAINTM[15:0]:** Channel interrupt mask
0: Masked interrupt
1: Unmasked interrupt
One bit per channel: Bit 0 for channel 0, bit 15 for channel 15

67.14.30 OTG host port control and status register (OTG_HPRT)

This register is available only in host mode. Currently, the OTG host supports only one port.

A single register holds USB port-related information such as USB reset, enable, suspend, resume, connect status, and test mode for each port. It is shown in *Figure 958*. The rc_w1 bits in this register can trigger an interrupt to the application through the host port interrupt bit of the core interrupt register (HPRTINT bit in OTG_GINTSTS). On a port interrupt, the application must read this register and clear the bit that caused the interrupt. For the rc_w1 bits, the application must write a 1 to the bit to clear the interrupt.

Address offset: 0x440

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSPD[1:0]		PTCTL[3]
													r	r	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PTCTL[2:0]			PPWR	PLSTS[1:0]		Res.	PRST	PSUSP	PRES	POC CHNG	POCA	PEN CHNG	PENA	PCDET	PCSTS
rw	rw	rw	rw	r	r		rw	rs	rw	rc_w1	r	rc_w1	rc_w1	rc_w1	r

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:17 **PSPD[1:0]:** Port speed

Indicates the speed of the device attached to this port.
01: Full speed
10: Low speed
11: Reserved
00: High speed

Bits 16:13 **PTCTL[3:0]:** Port test control

The application writes a nonzero value to this field to put the port into a Test mode, and the corresponding pattern is signaled on the port.
0000: Test mode disabled
0001: Test_J mode
0010: Test_K mode
0011: Test_SE0_NAK mode
0100: Test_Packet mode
0101: Test_Force_Enable
Others: Reserved

Bit 12 **PPWR:** Port power

The application uses this field to control power to this port, and the core clears this bit on an overcurrent condition. Note that this bit does not directly activate the voltage on the connector VBUS.
0: Power off
1: Power on

Bits 11:10 **PLSTS[1:0]:** Port line status

Indicates the current logic level USB data lines
Bit 10: Logic level of OTG_HS_DP
Bit 11: Logic level of OTG_HS_DM

Bit 9 Reserved, must be kept at reset value.

Bit 8 **PRST:** Port reset

When the application sets this bit, a reset sequence is started on this port. The application must time the reset period and clear this bit after the reset sequence is complete.

0: Port not in reset

1: Port in reset

The application must leave this bit set for a minimum duration of at least 10 ms to start a reset on the port. The application can leave it set for another 10 ms in addition to the required minimum duration, before clearing the bit, even though there is no maximum limit set by the USB standard.

High speed: 50 ms

Full speed/Low speed: 10 ms

Bit 7 **PSUSP:** Port suspend

The application sets this bit to put this port in suspend mode. The core only stops sending SOFs when this is set. To stop the PHY clock, the application must set the port clock stop bit, which asserts the suspend input pin of the PHY.

The read value of this bit reflects the current suspend status of the port. This bit is cleared by the core after a remote wake-up signal is detected or the application sets the port reset bit or port resume bit in this register or the resume/remote wake-up detected interrupt bit or disconnect detected interrupt bit in the core interrupt register (WKUPINT or DISCINT in OTG_GINTSTS, respectively).

0: Port not in suspend mode

1: Port in suspend mode

Bit 6 **PRES:** Port resume

The application sets this bit to drive resume signaling on the port. The core continues to drive the resume signal until the application clears this bit.

If the core detects a USB remote wake-up sequence, as indicated by the port resume/remote wake-up detected interrupt bit of the core interrupt register (WKUPINT bit in OTG_GINTSTS), the core starts driving resume signaling without application intervention and clears this bit when it detects a disconnect condition. The read value of this bit indicates whether the core is currently driving resume signaling.

0: No resume driven

1: Resume driven

When LPM is enabled and the core is in L1 state, the behavior of this bit is as follow:

1. The application sets this bit to drive resume signaling on the port.

2. The core continues to drive the resume signal until a predetermined time specified in BESLTHRS[3:0] field of OTG_GLPMCFG register.

3. If the core detects a USB remote wake-up sequence, as indicated by the port L1Resume/Remote L1wake-up detected interrupt bit of the core interrupt register (WKUPINT in OTG_GINTSTS), the core starts driving resume signaling without application intervention and clears this bit at the end of resume.This bit can be set or cleared by both the core and the application. This bit is cleared by the core even if there is no device connected to the host.

Bit 5 **POCCHNG:** Port overcurrent change

The core sets this bit when the status of the port overcurrent active bit (bit 4) in this register changes.

Bit 4 **POCA:** Port overcurrent active

Indicates the overcurrent condition of the port.

0: No overcurrent condition

1: Overcurrent condition

Bit 3 **PENCHNG:** Port enable/disable change

The core sets this bit when the status of the port enable bit 2 in this register changes.

Bit 2 **PENA:** Port enable

A port is enabled only by the core after a reset sequence, and is disabled by an overcurrent condition, a disconnect condition, or by the application clearing this bit. The application cannot set this bit by a register write. It can only clear it to disable the port. This bit does not trigger any interrupt to the application.

0: Port disabled

1: Port enabled

Bit 1 **PCDET:** Port connect detected

The core sets this bit when a device connection is detected to trigger an interrupt to the application using the host port interrupt bit in the core interrupt register (HPRTINT bit in OTG_GINTSTS). The application must write a 1 to this bit to clear the interrupt.

Bit 0 **PCSTS:** Port connect status

0: No device is attached to the port

1: A device is attached to the port

67.14.31 OTG host channel x characteristics register (OTG_HCCHARx)

Address offset: 0x500 + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CHENA	CHDIS	ODD FRM	DAD[6:0]							MCNT[1:0]		EPTYP[1:0]		LSDEV	Res.
rs	rs	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EPDIR	EPNUM[3:0]				MPSIZ[10:0]										
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **CHENA:** Channel enable

This field is set by the application and cleared by the OTG host.

0: Channel disabled

1: Channel enabled

Bit 30 **CHDIS:** Channel disable

The application sets this bit to stop transmitting/receiving data on a channel, even before the transfer for that channel is complete. The application must wait for the Channel disabled interrupt before treating the channel as disabled.

Bit 29 **ODDFRM:** Odd frame

This field is set (reset) by the application to indicate that the OTG host must perform a transfer in an odd frame. This field is applicable for only periodic (isochronous and interrupt) transactions.

0: Even frame

1: Odd frame

Bits 28:22 **DAD[6:0]:** Device address

This field selects the specific device serving as the data source or sink.

Bits 21:20 **MCNT[1:0]:** Multicount

This field indicates to the host the number of transactions that must be executed per frame for this periodic endpoint. For non-periodic transfers, this field is not used

00: Reserved. This field yields undefined results

01: 1 transaction

10: 2 transactions per frame to be issued for this endpoint

11: 3 transactions per frame to be issued for this endpoint

Note: This field must be set to at least 01.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

Indicates the transfer type selected.

00: Control

01: Isochronous

10: Bulk

11: Interrupt

Bit 17 **LSDEV:** Low-speed device

This field is set by the application to indicate that this channel is communicating to a low-speed device.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **EPDIR:** Endpoint direction

Indicates whether the transaction is IN or OUT.

0: OUT

1: IN

Bits 14:11 **EPNUM[3:0]:** Endpoint number

Indicates the endpoint number on the device serving as the data source or sink.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size

Indicates the maximum packet size of the associated endpoint.

67.14.32 OTG host channel x split control register (OTG_HCSPLTx)

Address offset: 0x504 + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SPLIT EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COMP LSPLT
rw															rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XACTPOS[1:0]		HUBADDR[6:0]							PRTADDR[6:0]						
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **SPLITEN:** Split enable

The application sets this bit to indicate that this channel is enabled to perform split transactions.

Bits 30:17 Reserved, must be kept at reset value.

Bit 16 **COMPLSPLT:** Do complete split

The application sets this bit to request the OTG host to perform a complete split transaction.

Bits 15:14 **XACTPOS[1:0]:** Transaction position
This field is used to determine whether to send all, first, middle, or last payloads with each OUT transaction.
11: All. This is the entire data payload of this transaction (which is less than or equal to 188 bytes)
10: Begin. This is the first data payload of this transaction (which is larger than 188 bytes)
00: Mid. This is the middle payload of this transaction (which is larger than 188 bytes)
01: End. This is the last payload of this transaction (which is larger than 188 bytes)

Bits 13:7 **HUBADDR[6:0]:** Hub address
This field holds the device address of the transaction translator hub.

Bits 6:0 **PRTADDR[6:0]:** Port address
This field is the port number of the recipient transaction translator.

67.14.33 OTG host channel x interrupt register (OTG_HCINTx)

This register indicates the status of a channel with respect to USB- and AHB-related events. It is shown in *Figure 958*. The application must read this register when the host channels interrupt bit in the core interrupt register (HCINT bit in OTG_GINTSTS) is set. Before the application can read this register, it must first read the host all channels interrupt (OTG_HAINT) register to get the exact channel number for the host channel-x interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_HAINT and OTG_GINTSTS registers.

Address offset: 0x508 + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	DTERR	FRM OR	BBERR	TXERR	NYET	ACK	NAK	STALL	AHB ERR	CHH	XFRC
					rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **DTERR:** Data toggle error.

Bit 9 **FRMOR:** Frame overrun.

Bit 8 **BBERR:** Babble error.

Bit 7 **TXERR:** Transaction error.
Indicates one of the following errors occurred on the USB.
CRC check failure
Timeout
Bit stuff error
False EOP

Bit 6 **NYET:** Not yet ready response received interrupt.

Bit 5 **ACK:** ACK response received/transmitted interrupt.

Bit 4 **NAK:** NAK response received interrupt.

Bit 3 **STALL:** STALL response received interrupt.

Bit 2 **AHBERR:** AHB error

This error is generated only in Internal DMA mode when an AHB error occurs during an AHB read/write operation. The application can read the corresponding DMA channel address register to get the error address.

Bit 1 **CHH:** Channel halted

This indicates that the transfer completed:

– because of any USB transaction error

– in response to disable request by the application

– normally

Bit 0 **XFRC:** Transfer completed.

Transfer completed normally without any errors.

67.14.34 OTG host channel x interrupt mask register (OTG_HCINTMSKx)

This register reflects the mask for each channel status described in the previous section.

Address offset: 0x50C + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	DTERRM	FRMORM	BBERRM	TXERRM	NYET	ACKM	NAKM	STALLM	AHBERRM	CHHM	XFRCM
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **DTERRM:** Data toggle error mask.

0: Masked interrupt

1: Unmasked interrupt

Bit 9 **FRMORM:** Frame overrun mask.

0: Masked interrupt

1: Unmasked interrupt

Bit 8 **BBERRM:** Babble error mask.

0: Masked interrupt

1: Unmasked interrupt

Bit 7 **TXERRM:** Transaction error mask.

0: Masked interrupt

1: Unmasked interrupt

Bit 6 **NYET:** response received interrupt mask.

0: Masked interrupt

1: Unmasked interrupt

Bit 5 **ACKM:** ACK response received/transmitted interrupt mask.
0: Masked interrupt
1: Unmasked interrupt

Bit 4 **NAKM:** NAK response received interrupt mask.
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **STALLM:** STALL response received interrupt mask.
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **AHBERRM:** AHB error.
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **CHHM:** Channel halted mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed mask
0: Masked interrupt
1: Unmasked interrupt

67.14.35 OTG host channel x transfer size register (OTG_HCTSIZx)

Address offset: 0x510 + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DO PNG	DPID[1:0]		PKTCNT[9:0]										XFRSIZ[18:16]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XFRSIZ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **DOPNG:** Do Ping
This bit is used only for OUT transfers. Setting this field to 1 directs the host to do PING protocol.
Note: Do not set this bit for IN transfers. If this bit is set for IN transfers, it disables the channel.

Bits 30:29 **DPID[1:0]:** Data PID
The application programs this field with the type of PID to use for the initial transaction. The host maintains this field for the rest of the transfer.
00: DATA0
01: DATA2
10: DATA1
11: SETUP (control) / MDATA (non-control)

Bits 28:19 **PKTCNT[9:0]:** Packet count

This field is programmed by the application with the expected number of packets to be transmitted (OUT) or received (IN).

The host decrements this count on every successful transmission or reception of an OUT/IN packet. Once this count reaches zero, the application is interrupted to indicate normal completion.

Bits 18:0 **XFRSIZ[18:0]:** Transfer size

For an OUT, this field is the number of data bytes the host sends during the transfer.

For an IN, this field is the buffer size that the application has reserved for the transfer. The application is expected to program this field as an integer multiple of the maximum packet size for IN transactions (periodic and non-periodic).

67.14.36 OTG host channel x DMA address register(OTG_HCDMAx)

Address offset: 0x514 + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMAADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAADDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DMAADDR[31:0]:** DMA address

This field holds the start address in the external memory from which the data for the endpoint must be fetched or to which it must be stored. This register is incremented on every AHB transaction.

67.14.37 Device-mode registers

These registers must be programmed every time the core changes to device mode

67.14.38 OTG device configuration register (OTG_DCFG)

This register configures the core in device mode after power-on or after certain control commands or enumeration. Do not make changes to this register after initial programming.

Address offset: 0x800

Reset value: 0x0220 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	PERSCHIVL[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ERRATIM	Res.	Res.	PFIVL[1:0]		DAD[6:0]							Res.	NZLSOHSK	DSPD[1:0]	
rw			rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:24 **PERSCHIVL[1:0]:** Periodic schedule interval

This field specifies the amount of time the Internal DMA engine must allocate for fetching periodic IN endpoint data. Based on the number of periodic endpoints, this value must be specified as 25, 50 or 75% of the (micro) frame.

- When any periodic endpoints are active, the internal DMA engine allocates the specified amount of time in fetching periodic IN endpoint data
- When no periodic endpoint is active, then the internal DMA engine services nonperiodic endpoints, ignoring this field
- After the specified time within a (micro) frame, the DMA switches to fetching nonperiodic endpoints

00: 25% of (micro)frame
01: 50% of (micro)frame
10: 75% of (micro)frame
11: Reserved

Bits 23:16 Reserved, must be kept at reset value.

Bit 15 **ERRATIM:** Erratic error interrupt mask

1: Mask early suspend interrupt on erratic error
0: Early suspend interrupt is generated on erratic error

Bit 14 Reserved, must be kept at reset value.

Bit 13 Reserved, must be kept at reset value.

Bits 12:11 **PFIVL[1:0]:** Periodic frame interval

Indicates the time within a frame at which the application must be notified using the end of periodic frame interrupt. This can be used to determine if all the isochronous traffic for that frame is complete.

00: 80% of the frame interval
01: 85% of the frame interval
10: 90% of the frame interval
11: 95% of the frame interval

Bits 10:4 **DAD[6:0]:** Device address

The application must program this field after every SetAddress control command.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **NZLSOHSK:** Non-zero-length status OUT handshake

The application can use this field to select the handshake the core sends on receiving a nonzero-length data packet during the OUT transaction of a control transfer's status stage.

1: Send a STALL handshake on a nonzero-length status OUT transaction and do not send the received OUT packet to the application.
0: Send the received OUT packet to the application (zero-length or nonzero-length) and send a handshake based on the NAK and STALL bits for the endpoint in the device endpoint control register.

Bits 1:0 **DSPD[1:0]:** Device speed

Indicates the speed at which the application requires the core to enumerate, or the maximum speed the application can support. However, the actual bus speed is determined only after the chirp sequence is completed, and is based on the speed of the USB host to which the core is connected.

00: High speed

01: Full speed

10: Reserved

11: Reserved

67.14.39 OTG device control register (OTG_DCTL)

Address offset: 0x804

Reset value: 0x0000 0002

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DSBESLRJCT	Res.	Res.
													rw		

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	POPRGDNE	CGONAK	SGONAK	CGINAK	SGINAK	TCTL[2:0]			GONSTS	GINSTS	SDIS	RWUSIG
				rw	w	w	w	w	rw	rw	rw	r	r	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **DSBESLRJCT:** Deep sleep BESL reject

Core rejects LPM request with BESL value greater than BESL threshold programmed. NYET response is sent for LPM tokens with BESL value greater than BESL threshold. By default, the deep sleep BESL reject feature is disabled.

Bits 17:12 Reserved, must be kept at reset value.

Bit 11 **POPRGDNE:** Power-on programming done

The application uses this bit to indicate that register programming is completed after a wake-up from power down mode.

Bit 10 **CGONAK:** Clear global OUT NAK

Writing 1 to this field clears the Global OUT NAK.

Bit 9 **SGONAK:** Set global OUT NAK

Writing 1 to this field sets the Global OUT NAK.
The application uses this bit to send a NAK handshake on all OUT endpoints.
The application must set the this bit only after making sure that the Global OUT NAK effective bit in the core interrupt register (GONAKEFF bit in OTG_GINTSTS) is cleared.

Bit 8 **CGINAK:** Clear global IN NAK

Writing 1 to this field clears the Global IN NAK.

Bit 7 **SGINAK:** Set global IN NAK

Writing 1 to this field sets the Global non-periodic IN NAK.The application uses this bit to send a NAK handshake on all non-periodic IN endpoints.
The application must set this bit only after making sure that the Global IN NAK effective bit in the core interrupt register (GINAKEFF bit in OTG_GINTSTS) is cleared.

Bits 6:4 **TCTL[2:0]:** Test control
000: Test mode disabled
001: Test_J mode
010: Test_K mode
011: Test_SE0_NAK mode
100: Test_Packet mode
101: Test_Force_Enable
Others: Reserved

Bit 3 **GONSTS:** Global OUT NAK status
0: A handshake is sent based on the FIFO status and the NAK and STALL bit settings.
1: No data is written to the Rx FIFO, irrespective of space availability. Sends a NAK handshake on all packets, except on SETUP transactions. All isochronous OUT packets are dropped.

Bit 2 **GINSTS:** Global IN NAK status
0: A handshake is sent out based on the data availability in the transmit FIFO.
1: A NAK handshake is sent out on all non-periodic IN endpoints, irrespective of the data availability in the transmit FIFO.

Bit 1 **SDIS:** Soft disconnect
The application uses this bit to signal the USB OTG core to perform a soft disconnect. As long as this bit is set, the host does not see that the device is connected, and the device does not receive signals on the USB. The core stays in the disconnected state until the application clears this bit.
0: Normal operation. When this bit is cleared after a soft disconnect, the core generates a device connect event to the USB host. When the device is reconnected, the USB host restarts device enumeration.
1: The core generates a device disconnect event to the USB host.

Bit 0 **RWUSIG:** Remote wake-up signaling
When the application sets this bit, the core initiates remote signaling to wake up the USB host. The application must set this bit to instruct the core to exit the suspend state. As specified in the USB 2.0 specification, the application must clear this bit 1 ms to 15 ms after setting it.
If LPM is enabled and the core is in the L1 (sleep) state, when the application sets this bit, the core initiates L1 remote signaling to wake up the USB host. The application must set this bit to instruct the core to exit the sleep state. As specified in the LPM specification, the hardware automatically clears this bit 50 µs ($T_{L1DevDrvResume}$) after being set by the application. The application must not set this bit when bRemoteWake from the previous LPM transaction is zero (refer to REMWAKE bit in GLPMCFG register).

Table 751 contains the minimum duration (according to device state) for which the Soft disconnect (SDIS) bit must be set for the USB host to detect a device disconnect. To accommodate clock jitter, it is recommended that the application add some extra delay to the specified minimum duration.

Table 751. Minimum duration for soft disconnect

Operating speed	Device state	Minimum duration
Full speed	Suspended	1 ms + 2.5 µs
Full speed	Idle	2.5 µs
Full speed	Not Idle or suspended (Performing transactions)	2.5 µs
High speed	Not Idle or suspended (Performing transactions)	125 µs

67.14.40 OTG device status register (OTG_DSTS)

This register indicates the status of the core with respect to USB-related events. It must be read on interrupts from the device all interrupts (OTG_DAINT) register.

Address offset: 0x808

Reset value: 0x0000 0010

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEVLNSTS[1:0]		FNSOF[13:8]					
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FNSOF[7:0]								Res.	Res.	Res.	Res.	EERR	ENUMSPD[1:0]		SUSP STS
r	r	r	r	r	r	r	r					r	r	r	r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:22 **DEVLNSTS[1:0]:** Device line status

Indicates the current logic level USB data lines.
Bit [23]: Logic level of D+
Bit [22]: Logic level of D-

Bits 21:8 **FNSOF[13:0]:** Frame number of the received SOF

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **EERR:** Erratic error

The core sets this bit to report any erratic errors.
Due to erratic errors, the OTG_HS controller goes into suspended state and an interrupt is generated to the application with Early suspend bit of the OTG_GINTSTS register (ESUSP bit in OTG_GINTSTS). If the early suspend is asserted due to an erratic error, the application can only perform a soft disconnect recover.

Bits 2:1 **ENUMSPD[1:0]:** Enumerated speed

Indicates the speed at which the OTG_HS controller has come up after speed detection through a chirp sequence.
00: High Speed
01: Full Speed
11: Reserved
Others: reserved

Bit 0 **SUSPSTS:** Suspend status

In device mode, this bit is set as long as a suspend condition is detected on the USB. The core enters the suspended state when there is no activity on the USB data lines for a period of 3 ms. The core comes out of the suspend:

– When there is an activity on the USB data lines
– When the application writes to the remote wake-up signaling bit in the OTG_DCTL register (RWUSIG bit in OTG_DCTL).

67.14.41 OTG device IN endpoint common interrupt mask register (OTG_DIEPMSK)

This register works with each of the OTG_DIEPINTx registers for all endpoints to generate an interrupt per IN endpoint. The IN endpoint interrupt for a specific status in the OTG_DIEPINTx register can be masked by writing to the corresponding bit in this register. Status bits are masked by default.

Address offset: 0x810

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	NAKM	Res.	Res.	Res.	Res.	TXFURM	Res.	INEPNEM	INEPNMM	ITTXFEMSK	TOM	AHBERRM	EPDM	XFRCM
		rw					rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **NAKM:** NAK interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 12:10 Reserved, must be kept at reset value.

Bit 9 Reserved, must be kept at reset value.

Bit 8 **TXFURM:** FIFO underrun mask
0: Masked interrupt
1: Unmasked interrupt

Bit 7 Reserved, must be kept at reset value.

Bit 6 **INEPNEM:** IN endpoint NAK effective mask
0: Masked interrupt
1: Unmasked interrupt

Bit 5 **INEPNMM:** IN token received with EP mismatch mask
0: Masked interrupt
1: Unmasked interrupt

Bit 4 **ITTXFEMSK:** IN token received when Tx FIFO empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **TOM:** Timeout condition mask (Non-isochronous endpoints)
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **AHBERRM:** AHB error mask
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **EPDM:** Endpoint disabled interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed interrupt mask
0: Masked interrupt
1: Unmasked interrupt

67.14.42 OTG device OUT endpoint common interrupt mask register (OTG_DOEPMSK)

This register works with each of the OTG_DOEPINTx registers for all endpoints to generate an interrupt per OUT endpoint. The OUT endpoint interrupt for a specific status in the OTG_DOEPINTx register can be masked by writing into the corresponding bit in this register. Status bits are masked by default.

Address offset: 0x814

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	NYET MSK	NAK MSK	BERR M	Res.	Res.	Res.	OUT PKT ERRM	Res.	B2B STUPM	STS PHSR XM	OTEPD M	STUPM	AHB ERRM	EPDM	XFRC M
	rw	rw	rw				rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **NYETMSK:** NYET interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 13 **NAKMSK:** NAK interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 12 **BERRM**: Babble error interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 Reserved, must be kept at reset value.

Bit 8 **OUTPKTERRM:** Out packet error mask
0: Masked interrupt
1: Unmasked interrupt

Bit 7 Reserved, must be kept at reset value.

Bit 6 **B2BSTUPM:** Back-to-back SETUP packets received mask
Applies to control OUT endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 5 **STSPHSRXM**: Status phase received for control write mask
0: Masked interrupt
1: Unmasked interrupt

Bit 4 **OTEPDM:** OUT token received when endpoint disabled mask. Applies to control OUT endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **STUPM:** SETUP phase done mask. Applies to control endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **AHBERRM:** AHB error mask
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **EPDM:** Endpoint disabled interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed interrupt mask
0: Masked interrupt
1: Unmasked interrupt

67.14.43 OTG device all endpoints interrupt register (OTG_DAINT)

When a significant event occurs on an endpoint, a OTG_DAINT register interrupts the application using the device OUT endpoints interrupt bit or device IN endpoints interrupt bit of the OTG_GINTSTS register (OEPINT or IEPINT in OTG_GINTSTS, respectively). There is one interrupt bit per endpoint, up to a maximum of 16 bits for OUT endpoints and 16 bits for IN endpoints. For a bidirectional endpoint, the corresponding IN and OUT interrupt bits are used. Bits in this register are set and cleared when the application sets and clears bits in the corresponding device endpoint-x interrupt register (OTG_DIEPINTx/OTG_DOEPINTx).

Address offset: 0x818

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OEPINT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IEPINT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **OEPINT[15:0]:** OUT endpoint interrupt bits
One bit per OUT endpoint:
Bit 16 for OUT endpoint 0, bit 19 for OUT endpoint 3.

Bits 15:0 **IEPINT[15:0]:** IN endpoint interrupt bits
One bit per IN endpoint:
Bit 0 for IN endpoint 0, bit 3 for endpoint 3.

67.14.44 OTG all endpoints interrupt mask register (OTG_DAINTMSK)

The OTG_DAINTMSK register works with the device endpoint interrupt register to interrupt the application when an event occurs on a device endpoint. However, the OTG_DAINT register bit corresponding to that interrupt is still set.

Address offset: 0x81C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OEPM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IEPM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **OEPM[15:0]:** OUT EP interrupt mask bits
One per OUT endpoint:
Bit 16 for OUT EP 0, bit 19 for OUT EP 3
0: Masked interrupt
1: Unmasked interrupt

Bits 15:0 **IEPM[15:0]:** IN EP interrupt mask bits
One bit per IN endpoint:
Bit 0 for IN EP 0, bit 3 for IN EP 3
0: Masked interrupt
1: Unmasked interrupt

67.14.45 OTG device threshold control register (OTG_DTHRCTL)

Address offset: 0x0830

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	ARPEN	Res.	RXTHRLEN[8:0]									RXTHREN
				rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	TXTHRLEN[8:0]									ISOTHREN	NONISOTHREN
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **ARPEN:** Arbiter parking enable
This bit controls internal DMA arbiter parking for IN endpoints. When thresholding is enabled and this bit is set to one, then the arbiter parks on the IN endpoint for which there is a token received on the USB. This is done to avoid getting into underrun conditions. By default parking is enabled.

Bit 26 Reserved, must be kept at reset value.

Bits 25:17 **RXTHRLEN[8:0]:** Receive threshold length
This field specifies the receive thresholding size in 32-bit words. This field also specifies the amount of data received on the USB before the core can start transmitting on the AHB. The threshold length has to be at least eight 32-bit words. The recommended value for RXTHRLEN is to be the same as the programmed AHB burst length (HBSTLEN bit in OTG_GAHBCFG).

Bit 16 **RXTHREN:** Receive threshold enable
When this bit is set, the core enables thresholding in the receive direction.

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:2 **TXTHRLEN[8:0]:** Transmit threshold length
This field specifies the transmit thresholding size in 32-bit words. This field specifies the amount of data in bytes to be in the corresponding endpoint transmit FIFO, before the core can start transmitting on the USB. The threshold length has to be at least eight 32-bit words. This field controls both isochronous and nonisochronous IN endpoint thresholds. The recommended value for TXTHRLEN is to be the same as the programmed AHB burst length (HBSTLEN bit in OTG_GAHBCFG).

Bit 1 **ISOTHREN:** ISO IN endpoint threshold enable
When this bit is set, the core enables thresholding for isochronous IN endpoints.

Bit 0 **NONISOTHREN:** Nonisochronous IN endpoints threshold enable
When this bit is set, the core enables thresholding for nonisochronous IN endpoints.

67.14.46 OTG device IN endpoint FIFO empty interrupt mask register (OTG_DIEPEMPMSK)

This register is used to control the IN endpoint FIFO empty interrupt generation (TXFE_OTG_DIEPINTx).

Address offset: 0x834

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INEPTXFEM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **INEPTXFEM[15:0]:** IN EP Tx FIFO empty interrupt mask bits
These bits act as mask bits for OTG_DIEPINTx.
TXFE interrupt one bit per IN endpoint:
Bit 0 for IN endpoint 0, bit 3 for IN endpoint 3
0: Masked interrupt
1: Unmasked interrupt

67.14.47 OTG device IN endpoint x control register [alternate] (OTG_DIEPCTLx)

Valid for INT/BULK endpoints, see next section for ISO endpoints.

The application uses this register to control the behavior of each logical endpoint other than endpoint 0.

Address offset: 0x900 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	SD1 PID	SD0 PID	SNAK	CNAK	TXFNUM[3:0]				STALL	Res.	EPTYP[1:0]		NAK STS	DPID
rs	rs	w	w	w	w	rw	rw	rw	rw	rw		rw	rw	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	MPSIZ[10:0]										
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **EPENA:** Endpoint enable

The application sets this bit to start transmitting data on an endpoint.
The core clears this bit before setting any of the following interrupts on this endpoint:
– SETUP phase done
– Endpoint disabled
– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application sets this bit to stop transmitting/receiving data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the endpoint disabled interrupt. The application must set this bit only if endpoint enable is already set for this endpoint.

Bit 29 **SD1PID:** Set DATA1 PID

Writing to this field sets the endpoint data PID (DPID) field in this register to DATA1.

Bit 28 **SD0PID:** Set DATA0 PID

Applies to interrupt/bulk IN endpoints only.
Writing to this field sets the endpoint data PID (DPID) field in this register to DATA0.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.
Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for OUT endpoints on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 **TXFNUM[3:0]:** Tx FIFO number

These bits specify the FIFO number associated with this endpoint. Each active IN endpoint must be programmed to a separate FIFO number.
This field is valid only for IN endpoints.

Bit 21 **STALL:** STALL handshake

Applies to non-control, non-isochronous IN endpoints only (access type is rw).

The application sets this bit to stall all tokens from the USB host to this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Only the application can clear this bit, never the core.

Bit 20 Reserved, must be kept at reset value.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

This is the transfer type supported by this logical endpoint.

00: Control

01: Isochronous

10: Bulk

11: Interrupt

Bit 17 **NAKSTS:** NAK status

It indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status.

1: The core is transmitting NAK handshakes on this endpoint.

When either the application or the core sets this bit:

For non-isochronous IN endpoints: The core stops transmitting any data on an IN endpoint, even if there are data available in the Tx FIFO.

For isochronous IN endpoints: The core sends out a zero-length data packet, even if there are data available in the Tx FIFO.

Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 **DPID:** Endpoint data PID

Applies to interrupt/bulk IN endpoints only.

Contains the PID of the packet to be received or transmitted on this endpoint. The application must program the PID of the first packet to be received or transmitted on this endpoint, after the endpoint is activated. The application uses the SD0PID and SD1PID register fields to program either DATA0 or DATA1 PID.

0: DATA0

1: DATA1

Bit 15 **USBAEP:** USB active endpoint

Indicates whether this endpoint is active in the current configuration and interface. The core clears this bit for all endpoints (other than EP 0) after detecting a USB reset. After receiving the SetConfiguration and SetInterface commands, the application must program endpoint registers accordingly and set this bit.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size

The application must program this field with the maximum packet size for the current logical endpoint. This value is in bytes.

67.14.48 OTG device IN endpoint x control register [alternate] (OTG_DIEPCTLx)

Valid for ISO endpoints, see previous section for INT/BULK endpoints.

The application uses this register to control the behavior of each logical endpoint other than endpoint 0.

Address offset: 0x900 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	SODD FRM	SEVN FRM	SNAK	CNAK	TXFNUM[3:0]				STALL	Res.	EPTYP[1:0]		NAK STS	EO NUM
rs	rs	w	w	w	w	rw	rw	rw	rw	rw		rw	rw	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	MPSIZ[10:0]										
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **EPENA:** Endpoint enable

The application sets this bit to start transmitting data on an endpoint.
The core clears this bit before setting any of the following interrupts on this endpoint:
– SETUP phase done
– Endpoint disabled
– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application sets this bit to stop transmitting/receiving data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the endpoint disabled interrupt. The application must set this bit only if endpoint enable is already set for this endpoint.

Bit 29 **SODDFRM:** Set odd frame

Applies to isochronous IN and OUT endpoints only.
Writing to this field sets the Even/Odd frame (EONUM) field to odd frame.

Bit 28 **SEVNFRM:** Set even frame

Applies to isochronous IN endpoints only.
Writing to this field sets the Even/Odd frame (EONUM) field to even frame.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.
Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for OUT endpoints on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 **TXFNUM[3:0]:** Tx FIFO number

These bits specify the FIFO number associated with this endpoint. Each active IN endpoint must be programmed to a separate FIFO number.
This field is valid only for IN endpoints.

Bit 21 **STALL:** STALL handshake

Applies to non-control, non-isochronous IN endpoints only (access type is rw).

The application sets this bit to stall all tokens from the USB host to this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Only the application can clear this bit, never the core.

Bit 20 Reserved, must be kept at reset value.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

This is the transfer type supported by this logical endpoint.

00: Control

01: Isochronous

10: Bulk

11: Interrupt

Bit 17 **NAKSTS:** NAK status

It indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status.

1: The core is transmitting NAK handshakes on this endpoint.

When either the application or the core sets this bit:

For non-isochronous IN endpoints: The core stops transmitting any data on an IN endpoint, even if there are data available in the Tx FIFO.

For isochronous IN endpoints: The core sends out a zero-length data packet, even if there are data available in the Tx FIFO.

Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 **EONUM:** Even/odd frame

Applies to isochronous IN endpoints only.

Indicates the frame number in which the core transmits/receives isochronous data for this endpoint. The application must program the even/odd frame number in which it intends to transmit/receive isochronous data for this endpoint using the SEVNFRM and SODDFRM fields in this register.

0: Even frame

1: Odd frame

Bit 15 **USBAEP:** USB active endpoint

Indicates whether this endpoint is active in the current configuration and interface. The core clears this bit for all endpoints (other than EP 0) after detecting a USB reset. After receiving the SetConfiguration and SetInterface commands, the application must program endpoint registers accordingly and set this bit.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size

The application must program this field with the maximum packet size for the current logical endpoint. This value is in bytes.

67.14.49 OTG device IN endpoint x interrupt register (OTG_DIEPINTx)

This register indicates the status of an endpoint with respect to USB- and AHB-related events. It is shown in *Figure 958*. The application must read this register when the IN endpoints interrupt bit of the core interrupt register (IEPINT in OTG_GINTSTS) is set. Before the application can read this register, it must first read the device all endpoints interrupt (OTG_DAINT) register to get the exact endpoint number for the device endpoint-x interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_DAINT and OTG_GINTSTS registers.

Address offset: 0x908 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0080

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	NAK	Res.	PKTDRPSTS	Res.	Res.	TXFIFOUDRN	TXFE	INEPNE	INEPNM	ITTXFE	TOC	AHBERR	EPDISD	XFRC
		rc_w1		rc_w1			rc_w1	r	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **NAK:** NAK input

The core generates this interrupt when a NAK is transmitted or received by the device. In case of isochronous IN endpoints the interrupt gets generated when a zero length packet is transmitted due to unavailability of data in the Tx FIFO.

Bit 12 Reserved, must be kept at reset value.

Bit 11 **PKTDRPSTS:** Packet dropped status

This bit indicates to the application that an ISOC OUT packet has been dropped. This bit does not have an associated mask bit and does not generate an interrupt.

Bit 10 Reserved, must be kept at reset value.

Bit 9 Reserved, must be kept at reset value.

Bit 8 **TXFIFOUDRN:** Transmit Fifo Underrun (TxfifoUndrn)

The core generates this interrupt when it detects a transmit FIFO underrun condition for this endpoint. Dependency: This interrupt is valid only when Thresholding is enabled

Bit 7 **TXFE:** Transmit FIFO empty

This interrupt is asserted when the Tx FIFO for this endpoint is either half or completely empty. The half or completely empty status is determined by the Tx FIFO Empty Level bit in the OTG_GAHBCFG register (TXFELVL bit in OTG_GAHBCFG).

Bit 6 **INEPNE:** IN endpoint NAK effective

This bit can be cleared when the application clears the IN endpoint NAK by writing to the CNAK bit in OTG_DIEPCTLx.

This interrupt indicates that the core has sampled the NAK bit set (either by the application or by the core). The interrupt indicates that the IN endpoint NAK bit set by the application has taken effect in the core.

This interrupt does not guarantee that a NAK handshake is sent on the USB. A STALL bit takes priority over a NAK bit.

Bit 5 **INEPNM**: IN token received with EP mismatch

Indicates that the data in the top of the non-periodic TxFIFO belongs to an endpoint other than the one for which the IN token was received. This interrupt is asserted on the endpoint for which the IN token was received.

Bit 4 **ITTXFE:** IN token received when Tx FIFO is empty

Indicates that an IN token was received when the associated Tx FIFO (periodic/non-periodic) was empty. This interrupt is asserted on the endpoint for which the IN token was received.

Bit 3 **TOC:** Timeout condition

Indicates that the core has detected a timeout condition on the USB for the last IN token on this endpoint.

Bit 2 **AHBERR**: AHB error

This is generated only in internal DMA mode when there is an AHB error during an AHB read/write. The application can read the corresponding endpoint DMA address register to get the error address.

Bit 1 **EPDISD:** Endpoint disabled interrupt

This bit indicates that the endpoint is disabled per the application's request.

Bit 0 **XFRC:** Transfer completed interrupt

This field indicates that the programmed transfer is complete on the AHB as well as on the USB, for this endpoint.

67.14.50 OTG device IN endpoint 0 transfer size register (OTG_DIEPTSIZ0)

The application must modify this register before enabling endpoint 0. Once endpoint 0 is enabled using the endpoint enable bit in the device control endpoint 0 control registers (EPENA in OTG_DIEPCTL0), the core modifies this register. The application can only read this register once the core has cleared the endpoint enable bit.

Nonzero endpoints use the registers for endpoints 1–3.

Address offset: 0x910

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTCNT[1:0]		Res.	Res.	Res.
											rw	rw			

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XFRSIZ[6:0]						
									rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:19 **PKTCNT[1:0]:** Packet count

Indicates the total number of USB packets that constitute the transfer size amount of data for endpoint 0.

This field is decremented every time a packet (maximum size or short packet) is read from the Tx FIFO.

Bits 18:7 Reserved, must be kept at reset value.

Bits 6:0 **XFRSIZ[6:0]:** Transfer size

Indicates the transfer size in bytes for endpoint 0. The core interrupts the application only after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.

The core decrements this field every time a packet from the external memory is written to the Tx FIFO.

67.14.51 OTG device IN endpoint x DMA address register (OTG_DIEPDMAx)

Address offset: 0x914 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMAADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAADDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DMAADDR[31:0]:** DMA Address

This field holds the start address in the external memory from which the data for the endpoint must be fetched. This register is incremented on every AHB transaction.

67.14.52 OTG device IN endpoint transmit FIFO status register (OTG_DTXFSTSx)

This read-only register contains the free space information for the device IN endpoint Tx FIFO.

Address offset: 0x918 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INEPTFSAV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **INEPTFSAV[15:0]:** IN endpoint Tx FIFO space available

Indicates the amount of free space available in the endpoint Tx FIFO.

Values are in terms of 32-bit words:

0x0: Endpoint Tx FIFO is full

0x1: 1 word available

0x2: 2 words available

0xn: n words available

Others: Reserved

67.14.53 OTG device IN endpoint x transfer size register (OTG_DIEPTSIZx)

The application must modify this register before enabling the endpoint. Once the endpoint is enabled using the endpoint enable bit in the OTG_DIEPCTLx registers (EPENA bit in OTG_DIEPCTLx), the core modifies this register. The application can only read this register once the core has cleared the endpoint enable bit.

Address offset: 0x910 + 0x20 * x, (x = 1 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	MCNT[1:0]		PKTCNT[9:0]										XFRSIZ[18:16]		
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XFRSIZ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **MCNT[1:0]:** Multi count

For periodic IN endpoints, this field indicates the number of packets that must be transmitted per frame on the USB. The core uses this field to calculate the data PID for isochronous IN endpoints.

01: 1 packet

10: 2 packets

11: 3 packets

Bits 28:19 **PKTCNT[9:0]:** Packet count

Indicates the total number of USB packets that constitute the transfer size amount of data for this endpoint.

This field is decremented every time a packet (maximum size or short packet) is read from the Tx FIFO.

Bits 18:0 **XFRSIZ[18:0]:** Transfer size

This field contains the transfer size in bytes for the current endpoint. The core only interrupts the application after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.

The core decrements this field every time a packet from the external memory is written to the Tx FIFO.

67.14.54 OTG device control OUT endpoint 0 control register (OTG_DOEPCTL0)

This section describes the OTG_DOEPCTL0 register. Nonzero control endpoints use registers for endpoints 1–8.

Address offset: 0xB00

Reset value: 0x0000 8000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	Res.	Res.	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EPTYP[1:0]		NAK STS	Res.
w	r			w	w					rs	rw	r	r	r	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MPSIZ[1:0]	
r														r	r

Bit 31 **EPENA:** Endpoint enable

The application sets this bit to start transmitting data on endpoint 0.
The core clears this bit before setting any of the following interrupts on this endpoint:

– SETUP phase done
– Endpoint disabled
– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application cannot disable control OUT endpoint 0.

Bits 29:28 Reserved, must be kept at reset value.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.
Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **STALL:** STALL handshake

The application can only set this bit, and the core clears it, when a SETUP token is received for this endpoint. If a NAK bit or Global OUT NAK is set along with this bit, the STALL bit takes priority. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 20 **SNPM:** Snoop mode

This bit configures the endpoint to Snoop mode. In Snoop mode, the core does not check the correctness of OUT packets before transferring them to application memory.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

Hardcoded to 00 for control.

Bit 17 **NAKSTS:** NAK status

Indicates the following:
0: The core is transmitting non-NAK handshakes based on the FIFO status.
1: The core is transmitting NAK handshakes on this endpoint.
When either the application or the core sets this bit, the core stops receiving data, even if there is space in the Rx FIFO to accommodate the incoming packet. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **USBAEP:** USB active endpoint

This bit is always set to 1, indicating that a control endpoint 0 is always active in all configurations and interfaces.

Bits 14:2 Reserved, must be kept at reset value.

Bits 1:0 **MPSIZ[1:0]:** Maximum packet size

The maximum packet size for control OUT endpoint 0 is the same as what is programmed in control IN endpoint 0.
00: 64 bytes
01: 32 bytes
10: 16 bytes
11: 8 bytes

67.14.55 OTG device OUT endpoint x interrupt register (OTG_DOEPINTx)

This register indicates the status of an endpoint with respect to USB- and AHB-related events. It is shown in *Figure 958*. The application must read this register when the OUT endpoints interrupt bit of the OTG_GINTSTS register (OEPINT bit in OTG_GINTSTS) is set. Before the application can read this register, it must first read the OTG_DAINT register to get the exact endpoint number for the OTG_DOEPINTx register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_DAINT and OTG_GINTSTS registers.

Address offset: 0xB08 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0080

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STPK TRX	NYET	NAK	BERR	Res.	Res.	Res.	OUT PKT ERR	Res.	B2B STUP	STSPH SRX	OTEP DIS	STUP	AHB ERR	EP DISD	XFRC
rc_w1	rc_w1	rc_w1	rc_w1				rc_w1		rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **STPKTRX:** Setup packet received

Applicable for control OUT endpoints in only in the Buffer DMA Mode. Set by the OTG_HS, this bit indicates that this buffer holds 8 bytes of setup data. There is only one setup packet per buffer. On receiving a setup packet, the OTG_HS closes the buffer and disables the corresponding endpoint after SETUP_COMPLETE status is seen in the Rx FIFO. OTG_HS puts a SETUP_COMPLETE status into the Rx FIFO when it sees the first IN or OUT token after the SETUP packet for that particular endpoint. The application must then re-enable the endpoint to receive any OUT data for the control transfer and reprogram the buffer start address. Because of the above behavior, OTG_HS can receive any number of back to back setup packets and one buffer for every setup packet is used.

Bit 14 **NYET:** NYET interrupt

This interrupt is generated when a NYET response is transmitted for a non isochronous OUT endpoint.

Bit 13 **NAK:** NAK input

The core generates this interrupt when a NAK is transmitted or received by the device. In case of isochronous IN endpoints the interrupt gets generated when a zero length packet is transmitted due to unavailability of data in the Tx FIFO.

Bit 12 **BERR:** Babble error interrupt
The core generates this interrupt when babble is received for the endpoint.

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 Reserved, must be kept at reset value.

Bit 8 **OUTPKTERR**: OUT packet error
This interrupt is asserted when the core detects an overflow or a CRC error for an OUT packet. This interrupt is valid only when thresholding is enabled.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **B2BSTUP:** Back-to-back SETUP packets received
Applies to control OUT endpoint only.
This bit indicates that the core has received more than three back-to-back SETUP packets for this particular endpoint.

Bit 5 **STSPHSRX**: Status phase received for control write
This interrupt is valid only for control OUT endpoints. This interrupt is generated only after OTG_HS has transferred all the data that the host has sent during the data phase of a control write transfer, to the system memory buffer. The interrupt indicates to the application that the host has switched from data phase to the status phase of a control write transfer. The application can use this interrupt to ACK or STALL the status phase, after it has decoded the data phase.

Bit 4 **OTEPDIS:** OUT token received when endpoint disabled
Applies only to control OUT endpoints.
Indicates that an OUT token was received when the endpoint was not yet enabled. This interrupt is asserted on the endpoint for which the OUT token was received.

Bit 3 **STUP:** SETUP phase done
Applies to control OUT endpoint only.Indicates that the SETUP phase for the control endpoint is complete and no more back-to-back SETUP packets were received for the current control transfer. On this interrupt, the application can decode the received SETUP data packet.

Bit 2 **AHBERR**: AHB error
This is generated only in internal DMA mode when there is an AHB error during an AHB read/write. The application can read the corresponding endpoint DMA address register to get the error address.

Bit 1 **EPDISD:** Endpoint disabled interrupt
This bit indicates that the endpoint is disabled per the application’s request.

Bit 0 **XFRC:** Transfer completed interrupt
This field indicates that the programmed transfer is complete on the AHB as well as on the USB, for this endpoint.

67.14.56 OTG device OUT endpoint 0 transfer size register (OTG_DOEPTSIZ0)

The application must modify this register before enabling endpoint 0. Once endpoint 0 is enabled using the endpoint enable bit in the OTG_DOEPCTL0 registers (EPENA bit in OTG_DOEPCTL0), the core modifies this register. The application can only read this register once the core has cleared the endpoint enable bit.

Nonzero endpoints use the registers for endpoints 1–8.

Address offset: 0xB10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	STUPCNT[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTCNT	Res.	Res.	Res.
	rw	rw										rw			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XFRSIZ[6:0]						
									rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **STUPCNT[1:0]:** SETUP packet count

This field specifies the number of back-to-back SETUP data packets the endpoint can receive.
01: 1 packet
10: 2 packets
11: 3 packets

Bits 28:20 Reserved, must be kept at reset value.

Bit 19 **PKTCNT:** Packet count

This field is decremented to zero after a packet is written into the Rx FIFO.

Bits 18:7 Reserved, must be kept at reset value.

Bits 6:0 **XFRSIZ[6:0]:** Transfer size

Indicates the transfer size in bytes for endpoint 0. The core interrupts the application only after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.
The core decrements this field every time a packet is read from the Rx FIFO and written to the external memory.

67.14.57 OTG device OUT endpoint x DMA address register (OTG_DOEPDMAx)

Address offset: 0xB14 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMAADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAADDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DMAADDR[31:0]:** DMA Address

This field holds the start address in the external memory from which the data for the endpoint must be fetched. This register is incremented on every AHB transaction.

67.14.58 OTG device OUT endpoint x control register [alternate] (OTG_DOEPCTLx)

Valid for INT/BULK endpoints, see next section for ISO endpoints.

The application uses this register to control the behavior of each logical endpoint other than endpoint 0.

Address offset: 0xB00 + 0x20 * x, (x = 1 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	SD1 PID	SD0 PID	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EPTYP[1:0]		NAK STS	DPID
rs	rs	w	w	w	w					rw	rw	rw	rw	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	MPSIZ[10:0]										
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **EPENA:** Endpoint enable

Applies to IN and OUT endpoints.

The application sets this bit to start transmitting data on an endpoint.

The core clears this bit before setting any of the following interrupts on this endpoint:

– SETUP phase done

– Endpoint disabled

– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application sets this bit to stop transmitting/receiving data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the endpoint disabled interrupt. The application must set this bit only if endpoint enable is already set for this endpoint.

Bit 29 **SD1PID:** Set DATA1 PID
Writing to this field sets the endpoint data PID (DPID) field in this register to DATA1.

Bit 28 **SD0PID:** Set DATA0 PID
Applies to interrupt/bulk OUT endpoints only.
Writing to this field sets the endpoint data PID (DPID) field in this register to DATA0.

Bit 27 **SNAK:** Set NAK
A write to this bit sets the NAK bit for the endpoint.
Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for OUT endpoints on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK
A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **STALL:** STALL handshake
Applies to non-control, non-isochronous OUT endpoints only (access type is rw).
The application sets this bit to stall all tokens from the USB host to this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Only the application can clear this bit, never the core.
Applies to control endpoints only (access type is rs).
The application can only set this bit, and the core clears it, when a SETUP token is received for this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 20 **SNPM:** Snoop mode
This bit configures the endpoint to Snoop mode. In Snoop mode, the core does not check the correctness of OUT packets before transferring them to application memory.

Bits 19:18 **EPTYP[1:0]:** Endpoint type
This is the transfer type supported by this logical endpoint.
00: Control
01: Isochronous
10: Bulk
11: Interrupt

Bit 17 **NAKSTS:** NAK status
Indicates the following:
0: The core is transmitting non-NAK handshakes based on the FIFO status.
1: The core is transmitting NAK handshakes on this endpoint.
When either the application or the core sets this bit:
The core stops receiving any data on an OUT endpoint, even if there is space in the Rx FIFO to accommodate the incoming packet.
Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 **DPID:** Endpoint data PID

Applies to interrupt/bulk OUT endpoints only.

Contains the PID of the packet to be received or transmitted on this endpoint. The application must program the PID of the first packet to be received or transmitted on this endpoint, after the endpoint is activated. The application uses the SD0PID and SD1PID register fields to program either DATA0 or DATA1 PID.

0: DATA0

1: DATA1

Bit 15 **USBAEP:** USB active endpoint

Indicates whether this endpoint is active in the current configuration and interface. The core clears this bit for all endpoints (other than EP 0) after detecting a USB reset. After receiving the SetConfiguration and SetInterface commands, the application must program endpoint registers accordingly and set this bit.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size

The application must program this field with the maximum packet size for the current logical endpoint. This value is in bytes.

67.14.59 OTG device OUT endpoint x control register [alternate] (OTG_DOEPCTLx)

Valid for ISO endpoints, see previous section for INT/BULK endpoints.

The application uses this register to control the behavior of each logical endpoint other than endpoint 0.

Address offset: 0xB00 + 0x20 * x, (x = 1 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	SODD FRM	SEVN FRM	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EPTYP[1:0]		NAK STS	EO NUM
rs	rs	w	w	w	w					rw	rw	rw	rw	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	MPSIZ[10:0]										
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **EPENA:** Endpoint enable

Applies to IN and OUT endpoints.

The application sets this bit to start transmitting data on an endpoint.

The core clears this bit before setting any of the following interrupts on this endpoint:

– SETUP phase done

– Endpoint disabled

– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application sets this bit to stop transmitting/receiving data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the endpoint disabled interrupt. The application must set this bit only if endpoint enable is already set for this endpoint.

Bit 29 **SODDFRM:** Set odd frame

Applies to isochronous IN and OUT endpoints only.
Writing to this field sets the Even/Odd frame (EONUM) field to odd frame.

Bit 28 **SEVNFRM:** Set even frame

Applies to isochronous OUT endpoints only.
Writing to this field sets the Even/Odd frame (EONUM) field to even frame.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.
Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for OUT endpoints on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **STALL:** STALL handshake

Applies to non-control, non-isochronous OUT endpoints only (access type is rw).
The application sets this bit to stall all tokens from the USB host to this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Only the application can clear this bit, never the core.
Applies to control endpoints only (access type is rs).
The application can only set this bit, and the core clears it, when a SETUP token is received for this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 20 **SNPM:** Snoop mode

This bit configures the endpoint to Snoop mode. In Snoop mode, the core does not check the correctness of OUT packets before transferring them to application memory.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

This is the transfer type supported by this logical endpoint.
00: Control
01: Isochronous
10: Bulk
11: Interrupt

Bit 17 **NAKSTS:** NAK status

Indicates the following:
0: The core is transmitting non-NAK handshakes based on the FIFO status.
1: The core is transmitting NAK handshakes on this endpoint.
When either the application or the core sets this bit:
The core stops receiving any data on an OUT endpoint, even if there is space in the Rx FIFO to accommodate the incoming packet.
Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 **EONUM:** Even/odd frame

Applies to isochronous OUT endpoints only.

Indicates the frame number in which the core transmits/receives isochronous data for this endpoint. The application must program the even/odd frame number in which it intends to transmit/receive isochronous data for this endpoint using the SEVNFRM and SODDFRM fields in this register.

0: Even frame

1: Odd frame

Bit 15 **USBAEP:** USB active endpoint

Indicates whether this endpoint is active in the current configuration and interface. The core clears this bit for all endpoints (other than EP 0) after detecting a USB reset. After receiving the SetConfiguration and SetInterface commands, the application must program endpoint registers accordingly and set this bit.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size

The application must program this field with the maximum packet size for the current logical endpoint. This value is in bytes.

67.14.60 OTG device OUT endpoint x transfer size register (OTG_DOEPTSIZx)

The application must modify this register before enabling the endpoint. Once the endpoint is enabled using endpoint enable bit of the OTG_DOEPCTLx registers (EPENA bit in OTG_DOEPCTLx), the core modifies this register. The application can only read this register once the core has cleared the endpoint enable bit.

Address offset: 0xB10 + 0x20 * x, (x = 1 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	RXDPID[1:0]		PKTCNT[9:0]										XFRSIZ[18:16]		
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XFRSIZ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **RXDPID[1:0]:**

Condition: isochronous OUT endpoints
Received data PID
This is the data PID received in the last packet for this endpoint.
00: DATA0
01: DATA2
10: DATA1
11: MDATA
Condition: control OUT endpoints
STUPCNT[1:0]: SETUP packet count
This field specifies the number of back-to-back SETUP data packets the endpoint can receive.
01: 1 packet
10: 2 packets
11: 3 packets

Bits 28:19 **PKTCNT[9:0]:** Packet count

Indicates the total number of USB packets that constitute the transfer size amount of data for this endpoint.
This field is decremented every time a packet (maximum size or short packet) is written to the Rx FIFO.

Bits 18:0 **XFRSIZ[18:0]:** Transfer size

This field contains the transfer size in bytes for the current endpoint. The core only interrupts the application after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.
The core decrements this field every time a packet is read from the Rx FIFO and written to the external memory.

67.14.61 OTG power and clock gating control register (OTG_PCGCCTL)

This register is available in host and device modes.

Address offset: 0xE00

Reset value: 0x200B 8000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUSP	PHY SLEEP	ENL1 GTG	PHY SUSP	Res.	Res.	GATE HCLK	STPP CLK
								r	r	rw	r			rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **SUSP:** Deep Sleep

This bit indicates that the PHY is in Deep Sleep when in L1 state.

Bit 6 **PHYSLEEP:** PHY in Sleep

This bit indicates that the PHY is in the Sleep state.

Bit 5 **ENL1GTG:** Enable sleep clock gating

When this bit is set, core internal clock gating is enabled in Sleep state if the core cannot assert utmi_l1_suspend_n. When this bit is not set, the PHY clock is not gated in Sleep state.

Bit 4 **PHYSUSP:** PHY suspended

Indicates that the PHY has been suspended. This bit is updated once the PHY is suspended after the application has set the STPPCLK bit.

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **GATEHCLK:** Gate HCLK

The application sets this bit to gate HCLK to modules other than the AHB Slave and Master and wake-up logic when the USB is suspended or the session is not valid. The application clears this bit when the USB is resumed or a new session starts.

Bit 0 **STPPCLK:** Stop PHY clock

The application sets this bit to stop the PHY clock when the USB is suspended, the session is not valid, or the device is disconnected. The application clears this bit when the USB is resumed or a new session starts.

67.14.62 OTG power and clock gating control register 1 (OTG_PCGCCTL1)

This register is available in host and device modes.

Address offset: 0xE04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RAM GATE EN	CNTGATECLK [1:0]		GATE EN
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **RAMGATEEN:** Enable RAM clock gating

Enable gating of the FIFO RAM.

Bits 2:1 **CNTGATECLK[1:0]:** Counter for clock gating

Indicates to the controller how many PHY Clock cycles and AHB Clock cycles of 'IDLE' (no activity) the controller waits for before Gating the respective PHY and AHB clocks internal to the controller.

00: 64 clocks

01: 128 clocks

10: Reserved

11: Reserved

Bit 0 **GATEEN:** Enable active clock gating

The application programs GATEEN to enable Active Clock Gating feature for the PHY and AHB clocks.

67.14.63 OTG_HS register map

The table below gives the USB OTG register map and reset values.

Table 752. OTG_HS register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	OTG_ GOTGCTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CURMOD	OTGVER	BSVLD	ASVLD	DBCT	CIDSTS	Res.	Res.	Res.	EHEN	Res.	Res.	Res.	Res.	BVALOVAL	BVALOEN	AVALOVAL	AVALOEN	VBVALOVA	VBVALOEN	Res.	Res.
	Reset value											0	0	0	0	0	1				0					0	0	0	0	0	0		
0x004	OTG_ GOTGINT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADTOCHG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEDET	Res.	Res.
	Reset value														0								-								0		
0x008	OTG_ GAHBCFG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PTXFELVL	TXFELVL	Res.	DMAEN	HBSTLEN				GINTMSK
	Reset value																								0	0		0	0	0	0	0	0
0x00C	OTG_ GUSBCFG	Res.	FDMOD	FHMOD	Res.	Res.	Res.	Res.	Res.	Res.	TSDPS	Res.	Res.	Res.	Res.	Res.	Res.	PHYLPC	Res.	TRDT				Res.	Res.	Res.	Res.	Res.	Res.	Res.	TOCAL		
	Reset value		0	0							0							0		0	1	0	1								0	0	0
0x010	OTG_GRSTCTL	AHBIDL	DMAREQ	CSRSTDONE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXFNUM					TXFFLSH	RXFFLSH	Res.	FCRST	PSRST	CSRST
	Reset value	1	0	0																			0	0	0	0	0	0	0		0	0	0
0x014	OTG_GINTSTS (Device mode)	WKUPINT	SRQINT	DISCINT	CIDSCHG	LPMINT	PTXFE	HCINT	HPRTINT	RSTDET	DATAFSUSP	IPXFR	IISOIXFR	OEPINT	IEPINT	Res.	Res.	EOPF	ISOODRP	ENUMDNE	USBRST	USBSUSP	ESUSP	Res.	Res.	GONAKEFF	GINAKEFF	NPTXFE	RXFLVL	SOF	OTGINT	MMIS	CMOD
	Reset value	0	0	0	0	0	1	0	0	0	0	0	0	0	0			0	0	0	0	0	0			0	0	1	0	0	0	0	0
	OTG_GINTSTS (Host mode)	WKUPINT	SRQINT	DISCINT	CIDSCHG	LPMINT	PTXFE	HCINT	HPRTINT	RSTDET	DATAFSUSP	INCOMPISOOUT	IISOIXFR	OEPINT	IEPINT	Res.	Res.	EOPF	ISOODRP	ENUMDNE	USBRST	USBSUSP	ESUSP	Res.	Res.	GONAKEFF	GINAKEFF	NPTXFE	RXFLVL	SOF	OTGINT	MMIS	CMOD
	Reset value	0	0	0	0	0	1	0	0	0	0	0	0	0	0			0	0	0	0	0	0			0	0	1	0	0	0	0	0

Table 752. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x018	OTG_GINTMSK (Device mode)	WUIM	SRQIM	DISCINT	CIDSCHGM	LPMINTM	PTXFEM	HCIM	PRTIM	RSTDETM	FSUSPM	IPXFRM	IISOIXFRM	OEPINT	IEPINT	Res.	Res.	EOPFM	ISOODRPM	ENUMDNEM	USBRST	USBSUSPM	ESUSPM	Res.	Res.	GONAKEFFM	GINAKEFFM	NPTXFEM	RXFLVLM	SOFM	OTGINT	MMISM	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0	0	
	OTG_GINTMSK (Host mode)	WUIM	SRQIM	DISCINT	CIDSCHGM	LPMINTM	PTXFEM	HCIM	PRTIM	RSTDETM	FSUSPM	IISOOXFRM	IISOIXFRM	OEPINT	IEPINT	Res.	Res.	EOPFM	ISOODRPM	ENUMDNEM	USBRST	USBSUSPM	ESUSPM	Res.	Res.	GONAKEFFM	GINAKEFFM	NPTXFEM	RXFLVLM	SOFM	OTGINT	MMISM	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0	0	
0x01C	OTG_GRXSTSR (Device mode)	Res.	Res.	Res.	Res.	STSPHST	Res.	Res.	FRMNUM				PKTSTS				DPID		BCNT											EPNUM			
	Reset value					0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OTG_GRXSTSR (Host mode)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTSTS				DPID		BCNT											CHNUM			
	Reset value												0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	OTG_GRXSTSP (Device mode)	Res.	Res.	Res.	Res.	STSPHST	Res.	Res.	FRMNUM				PKTSTS				DPID		BCNT											EPNUM			
	Reset value					0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OTG_ GRXSTSP (Host mode)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTSTS				DPID		BCNT											CHNUM			
	Reset value												0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	OTG_ GRXFSIZ	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXFD															
	Reset value																	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x028	OTG_ HNPTXFSIZ (Device mode)	NPTXFD																NPTXFSA															
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	OTG_ DIEPTXF0 (Host mode)	TX0FD																TX0FSA															
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x02C	OTG_ HNPTXSTS	Res.	NPTXQTOP							NPTQXSAV								NPTXFSAV															
	Reset value		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x038	OTG_GCCFG	Res.	Res.	Res.	Res.	Res.		FORCEHOSTPD	VBVALOVEN	FORCEHOSTPD	SDEN	Res.	PDEN	DCDEN	HVDMSRCEN	HCDPDETEN	HCDPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSVMINUS	FSVPLUS	CHGDET
	Reset value						0	0	0	0	0		0	0	0	0	0														X	X	X

Table 752. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x03C	**OTG_CID**	PRODUCT_ID																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0
0x054	OTG_GLPMCFG	Res.	Res.	Res.	ENBESL	LPMR CNTSTS			SNDLPM	LPM RCNT			LPMCHIDX				L1RSMOK	SLPSTS	LPM RSP		L1DSEN	BESLTHRS				L1SSEN	REMWAKE	BESL				LPMACK	LPMEN
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x100	OTG_HPTXFSIZ	PTXFSIZ																PTXSA															
	Reset value	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
0x104	OTG_ DIEPTXF1	INEPTXFD																INEPTXSA															
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
. . . .	. . . .	.																															
0x120	OTG_DIEPTXF7	INEPTXFD																INEPTXSA															
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
0x400	OTG_HCFG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSLSS	FSLS PCS	
	Reset value																														0	0	0
0x404	OTG_HFIR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RLDCTRL	FRIVL															
	Reset value																0	1	1	1	0	1	0	1	0	0	1	1	0	0	0	0	0
0x408	OTG_HFNUM	FTREM																FRNUM															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x410	OTG_HPTXSTS	PTXQTOP								PTXQSAV								PTXFSAVL															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0x414	OTG_HAINT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HAINT															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x418	OTG_ HAINTMSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HAINTM															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x440	OTG_HPRT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSP D	PTCTL					PPWR	PLSTS		Res.	PRST	PSUSP	PRES	POCCHNG	POCA	PENCHNG	PENA	PCDET	PCSTS
	Reset value														0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0
0x500	OTG_ HCCHAR0	CHENA	CHDIS	ODDFRM	DAD							MCNT		EPTYP	LSDEV	Res.	EPDIR	EPNUM				MPSIZ											
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 752. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x504	OTG_ HCSPLT0	SPLITEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COMPLSPLT	XACTPOS		HUBADDR							PRTADDR							
	Reset value	0															0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x508	OTG_HCINT0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERR	FRMOR	BBERR	TXERR	Res.	ACK	NAK	STALL	Res.	CHH	XFRC
	Reset value																						0	0	0	0		0	0	0		0	0
0x508	OTG_HCINT0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERR	FRMOR	BBERR	TXERR	NYET	ACK	NAK	STALL	AHBERR	CHH	XFRC
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x50C	OTG_ HCINTMSK0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERRM	FRMORM	BBERRM	TXERRM	NYET	ACKM	NAKM	STALLM	Res.	CHHM	XFRCM
	Reset value																						0	0	0	0	0	0	0	0		0	0
0x510	OTG_HCTSIZ0	DOPNG	DPID		PKTCNT										XFRSIZ																		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x514	OTG_HCDMA0	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
. . . .	. . . .	.Iterating preceding block of registers starting at offset 0x500..																															
0x6E0	OTG_ HCCHAR15	CHENA	CHDIS	ODDFRM	DAD							MCNT		EPTYP		LSDEV	Res.	EPDIR		EPNUM				MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x6E4	OTG_ HCSPLT15	SPLITEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COMPLSPLT	XACTPOS		HUBADDR							PRTADDR							
	Reset value	0															0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x6E8	OTG_HCINT15	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERR	FRMOR	BBERR	TXERR	Res.	ACK	NAK	STALL	Res.	CHH	XFRC
	Reset value																						0	0	0	0		0	0	0		0	0
0x6EC	OTG_ HCINTMSK15	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERRM	FRMORM	BBERRM	TXERRM	NYET	ACKM	NAKM	STALLM	Res.	CHHM	XFRCM
	Reset value																						0	0	0	0	0	0	0	0		0	0

Table 752. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x6F0	OTG_ HCTSIZ15	DOPNG	DPID		PKTCNT										XFRSIZ																		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x6F4	OTG_HCDMA15	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x800	OTG_DCFG	Res.	Res.	Res.	Res.	Res.	Res.	PERSCHIVL		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ERRATIM	XCVRDLY	Res.	PFIVL		DAD							Res.	NZLSOHSK	DSPD	
	Reset value							0	0									0	0		0	0	0	0	0	0	0	0		0	0	0
0x804	OTG_DCTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DSBESLRJCT	Res.	Res.	Res.	Res.	Res.	Res.	POPRGDNE	CGONAK	SGONAK	CGINAK	SGINAK	TCTL			GONSTS	GINSTS	SDIS	RWUSIG
	Reset value														0							0	0	0	0	0	0	0	0	0	1	0
0x808	OTG_DSTS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEVLNSTS		FNSOF															Res.	Res.	Res.	Res.	EERR	ENUMSPD		SUSPSTS
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0
0x810	OTG_DIEPMSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAKM	Res.	Res.	Res.		TXFURM	Res.	INEPNEM	INEPNMM	ITTXFEMSK	TOM	AHBERRM	EPDM	XFRCM
	Reset value																			0					0		0	0	0	0	0	0	0
0x814	OTG_DOEPMSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NYETMSK	NAKMSK	BERRM	Res.	Res.	Res.	OUTPKTERRM	Res.	B2BSTUPM	Res.	OTEPDM	STUPM	AHBERRM	EPDM	XFRCM
	Reset value																		0	0	0				0		0		0	0	0	0	0
0x818	OTG_DAINT	OEPINT																IEPINT															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x81C	OTG_ DAINTMSK	OEPM																IEPM															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x830	OTG_ DTHRCTL	Res.	Res.	Res.	Res.	ARPEN	Res.	RXTHRLEN							RXTHREN	Res.	Res.	Res.	Res.	TXTHRLEN												ISOTHREN	NONISOTHREN
	Reset value					0									0							0	0	0	0	0	0	0	0	0	0	0	0
0x834	OTG_DIE PEMPMSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INEPTXFEM															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 752. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x900	OTG_ DIEPCTL0 (INT/BULK)	EPENA	EPDIS	SD1PID	SD1P0D	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
	OTG_ DIEPCTL0 (ISO)	EPENA	EPDIS	SODDFRM	SEVNFRM	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	EONUM	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
0x908	OTG_ DIEPINT0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAK	Res.	PKTDRPSTS	Res.	Res.	TXFIFOUDRN	TXFE	INEPNE	INEPNM	ITTXFE	TOC	AHBERR	EPDISD	XFRC
	Reset value																			0		0			0	1	0	0	0	0	0	0	0
0x910	OTG_ DIEPTSIZ0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKT CNT		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XFRSIZ						
	Reset value												0	0													0	0	0	0	0	0	0
0x914	OTG_ DIEPDMA0	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x918	OTG_ DTXFSTS0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INEPTFSAV															
	Reset value																	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
. . . .	. . . .	Iterating preceding block of registers starting at offset 0x900.																															
0x9E0	OTG_ DIEPCTL7 (INT/BULK)	EPENA	EPDIS	SD1PID	SD1P0D	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
	OTG_ DIEPCTL7 (ISO)	EPENA	EPDIS	SODDFRM	SEVNFRM	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	EONUM	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
0x9E8	OTG_ DIEPINT7	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAK	Res.	PKTDRPSTS	Res.	Res.	TXFIFOUDRN	TXFE	INEPNE	INEPNM	ITTXFE	TOC	AHBERR	EPDISD	XFRC
	Reset value																			0		0			0	1	0	0	0	0	0	0	0
0x9F0	OTG_ DIEPTSIZ7	Res.	MCNT		PKTCNT									XFRSIZ																			
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x9F8	OTG_ DTXFSTS7	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INEPTFSAV															
	Reset value																	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Table 752. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xB00	OTG_ DOEPCTL0	EPENA	EPDIS	Res.	Res.	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EPTYP		NAKSTS	Res.	USBAEP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MPSIZ	
	Reset value	0	0			0	0					0	0	0	0	0		1														0	0
0xB08	OTG_ DOEPINT0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STPKTRX	NYET	NAK	BERR	Res.	Res.	Res.	OUTPKTERR	Res.	B2BSTUP	STSPHSRX	OTEPDIS	STUP	AHBERR	EPDISD	XFRC
	Reset value																	0	0	0	0				0		0	0	0	0	0	0	0
0xB10	OTG_ DOEPTSIZ0	Res.	STUP CNT		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTCNT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XFRSIZ						
	Reset value		0	0										0													0	0	0	0	0	0	0
0xB14	OTG_ DOEPDMA0	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xB20	OTG_ DOEPCTL1 (INT/BULK)	EPENA	EPDIS	SD1PID	SD0PID	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EP TYP		NAKSTS	DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0					0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
	OTG_ DOEPCTL1 (ISO)	EPENA	EPDIS	SODDFRM	SEVNFRM	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EP TYP		NAKSTS	EONUM	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0					0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
0xB28	OTG_ DOEPINT1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STPKTRX	NYET	NAK	BERR	Res.	Res.	Res.	OUTPKTERR	Res.	B2BSTUP	STSPHSRX	OTEPDIS	STUP	AHBERR	EPDISD	XFRC
	Reset value																	0	0	0	0				0		0	0	0	0	0	0	0
0xB30	OTG_ DOEPTSIZ1	Res.	RXDPID/ STUPCNT		PKTCNT										XFRSIZ																		
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xB34	OTG_ DOEPDMA1	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
. . . .	. . . .	. Iterating preceding block of registers starting at offset 0xB20. .																															

Table 752. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xC00	OTG_ DOEPCTL8 (INT/BULK)	EPENA	EPDIS	SD1PID	SD0PID	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EP TYP		NAKSTS	DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0					0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
	OTG_ DOEPCTL8 (ISO)	EPENA	EPDIS	SODDFRM	SEVNFRM	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EP TYP		NAKSTS	EONUM	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0					0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
0xC08	OTG_ DOEPINT8	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STPKTRX	NYET	NAK	BERR	Res.	Res.	Res.	OUTPKTERR	Res.	B2BSTUP	STSPHSRX	OTEPDIS	STUP	AHBERR	EPDISD	XFRC
	Reset value																	0	0	0	0		-		0		0	0	0	0	0	0	0
0xC10	OTG_ DOEPTSIZ8	Res.	RXDPID/ STUPCNT		PKTCNT											XFRSIZ																	
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xC14	OTG_ DOEPDMA8	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xE00	OTG_ PCGCCTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUSP	PHYSLEEP	ENL1GTG	PHYSUSP	Res.	Res.	GATEHCLK	STPPCLK
	Reset value																									0	0	0	0			0	0
0xE04	OTG_ PCGCCTL1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RAMGATEEN	CNTGATECLK		GATEEN
	Reset value																													0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

67.15 OTG_HS programming model

67.15.1 Core initialization

The application must perform the core initialization sequence. If the cable is connected during power-up, the current mode of operation bit in the OTG_GINTSTS (CMOD bit in OTG_GINTSTS) reflects the mode. The OTG_HS controller enters host mode when an “A” plug is connected or device mode when a “B” plug is connected.

This section explains the initialization of the OTG_HS controller after power-on. The application must follow the initialization sequence irrespective of host or device mode operation. All core global registers are initialized according to the core's configuration:

1. Program the following fields in the OTG_GAHBCFG register:
   – Global interrupt mask bit GINTMSK = 1
   – Rx FIFO non-empty (RXFLVL bit in OTG_GINTSTS)
   – Periodic Tx FIFO empty level
2. Program the following fields in the OTG_GUSBCFG register:
   – OTG_HS timeout calibration field
   – USB turnaround time field
3. The software must unmask the following bits in the OTG_GINTMSK register:
   OTG interrupt mask
   Mode mismatch interrupt mask
4. The software can read the CMOD bit in OTG_GINTSTS to determine whether the OTG_HS controller is operating in host or device mode.

67.15.2 Host initialization

To initialize the core as host, the application must perform the following steps:

1. Program the HPRTINT in the OTG_GINTMSK register to unmask
2. Program the OTG_HCFG register to select full-speed host
3. Program the PPWR bit in OTG_HPRT to 1. The port is now considered powered however this does not actually drive V_{BUS} on the USB, so a further action must be taken to control the external circuitry in the system so as to enable V_{BUS} generation.
4. Wait for the PCDET interrupt in OTG_HPRT0. This indicates that a device is connecting to the port.
5. Program the PRST bit in OTG_HPRT to 1. This starts the reset process.
6. Wait at least 10 ms for the reset process to complete.
7. Program the PRST bit in OTG_HPRT to 0.
8. Wait for the PENCHNG interrupt in OTG_HPRT.
9. Read the PSPD bit in OTG_HPRT to get the enumerated speed.
10. Program the HFIR register with a value corresponding to the selected PHY clock 1
11. Program the FSLSPCS field in the OTG_HCFG register following the speed of the device detected in step 9. If FSLSPCS has been changed a port reset must be performed.
12. Program the OTG_GRXFSIZ register to select the size of the receive FIFO.
13. Program the OTG_HNPTXFSIZ register to select the size and the start address of the Non-periodic transmit FIFO for non-periodic transactions.
14. Program the OTG_HPTXFSIZ register to select the size and start address of the periodic transmit FIFO for periodic transactions.

To communicate with devices, the system software must initialize and enable at least one channel.

67.15.3 Device initialization

The application must perform the following steps to initialize the core as a device on power-up or after a mode change from host to device.

1. Program the following fields in the OTG_DCFG register:
   - Device speed
   - Non-zero-length status OUT handshake
   - Periodic Frame Interval
2. Program the Device threshold control register. This is required only if you are using DMA mode and you are planning to enable thresholding.
3. Clear the DCTL.SDIS bit. The core issues a connect after this bit is cleared.
4. Program the OTG_GINTMSK register to unmask the following interrupts:
   - USB reset
   - Enumeration done
   - Early suspend
   - USB suspend
   - SOF
5. Wait for the USBRST interrupt in OTG_GINTSTS. It indicates that a reset has been detected on the USB that lasts for about 10 ms on receiving this interrupt.
6. Wait for the ENUMDNE interrupt in OTG_GINTSTS. This interrupt indicates the end of reset on the USB. On receiving this interrupt, the application must read the OTG_DSTS register to determine the enumeration speed and perform the steps listed in *Endpoint initialization on enumeration completion*.

At this point, the device is ready to accept SOF packets and perform control transfers on control endpoint 0.

67.15.4 DMA mode

The OTG host uses the AHB master interface to fetch the transmit packet data (AHB to USB) and receive the data update (USB to AHB). The AHB master uses the programmed DMA address (OTG_HCDMAx register in host mode and OTG_DIEPDMAx/OTG_DOEPDMAx register in peripheral mode) to access the data buffers.

67.15.5 Host programming model

Channel initialization

The application must initialize one or more channels before it can communicate with connected devices. To initialize and enable a channel, the application must perform the following steps:

1. Program the OTG_GINTMSK register to unmask the following:
2. Channel interrupt
   – Non-periodic transmit FIFO empty for OUT transactions (applicable when operating in pipelined transaction-level with the packet count field programmed with more than one).
   – Non-periodic transmit FIFO half-empty for OUT transactions (applicable when operating in pipelined transaction-level with the packet count field programmed with more than one).
3. Program the OTG_HAINTMSK register to unmask the selected channels' interrupts.
4. Program the OTG_HCINTMSK register to unmask the transaction-related interrupts of interest given in the host channel interrupt register.
5. Program the selected channel's OTG_HCTSIZx register with the total transfer size, in bytes, and the expected number of packets, including short packets. The application must program the PID field with the initial data PID (to be used on the first OUT transaction or to be expected from the first IN transaction).
6. Program the OTG_HCCHARx register of the selected channel with the device's endpoint characteristics, such as type, speed, direction, and so forth. (The channel can be enabled by setting the channel enable bit to 1 only when the application is ready to transmit or receive any packet).
7. Program the selected channels in the OTG_HCSPLTx register(s) with the hub and port addresses (split transactions only).
8. Program the selected channels in the OTG_HCDMAx register(s) with the buffer start address (DMA transactions only).

Halting a channel

The application can disable any channel by programming the OTG_HCCHARx register with the CHDIS and CHENA bits set to 1. This enables the OTG_HS host to flush the posted requests (if any) and generates a channel halted interrupt. The application must wait for the CHH interrupt in OTG_HCINTx before reallocating the channel for other transactions. The OTG_HS host does not interrupt the transaction that has already been started on the USB.

To disable a channel in DMA mode operation, the application does not need to check for space in the request queue. The OTG_HS host checks for space to write the disable

request on the disabled channel's turn during arbitration. Meanwhile, all posted requests are dropped from the request queue when the CHDIS bit in OTG_HCCHARx is set to 1.

Before disabling a channel, the application must ensure that there is at least one free space available in the non-periodic request queue (when disabling a non-periodic channel) or the periodic request queue (when disabling a periodic channel). The application can simply flush the posted requests when the request queue is full (before disabling the channel), by programming the OTG_HCCHARx register with the CHDIS bit set to 1 which automatically clears the CHENA bit to 0.

The application is expected to disable a channel on any of the following conditions:

1. When an STALL, TXERR, BBERR or DTERR interrupt in OTG_HCINTx is received for an IN or OUT channel. The application must be able to receive other interrupts (DTERR, Nak, data, TXERR) for the same channel before receiving the halt.
2. When an XFRC interrupt in OTG_HCINTx is received during a non periodic IN transfer or high-bandwidth interrupt IN transfer
3. When a DISCINT (disconnect device) interrupt in OTG_GINTSTS is received. (The application is expected to disable all enabled channels).
4. When the application aborts a transfer before normal completion.

Ping protocol

When the OTG_HS host operates in high speed, the application must initiate the ping protocol when communicating with high-speed bulk or control (data and status stage) OUT endpoints. The application must initiate the ping protocol when it receives a NAK/NYET/TXERR interrupt. When the OTG_HS host receives one of the above responses, it does not continue any transaction for a specific endpoint, drops all posted or fetched OUT requests (from the request queue), and flushes the corresponding data (from the transmit FIFO).This is valid in slave mode only. In Slave mode, the application can send a ping token either by setting the DOPING bit in OTG_HCTSIZx before enabling the channel or by just writing the OTG_HCTSIZx register with the DOPING bit set when the channel is already enabled. This enables the OTG_HS host to write a ping request entry to the request queue. The application must wait for the response to the ping token (a NAK, ACK, or TXERR interrupt) before continuing the transaction or sending another ping token. The application can continue the data transaction only after receiving an ACK from the OUT endpoint for the requested ping. In DMA mode operation, the application does not need to set the DOPING bit in OTG_HCTSIZx for a NAK/NYET response in case of bulk/control OUT. The OTG_HS host automatically sets the DOPING bit in OTG_HCTSIZx, and issues the ping tokens for bulk/control OUT. The OTG_HS host continues sending ping tokens until it receives an ACK, and then switches automatically to the data transaction.

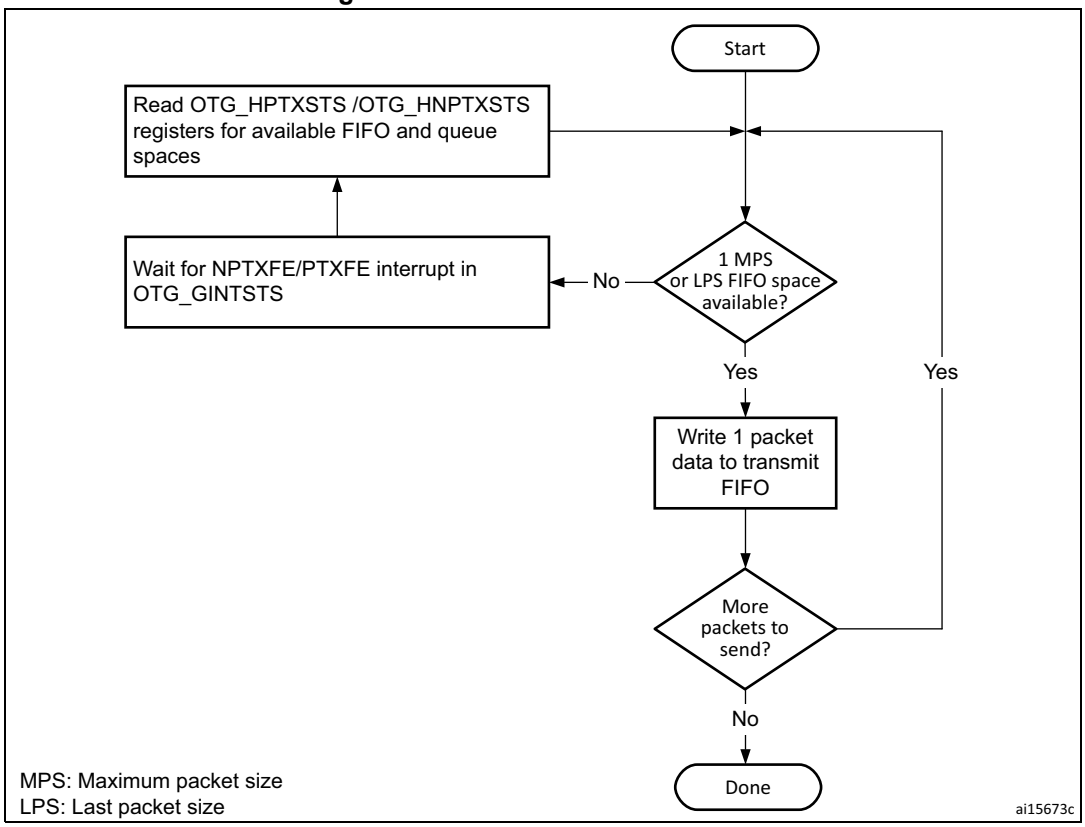
Operational model

The application must initialize a channel before communicating to the connected device. This section explains the sequence of operation to be performed for different types of USB transactions.

- **Writing the transmit FIFO**

  The OTG_HS host automatically writes an entry (OUT request) to the periodic/non-periodic request queue, along with the last 32-bit word write of a packet. The application must ensure that at least one free space is available in the periodic/non-periodic request queue before starting to write to the transmit FIFO. The application must always write to the transmit FIFO in 32-bit words. If the packet size is non-32-bit word aligned, the application must use padding. The OTG_HS host determines the actual packet size based on the programmed maximum packet size and transfer size.

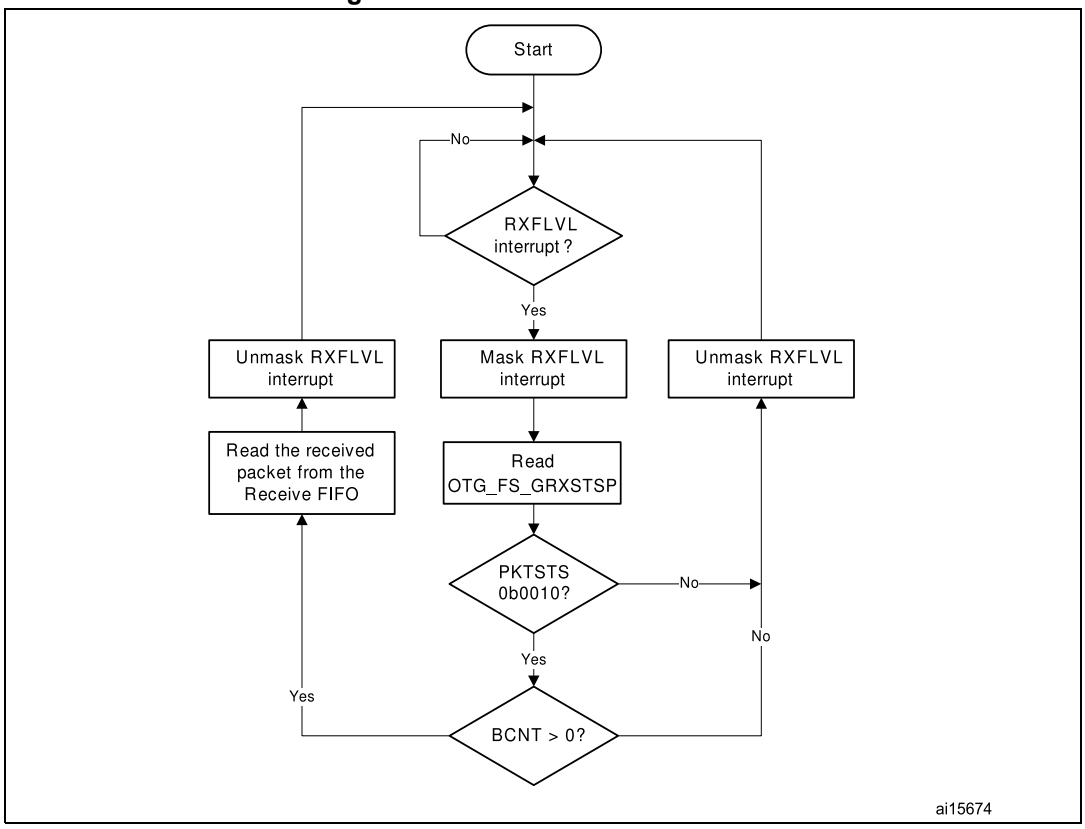
Figure 959. Transmit FIFO write task



- **Reading the receive FIFO**

  The application must ignore all packet statuses other than IN data packet (bx0010).

Figure 960. Receive FIFO read task



- **Bulk and control OUT/SETUP transactions**

  A typical bulk or control OUT/SETUP pipelined transaction-level operation is shown in *Figure 961*. See channel 1 (ch_1). Two bulk OUT packets are transmitted. A control SETUP transaction operates in the same way but has only one packet. The assumptions are:

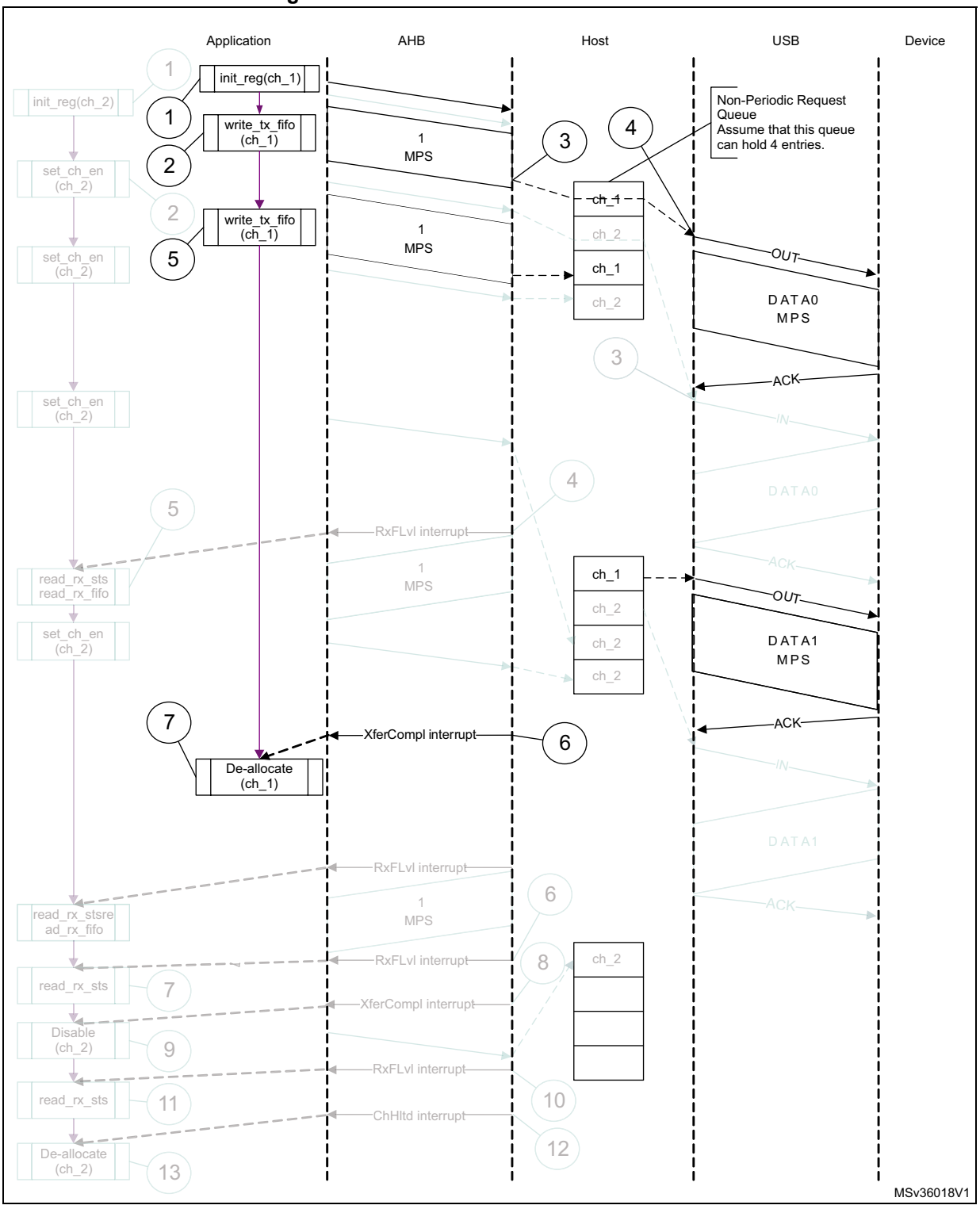
  – The application is attempting to send two maximum-packet-size packets (transfer size = 1, 024 bytes).
  – The non-periodic transmit FIFO can hold two packets (1 Kbyte for HS).
  – The non-periodic request queue depth = 4.

- **Normal bulk and control OUT/SETUP operations**

  The sequence of operations in (channel 1) is as follows:

1. Initialize channel 1
2. Write the first packet for channel 1
3. Along with the last word write, the core writes an entry to the non-periodic request queue
4. As soon as the non-periodic queue becomes non-empty, the core attempts to send an OUT token in the current frame
5. Write the second (last) packet for channel 1
6. The core generates the XFRC interrupt as soon as the last transaction is completed successfully
7. In response to the XFRC interrupt, de-allocate the channel for other transfers
8. Handling non-ACK responses

Figure 961. Normal bulk/control OUT/SETUP



1. The grayed elements are not relevant in the context of this figure.

The channel-specific interrupt service routine for bulk and control OUT/SETUP transactions is shown in the following code samples.

- **Interrupt service routine for bulk/control OUT/SETUP and bulk/control IN transactions**

  a) Bulk/control OUT/SETUP

```
Unmask (NAK/TXERR/STALL/XFRC)
if (XFRC)
   {
   Reset Error Count
   Mask ACK
   De-allocate Channel
   }
else if (STALL)
   {
   Transfer Done = 1
   Unmask CHH
   Disable Channel
   }
else if (NAK or TXERR )
   {
   Rewind Buffer Pointers
   Unmask CHH
   Disable Channel
   if (TXERR)
      {
      Increment Error Count
      Unmask ACK
      }
   else
      {
      Reset Error Count
      }
      }
else if (CHH)
   {
   Mask CHH
   if (Transfer Done or (Error_count == 3))
      {
      De-allocate Channel
      }
   else
      {
      Re-initialize Channel
      }
   }
```

```
   else if (ACK)
      {
      Reset Error Count
      Mask ACK
      }
```

The application is expected to write the data packets into the transmit FIFO when the space is available in the transmit FIFO and the request queue. The application can make use of the NPTXFE interrupt in OTG_GINTSTS to find the transmit FIFO space.

b) Bulk/control IN

```
Unmask (TXERR/XFRC/BBERR/STALL/DTERR)
if (XFRC)
   {
   Reset Error Count
   Unmask CHH
   Disable Channel
   Reset Error Count
   Mask ACK
   }
else if (TXERR or BBERR or STALL)
   {
   Unmask CHH
   Disable Channel
   if (TXERR)
      {
      Increment Error Count
      Unmask ACK
      }
   }
else if (CHH)
   {
   Mask CHH
   if (Transfer Done or (Error_count == 3))
      {
      De-allocate Channel
      }
   else
      {
      Re-initialize Channel
      }
   }
else if (ACK)
   {
   Reset Error Count
   Mask ACK
   }
```

```
else if (DTERR)
   {
   Reset Error Count
   }
```

The application is expected to write the requests as and when the request queue space is available and until the XFRC interrupt is received.

- **Bulk and control IN transactions**

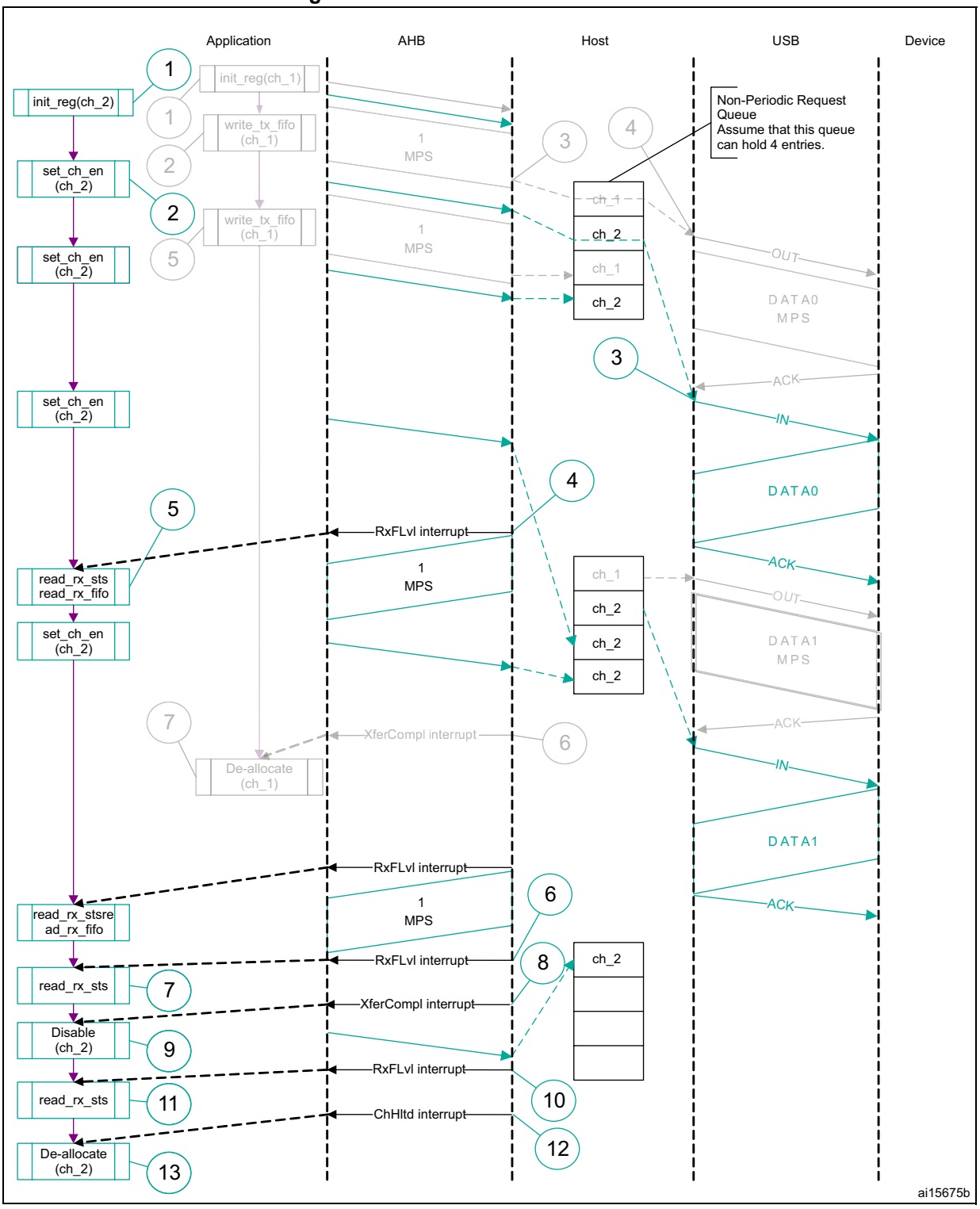
  A typical bulk or control IN pipelined transaction-level operation is shown in *Figure 962*. See channel 2 (ch_2). The assumptions are:

  – The application is attempting to receive two maximum-packet-size packets (transfer size = 1 024 bytes).

  – The receive FIFO can contain at least one maximum-packet-size packet and two status words per packet (520 bytes for HS).

  – The non-periodic request queue depth = 4.

Figure 962. Bulk/control IN transactions



1. The grayed elements are not relevant in the context of this figure.

The sequence of operations is as follows:

1. Initialize channel 2.
2. Set the CHENA bit in OTG_HCCHAR2 to write an IN request to the non-periodic request queue.
3. The core attempts to send an IN token after completing the current OUT transaction.
4. The core generates an RXFLVL interrupt as soon as the received packet is written to the receive FIFO.
5. In response to the RXFLVL interrupt, mask the RXFLVL interrupt and read the received packet status to determine the number of bytes received, then read the receive FIFO accordingly. Following this, unmask the RXFLVL interrupt.
6. The core generates the RXFLVL interrupt for the transfer completion status entry in the receive FIFO.
7. The application must read and ignore the receive packet status when the receive packet status is not an IN data packet (PKTSTS in OTG_GRXSTSR ≠ 0b0010).
8. The core generates the XFRC interrupt as soon as the receive packet status is read.
9. In response to the XFRC interrupt, disable the channel and stop writing the OTG_HCCHAR2 register for further requests. The core writes a channel disable request to the non-periodic request queue as soon as the OTG_HCCHAR2 register is written.
10. The core generates the RXFLVL interrupt as soon as the halt status is written to the receive FIFO.
11. Read and ignore the receive packet status.
12. The core generates a CHH interrupt as soon as the halt status is popped from the receive FIFO.
13. In response to the CHH interrupt, de-allocate the channel for other transfers.
14. Handling non-ACK responses

- **Control transactions**

  Setup, data, and status stages of a control transfer must be performed as three separate transfers. setup-, data- or status-stage OUT transactions are performed similarly to the bulk OUT transactions explained previously. Data- or status-stage IN transactions are performed similarly to the bulk IN transactions explained previously. For all three stages, the application is expected to set the EPTYP field in

OTG_HCCHAR1 to control. During the setup stage, the application is expected to set the PID field in OTG_HCTSIZ1 to SETUP.

- **Interrupt OUT transactions**

  A typical interrupt OUT operation is shown in *Figure 963*. The assumptions are:

  – The application is attempting to send one packet in every frame (up to 1 maximum packet size), starting with the odd frame (transfer size = 1 024 bytes)

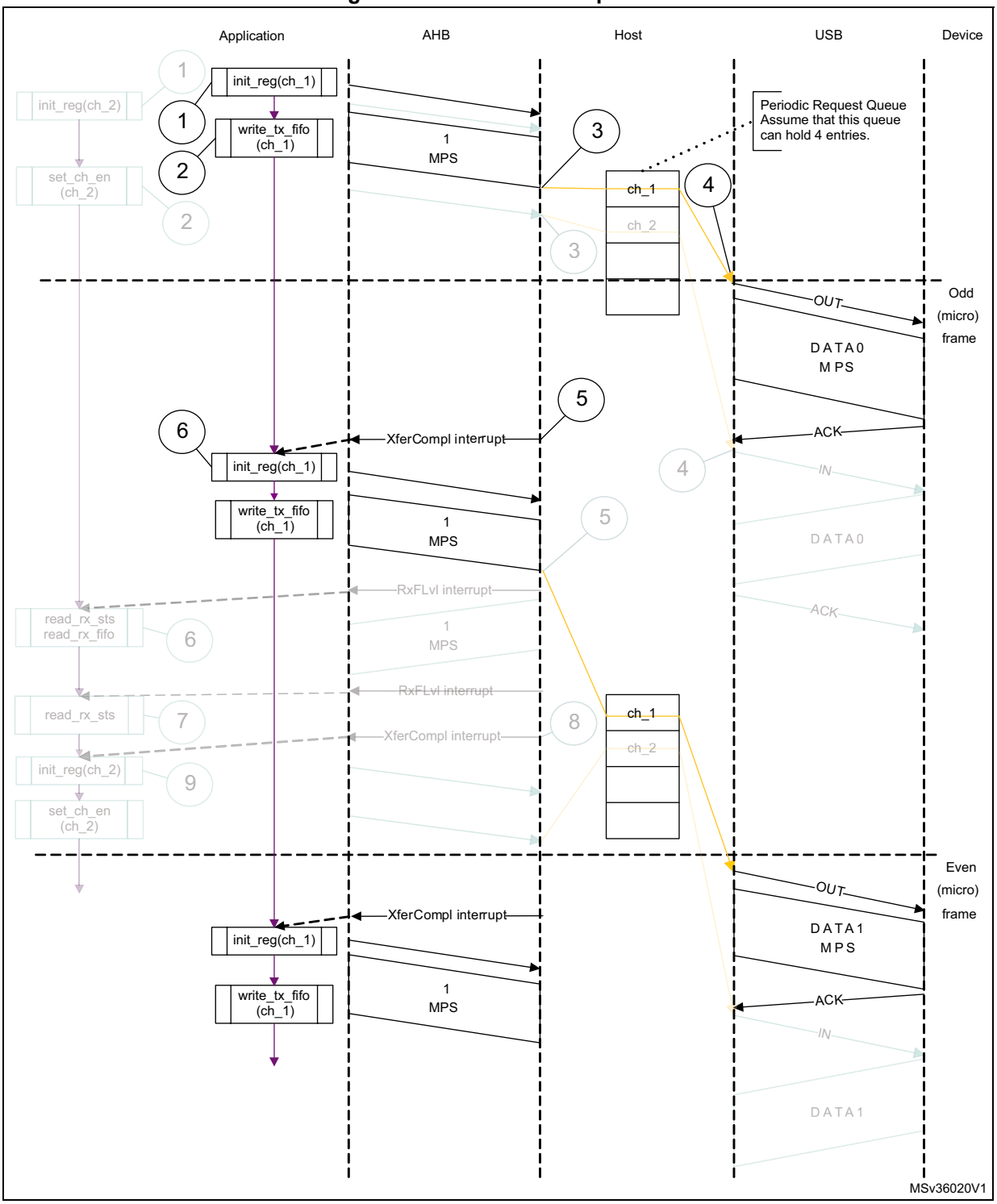
  – The periodic transmit FIFO can hold one packet (1 Kbyte)

  – Periodic request queue depth = 4

  The sequence of operations is as follows:

1. Initialize and enable channel 1. The application must set the ODDFRM bit in OTG_HCCHAR1.
2. Write the first packet for channel 1.
3. Along with the last word write of each packet, the OTG_HS host writes an entry to the periodic request queue.
4. The OTG_HS host attempts to send an OUT token in the next (odd) frame.
5. The OTG_HS host generates an XFRC interrupt as soon as the last packet is transmitted successfully.
6. In response to the XFRC interrupt, reinitialize the channel for the next transfer.

Figure 963. Normal interrupt OUT



1. The grayed elements are not relevant in the context of this figure.

- **Interrupt service routine for interrupt OUT/IN transactions**

  a) Interrupt OUT

`Unmask (NAK/TXERR/STALL/XFRC/FRMOR)`

```
if (XFRC)
   {
   Reset Error Count
   Mask ACK
   De-allocate Channel
   }
else
   if (STALL or FRMOR)
      {
      Mask ACK
      Unmask CHH
      Disable Channel
      if (STALL)
         {
         Transfer Done = 1
         }
      }
   else
      if (NAK or TXERR)
         {
         Rewind Buffer Pointers
         Reset Error Count
         Mask ACK
         Unmask CHH
         Disable Channel
         }
      else
         if (CHH)
         {
         Mask CHH
         if (Transfer Done or (Error_count == 3))
            {
            De-allocate Channel
            }
         else
            {
            Re-initialize Channel (in next b_interval - 1 Frame)
            }
         }
      else
         if (ACK)
         {
         Reset Error Count
         Mask ACK
         }
```

```
The application uses the NPTXFE interrupt in OTG_GINTSTS to find the
transmit FIFO space.
Interrupt IN
Unmask (NAK/TXERR/XFRC/BBERR/STALL/FRMOR/DTERR)
if (XFRC)
   {
   Reset Error Count
   Mask ACK
   if (OTG_HCTSIZx.PKTCNT == 0)
      {
      De-allocate Channel
      }
   else
      {
      Transfer Done = 1
      Unmask CHH
      Disable Channel
      }
   }
else
   if (STALL or FRMOR or NAK or DTERR or BBERR)
      {
      Mask ACK
      Unmask CHH
      Disable Channel
      if (STALL or BBERR)
         {
         Reset Error Count
         Transfer Done = 1
         }
      else
         if (!FRMOR)
         {
         Reset Error Count
         }
      }
else
   if (TXERR)
      {
      Increment Error Count
      Unmask ACK
      Unmask CHH
      Disable Channel
      }
else
```

```
   if (CHH)
      {
      Mask CHH
      if (Transfer Done or (Error_count == 3))
         {
         De-allocate Channel
         }
      else
         Re-initialize Channel (in next b_interval - 1 /Frame)
      }
   }
else
   if (ACK)
      {
      Reset Error Count
      Mask ACK
      }
```

- **Interrupt IN transactions**

  The assumptions are:

  – The application is attempting to receive one packet (up to 1 maximum packet size) in every frame, starting with odd (transfer size = 1 024 bytes).

  – The receive FIFO can hold at least one maximum-packet-size packet and two status words per packet (1 031 bytes).

  – Periodic request queue depth = 4.

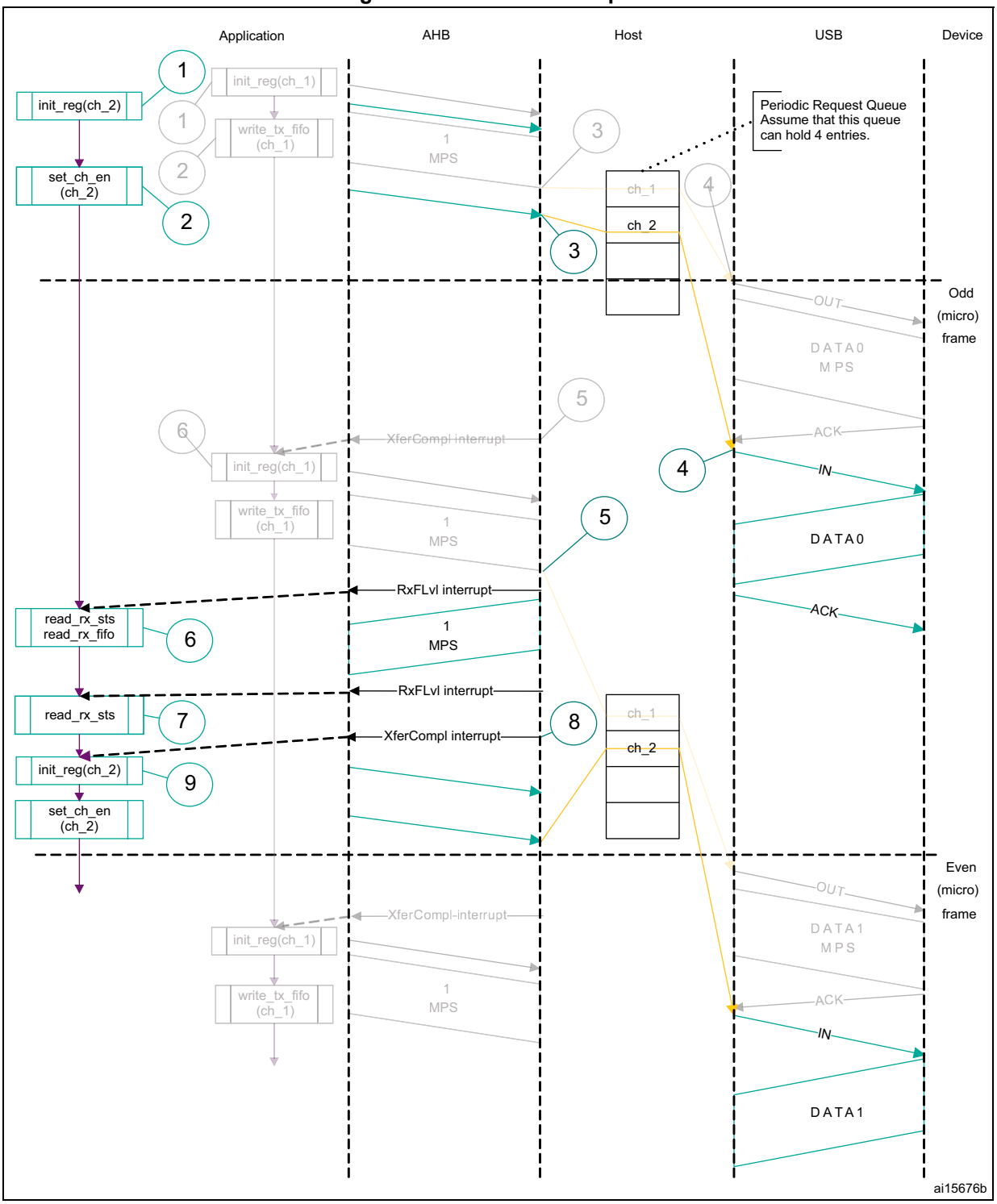
- **Normal interrupt IN operation**

  The sequence of operations is as follows:

1. Initialize channel 2. The application must set the ODDFRM bit in OTG_HCCHAR2.
2. Set the CHENA bit in OTG_HCCHAR2 to write an IN request to the periodic request queue.
3. The OTG_HS host writes an IN request to the periodic request queue for each OTG_HCCHAR2 register write with the CHENA bit set.
4. The OTG_HS host attempts to send an IN token in the next (odd) frame.
5. As soon as the IN packet is received and written to the receive FIFO, the OTG_HS host generates an RXFLVL interrupt.
6. In response to the RXFLVL interrupt, read the received packet status to determine the number of bytes received, then read the receive FIFO accordingly. The application must mask the RXFLVL interrupt before reading the receive FIFO, and unmask after reading the entire packet.
7. The core generates the RXFLVL interrupt for the transfer completion status entry in the receive FIFO. The application must read and ignore the receive packet status when the receive packet status is not an IN data packet (PKTSTS in GRXSTSR ≠ 0b0010).
8. The core generates an XFRC interrupt as soon as the receive packet status is read.
9. In response to the XFRC interrupt, read the PKTCNT field in OTG_HCTSIZ2. If the PKTCNT bit in OTG_HCTSIZ2 is not equal to 0, disable the channel before re-

initializing the channel for the next transfer, if any). If PKTCNT bit in OTG_HCTSIZ2 = 0, reinitialize the channel for the next transfer. This time, the application must reset the ODDFRM bit in OTG_HCCHAR2.

Figure 964. Normal interrupt IN



1. The grayed elements are not relevant in the context of this figure.

- **Isochronous OUT transactions**

  A typical isochronous OUT operation is shown in *Figure 965*. The assumptions are:

  – The application is attempting to send one packet every frame (up to 1 maximum

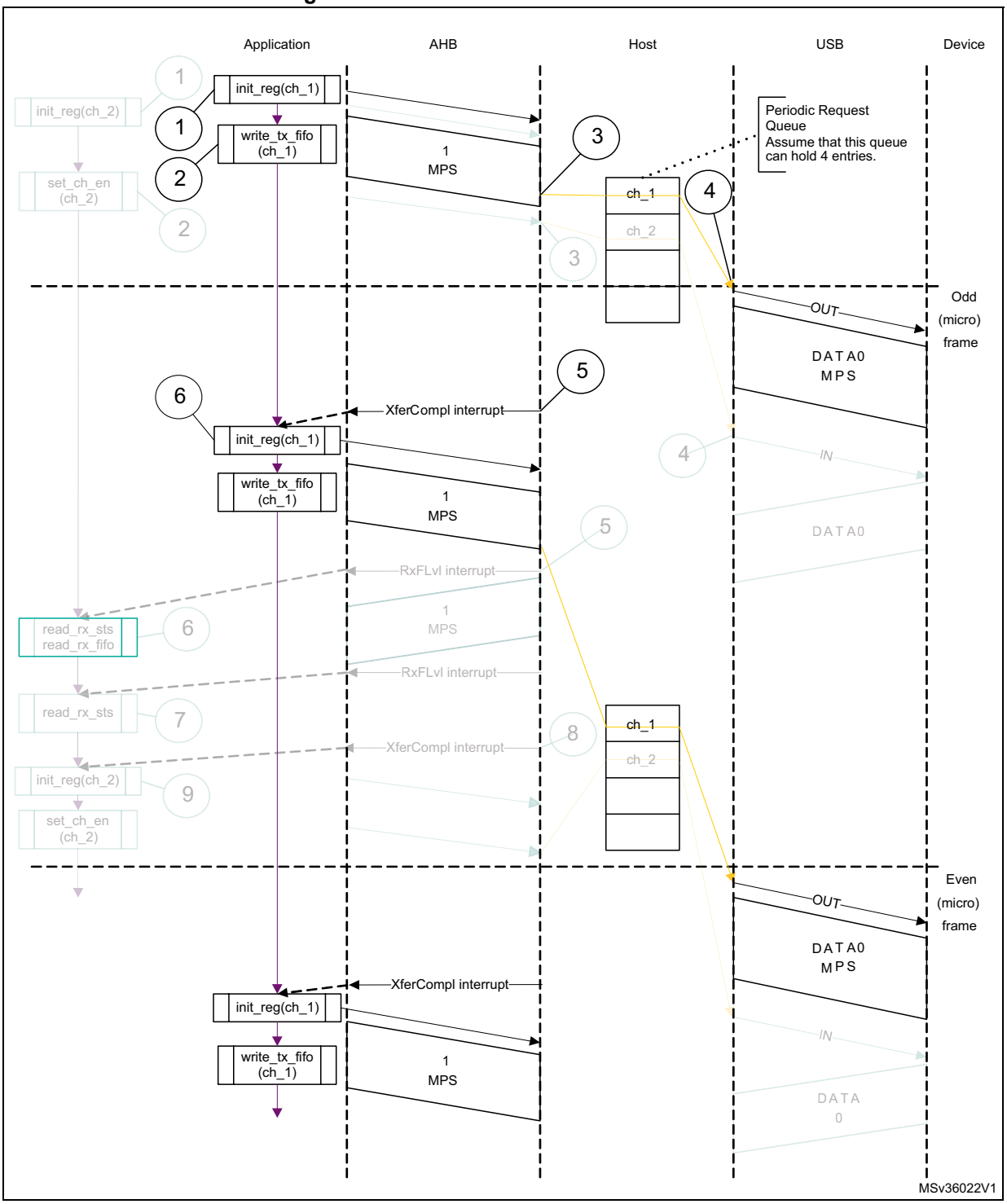
packet size), starting with an odd frame. (transfer size = 1 024 bytes).

– The periodic transmit FIFO can hold one packet (1 Kbyte).
– Periodic request queue depth = 4.

The sequence of operations is as follows:

1. Initialize and enable channel 1. The application must set the ODDFRM bit in OTG_HCCHAR1.
2. Write the first packet for channel 1.
3. Along with the last word write of each packet, the OTG_HS host writes an entry to the periodic request queue.
4. The OTG_HS host attempts to send the OUT token in the next frame (odd).
5. The OTG_HS host generates the XFRC interrupt as soon as the last packet is transmitted successfully.
6. In response to the XFRC interrupt, reinitialize the channel for the next transfer.
7. Handling non-ACK responses

Figure 965. Isochronous OUT transactions



1. The grayed elements are not relevant in the context of this figure.

- **Interrupt service routine for isochronous OUT/IN transactions**

  Code sample: isochronous OUT

```
Unmask (FRMOR/XFRC)
if (XFRC)
```

```
   {
   De-allocate Channel
   }
else
   if (FRMOR)
      {
      Unmask CHH
      Disable Channel
      }
   else
   if (CHH)
      {
      Mask CHH
      De-allocate Channel
      }
Code sample: Isochronous IN
Unmask (TXERR/XFRC/FRMOR/BBERR)
if (XFRC or FRMOR)
   {
   if (XFRC and (OTG_HCTSIZx.PKTCNT == 0))
      {
      Reset Error Count
      De-allocate Channel
      }
   else
      {
      Unmask CHH
      Disable Channel
      }
   }
   else
      if (TXERR or BBERR)
         {
         Increment Error Count
         Unmask CHH
         Disable Channel
         }
      else
         if (CHH)
            {
            Mask CHH
            if (Transfer Done or (Error_count == 3))
               {
               De-allocate Channel
               }
```

```
else
   {
   Re-initialize Channel
   }
}
```

- **Isochronous IN transactions**

  The assumptions are:

  – The application is attempting to receive one packet (up to 1 maximum packet size) in every frame starting with the next odd frame (transfer size = 1 024 bytes).

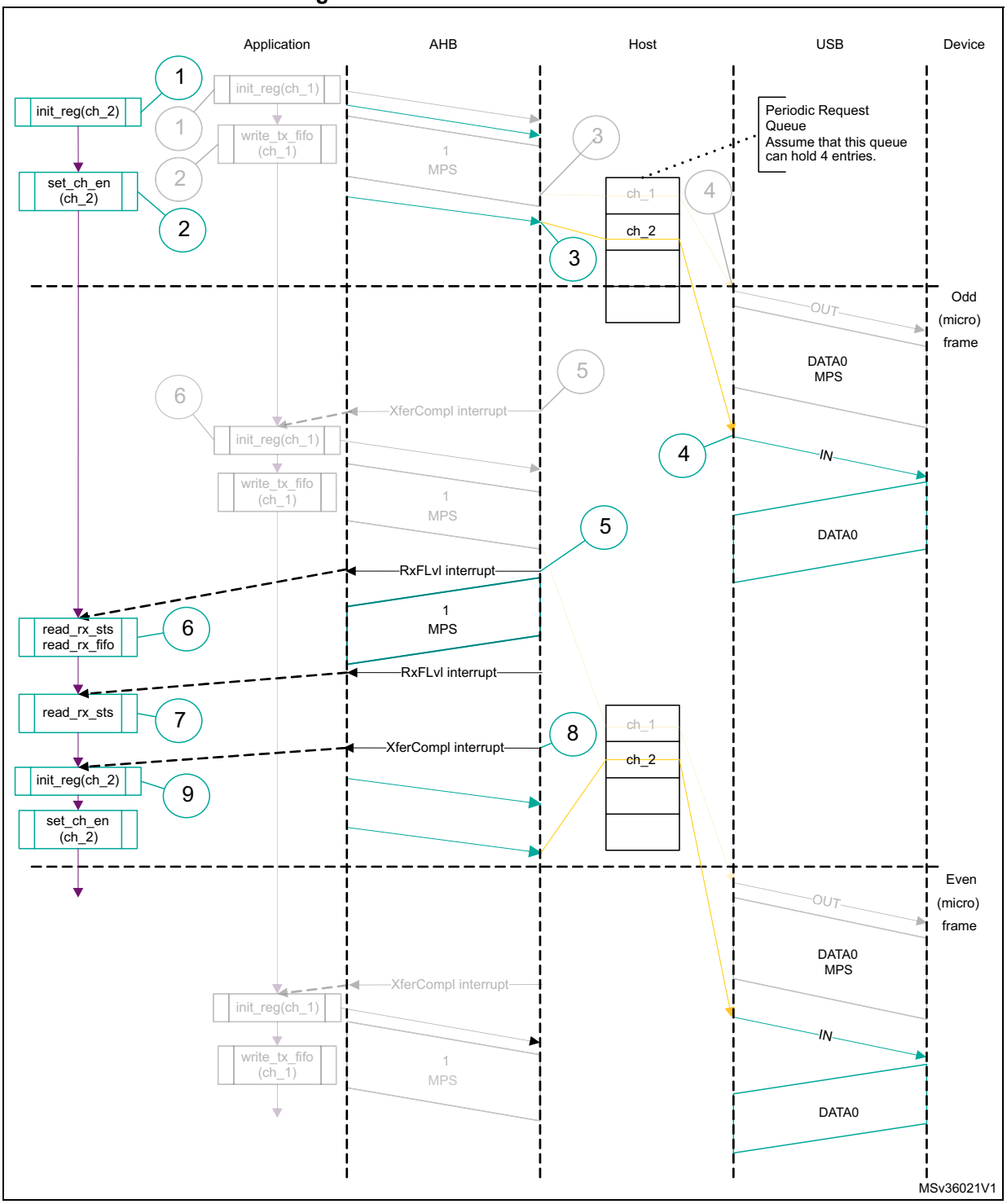
  – The receive FIFO can hold at least one maximum-packet-size packet and two status word per packet (1 031 bytes).

  – Periodic request queue depth = 4.

  The sequence of operations is as follows:

1. Initialize channel 2. The application must set the ODDFRM bit in OTG_HCCHAR2.
2. Set the CHENA bit in OTG_HCCHAR2 to write an IN request to the periodic request queue.
3. The OTG_HS host writes an IN request to the periodic request queue for each OTG_HCCHAR2 register write with the CHENA bit set.
4. The OTG_HS host attempts to send an IN token in the next odd frame.
5. As soon as the IN packet is received and written to the receive FIFO, the OTG_HS host generates an RXFLVL interrupt.
6. In response to the RXFLVL interrupt, read the received packet status to determine the number of bytes received, then read the receive FIFO accordingly. The application must mask the RXFLVL interrupt before reading the receive FIFO, and unmask it after reading the entire packet.
7. The core generates an RXFLVL interrupt for the transfer completion status entry in the receive FIFO. This time, the application must read and ignore the receive packet status when the receive packet status is not an IN data packet (PKTSTS bit in OTG_GRXSTSR ≠ 0b0010).
8. The core generates an XFRC interrupt as soon as the receive packet status is read.
9. In response to the XFRC interrupt, read the PKTCNT field in OTG_HCTSIZ2. If PKTCNT ≠ 0 in OTG_HCTSIZ2, disable the channel before re-initializing the channel for the next transfer, if any. If PKTCNT = 0 in OTG_HCTSIZ2, reinitialize the channel for the next transfer. This time, the application must reset the ODDFRM bit in OTG_HCCHAR2.

Figure 966. Isochronous IN transactions



1. The grayed elements are not relevant in the context of this figure.

- **Selecting the queue depth**

  Choose the periodic and non-periodic request queue depths carefully to match the number of periodic/non-periodic endpoints accessed.

  The non-periodic request queue depth affects the performance of non-periodic

transfers. The deeper the queue (along with sufficient FIFO size), the more often the core is able to pipeline non-periodic transfers. If the queue size is small, the core is able to put in new requests only when the queue space is freed up.

The core's periodic request queue depth is critical to perform periodic transfers as scheduled. Select the periodic queue depth, based on the number of periodic transfers scheduled in a microframe. If the periodic request queue depth is smaller than the periodic transfers scheduled in a microframe, a frame overrun condition occurs.

- **Handling babble conditions**

  OTG_HS controller handles two cases of babble: packet babble and port babble. Packet babble occurs if the device sends more data than the maximum packet size for the channel. Port babble occurs if the core continues to receive data from the device at EOF2 (the end of frame 2, which is very close to SOF).

  When OTG_HS controller detects a packet babble, it stops writing data into the Rx buffer and waits for the end of packet (EOP). When it detects an EOP, it flushes already written data in the Rx buffer and generates a Babble interrupt to the application.

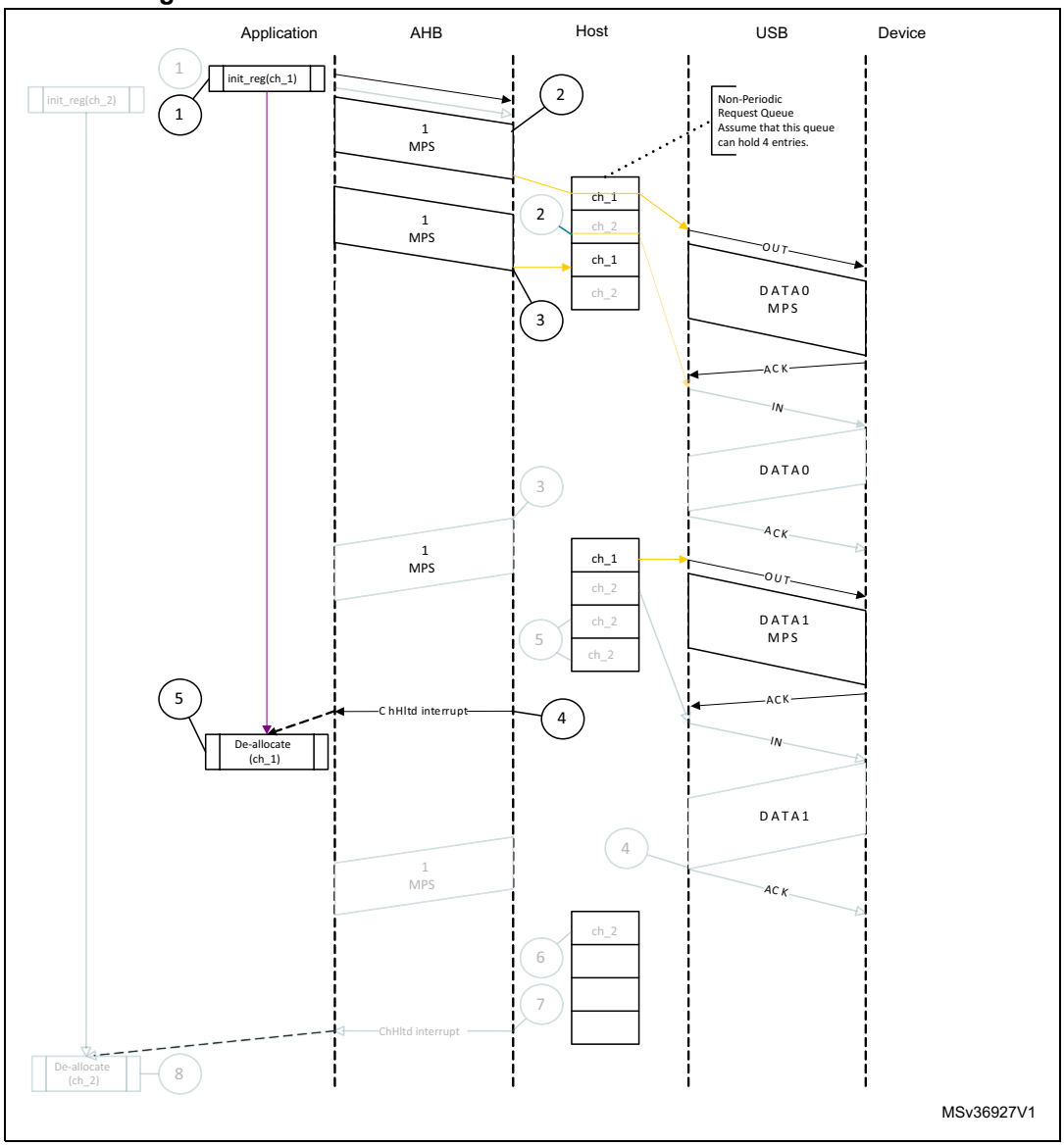
  When OTG_HS controller detects a port babble, it flushes the Rx FIFO and disables the port. The core then generates a port disabled interrupt (HPRTINT in OTG_GINTSTS, PENCHNG in OTG_HPRT). On receiving this interrupt, the application must determine that this is not due to an overcurrent condition (another cause of the port disabled interrupt) by checking POCA in OTG_HPRT, then perform a soft reset. The core does not send any more tokens after it has detected a port babble condition.

- **Bulk and control OUT/SETUP transactions in DMA mode**

  The sequence of operations is as follows:

1. Initialize and enable channel 1 as explained in *Section : Channel initialization*.
2. The OTG_HS host starts fetching the first packet as soon as the channel is enabled. For internal DMA mode, the OTG_HS host uses the programmed DMA address to fetch the packet.
3. After fetching the last 32-bit word of the second (last) packet, the OTG_HS host masks channel 1 internally for further arbitration.
4. The OTG_HS host generates a CHH interrupt as soon as the last packet is sent.
5. In response to the CHH interrupt, de-allocate the channel for other transfers.

Figure 967. Normal bulk/control OUT/SETUP transactions - DMA



- **NAK and NYET handling with internal DMA:**

1. The OTG_HS host sends a bulk OUT transaction.
2. The device responds with NAK or NYET.
3. If the application has unmasked NAK or NYET, the core generates the corresponding interrupt(s) to the application. The application is not required to service these interrupts, since the core takes care of rewinding the buffer pointers and re-initializing the Channel without application intervention.
4. The core automatically issues a ping token.
5. When the device returns an ACK, the core continues with the transfer. Optionally, the application can utilize these interrupts, in which case the NAK or NYET interrupt is masked by the application.

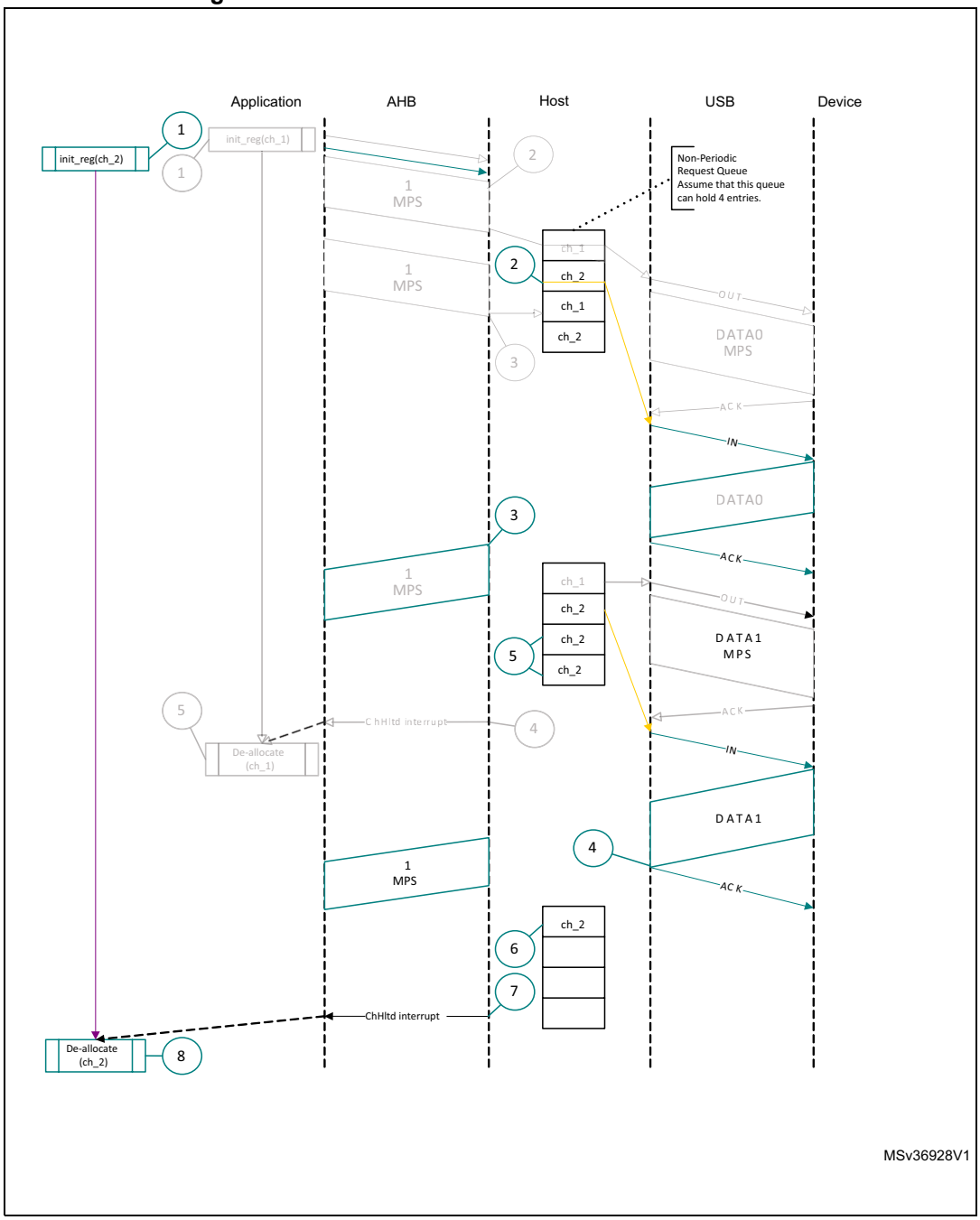
The core does not generate a separate interrupt when NAK or NYET is received by the host functionality.

- **Bulk and control IN transactions in DMA mode**

  The sequence of operations is as follows:

1. Initialize and enable the used channel (channel x) as explained in *Section : Channel initialization*.
2. The OTG_HS host writes an IN request to the request queue as soon as the channel receives the grant from the arbiter (arbitration is performed in a round-robin fashion).
3. The OTG_HS host starts writing the received data to the system memory as soon as the last byte is received with no errors.
4. When the last packet is received, the OTG_HS host sets an internal flag to remove any extra IN requests from the request queue.
5. The OTG_HS host flushes the extra requests.
6. The final request to disable channel x is written to the request queue. At this point, channel 2 is internally masked for further arbitration.
7. The OTG_HS host generates the CHH interrupt as soon as the disable request comes to the top of the queue.
8. In response to the CHH interrupt, de-allocate the channel for other transfers.

Figure 968. Normal bulk/control IN transaction - DMA

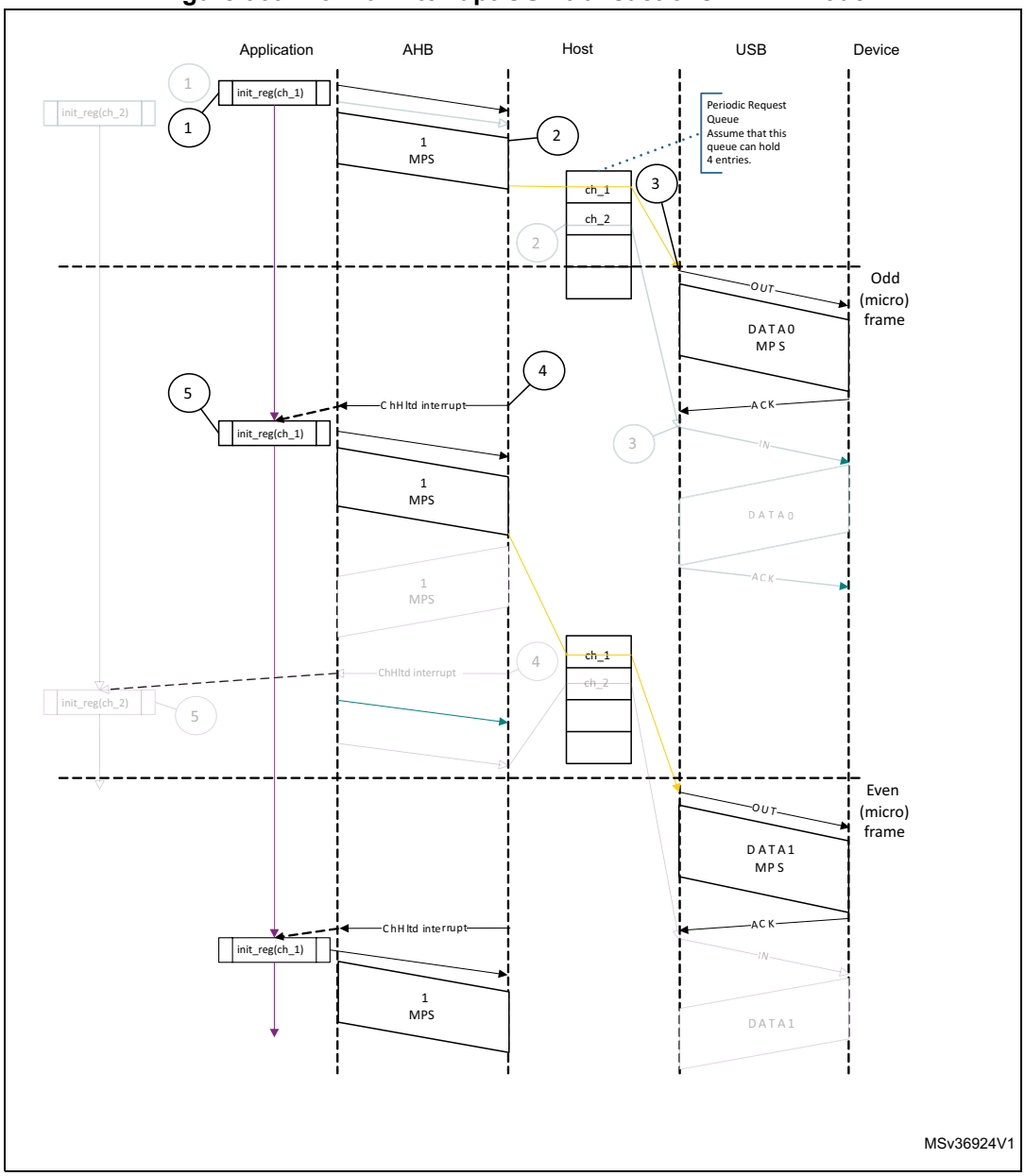


- **Interrupt OUT transactions in DMA mode**

1. Initialize and enable channel x as explained in *Section : Channel initialization*.
2. The OTG_HS host starts fetching the first packet as soon the channel is enabled and writes the OUT request along with the last 32-bit word fetch. In high-bandwidth transfers, the OTG_HS host continues fetching the next packet (up to the value specified in the MC field) before switching to the next channel.
3. The OTG_HS host attempts to send the OUT token at the beginning of the next odd frame/micro-frame.

4. After successfully transmitting the packet, the OTG_HS host generates a CHH interrupt.
5. In response to the CHH interrupt, reinitialize the channel for the next transfer.

Figure 969. Normal interrupt OUT transactions - DMA mode



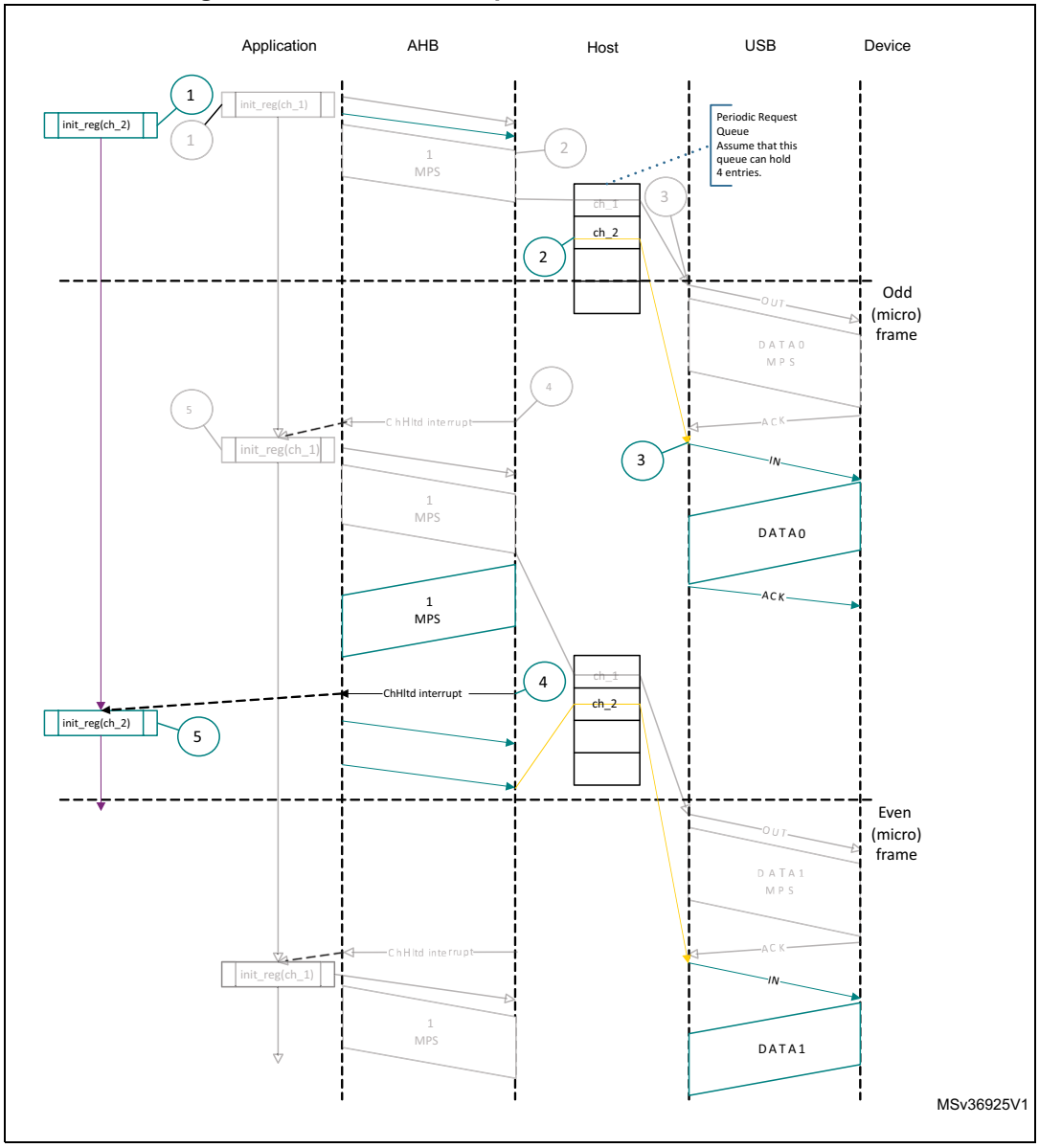
- **Interrupt IN transactions in DMA mode**

  The sequence of operations (channelx) is as follows:

1. Initialize and enable channel x as explained in *Section : Channel initialization*.
2. The OTG_HS host writes an IN request to the request queue as soon as the channel x gets the grant from the arbiter (round-robin with fairness). In high-bandwidth transfers, the OTG_HS host writes consecutive writes up to MC times.

3. The OTG_HS host attempts to send an IN token at the beginning of the next (odd) frame/micro-frame.
4. As soon the packet is received and written to the receive FIFO, the OTG_HS host generates a CHH interrupt.
5. In response to the CHH interrupt, reinitialize the channel for the next transfer.

Figure 970. Normal interrupt IN transactions - DMA mode



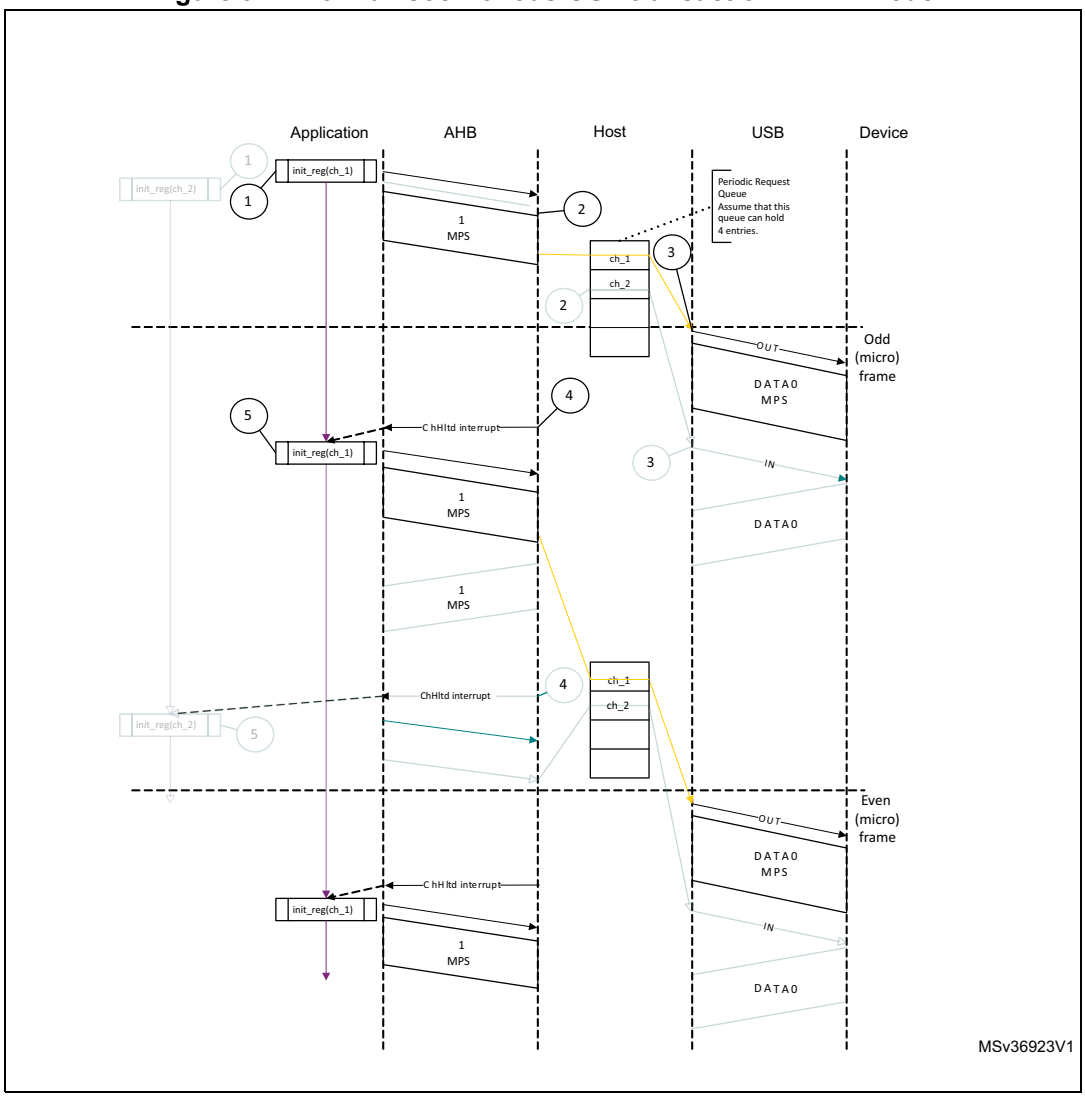
- **Isochronous OUT transactions in DMA mode**

1. Initialize and enable channel x as explained in *Section : Channel initialization*.
2. The OTG_HS host starts fetching the first packet as soon as the channel is enabled, and writes the OUT request along with the last 32-bit word fetch. In high-bandwidth

transfers, the OTG_HS host continues fetching the next packet (up to the value specified in the MC field) before switching to the next channel.

3. The OTG_HS host attempts to send an OUT token at the beginning of the next (odd) frame/micro-frame.
4. After successfully transmitting the packet, the OTG_HS host generates a CHH interrupt.
5. In response to the CHH interrupt, reinitialize the channel for the next transfer.

Figure 971. Normal isochronous OUT transaction - DMA mode



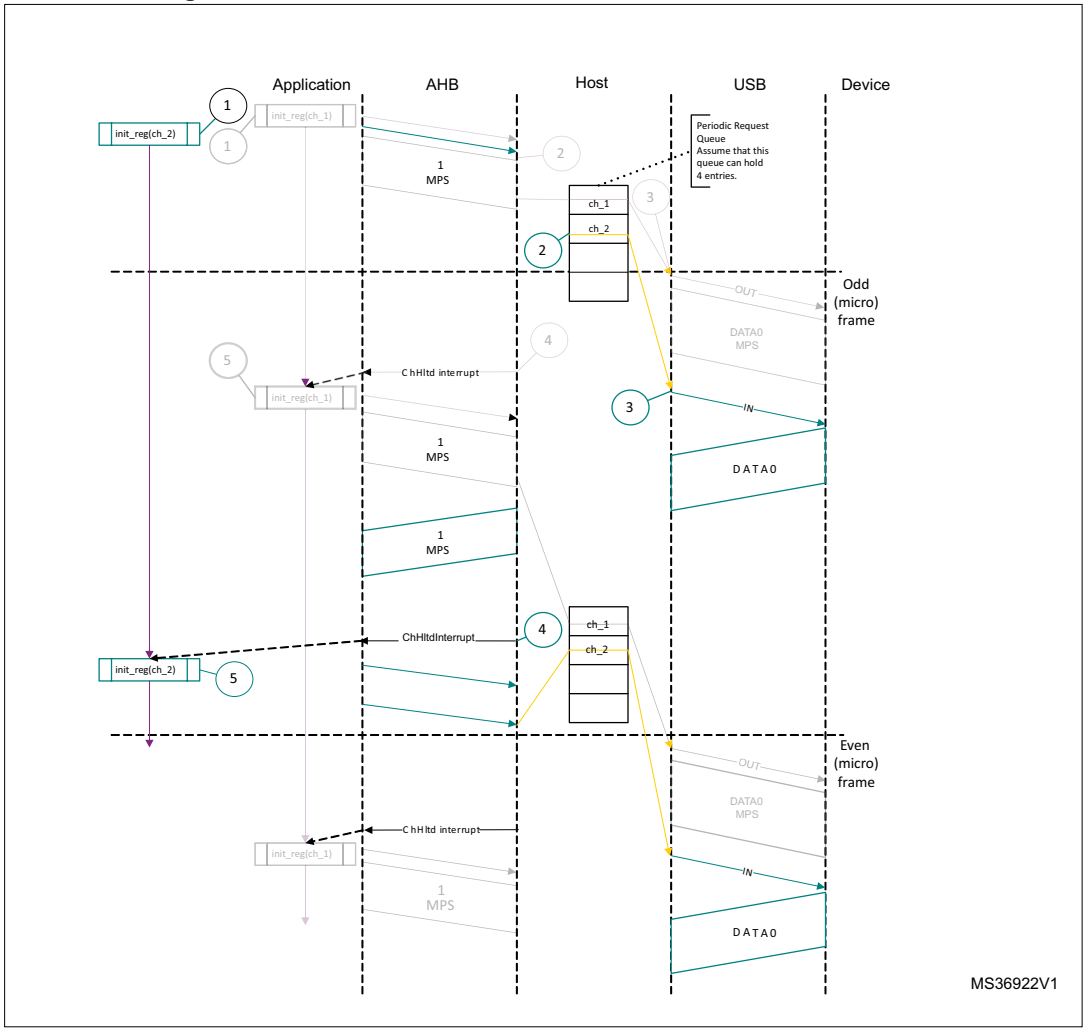
- **Isochronous IN transactions in DMA mode**

The sequence of operations ((channel x) is as follows:

1. Initialize and enable channel x as explained in *Section : Channel initialization*.
2. The OTG_HS host writes an IN request to the request queue as soon as the channel x gets the grant from the arbiter (round-robin with fairness). In high-bandwidth transfers, the OTG_HS host performs consecutive write operations up to MC times.

3. The OTG_HS host attempts to send an IN token at the beginning of the next (odd) frame/micro-frame.
4. As soon the packet is received and written to the receive FIFO, the OTG_HS host generates a CHH interrupt.
5. In response to the CHH interrupt, reinitialize the channel for the next transfer.

Figure 972. Normal isochronous IN transactions - DMA mode



- **Bulk and control OUT/SETUP split transactions in DMA mode**

  The sequence of operations in (channel x) is as follows:

1. Initialize and enable channel x for start split as explained in *Section : Channel initialization*.
2. The OTG_HS host starts fetching the first packet as soon the channel is enabled and writes the OUT request along with the last 32-bit word fetch.
3. After successfully transmitting start split, the OTG_HS host generates the CHH interrupt.
4. In response to the CHH interrupt, set the COMPLSPLT bit in OTG_HCSPLT1 to send the complete split.

5. After successfully transmitting complete split, the OTG_HS host generates the CHH interrupt.
6. In response to the CHH interrupt, de-allocate the channel.

- **Bulk/control IN split transactions in DMA mode**

The sequence of operations (channel x) is as follows:

1. Initialize and enable channel x as explained in *Section : Channel initialization*.
2. The OTG_HS host writes the start split request to the nonperiodic request after getting the grant from the arbiter. The OTG_HS host masks the channel x internally for the arbitration after writing the request.
3. As soon as the IN token is transmitted, the OTG_HS host generates the CHH interrupt.
4. In response to the CHH interrupt, set the COMPLSPLT bit in OTG_HCSPLT2 and re-enable the channel to send the complete split token. This unmasks channel x for arbitration.
5. The OTG_HS host writes the complete split request to the nonperiodic request after receiving the grant from the arbiter.
6. The OTG_HS host starts writing the packet to the system memory after receiving the packet successfully.
7. As soon as the received packet is written to the system memory, the OTG_HS host generates a CHH interrupt.
8. In response to the CHH interrupt, de-allocate the channel.

- **Interrupt OUT split transactions in DMA mode**

The sequence of operations in (channel x) is as follows:

1. Initialize and enable channel 1 for start split as explained in *Section : Channel initialization*. The application must set the ODDFRM bit in OTG_HCCHAR1.
2. The OTG_HS host starts reading the packet.
3. The OTG_HS host attempts to send the start split transaction.
4. After successfully transmitting the start split, the OTG_HS host generates the CHH interrupt.
5. In response to the CHH interrupt, set the COMPLSPLT bit in OTG_HCSPLT1 to send the complete split.
6. After successfully completing the complete split transaction, the OTG_HS host generates the CHH interrupt.
7. In response to CHH interrupt, de-allocate the channel.

- **Interrupt IN split transactions in DMA mode**

The sequence of operations in (channel x) is as follows:

1. Initialize and enable channel x for start split as explained in *Section : Channel initialization*.
2. The OTG_HS host writes an IN request to the request queue as soon as channel x receives the grant from the arbiter.
3. The OTG_HS host attempts to send the start split IN token at the beginning of the next odd micro-frame.
4. The OTG_HS host generates the CHH interrupt after successfully transmitting the start split IN token.
5. In response to the CHH interrupt, set the COMPLSPLT bit in OTG_HCSPLT2 to send the complete split.

6. As soon as the packet is received successfully, the OTG_HS host starts writing the data to the system memory.
7. The OTG_HS host generates the CHH interrupt after transferring the received data to the system memory.
8. In response to the CHH interrupt, de-allocate or reinitialize the channel for the next start split.

- **Isochronous OUT split transactions in DMA mode**

The sequence of operations (channel x) is as follows:

1. Initialize and enable channel x for start split (begin) as explained in *Section : Channel initialization*. The application must set the ODDFRM bit in OTG_HCCHAR1. Program the MPS field.
2. The OTG_HS host starts reading the packet.
3. After successfully transmitting the start split (begin), the OTG_HS host generates the CHH interrupt.
4. In response to the CHH interrupt, reinitialize the registers to send the start split (end).
5. After successfully transmitting the start split (end), the OTG_HS host generates a CHH interrupt.
6. In response to the CHH interrupt, de-allocate the channel.

- **Isochronous IN split transactions in DMA mode**

The sequence of operations (channel x) is as follows:

1. Initialize and enable channel x for start split as explained in *Section : Channel initialization*.
2. The OTG_HS host writes an IN request to the request queue as soon as channel x receives the grant from the arbiter.
3. The OTG_HS host attempts to send the start split IN token at the beginning of the next odd micro-frame.
4. The OTG_HS host generates the CHH interrupt after successfully transmitting the start split IN token.
5. In response to the CHH interrupt, set the COMPLSPLT bit in OTG_HCSPLT2 to send the complete split.
6. As soon as the packet is received successfully, the OTG_HS host starts writing the data to the system memory.

   The OTG_HS host generates the CHH interrupt after transferring the received data to the system memory. In response to the CHH interrupt, de-allocate the channel or reinitialize the channel for the next start split.

67.15.6 Device programming model

Endpoint initialization on USB reset

1. Set the NAK bit for all OUT endpoints
   – SNAK = 1 in OTG_DOEPCTLx (for all OUT endpoints)
2. Unmask the following interrupt bits
   – INEP0 = 1 in OTG_DAINTMSK (control 0 IN endpoint)
   – OUTEP0 = 1 in OTG_DAINTMSK (control 0 OUT endpoint)
   – STUPM = 1 in OTG_DOEPMSK
   – XFRCM = 1 in OTG_DOEPMSK
   – XFRCM = 1 in OTG_DIEPMSK
   – TOM = 1 in OTG_DIEPMSK
3. Set up the data FIFO RAM for each of the FIFOs
   – Program the OTG_GRXFSIZ register, to be able to receive control OUT data and setup data. If thresholding is not enabled, at a minimum, this must be equal to 1 max packet size of control endpoint 0 + 2 words (for the status of the control OUT data packet) + 10 words (for setup packets).
   – Program the OTG_DIEPTXF0 register (depending on the FIFO number chosen) to be able to transmit control IN data. At a minimum, this must be equal to 1 max packet size of control endpoint 0.
4. Program the following fields in the endpoint-specific registers for control OUT endpoint 0 to receive a SETUP packet
   – STUPCNT = 3 in OTG_DOEPTSIZ0 (to receive up to 3 back-to-back SETUP packets)
5. For USB OTG_HS in DMA mode, the OTG_DOEPDMA0 register must have a valid memory address to store any SETUP packets received.

At this point, all initialization required to receive SETUP packets is done.

Endpoint initialization on enumeration completion

1. On the Enumeration Done interrupt (ENUMDNE in OTG_GINTSTS), read the OTG_DSTS register to determine the enumeration speed.
2. Program the MPSIZ field in OTG_DIEPCTL0 to set the maximum packet size. This step configures control endpoint 0. The maximum packet size for a control endpoint depends on the enumeration speed.
3. For USB OTG_HS in DMA mode, program the OTG_DOEPCTL0 register to enable control OUT endpoint 0, to receive a SETUP packet.

At this point, the device is ready to receive SOF packets and is configured to perform control transfers on control endpoint 0.

Endpoint initialization on SetAddress command

This section describes what the application must do when it receives a SetAddress command in a SETUP packet.

1. Program the OTG_DCFG register with the device address received in the SetAddress command
2. Program the core to send out a status IN packet

Endpoint initialization on SetConfiguration/SetInterface command

This section describes what the application must do when it receives a SetConfiguration or SetInterface command in a SETUP packet.

1. When a SetConfiguration command is received, the application must program the endpoint registers to configure them with the characteristics of the valid endpoints in the new configuration.
2. When a SetInterface command is received, the application must program the endpoint registers of the endpoints affected by this command.
3. Some endpoints that were active in the prior configuration or alternate setting are not valid in the new configuration or alternate setting. These invalid endpoints must be deactivated.
4. Unmask the interrupt for each active endpoint and mask the interrupts for all inactive endpoints in the OTG_DAINTMSK register.
5. Set up the data FIFO RAM for each FIFO.
6. After all required endpoints are configured; the application must program the core to send a status IN packet.

At this point, the device core is configured to receive and transmit any type of data packet.

Endpoint activation

This section describes the steps required to activate a device endpoint or to configure an existing device endpoint to a new type.

1. Program the characteristics of the required endpoint into the following fields of the OTG_DIEPCTLx register (for IN or bidirectional endpoints) or the OTG_DOEPCTLx register (for OUT or bidirectional endpoints).
   - Maximum packet size
   - USB active endpoint = 1
   - Endpoint start data toggle (for interrupt and bulk endpoints)
   - Endpoint type
   - Tx FIFO number
2. Once the endpoint is activated, the core starts decoding the tokens addressed to that endpoint and sends out a valid handshake for each valid token received for the endpoint.

Endpoint deactivation

This section describes the steps required to deactivate an existing endpoint.

1. In the endpoint to be deactivated, clear the USB active endpoint bit in the OTG_DIEPCTLx register (for IN or bidirectional endpoints) or the OTG_DOEPCTLx register (for OUT or bidirectional endpoints).
2. Once the endpoint is deactivated, the core ignores tokens addressed to that endpoint, which results in a timeout on the USB.

Note: The application must meet the following conditions to set up the device core to handle traffic:
NPTXFEM and RXFLVLM in the OTG_GINTMSK register must be cleared.

Operational model

SETUP and OUT data transfers:

This section describes the internal data flow and application-level operations during data OUT transfers and SETUP transactions.

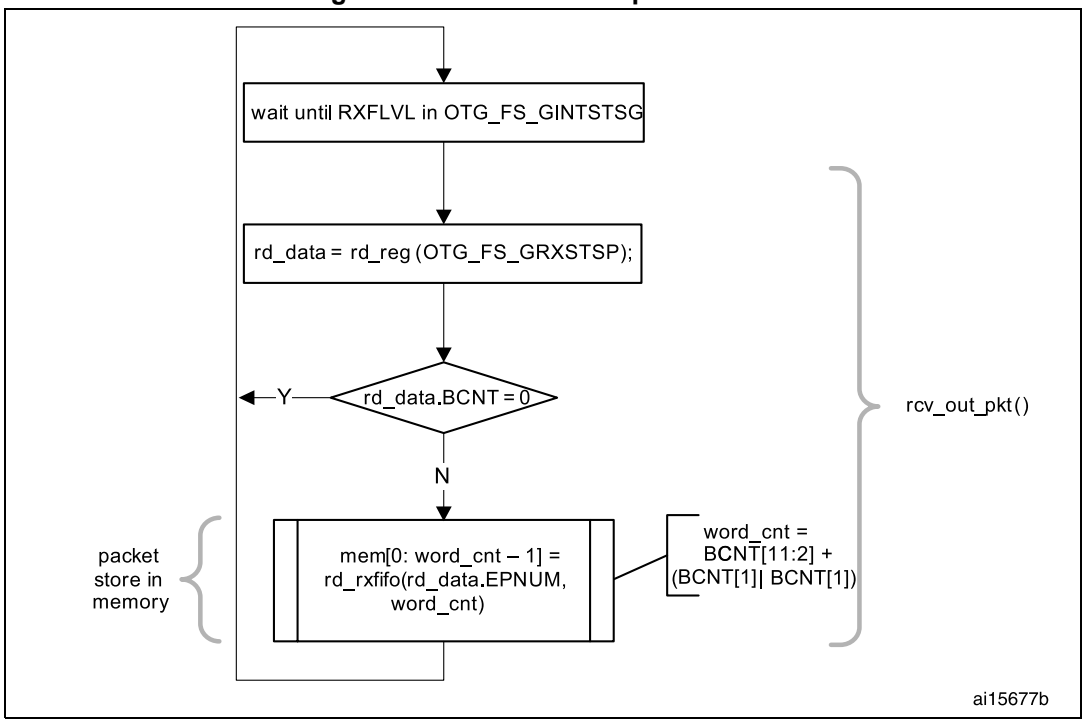
- **Packet read**

This section describes how to read packets (OUT data and SETUP packets) from the receive FIFO.

1. On catching an RXFLVL interrupt (OTG_GINTSTS register), the application must read the receive status pop register (OTG_GRXSTSP).
2. The application can mask the RXFLVL interrupt (in OTG_GINTSTS) by writing to RXFLVLM = 0 (in OTG_GINTMSK), until it has read the packet from the receive FIFO.
3. If the received packet's byte count is not 0, the byte count amount of data is popped from the receive data FIFO and stored in memory. If the received packet byte count is 0, no data is popped from the receive data FIFO.
4. The receive status readout of the packet of FIFO indicates one of the following:
   a) Global OUT NAK pattern:
   PKTSTS = Global OUT NAK, BCNT = 0x000, EPNUM = (0x0),
   DPID = (0b00).
   These data indicate that the global OUT NAK bit has taken effect.
   b) SETUP packet pattern:
   PKTSTS = SETUP, BCNT = 0x008, EPNUM = Control EP Num,
   DPID = DATA0. These data indicate that a SETUP packet for the specified endpoint is now available for reading from the receive FIFO.
   c) Setup stage done pattern:
   PKTSTS = Setup Stage Done, BCNT = 0x0, EPNUM = Control EP Num,
   DPID = (0b00).
   These data indicate that the setup stage for the specified endpoint has completed and the data stage has started. After this entry is popped from the receive FIFO, the core asserts a setup interrupt on the specified control OUT endpoint.
   d) Data OUT packet pattern:
   PKTSTS = DataOUT, BCNT = size of the received data OUT packet (0 ≤ BCNT ≤ 1 024), EPNUM = EPNUM on which the packet was received, DPID = Actual Data PID.
   e) Data transfer completed pattern:
   PKTSTS = Data OUT transfer done, BCNT = 0x0, EPNUM = OUT EP Num on which the data transfer is complete, DPID = (0b00).
   These data indicate that an OUT data transfer for the specified OUT endpoint has completed. After this entry is popped from the receive FIFO, the core asserts a transfer completed interrupt on the specified OUT endpoint.
5. After the data payload is popped from the receive FIFO, the RXFLVL interrupt (OTG_GINTSTS) must be unmasked.
6. Steps 1–5 are repeated every time the application detects assertion of the interrupt line due to RXFLVL in OTG_GINTSTS. Reading an empty receive FIFO can result in undefined core behavior.

Figure 973 provides a flowchart of the above procedure.

Figure 973. Receive FIFO packet read



SETUP transactions

This section describes how the core handles SETUP packets and the application's sequence for handling SETUP transactions.

- **Application requirements**

1. To receive a SETUP packet, the STUPCNT field (OTG_DOEPTSIZx) in a control OUT endpoint must be programmed to a non-zero value. When the application programs the STUPCNT field to a non-zero value, the core receives SETUP packets and writes them to the receive FIFO, irrespective of the NAK status and EPENA bit setting in OTG_DOEPCTLx. The STUPCNT field is decremented every time the control endpoint receives a SETUP packet. If the STUPCNT field is not programmed to a proper value before receiving a SETUP packet, the core still receives the SETUP packet and decrements the STUPCNT field, but the application may not be able to determine the correct number of SETUP packets received in the setup stage of a control transfer.
   – STUPCNT = 3 in OTG_DOEPTSIZx
2. The application must always allocate some extra space in the receive data FIFO, to be able to receive up to three SETUP packets on a control endpoint.
   – The space to be reserved is 10 words. Three words are required for the first SETUP packet, 1 word is required for the setup stage done word and 6 words are required to store two extra SETUP packets among all control endpoints.
   – 3 words per SETUP packet are required to store 8 bytes of SETUP data and 4 bytes of SETUP status (setup packet pattern). The core reserves this space in the

receive data FIFO to write SETUP data only, and never uses this space for data packets.

3. The application must read the 2 words of the SETUP packet from the receive FIFO.
4. The application must read and discard the setup stage done word from the receive FIFO.

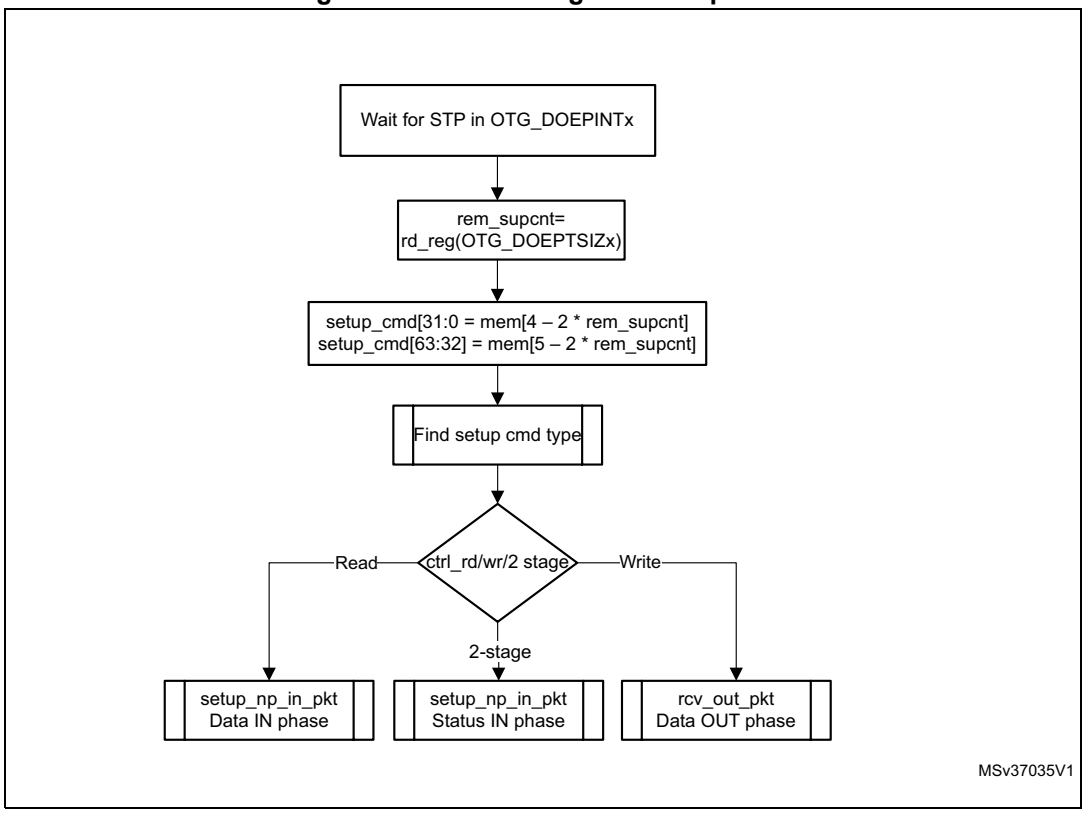
- **Internal data flow**

1. When a SETUP packet is received, the core writes the received data to the receive FIFO, without checking for available space in the receive FIFO and irrespective of the endpoint's NAK and STALL bit settings.
   – The core internally sets the IN NAK and OUT NAK bits for the control IN/OUT endpoints on which the SETUP packet was received.
2. For every SETUP packet received on the USB, 3 words of data are written to the receive FIFO, and the STUPCNT field is decremented by 1.
   – The first word contains control information used internally by the core
   – The second word contains the first 4 bytes of the SETUP command
   – The third word contains the last 4 bytes of the SETUP command
3. When the setup stage changes to a data IN/OUT stage, the core writes an entry (setup stage done word) to the receive FIFO, indicating the completion of the setup stage.
4. On the AHB side, SETUP packets are emptied by the application.
5. When the application pops the setup stage done word from the receive FIFO, the core interrupts the application with an STUP interrupt (OTG_DOEPINTx), indicating it can process the received SETUP packet.
6. The core clears the endpoint enable bit for control OUT endpoints.

- **Application programming sequence**

1. Program the OTG_DOEPTSIZx register.
   – STUPCNT = 3
2. Wait for the RXFLVL interrupt (OTG_GINTSTS) and empty the data packets from the receive FIFO.
3. Assertion of the STUP interrupt (OTG_DOEPINTx) marks a successful completion of the SETUP data transfer.
   – On this interrupt, the application must read the OTG_DOEPTSIZx register to determine the number of SETUP packets received and process the last received SETUP packet.

Figure 974. Processing a SETUP packet



- **Handling more than three back-to-back SETUP packets**

Per the USB 2.0 specification, normally, during a SETUP packet error, a host does not send more than three back-to-back SETUP packets to the same endpoint. However, the USB 2.0 specification does not limit the number of back-to-back SETUP packets a host can send to the same endpoint. When this condition occurs, the OTG_HS controller generates an interrupt (B2BSTUP in OTG_DOEPINTx).

- **Setting the global OUT NAK**

Internal data flow:

1. When the application sets the Global OUT NAK (SGONAK bit in OTG_DCTL), the core stops writing data, except SETUP packets, to the receive FIFO. Irrespective of the space availability in the receive FIFO, non-isochronous OUT tokens receive a NAK handshake response, and the core ignores isochronous OUT data packets
2. The core writes the Global OUT NAK pattern to the receive FIFO. The application must reserve enough receive FIFO space to write this data pattern.
3. When the application pops the Global OUT NAK pattern word from the receive FIFO, the core sets the GONAKEFF interrupt (OTG_GINTSTS).
4. Once the application detects this interrupt, it can assume that the core is in Global OUT NAK mode. The application can clear this interrupt by clearing the SGONAK bit in OTG_DCTL.

Application programming sequence:

1. To stop receiving any kind of data in the receive FIFO, the application must set the Global OUT NAK bit by programming the following field:
   – SGONAK = 1 in OTG_DCTL
2. Wait for the assertion of the GONAKEFF interrupt in OTG_GINTSTS. When asserted, this interrupt indicates that the core has stopped receiving any type of data except SETUP packets.
3. The application can receive valid OUT packets after it has set SGONAK in OTG_DCTL and before the core asserts the GONAKEFF interrupt (OTG_GINTSTS).
4. The application can temporarily mask this interrupt by writing to the GONAKEFFM bit in the OTG_GINTMSK register.
   – GONAKEFFM = 0 in the OTG_GINTMSK register
5. Whenever the application is ready to exit the Global OUT NAK mode, it must clear the SGONAK bit in OTG_DCTL. This also clears the GONAKEFF interrupt (OTG_GINTSTS).
   – CGONAK = 1 in OTG_DCTL
6. If the application has masked this interrupt earlier, it must be unmasked as follows:
   – GONAKEFFM = 1 in OTG_GINTMSK

- **Disabling an OUT endpoint**

The application must use this sequence to disable an OUT endpoint that it has enabled.

Application programming sequence:

1. Before disabling any OUT endpoint, the application must enable Global OUT NAK mode in the core.
   – SGONAK = 1 in OTG_DCTL
2. Wait for the GONAKEFF interrupt (OTG_GINTSTS)
3. Disable the required OUT endpoint by programming the following fields:
   – EPDIS = 1 in OTG_DOEPCTLx
   – SNAK = 1 in OTG_DOEPCTLx
4. Wait for the EPDISD interrupt (OTG_DOEPINTx), which indicates that the OUT endpoint is completely disabled. When the EPDISD interrupt is asserted, the core also clears the following bits:
   – EPDIS = 0 in OTG_DOEPCTLx
   – EPENA = 0 in OTG_DOEPCTLx
5. The application must clear the Global OUT NAK bit to start receiving data from other non-disabled OUT endpoints.
   – SGONAK = 0 in OTG_DCTL

- **Transfer Stop Programming for OUT endpoints**

The application must use the following programing sequence to stop any transfers (because of an interrupt from the host, typically a reset).

Sequence of operations:

1. Enable all OUT endpoints by setting
   – EPENA = 1 in all OTG_DOEPCTLx registers.
2. Flush the RxFIFO as follows
   – Poll OTG_GRSTCTL.AHBIDL until it is 1. This indicates that AHB master is idle.
   – Perform read modify write operation on OTG_GRSTCTL.RXFFLSH =1
   – Poll OTG_GRSTCTL.RXFFLSH until it is 0, but also using a timeout of less than 10 milli-seconds (corresponds to minimum reset signaling duration). If 0 is seen before the timeout, then the RxFIFO flush is successful. If at the moment the timeout occurs, there is still a 1, (this may be due to a packet on EP0 coming from the host) then go back (once only) to the previous step (“Perform read modify write operation”).
3. Before disabling any OUT endpoint, the application must enable Global OUT NAK mode in the core, according to the instructions in “*Setting the global OUT NAK*”. This ensures that data in the RxFIFO is sent to the application successfully. Set SGONAK = 1 in OTG_DCTL
4. Wait for the GONAKEFF interrupt (OTG_GINTSTS)
5. Disable all active OUT endpoints by programming the following register bits:
   – EPDIS = 1 in registers OTG_DOEPCTLx
   – SNAK = 1 in registers OTG_DOEPCTLx
6. Wait for the EPDIS interrupt in OTG_DOEPINTx for each OUT endpoint programmed in the previous step. The EPDIS interrupt in OTG_DOEPINTx indicates that the corresponding OUT endpoint is completely disabled. When the EPDIS interrupt is asserted, the following bits are cleared:
   – EPENA = 0 in registers OTG_DOEPCTLx
   – EPDIS = 0 in registers OTG_DOEPCTLx
   – SNAK = 0 in registers OTG_DOEPCTLx

- **Generic non-isochronous OUT data transfers**

This section describes a regular non-isochronous OUT data transfer (control, bulk, or interrupt).

Application requirements:

1. Before setting up an OUT transfer, the application must allocate a buffer in the memory to accommodate all data to be received as part of the OUT transfer.
2. For OUT transfers, the transfer size field in the endpoint’s transfer size register must be a multiple of the maximum packet size of the endpoint, adjusted to the word boundary.
   – transfer size[EPNUM] = n × (MPSIZ[EPNUM] + 4 – (MPSIZ[EPNUM] mod 4))
   – packet count[EPNUM] = n
   – n > 0
3. On any OUT endpoint interrupt, the application must read the endpoint’s transfer size register to calculate the size of the payload in the memory. The received payload size can be less than the programmed transfer size.
   – Payload size in memory = application programmed initial transfer size – core updated final transfer size
   – Number of USB packets in which this payload was received = application programmed initial packet count – core updated final packet count

Internal data flow:

1. The application must set the transfer size and packet count fields in the endpoint-specific registers, clear the NAK bit, and enable the endpoint to receive the data.
2. Once the NAK bit is cleared, the core starts receiving data and writes it to the receive FIFO, as long as there is space in the receive FIFO. For every data packet received on the USB, the data packet and its status are written to the receive FIFO. Every packet (maximum packet size or short packet) written to the receive FIFO decrements the packet count field for that endpoint by 1.
   - OUT data packets received with bad data CRC are flushed from the receive FIFO automatically.
   - After sending an ACK for the packet on the USB, the core discards non-isochronous OUT data packets that the host, which cannot detect the ACK, re-sends. The application does not detect multiple back-to-back data OUT packets on the same endpoint with the same data PID. In this case the packet count is not decremented.
   - If there is no space in the receive FIFO, isochronous or non-isochronous data packets are ignored and not written to the receive FIFO. Additionally, non-isochronous OUT tokens receive a NAK handshake reply.
   - In all the above three cases, the packet count is not decremented because no data are written to the receive FIFO.
3. When the packet count becomes 0 or when a short packet is received on the endpoint, the NAK bit for that endpoint is set. Once the NAK bit is set, the isochronous or non-isochronous data packets are ignored and not written to the receive FIFO, and non-isochronous OUT tokens receive a NAK handshake reply.
4. After the data are written to the receive FIFO, the application reads the data from the receive FIFO and writes it to external memory, one packet at a time per endpoint.
5. At the end of every packet write on the AHB to external memory, the transfer size for the endpoint is decremented by the size of the written packet.
6. The OUT data transfer completed pattern for an OUT endpoint is written to the receive FIFO on one of the following conditions:
   - The transfer size is 0 and the packet count is 0
   - The last OUT data packet written to the receive FIFO is a short packet (0 ≤ packet size < maximum packet size)
7. When either the application pops this entry (OUT data transfer completed), a transfer completed interrupt is generated for the endpoint and the endpoint enable is cleared.

Application programming sequence:

1. Program the OTG_DOEPTSIZx register for the transfer size and the corresponding packet count.
2. Program the OTG_DOEPCTLx register with the endpoint characteristics, and set the EPENA and CNAK bits.
   – EPENA = 1 in OTG_DOEPCTLx
   – CNAK = 1 in OTG_DOEPCTLx
3. Wait for the RXFLVL interrupt (in OTG_GINTSTS) and empty the data packets from the receive FIFO.
   – This step can be repeated many times, depending on the transfer size.
4. Asserting the XFRC interrupt (OTG_DOEPINTx) marks a successful completion of the non-isochronous OUT data transfer.
5. Read the OTG_DOEPTSIZx register to determine the size of the received data payload.

- **Generic isochronous OUT data transfer**

This section describes a regular isochronous OUT data transfer.

Application requirements:

1. All the application requirements for non-isochronous OUT data transfers also apply to isochronous OUT data transfers.
2. For isochronous OUT data transfers, the transfer size and packet count fields must always be set to the number of maximum-packet-size packets that can be received in a single frame and no more. Isochronous OUT data transfers cannot span more than 1 frame.
3. The application must read all isochronous OUT data packets from the receive FIFO (data and status) before the end of the periodic frame (EOPF interrupt in OTG_GINTSTS).
4. To receive data in the following frame, an isochronous OUT endpoint must be enabled after the EOPF (OTG_GINTSTS) and before the SOF (OTG_GINTSTS).

Internal data flow:

1. The internal data flow for isochronous OUT endpoints is the same as that for non-isochronous OUT endpoints, but for a few differences.
2. When an isochronous OUT endpoint is enabled by setting the endpoint enable and clearing the NAK bits, the Even/Odd frame bit must also be set appropriately. The core receives data on an isochronous OUT endpoint in a particular frame only if the following condition is met:
   – EONUM (in OTG_DOEPCTLx) = FNSOF[0] (in OTG_DSTS)
3. When the application completely reads an isochronous OUT data packet (data and status) from the receive FIFO, the core updates the RXDPID field in OTG_DOEPTSIZx with the data PID of the last isochronous OUT data packet read from the receive FIFO.

Application programming sequence:

1. Program the OTG_DOEPTSIZx register for the transfer size and the corresponding packet count
2. Program the OTG_DOEPCTLx register with the endpoint characteristics and set the endpoint enable, ClearNAK, and Even/Odd frame bits.
   – EPENA = 1
   – CNAK = 1
   – EONUM = (0: Even/1: Odd)
3. Wait for the RXFLVL interrupt (in OTG_GINTSTS) and empty the data packets from the receive FIFO
   – This step can be repeated many times, depending on the transfer size.
4. The assertion of the XFRC interrupt (in OTG_DOEPINTx) marks the completion of the isochronous OUT data transfer. This interrupt does not necessarily mean that the data in memory are good.
5. This interrupt cannot always be detected for isochronous OUT transfers. Instead, the application can detect the INCOMPISOOUT interrupt in OTG_GINTSTS.
6. Read the OTG_DOEPTSIZx register to determine the size of the received transfer and to determine the validity of the data received in the frame. The application must treat the data received in memory as valid only if one of the following conditions is met:
   – RXDPID = DATA0 (in OTG_DOEPTSIZx) and the number of USB packets in which this payload was received = 1
   – RXDPID = DATA1 (in OTG_DOEPTSIZx) and the number of USB packets in which this payload was received = 2

     RXDPID = D2 (in OTG_DOEPTSIZx) and the number of USB packets in which this payload was received = 3The number of USB packets in which this payload was received =
     Application programmed initial packet count – core updated final packet count

   The application can discard invalid data packets.

- **Incomplete isochronous OUT data transfers**

This section describes the application programming sequence when isochronous OUT data packets are dropped inside the core.

Internal data flow:

1. For isochronous OUT endpoints, the XFRC interrupt (in OTG_DOEPINTx) may not always be asserted. If the core drops isochronous OUT data packets, the application may fail to detect the XFRC interrupt (OTG_DOEPINTx) under the following circumstances:
   – When the receive FIFO cannot accommodate the complete ISO OUT data packet, the core drops the received ISO OUT data
   – When the isochronous OUT data packet is received with CRC errors
   – When the isochronous OUT token received by the core is corrupted
   – When the application is very slow in reading the data from the receive FIFO
2. When the core detects an end of periodic frame before transfer completion to all isochronous OUT endpoints, it asserts the incomplete isochronous OUT data interrupt (INCOMPISOOUT in OTG_GINTSTS), indicating that an XFRC interrupt (in OTG_DOEPINTx) is not asserted on at least one of the isochronous OUT endpoints. At

this point, the endpoint with the incomplete transfer remains enabled, but no active transfers remain in progress on this endpoint on the USB.

Application programming sequence:

1. Asserting the INCOMPISOOUT interrupt (OTG_GINTSTS) indicates that in the current frame, at least one isochronous OUT endpoint has an incomplete transfer.
2. If this occurs because isochronous OUT data is not completely emptied from the endpoint, the application must ensure that the application empties all isochronous OUT data (data and status) from the receive FIFO before proceeding.
   – When all data are emptied from the receive FIFO, the application can detect the XFRC interrupt (OTG_DOEPINTx). In this case, the application must re-enable the endpoint to receive isochronous OUT data in the next frame.
3. When it receives an INCOMPISOOUT interrupt (in OTG_GINTSTS), the application must read the control registers of all isochronous OUT endpoints (OTG_DOEPCTLx) to determine which endpoints had an incomplete transfer in the current microframe. An endpoint transfer is incomplete if both the following conditions are met:
   – EONUM bit (in OTG_DOEPCTLx) = FNSOF[0] (in OTG_DSTS)
   – EPENA = 1 (in OTG_DOEPCTLx)
4. The previous step must be performed before the SOF interrupt (in OTG_GINTSTS) is detected, to ensure that the current frame number is not changed.
5. For isochronous OUT endpoints with incomplete transfers, the application must discard the data in the memory and disable the endpoint by setting the EPDIS bit in OTG_DOEPCTLx.
6. Wait for the EPDISD interrupt (in OTG_DOEPINTx) and enable the endpoint to receive new data in the next frame.
   – Because the core can take some time to disable the endpoint, the application may not be able to receive the data in the next frame after receiving bad isochronous data.

- **Stalling a non-isochronous OUT endpoint**

This section describes how the application can stall a non-isochronous endpoint.

1. Put the core in the Global OUT NAK mode.
2. Disable the required endpoint
   – When disabling the endpoint, instead of setting the SNAK bit in OTG_DOEPCTL, set STALL = 1 (in OTG_DOEPCTL).

   The STALL bit always takes precedence over the NAK bit.
3. When the application is ready to end the STALL handshake for the endpoint, the STALL bit (in OTG_DOEPCTLx) must be cleared.
4. If the application is setting or clearing a STALL for an endpoint due to a SetFeature.Endpoint Halt or ClearFeature.Endpoint Halt command, the STALL bit must be set or cleared before the application sets up the status stage transfer on the control endpoint.

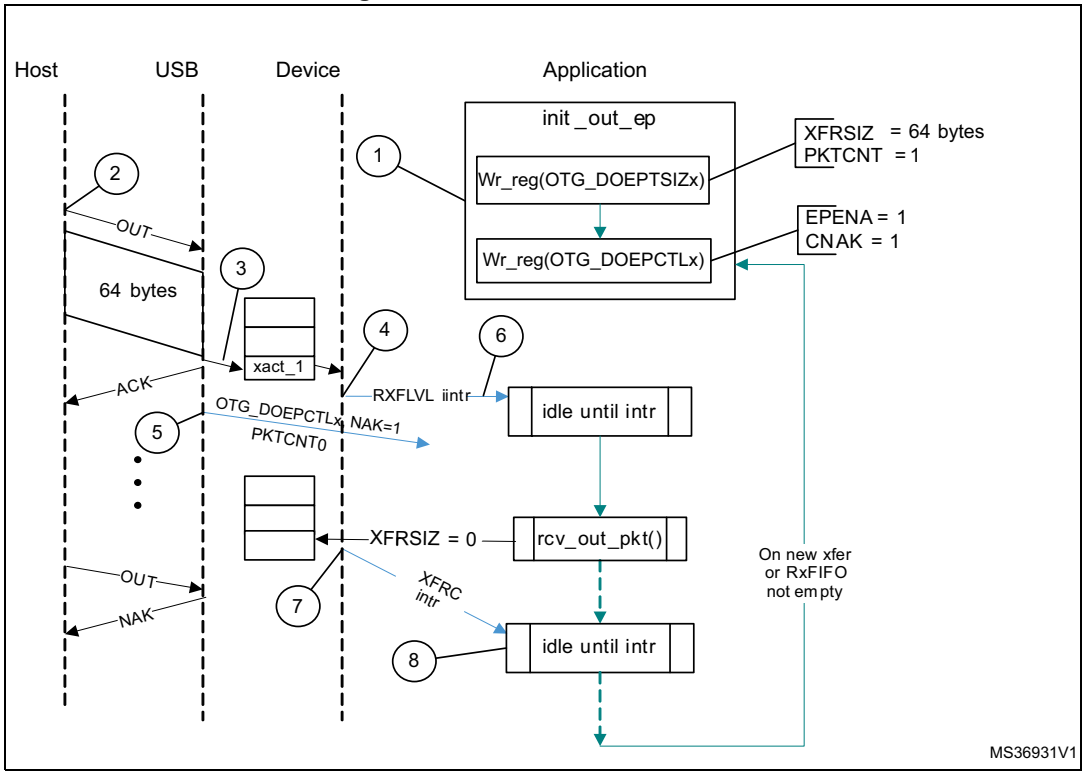
Examples

This section describes and depicts some fundamental transfer types and scenarios.

- Bulk OUT transaction

Figure 975 depicts the reception of a single Bulk OUT data packet from the USB to the AHB and describes the events involved in the process.

Figure 975. Bulk OUT transaction



After a SetConfiguration/SetInterface command, the application initializes all OUT endpoints by setting CNAK = 1 and EPENA = 1 (in OTG_DOEPCTLx), and setting a suitable XFRSIZ and PKTCNT in the OTG_DOEPTSIZx register.

1. host attempts to send data (OUT token) to an endpoint.
2. When the core receives the OUT token on the USB, it stores the packet in the Rx FIFO because space is available there.
3. After writing the complete packet in the Rx FIFO, the core then asserts the RXFLVL interrupt (in OTG_GINTSTS).
4. On receiving the PKTCNT number of USB packets, the core internally sets the NAK bit for this endpoint to prevent it from receiving any more packets.
5. The application processes the interrupt and reads the data from the Rx FIFO.
6. When the application has read all the data (equivalent to XFRSIZ), the core generates an XFRC interrupt (in OTG_DOEPINTx).
7. The application processes the interrupt and uses the setting of the XFRC interrupt bit (in OTG_DOEPINTx) to determine that the intended transfer is complete.

IN data transfers

- **Packet write**

This section describes how the application writes data packets to the endpoint FIFO when dedicated transmit FIFOs are enabled.

1. The application can either choose the polling or the interrupt mode.
   – In polling mode, the application monitors the status of the endpoint transmit data FIFO by reading the OTG_DTXFSTSx register, to determine if there is enough space in the data FIFO.
   – In interrupt mode, the application waits for the TXFE interrupt (in OTG_DIEPINTx) and then reads the OTG_DTXFSTSx register, to determine if there is enough space in the data FIFO.
   – To write a single non-zero length data packet, there must be space to write the entire packet in the data FIFO.
   – To write zero length packet, the application must not look at the FIFO space.
2. Using one of the above mentioned methods, when the application determines that there is enough space to write a transmit packet, the application must first write into the endpoint control register, before writing the data into the data FIFO. Typically, the application, must do a read modify write on the OTG_DIEPCTLx register to avoid modifying the contents of the register, except for setting the endpoint enable bit.

The application can write multiple packets for the same endpoint into the transmit FIFO, if space is available. For periodic IN endpoints, the application must write packets only for one microframe. It can write packets for the next periodic transaction only after getting transfer complete for the previous transaction.

- **Setting IN endpoint NAK**

Internal data flow:

1. When the application sets the IN NAK for a particular endpoint, the core stops transmitting data on the endpoint, irrespective of data availability in the endpoint's transmit FIFO.
2. Non-isochronous IN tokens receive a NAK handshake reply
   – Isochronous IN tokens receive a zero-data-length packet reply
3. The core asserts the INEPNE (IN endpoint NAK effective) interrupt in OTG_DIEPINTx in response to the SNAK bit in OTG_DIEPCTLx.
4. Once this interrupt is seen by the application, the application can assume that the endpoint is in IN NAK mode. This interrupt can be cleared by the application by setting the CNAK bit in OTG_DIEPCTLx.

Application programming sequence:

1. To stop transmitting any data on a particular IN endpoint, the application must set the IN NAK bit. To set this bit, the following field must be programmed.
   – SNAK = 1 in OTG_DIEPCTLx
2. Wait for assertion of the INEPNE interrupt in OTG_DIEPINTx. This interrupt indicates that the core has stopped transmitting data on the endpoint.
3. The core can transmit valid IN data on the endpoint after the application has set the NAK bit, but before the assertion of the NAK Effective interrupt.
4. The application can mask this interrupt temporarily by writing to the INEPNEM bit in OTG_DIEPMSK.
   – INEPNEM = 0 in OTG_DIEPMSK
5. To exit endpoint NAK mode, the application must clear the NAK status bit (NAKSTS) in OTG_DIEPCTLx. This also clears the INEPNE interrupt (in OTG_DIEPINTx).

– CNAK = 1 in OTG_DIEPCTLx

6. If the application masked this interrupt earlier, it must be unmasked as follows:
   – INEPNEM = 1 in OTG_DIEPMSK

- **IN endpoint disable**

Use the following sequence to disable a specific IN endpoint that has been previously enabled.

Application programming sequence:

1. The application must stop writing data on the AHB for the IN endpoint to be disabled.
2. The application must set the endpoint in NAK mode.
   – SNAK = 1 in OTG_DIEPCTLx
3. Wait for the INEPNE interrupt in OTG_DIEPINTx.
4. Set the following bits in the OTG_DIEPCTLx register for the endpoint that must be disabled.
   – EPDIS = 1 in OTG_DIEPCTLx
   – SNAK = 1 in OTG_DIEPCTLx
5. Assertion of the EPDISD interrupt in OTG_DIEPINTx indicates that the core has completely disabled the specified endpoint. Along with the assertion of the interrupt, the core also clears the following bits:
   – EPENA = 0 in OTG_DIEPCTLx
   – EPDIS = 0 in OTG_DIEPCTLx
6. The application must read the OTG_DIEPTSIZx register for the periodic IN EP, to calculate how much data on the endpoint were transmitted on the USB.
7. The application must flush the data in the endpoint transmit FIFO, by setting the following fields in the OTG_GRSTCTL register:
   – TXFNUM (in OTG_GRSTCTL) = Endpoint transmit FIFO number
   – TXFFLSH in (OTG_GRSTCTL) = 1

The application must poll the OTG_GRSTCTL register, until the TXFFLSH bit is cleared by the core, which indicates the end of flush operation. To transmit new data on this endpoint, the application can re-enable the endpoint at a later point.

- **Transfer Stop Programming for IN endpoints**

The application must use the following programing sequence to stop any transfers (because of an interrupt from the host, typically a reset).

Sequence of operations:

1. Disable the IN endpoint by setting:
   – EPDIS = 1 in all OTG_DIEPCTLx registers
2. Wait for the EPDIS interrupt in OTG_DIEPINTx, which indicates that the IN endpoint is completely disabled. When the EPDIS interrupt is asserted the following bits are cleared:
   – EPDIS = 0 in OTG_DIEPCTLx
   – EPENA = 0 in OTG_DIEPCTLx
3. Flush the TxFIFO by programming the following bits:
   – TXFFLSH = 1 in OTG_GRSTCTL
   – TXFNUM = “FIFO number specific to endpoint” in OTG_GRSTCTL
4. The application can start polling till TXFFLSH in OTG_GRSTCTL is cleared. When this bit is cleared, it ensures that there is no data left in the Tx FIFO.

- **Generic non-periodic IN data transfers**

Application requirements:

1. Before setting up an IN transfer, the application must ensure that all data to be transmitted as part of the IN transfer are part of a single buffer.
2. For IN transfers, the transfer size field in the endpoint transfer size register denotes a payload that constitutes multiple maximum-packet-size packets and a single short packet. This short packet is transmitted at the end of the transfer.
   – To transmit a few maximum-packet-size packets and a short packet at the end of the transfer:
     Transfer size[EPNUM] = *x* × MPSIZ[EPNUM] + sp
     If (sp > 0), then packet count[EPNUM] = x + 1.
     Otherwise, packet count[EPNUM] = *x*
   – To transmit a single zero-length data packet:
     Transfer size[EPNUM] = 0
     Packet count[EPNUM] = 1
   – To transmit a few maximum-packet-size packets and a zero-length data packet at the end of the transfer, the application must split the transfer into two parts. The first sends maximum-packet-size data packets and the second sends the zero-length data packet alone.
     First transfer: transfer size[EPNUM] = *x* × MPSIZ[epnum]; packet count = *n*;
     Second transfer: transfer size[EPNUM] = 0; packet count = 1;
3. Once an endpoint is enabled for data transfers, the core updates the transfer size register. At the end of the IN transfer, the application must read the transfer size register to determine how much data posted in the transmit FIFO have already been sent on the USB.
4. Data fetched into transmit FIFO = Application-programmed initial transfer size – core-updated final transfer size
   – Data transmitted on USB = (application-programmed initial packet count – core updated final packet count) × MPSIZ[EPNUM]
   – Data yet to be transmitted on USB = (Application-programmed initial transfer size – data transmitted on USB)

Internal data flow:

1. The application must set the transfer size and packet count fields in the endpoint-specific registers and enable the endpoint to transmit the data.
2. The application must also write the required data to the transmit FIFO for the endpoint.
3. Every time a packet is written into the transmit FIFO by the application, the transfer size for that endpoint is decremented by the packet size. The data is fetched from the memory by the application, until the transfer size for the endpoint becomes 0. After writing the data into the FIFO, the “number of packets in FIFO” count is incremented (this is a 3-bit count, internally maintained by the core for each IN endpoint transmit FIFO. The maximum number of packets maintained by the core at any time in an IN endpoint FIFO is eight). For zero-length packets, a separate flag is set for each FIFO, without any data in the FIFO.
4. Once the data are written to the transmit FIFO, the core reads them out upon receiving an IN token. For every non-isochronous IN data packet transmitted with an ACK handshake, the packet count for the endpoint is decremented by one, until the packet count is zero. The packet count is not decremented on a timeout.
5. For zero length packets (indicated by an internal zero length flag), the core sends out a zero-length packet for the IN token and decrements the packet count field.
6. If there are no data in the FIFO for a received IN token and the packet count field for that endpoint is zero, the core generates an “IN token received when Tx FIFO is empty” (ITTXFE) interrupt for the endpoint, provided that the endpoint NAK bit is not set. The core responds with a NAK handshake for non-isochronous endpoints on the USB.
7. The core internally rewinds the FIFO pointers and no timeout interrupt is generated.
8. When the transfer size is 0 and the packet count is 0, the transfer complete (XFRC) interrupt for the endpoint is generated and the endpoint enable is cleared.

Application programming sequence:

1. Program the OTG_DIEPTSIZx register with the transfer size and corresponding packet count.
2. Program the OTG_DIEPCTLx register with the endpoint characteristics and set the CNAK and EPENA (endpoint enable) bits.
3. When transmitting non-zero length data packet, the application must poll the OTG_DTXFSTSx register (where x is the FIFO number associated with that endpoint) to determine whether there is enough space in the data FIFO. The application can optionally use TXFE (in OTG_DIEPINTx) before writing the data.

- **Generic periodic IN data transfers**

This section describes a typical periodic IN data transfer.

Application requirements:

1. Application requirements 1, 2, 3, and 4 of *Generic non-periodic IN data transfers* also apply to periodic IN data transfers, except for a slight modification of requirement 2.
   – The application can only transmit multiples of maximum-packet-size data packets or multiples of maximum-packet-size packets, plus a short packet at the end. To

transmit a few maximum-packet-size packets and a short packet at the end of the transfer, the following conditions must be met:

transfer size[EPNUM] = x × MPSIZ[EPNUM] + sp
(where *x* is an integer ≥ 0, and 0 ≤ sp < MPSIZ[EPNUM])

If (sp > 0), packet count[EPNUM] = *x* + 1
Otherwise, packet count[EPNUM] = *x*;

MCNT[EPNUM] = packet count[EPNUM]

– The application cannot transmit a zero-length data packet at the end of a transfer. It can transmit a single zero-length data packet by itself. To transmit a single zero-length data packet:
– transfer size[EPNUM] = 0

packet count[EPNUM] = 1

MCNT[EPNUM] = packet count[EPNUM]

2. The application can only schedule data transfers one frame at a time.
   – (MCNT – 1) × MPSIZ ≤ XFERSIZ ≤ MCNT × MPSIZ
   – PKTCNT = MCNT (in OTG_DIEPTSIZx)
   – If XFERSIZ < MCNT × MPSIZ, the last data packet of the transfer is a short packet.
   – Note that: MCNT is in OTG_DIEPTSIZx, MPSIZ is in OTG_DIEPCTLx, PKTCNT is in OTG_DIEPTSIZx and XFERSIZ is in OTG_DIEPTSIZx
3. The complete data to be transmitted in the frame must be written into the transmit FIFO by the application, before the IN token is received. Even when 1 word of the data to be transmitted per frame is missing in the transmit FIFO when the IN token is received, the core behaves as when the FIFO is empty. When the transmit FIFO is empty:
   – A zero data length packet would be transmitted on the USB for isochronous IN endpoints
   – A NAK handshake would be transmitted on the USB for interrupt IN endpoints

Internal data flow:

1. The application must set the transfer size and packet count fields in the endpoint-specific registers and enable the endpoint to transmit the data.
2. The application must also write the required data to the associated transmit FIFO for the endpoint.
3. Every time the application writes a packet to the transmit FIFO, the transfer size for that endpoint is decremented by the packet size. The data are fetched from application memory until the transfer size for the endpoint becomes 0.
4. When an IN token is received for a periodic endpoint, the core transmits the data in the FIFO, if available. If the complete data payload (complete packet, in dedicated FIFO

mode) for the frame is not present in the FIFO, then the core generates an IN token received when Tx FIFO empty interrupt for the endpoint.
   – A zero-length data packet is transmitted on the USB for isochronous IN endpoints
   – A NAK handshake is transmitted on the USB for interrupt IN endpoints
5. The packet count for the endpoint is decremented by 1 under the following conditions:
   – For isochronous endpoints, when a zero- or non-zero-length data packet is transmitted
   – For interrupt endpoints, when an ACK handshake is transmitted
   – When the transfer size and packet count are both 0, the transfer completed interrupt for the endpoint is generated and the endpoint enable is cleared.
6. At the “Periodic frame Interval” (controlled by PFIVL in OTG_DCFG), when the core finds non-empty any of the isochronous IN endpoint FIFOs scheduled for the current frame non-empty, the core generates an IISOIXFR interrupt in OTG_GINTSTS.

Application programming sequence:

1. Program the OTG_DIEPCTLx register with the endpoint characteristics and set the CNAK and EPENA bits.
2. Write the data to be transmitted in the next frame to the transmit FIFO.
3. Asserting the ITTXFE interrupt (in OTG_DIEPINTx) indicates that the application has not yet written all data to be transmitted to the transmit FIFO.
4. If the interrupt endpoint is already enabled when this interrupt is detected, ignore the interrupt. If it is not enabled, enable the endpoint so that the data can be transmitted on the next IN token attempt.
5. Asserting the XFRC interrupt (in OTG_DIEPINTx) with no ITTXFE interrupt in OTG_DIEPINTx indicates the successful completion of an isochronous IN transfer. A read to the OTG_DIEPTSIZx register must give transfer size = 0 and packet count = 0, indicating all data were transmitted on the USB.
6. Asserting the XFRC interrupt (in OTG_DIEPINTx), with or without the ITTXFE interrupt (in OTG_DIEPINTx), indicates the successful completion of an interrupt IN transfer. A read to the OTG_DIEPTSIZx register must give transfer size = 0 and packet count = 0, indicating all data were transmitted on the USB.
7. Asserting the incomplete isochronous IN transfer (IISOIXFR) interrupt in OTG_GINTSTS with none of the aforementioned interrupts indicates the core did not receive at least 1 periodic IN token in the current frame.

- **Incomplete isochronous IN data transfers**

This section describes what the application must do on an incomplete isochronous IN data transfer.

Internal data flow:

1. An isochronous IN transfer is treated as incomplete in one of the following conditions:
   a) The core receives a corrupted isochronous IN token on at least one isochronous IN endpoint. In this case, the application detects an incomplete isochronous IN transfer interrupt (IISOIXFR in OTG_GINTSTS).
   b) The application is slow to write the complete data payload to the transmit FIFO and an IN token is received before the complete data payload is written to the FIFO. In this case, the application detects an IN token received when Tx FIFO empty interrupt in OTG_DIEPINTx. The application can ignore this interrupt, as it

eventually results in an incomplete isochronous IN transfer interrupt (IISOIXFR in OTG_GINTSTS) at the end of periodic frame.

The core transmits a zero-length data packet on the USB in response to the received IN token.

2. The application must stop writing the data payload to the transmit FIFO as soon as possible.
3. The application must set the NAK bit and the disable bit for the endpoint.
4. The core disables the endpoint, clears the disable bit, and asserts the endpoint disable interrupt for the endpoint.

Application programming sequence:

1. The application can ignore the IN token received when Tx FIFO empty interrupt in OTG_DIEPINTx on any isochronous IN endpoint, as it eventually results in an incomplete isochronous IN transfer interrupt (in OTG_GINTSTS).
2. Assertion of the incomplete isochronous IN transfer interrupt (in OTG_GINTSTS) indicates an incomplete isochronous IN transfer on at least one of the isochronous IN endpoints.
3. The application must read the endpoint control register for all isochronous IN endpoints to detect endpoints with incomplete IN data transfers.
4. The application must stop writing data to the Periodic Transmit FIFOs associated with these endpoints on the AHB.
5. Program the following fields in the OTG_DIEPCTLx register to disable the endpoint:
   – SNAK = 1 in OTG_DIEPCTLx
   – EPDIS = 1 in OTG_DIEPCTLx
6. The assertion of the endpoint disabled interrupt in OTG_DIEPINTx indicates that the core has disabled the endpoint.
   – At this point, the application must flush the data in the associated transmit FIFO or overwrite the existing data in the FIFO by enabling the endpoint for a new transfer in the next microframe. To flush the data, the application must use the OTG_GRSTCTL register.

- **Stalling non-isochronous IN endpoints**

This section describes how the application can stall a non-isochronous endpoint.

Application programming sequence:

1. Disable the IN endpoint to be stalled. Set the STALL bit as well.
2. EPDIS = 1 in OTG_DIEPCTLx, when the endpoint is already enabled
   – STALL = 1 in OTG_DIEPCTLx
   – The STALL bit always takes precedence over the NAK bit
3. Assertion of the endpoint disabled interrupt (in OTG_DIEPINTx) indicates to the application that the core has disabled the specified endpoint.
4. The application must flush the non-periodic or periodic transmit FIFO, depending on the endpoint type. In case of a non-periodic endpoint, the application must re-enable the other non-periodic endpoints that do not need to be stalled, to transmit data.
5. Whenever the application is ready to end the STALL handshake for the endpoint, the STALL bit must be cleared in OTG_DIEPCTLx.
6. If the application sets or clears a STALL bit for an endpoint due to a SetFeature.Endpoint Halt command or ClearFeature.Endpoint Halt command, the STALL bit must be set or cleared before the application sets up the status stage transfer on the control endpoint.

Special case: stalling the control OUT endpoint

The core must stall IN/OUT tokens if, during the data stage of a control transfer, the host sends more IN/OUT tokens than are specified in the SETUP packet. In this case, the application must enable the ITTXFE interrupt in OTG_DIEPINTx and the OTEPDIS interrupt in OTG_DOEPINTx during the data stage of the control transfer, after the core has transferred the amount of data specified in the SETUP packet. Then, when the application receives this interrupt, it must set the STALL bit in the corresponding endpoint control register, and clear this interrupt.

67.15.7 Worst case response time

When the OTG_HS controller acts as a device, there is a worst case response time for any tokens that follow an isochronous OUT. This worst case response time depends on the AHB clock frequency.

The core registers are in the AHB domain, and the core does not accept another token before updating these register values. The worst case is for any token following an isochronous OUT, because for an isochronous transaction, there is no handshake and the next token may come sooner. This worst case value is 7 PHY clocks when the AHB clock is the same as the PHY clock. When the AHB clock is faster, this value is smaller.

If this worst case condition occurs, the core responds to bulk/interrupt tokens with a NAK and drops isochronous and SETUP tokens. The host interprets this as a timeout condition for SETUP and retries the SETUP packet. For isochronous transfers, the Incomplete isochronous IN transfer interrupt (IISOIXFR) and Incomplete isochronous OUT transfer interrupt (IISOOXFR) inform the application that isochronous IN/OUT packets were dropped.

Choosing the value of TRDT in OTG_GUSBCFG

The value in TRDT (OTG_GUSBCFG) is the time it takes for the MAC, in terms of PHY clocks after it has received an IN token, to get the FIFO status, and thus the first data from the PFC block. This time involves the synchronization delay between the PHY and AHB clocks. The worst case delay for this is when the AHB clock is the same as the PHY clock. In this case, the delay is 5 clocks.

Once the MAC receives an IN token, this information (token received) is synchronized to the AHB clock by the PFC (the PFC runs on the AHB clock). The PFC then reads the data from the SPRAM and writes them into the dual clock source buffer. The MAC then reads the data out of the source buffer (4 deep).

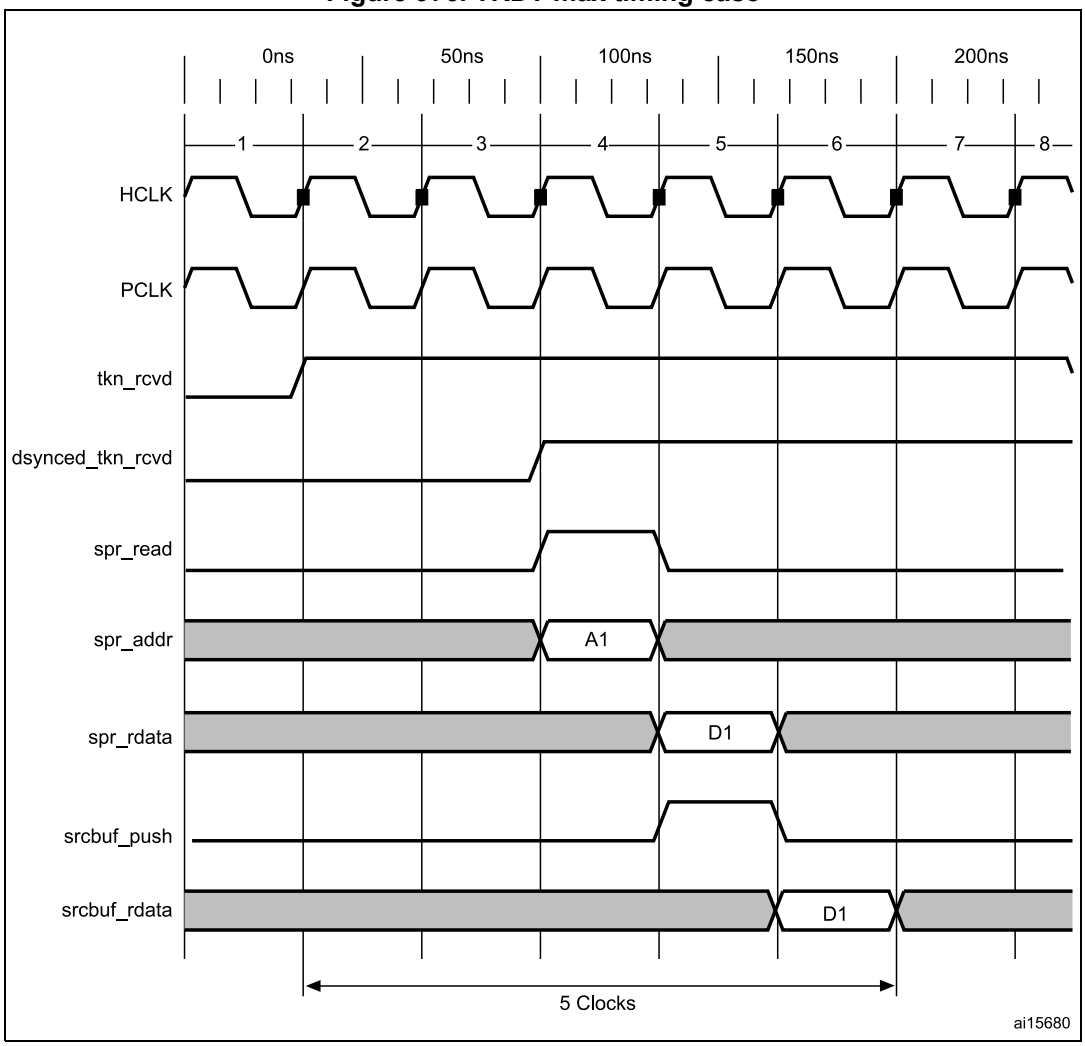
If the AHB is running at a higher frequency than the PHY, the application can use a smaller value for TRDT (in OTG_GUSBCFG).

Figure 976 has the following signals:

- tkn_rcvd: Token received information from MAC to PFC
- dynced_tkn_rcvd: Doubled sync tkn_rcvd, from PCLK to HCLK domain
- spr_read: Read to SPRAM
- spr_addr: Address to SPRAM
- spr_rdata: Read data from SPRAM
- srcbuf_push: Push to the source buffer
- srcbuf_rdata: Read data from the source buffer. Data seen by MAC

To calculate the value of TRDT, refer to *Table 750: TRDT values*.

Figure 976. TRDT max timing case



67.15.8 OTG programming model

The OTG_HS controller is an OTG device. When the core is connected to an “A” plug, it is referred to as an A-device. When the core is connected to a “B” plug it is referred to as a B-device.

68 USB Type-C®/USB Power Delivery interface (UCPD)

68.1 UCPD introduction

The USB Type-C/USB Power Delivery interface complies with:

- Universal Serial Bus Type-C Cable and Connector Specification: release 2.4, Oct 2024
- Universal Serial Bus Power Delivery specifications:
  - revision 2.0, version 1.3, January 12, 2017
  - revision 3.2, version 1.1, October 2024

It integrates the physical layer of the Power Delivery (PD) specification, with CC signaling method (no VBUS), for operation with Type-C cables.

68.2 UCPD main features

- Compliance with USB Type-C specification release 2.4
- Compliance with USB Power Delivery specifications revision 2.0 and 3.2
  - Enabling advanced applications such as PPS (programmable power supply)
- Stop mode low-power operation support
- Built-in analog PHY
  - USB Type-C pull-up (Rp, all values) and pull-down (Rd) resistors
  - “Dead battery” Rd support
  - USB Power Delivery message transmission and reception
  - FRS (fast role swap) Rx support
- Digital controller
  - BMC (bi-phase mark coding) encode and decode
  - 4b5b encode and decode
  - USB Type-C level detection with de-bounce, generating interrupts
  - FRS signaling
  - FRS detection, generating an interrupt
  - DMA-compatible byte-level interface for USB Power Delivery payload, generating interrupts
  - USB Power Delivery clock pre-scaler / dividers
  - CRC generation/checking
  - Support of ordered sets, with a programmable ordered set mask at receive
  - Clock recovery from incoming Rx stream

68.3 UCPD implementation

The devices have one UCPD controller to support one USB Type-C port.

In the following table, “X” denotes *supported*, and “-” *not supported*.

Table 753. UCPD implementation

UCPD feature	UCPD1
Dead battery support via UCPDx_DBCC1 and UCPDx_DBCC2 external signals	X
UCPDx_FRSTX as alternate function pin	X
Fully automatic trimming	X(1)
USB PD receiver hardware filter control	X
Discrete-component PHY support	-

1. No software trimming required.

68.4 UCPD functional description

The UCPD peripheral provides hardware support for the USB Power Delivery control interface specification, using I/Os specifically designed for that purpose.

The built-in PHY directly detects Type-C voltage levels, supports Power Delivery BIST carrier mode 2 (Tx only), BIST test data (Tx and Rx), and Power Delivery Rx FRS signaling.

For Power Delivery FRS Tx signaling, the device can be configured to control, through UCPD_FRSTX pin (alternate function), external NMOS transistors that ensure low-resistance pull-down on CC lines.

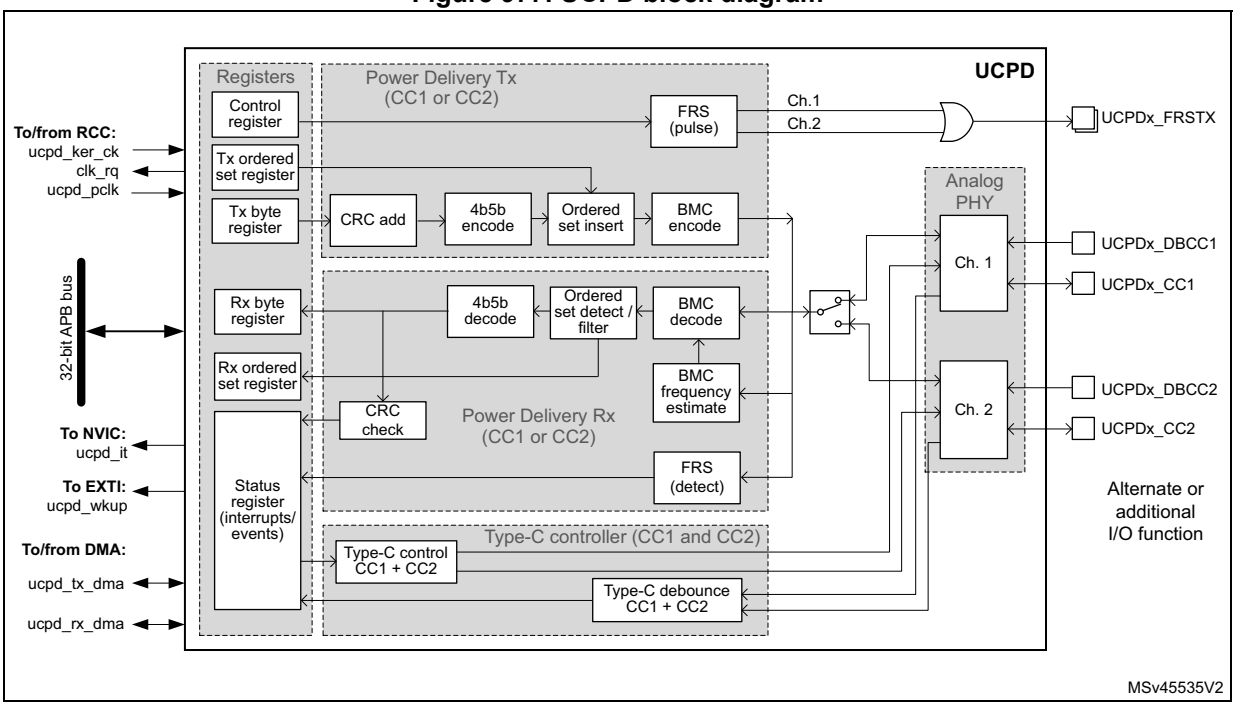
The UCPD transmitter BMC (bi-phase mark) encodes and transmits data: preamble, SOP, payload data from protocol layer (after 4b5b-encoding), CRC, and EOP on the Type-C connector CC lines. It automatically inserts inter-frame gap and executes “Hard Reset”.

The UCPD receiver detects SOP, BMC-decodes the incoming stream, recovers the preamble, 4b5b-decodes payload data, detects EOP, and checks CRC. It automatically detects five K-code SOP and two Reset ordered sets, plus two software-defined patterns (allows for only three out of four K-codes being correctly received, as defined by the standard).

In Stop mode, the peripheral maintains the ability to detect incoming USB Power Delivery messages and FRS signaling, which allows low-power operation.

68.4.1 UCPD block diagram

Figure 977. UCPD block diagram



The following table lists external signals (alternate or additional I/O functions).

Table 754. UCPD signals on pins

Pin name	Signal type	Description
UCPDx_FRSTX	Output	USB Type-C fast role swap (FRS) signaling control, applicable to DRPs only. The signal (active high) drives an external NMOS transistor that pulls down the active CC line. A typical application has two such transistors (one per CC line) and reserves a separate I/O to drive either NMOS. Initially, the I/Os are configured as low-driving GPIOs. Upon detecting, through the Type-C state machine, the orientation of the cable attached, which determines the active CC line, the I/O of the active CC line must be set to its UCPDx_FRSTX alternate function and the I/O of the inactive CC line as low-driving GPIO.
UCPDx_CC1	Input/output	USB Type-C configuration control line 1, to be routed to the USB Type-C connector CC1 terminal.
UCPDx_CC2	Input/output	USB Type-C configuration control line 2, to be routed to the USB Type-C connector CC2 terminal.
UCPDx_DBCC1	Input	USB Type-C configuration control line 1 dead battery signal, to be routed to the USB Type-C connector CC1 terminal if dead battery support is required.
UCPDx_DBCC2	Input	USB Type-C configuration control line 2 dead battery signal, to be routed to the USB Type-C connector CC2 terminal if dead battery support is required.

The following table lists key internal signals.

Table 755. UCPD internal signals

Internal signal name	Signal type	Description
ucpd_pclk	Input	APB clock for registers
ucpd_ker_ck	Input	Kernel clock
ucpd_tx_dma	Input/Output	Rx DMA acknowledge / request
ucpd_rx_dma	Input/Output	Tx DMA acknowledge / request
ucpd_it	Output	Interrupt request (all interrupts OR-ed) connected to NVIC
ucpd_wkup	Output	Wake-up request connected to EXTI
clk_rq	Output	Clock request connected to RCC

68.4.2 UCPD reset and clocks

The peripheral has a single reset signal (APB bus reset).

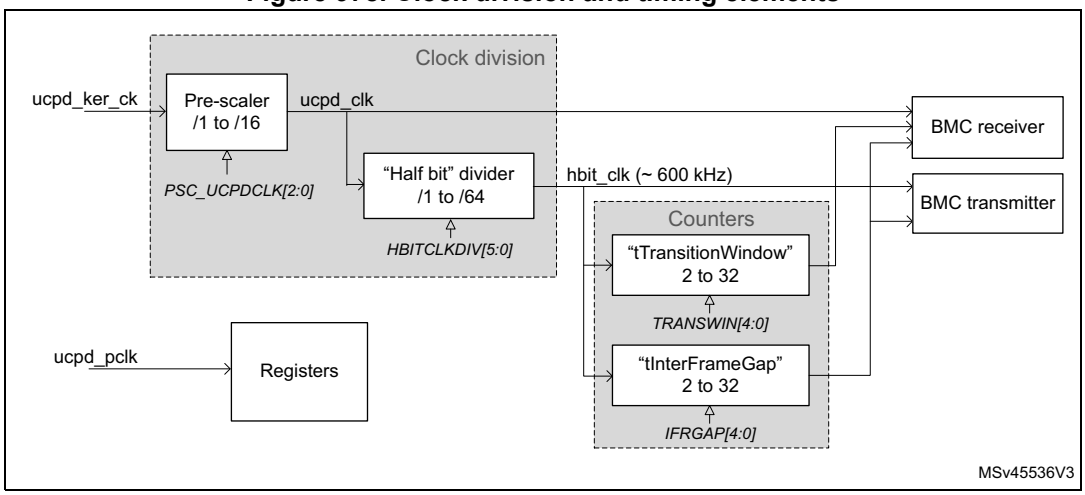
The register section is clocked with the APB clock (ucpd_pclk).

The main functional part of the transmitter is clocked with ucpd_clk clock, pre-scaled from the ucpd_ker_ck clock according to the PSC_UCPDCLK[2:0] bitfield of the UCPD_CFGR1 register. The main functional part of the receiver is clocked with the ucpd_rx_clk recovered from the incoming bitstream.

The receiver is designed to work in the clock frequency range from 6 to 18 MHz. However, the optimum performance is ensured in the range from 6 to 12 MHz.

The following diagram shows the clocking and timing elements of the UCPD peripheral.

Figure 978. Clock division and timing elements



Refer to the USB PD specification in order to set appropriate delays. For *tTransitionWindow* and especially for *tInterFrameGap*, the clock frequency uncertainty must be taken into account so as to respect specified timings in all cases.

68.4.3 Physical layer protocol

The physical layer covers the signaling underlying the USB Power Delivery specification.

On the transmitter side its main function is to form packets according to the defined packet format including generally:

- preamble
- start of packet (SOP, ordered set)
- payload header
- payload data
- cyclic redundancy check (CRC) information
- end of packet (EOP)

Before going on the CC line, the data stream is BMC-encoded, respecting specified timing restrictions.

On the receive side, the principle task is to:

- extract start of packet (SOP, ordered set) information
- extract payload header
- extract payload data
- receive and check CRC
- receive end of packet (EOP)

The receive is basically a reverse of the transmit process, thus starting with BMC data stream decoding.

Symbol encoding

Apart from the preamble all symbols are encoded with a 4b5b scheme according to the specification shown in the following table.

Table 756. 4b5b symbol encoding table

Name	4b	5b	Symbol description
0	0000	11110	hex data 0
1	0001	01001	hex data 1
2	0010	10100	hex data 2
3	0011	10101	hex data 3
4	0100	01010	hex data 4
5	0101	01011	hex data 5
6	0110	01110	hex data 6
7	0111	01111	hex data 7
8	1000	10010	hex data 8
9	1001	10011	hex data 9
A	1010	10110	hex data A
B	1011	10111	hex data B
C	1100	11010	hex data C

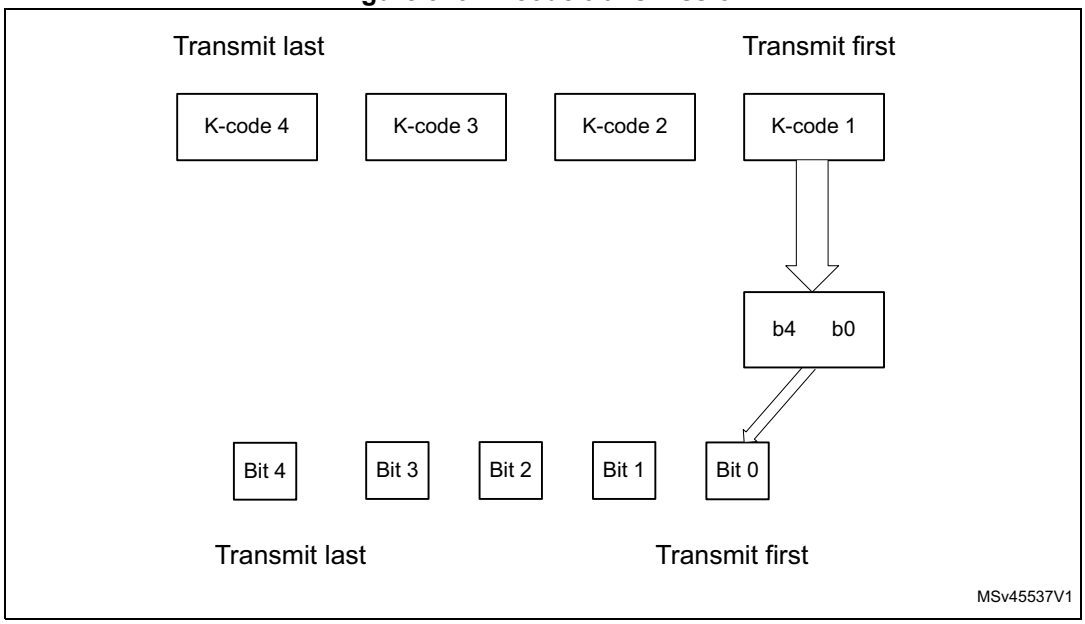
Table 756. 4b5b symbol encoding table (continued)

Name	4b	5b	Symbol description
D	1101	11011	hex data D
E	1110	11100	hex data E
F	1111	11101	hex data F
Sync-1	K-code	11000	Startsynch #1
Sync-2	K-code	10001	Startsynch #2
RST-1	K-code	00111	Hard Reset #1
RST-2	K-code	11001	Hard Reset #2
EOP	K-code	01101	EOP
Reserved	Error	00000	Do Not Use
Reserved	Error	00001	Do Not Use
Reserved	Error	00010	Do Not Use
Reserved	Error	00011	Do Not Use
Reserved	Error	00100	Do Not Use
Reserved	Error	00101	Do Not Use
Sync-3	K-code	00110	Startsynch #3
Reserved	Error	01000	Do Not Use
Reserved	Error	01100	Do Not Use
Reserved	Error	10000	Do Not Use
Reserved	Error	11111	Do Not Use

Ordered sets

An ordered set consists of four K-codes as shown in the following figure.

Figure 979. K-code transmission



The following table lists the defined ordered sets, including all possible SOP* sequences.

At the physical layer, the Hard Reset has higher priority than the other ordered sets so it can interrupt an ongoing Tx message.

Table 757. Ordered sets

Ordered set name	K-code #1	K-code #2	K-code #3	K-code #4
SOP	Sync-1	Sync-1	Sync-1	Sync-2
SOP’	Sync-1	Sync-1	Sync-3	Sync-3
SOP’’	Sync-1	Sync-3	Sync-1	Sync-3
Hard Reset	RST-1	RST-1	RST-1	RST-2
Cable Reset	RST-1	Sync-1	RST-1	Sync-3
SOP’_Debug	Sync-1	RST-2	RST-2	Sync-3
SOP’’_Debug	Sync-1	RST-2	Sync-3	Sync-2

On reception, the physical layer must accept ordered sets with any combination of three correct K-codes out of four, as shown in the following table:

Table 758. Validation of ordered sets

Status	1st code	2nd code	3rd code	4th code
Valid	Corrupt	K-code	K-code	K-code
Valid	K-code	Corrupt	K-code	K-code

Table 758. Validation of ordered sets (continued)

Status	1st code	2nd code	3rd code	4th code
Valid	K-code	K-code	Corrupt	K-code
Valid	K-code	K-code	K-code	Corrupt
Valid (perfect)	K-code	K-code	K-code	K-code
Not valid (example)	K-code	Corrupt	K-code	Corrupt

Bit ordering at transmission

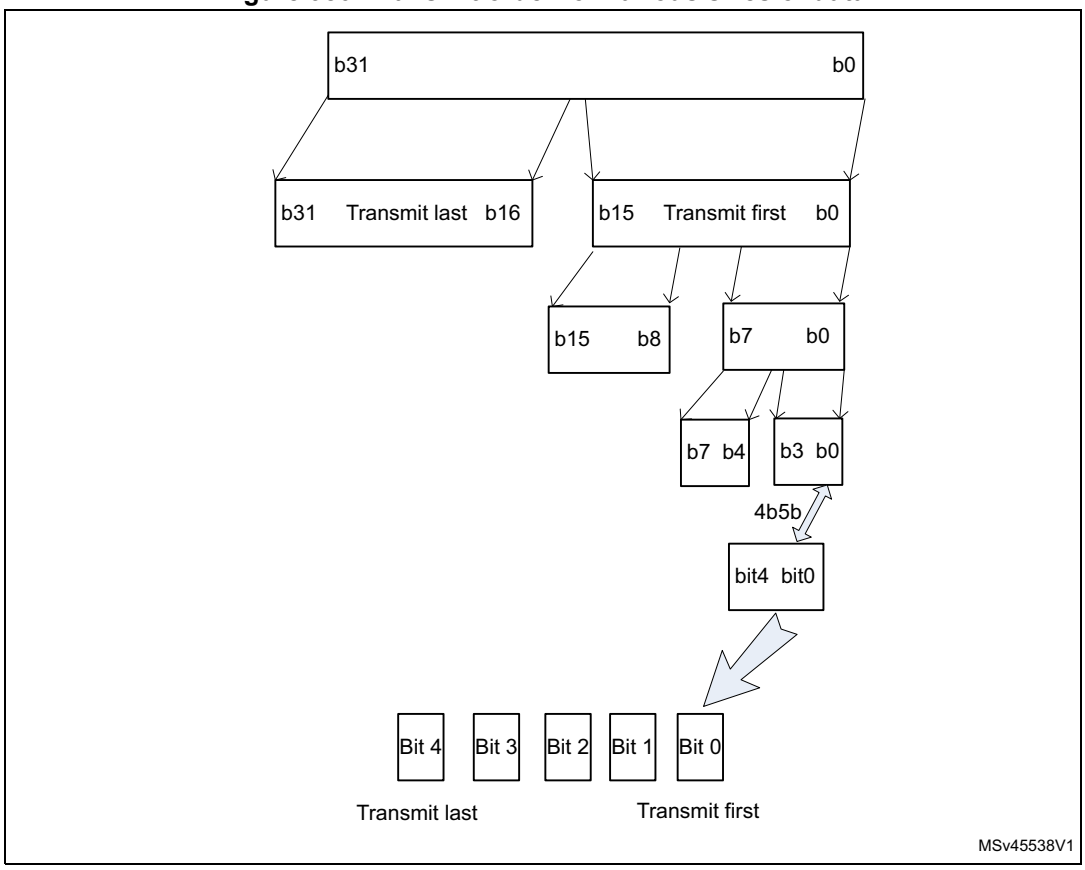
Allowed transmission data units / data sizes are in the following table.

Table 759. Data size

Data unit	Non-encoded	Encoded
Byte	8-bits	10-bits
Word	16-bits	20-bits
DWord	32-bits	40-bits

The bit transmission order is shown in the following figure.

Figure 980. Transmit order for various sizes of data

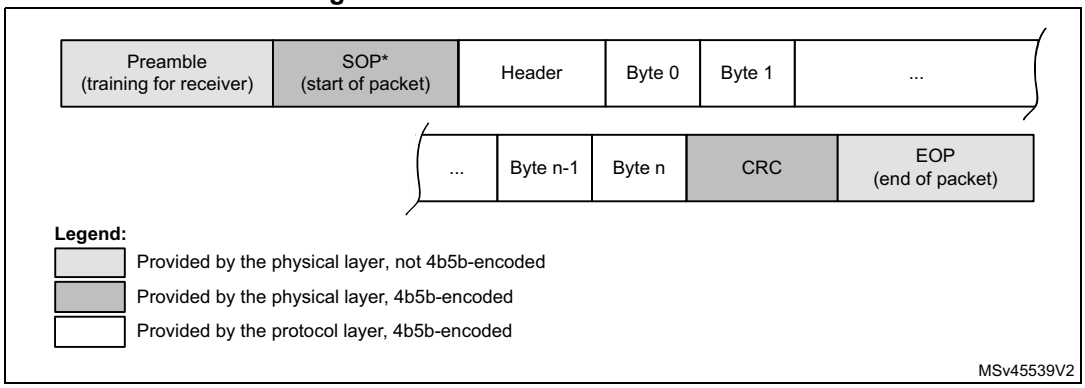


Packet format

Messages other than Hard Reset and Cable Reset

The packet format is shown in the following figure, with information on 4b5b encode and data source.

Figure 981. Packet format



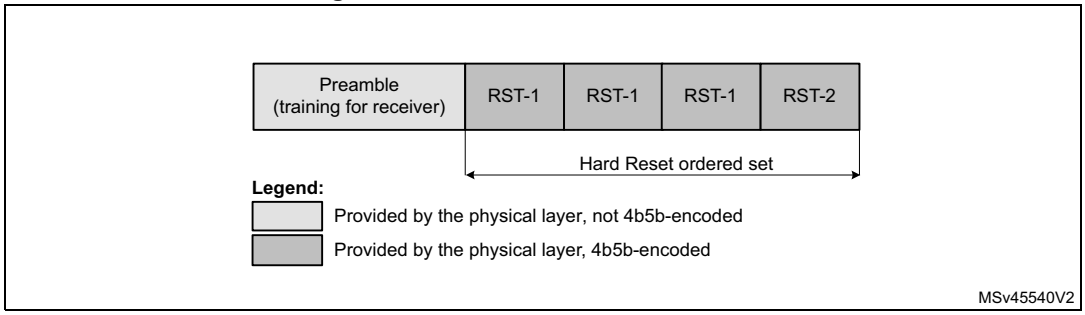
Hard Reset

The physical layer handles the Hard Reset signaling differently than the other types of message as it has higher priority to be able to interrupt an ongoing transfer.

The physical layer specification implies the following sequence in the case of an ongoing Tx message:

1. Terminate the message by sending an EOP K-code and discard the rest of the message.
2. Wait for *tInterFrameGap* time.
3. If the CC line is not idle, wait until it goes idle.
4. Send the preamble followed by the four K-codes of Hard Reset signaling.
5. Disable the CC channel (stop sending and receiving), reset the physical layer and inform the protocol layer that the physical layer is reset.
6. Re-enable the channel when requested by the protocol layer.

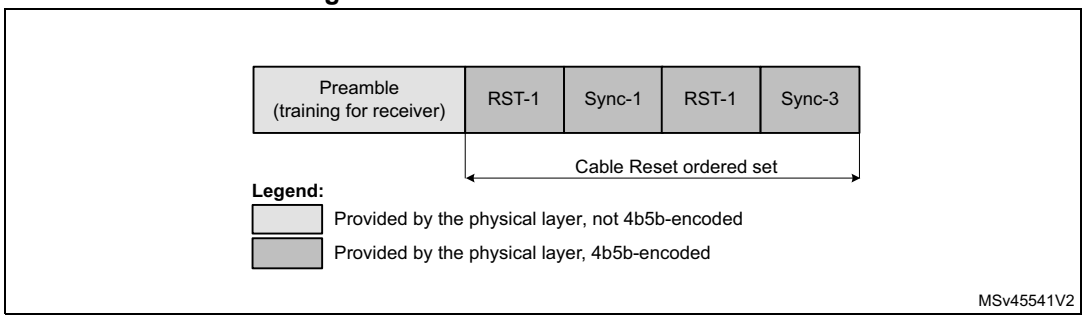
Figure 982. Line format of Hard Reset



Cable Reset

Cable Reset shown in the following figure is similar in format to Hard Reset, but unlike Hard Reset it does not require a specific high-priority treatment.

Figure 983. Line format of Cable Reset



Collision avoidance

The physical layer respects the *tInterFrameGap* delay between end of last-transmitted bit of a Tx message, and the first bit of a following message.

It also checks the idle state of the CC line before starting transmission. The CC line is considered idle if it shows less than three (*nTransitionCount*) transitions within *tTransitionWindow* (12 to 20 µs). The Power Delivery specification revision 3.1 also requires to manage the Rp value (source) and monitor Type-C voltage level for these Rp modifications (at the sink).

Physical layer signaling schemes

The bit are signaled with bi-phase mark coding (BMC).

BIST

Depending on the BIST action required by the protocol layer, either of the following can be run:

- a Tx BIST pattern test, achieved by writing TXMODE and TXSEND
- an Rx BIST pattern test, achieved by writing RXMODE to the correct value for RXBIST.

The two possible patterns supported in UCPD (corresponding to “BMC” mode) are:

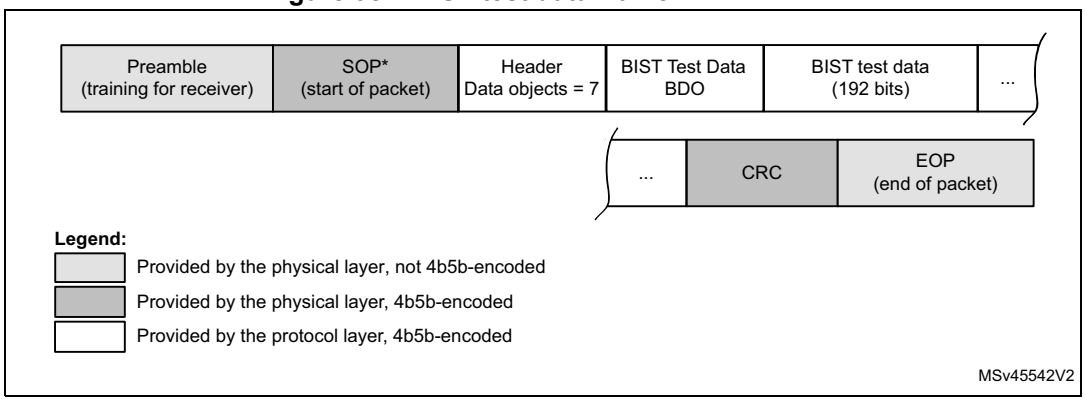
- BIST Test Data (192 bit pattern), applies to Tx and Rx. In the case of Rx, the message is received (but discarded rather than passing to the protocol layer, which must nevertheless still generate a GoodCRC Tx message in acknowledgment).
- BIST Carrier Mode 2 (single pattern, infinite length message), applies to Tx only. As opposed to Tx, the receiver in this mode simply ignores the CC line during this state.

BIST test data pattern

The test data pattern is not viewed as a special case in UCPD.

The BIST test data packet frame format is shown in the following figure.

Figure 984. BIST test data frame



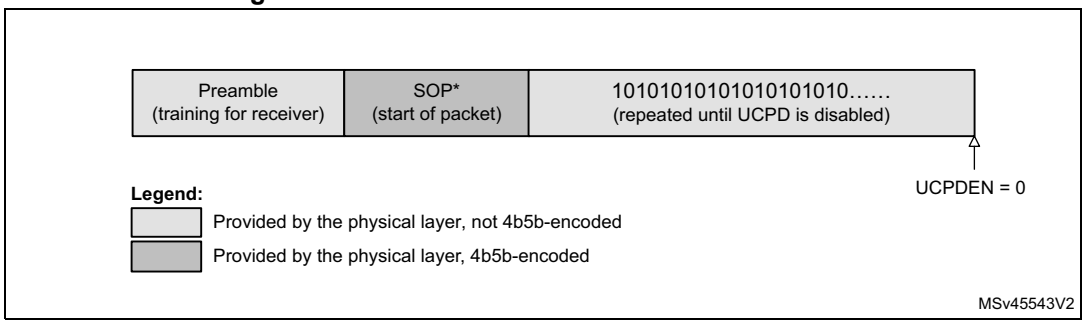
This is a fixed length test data pattern. In reality the only aspect that marks its difference from the general packet format already shown in *Figure 981: Packet format* is the contents of the Header. As UCPD receives the Tx Header contents via programming (it is simply viewed as part of the payload), it is only this programming (and not the block's behavior) that differentiates the general packet from the BIST Test Data packet.

BIST Carrier Mode 2

When required, this BIST test mode sends an alternating pattern of 1010 that is continually repeated. As this mode is intended for signal analysis it is stable condition with (in V1.0 of the USB PD specification) no defined length. Starting from V1.1 of the USB PD specification, the protocol layer defines a counter that indicates when to exit this mode.

The way to quit the infinite 1010 sequence (according to requirements of the USB PD specification) is to disable the UCPD peripheral via the UCPDEN bit.

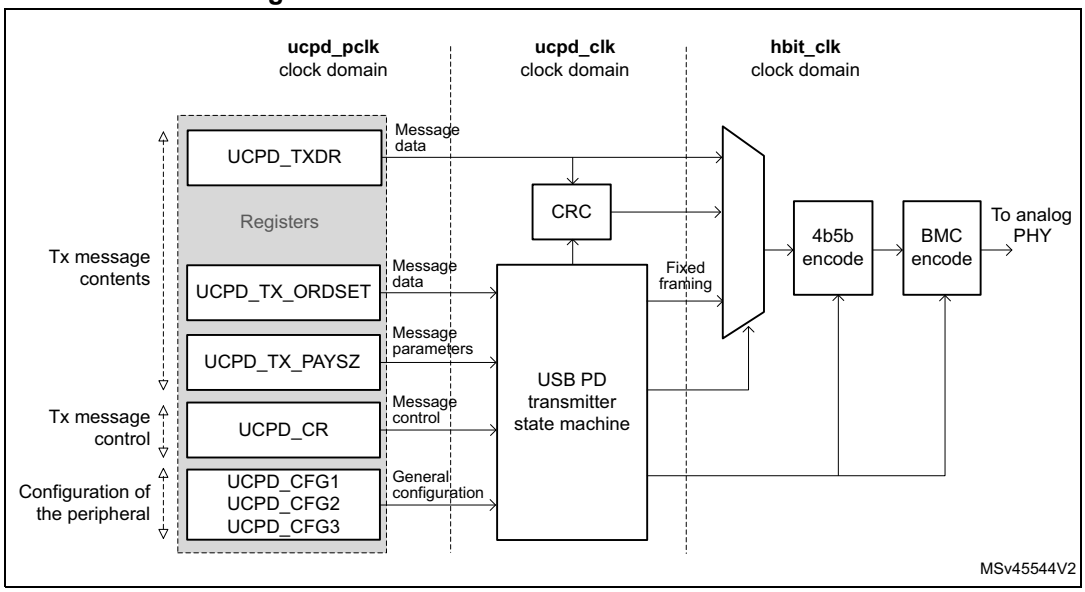
Figure 985. BIST Carrier Mode 2 frame



68.4.4 UCPD BMC transmitter

The BMC transmitter comprises 4b5b encoding, CRC generation, and BMC encode, as shown in the following figure. Its output goes to the analog PHY through a channel switch.

Figure 986. UCPD BMC transmitter architecture



BMC encoder

The bi-phase mark coding method is defined in the *IEC 60958-1 Digital Audio Interface Part:1 General Edition 3.0 2008-09 www.iec.ch* specification.

The half-bit clock hbit_clk is derived from ucpd_clk through a simple divider controlled by the HBITCLKDIV[5:0] bitfield of the UCPD_CFGR1 register. This ensures the same duration of high and low half-bit periods (if neglecting a small difference due to different rising and falling edge duration and due to jitter), and the same bit duration (if neglecting jitter).

Transmitter timing and collision avoidance

Hardware support of collision avoidance is made as a function of the half bit time for the transmitter. Two counters are implemented:

– *tInterFrameGap*: via IFRGAP (pre-defined value, can be altered)
– *tTransitionWindow*: via TRANSWIN (pre-defined value, can be altered)

These two counters once set correctly generates the interframe gap.

Hard Reset in transmitter

In order to facilitate generation of a Hard Reset, a special code of TXMODE field is used. No other fields need to be written.

On writing the correct code, the hardware forces Hard Reset Tx under the correct (optimal) timings with respect to an ongoing Tx message, which (if still in progress) is cleanly terminated by truncating the current sequence and directly appending an EOP K-code sequence. No specific interrupt is generated relating to this truncation event.

Transmitter behavior in the case of errors

The under-run condition (TXUND interrupt) may happen by accident and in this case, the UCPD is starved of (the correct) Tx payload and is not able to complete the Tx message correctly. This is a serious error (for this to happen the software fails to respond in time). As a result the hardware ensures the CRC is incorrect at the end of the message, thus guaranteeing the message to be discarded at the receiver.

68.4.5 UCPD BMC receiver

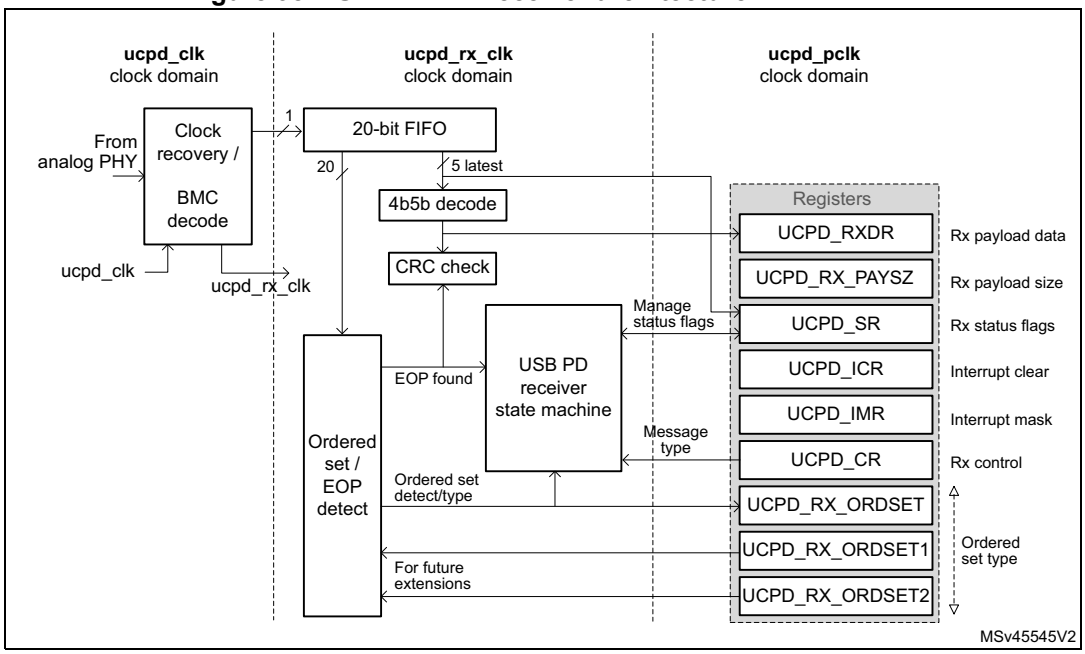
The UCPD BMC receiver performs:

- Clock recovery
- Preamble detection / timing derivation
- BMC decoding
- 4b5b decoding
- K-code ordered set recognition
- CRC checking
- SOP detection
- EOP detection

The receiver is activated as soon as the UCPD peripheral is enabled (via UCPDEN), but it waits for an idle CC line state before attempting to receive a message.

The following figure shows the UCPD BMC receiver high-level architecture.

Figure 987. UCPD BMC receiver architecture



CRC checker

The received bits are fed into a CRC checker which evolves a 32-bit state during the received the payload bitstream. At the end the 32 bits of the CRC also fed into the logic

The EOP detection (5 bits) halts the process and a check is performed for the fixed residual state which confirms correct reception of the payload (in fact the residual is 0xC704DD78).

At this point the UCPD raises interrupt RXMSGEND. If the CRC was not correct then RXERR is set true and the receive data must be discarded.

Under normal operation, this interrupt would previously have been acknowledged and thus cleared. If this is not the case, a different interrupt RXOVR is generated in place of RXMSGEND.

Ordered set detection

This function detects the different ordered sets each consisting of four 5-bit K-codes.

Once we are in the preamble we opens a sliding window detection of the ordered set (4 words of 5 bits).

The ordered sets detected include all SOP* codes (SOP, SOP', and SOP''), but also Hard Reset, Cable Reset, SOP'_Debug, SOP''_Debug, and two extensions defined by registers UCPD_RX_ORDEXT1 and UCPD_RX_ORDEXT2.

EOP detection and Hard Reset exception handling

EOP is a fixed 5-bit K-code marking the end of a message.

The way in which a transmitter is required to send a Hard Reset (if a previous message transmit is still in progress) is that this previous message is truncated early with an EOP.

If Hard Reset were ignored, then the EOP detection can be done only at the expected time. However, due to the Hard Reset issue, the EOP detector must be active while an Rx message is arriving. When an "early EOP" is detected, the truncated Rx message is immediately discarded.

Truncated or corrupted message exception

Once the ordered set has been detected, depending on the message, there may be data bytes to be received which is completed with a CRC and EOP. If at any point during these phases an error condition happens:

- the line becomes static for a time significantly longer than one "UI" period (the exact threshold for this condition is not critical but the exception must occur before three UIs), or
- the message goes to the end but it is not recognized (for example EOP is corrupted).

In both cases, the receiver quits the current message, raising RXMSGEND and RXERR flags.

Short preamble or incomplete ordered set exception

In the exceptional case of the receiver seeing less that half of the expected preamble, the frequency estimation allowing correct BMC-decode becomes impossible. Even if the full preamble is seen, allowing frequency estimation, but the ordered set is not fully received before the line becomes static, the receiver state machine does not start.

In both of these cases, the clock-recovery/BMC decoder re-starts, checking initially for an IDLE condition, followed by a preamble, and then estimating frequency.

68.4.6 UCPD Type-C pull-ups (Rp) and pull-downs (Rd)

UCPD offers simple control of these resistors via ANAMODE and ANASUBMODE[1:0]. In case only one of the CC lines is to be used, it is possible to optimize power consumption by disabling control on the other line, through the CCENABLE[1:0] bitfield.

When the MCU is unpowered, it still presents the "dead battery" Rd, provided that UCPDx_DBCC1 and UCPDx_DBCC2 pins are each connected to UCPDx_CC1 and UCPDx_CC2 pins, respectively.

If dead battery behavior is not required (for example for source only products), then UCPDx_DBCC1 and UCPDx_DBCC2 pins must both be tied to ground.

After power arrives and the MCU boots, the desired behavior (for example source) must be programmed into ANAMODE and ANASUBMODE[1:0] before setting the UCPD_DBDIS bit of the PWR_UCPDR register to remove dead battery pull-down resistor and allow the values just programmed to take effect.

Use of Standby low-power mode is possible for sinks in the unattached state.

Note: In order to guarantee the correct behavior of the Rd resistors, please set the USBPD_DIS option bit to 0 (following the procedure described in the "modification" section of the FLASH chapter).

68.4.7 UCPD Type-C voltage monitoring and de-bouncing

For correct operation of the Type-C state machine and for detecting the cable orientation, the CC1/2 lines must be monitored for voltage level, while ignoring fast events such as peaks.

Thresholds between voltage levels on the CC1/2 lines are determined through PHY threshold detector settings.

The TYPEC_VSTATE_CC1/2[1:0] bitfields reflect the CC1/2 line levels processed with a hardware de-bouncing filter that suppresses high-speed line events such as peaks. The PHYCCSEL bit selects the line, CC1 or CC2, to be used for Power Delivery signaling.

For minimizing the power consumption, it is recommended to use the polling method, with the Type-C detectors only turned on for the instant of polling, rather than keeping the Type-C detectors permanently on and wake the device up from Stop mode upon CC1/2 line events.

68.4.8 UCPD fast role swap (FRS)

FRS signaling

The FRS condition (a pulse of a specific length), is generated upon setting the FRSTX bit.

For the duration of FRS condition, the I/O configured as UCPD_FRSTX (alternate function) controls, with high level, the gate of an external NMOS transistor that pulls the active CC line down.

FRS detection

FRS monitoring is enabled by setting the bit FRSRXEN, after writing PHYCCSEL that selects the active CC line depending on the cable orientation detected.

68.4.9 UCPD DMA Interface

DMA is implemented in the UCPD and when it is enabled the byte-level interrupts to handle UCPD1_TXDR and UCPD1_RXDR registers (Tx and Rx data register, each one byte) are no longer needed.

By enabling bits TXDMAEN and/or RXDMAEN, DMA can be activated independently for Tx and/or Rx functionality.

68.4.10 Wake-up from Stop mode

For power consumption optimization, it is useful to use Stop mode and wait for events on CC lines to wake the MCU up.

In order for this to work, it must be first enabled by writing a 1 to WUPEN.

The events causing the wake-up can be:

- Events on the BMC receiver (RXORDDET, RXHRSTDET), hardware enable PHYRXEN
- Event on the FRS detector (FRSEVT), hardware enable FRSRXEN
- Events on the Type-C detectors (TYPECEVT1, TYPECEVT2), hardware enables CC1TCDIS, CC2TCDIS

68.5 UCPD programming sequences

The normal sequence of use of the UCPD unit is:

1. Configure UCPD.
2. Enable UCPD.
3. Concurrently:
   – On demand from protocol layer, send Tx message
   – Intercept (poll or wait for interrupt) relevant Rx messages and recover detail to hand off to protocol layer

Repeat the last point infinitely.

68.5.1 Initialization phase

Use the following sequence for a clean startup:

1. Prepare all initial clock divider values, by writing the UCPD_CFG register.
2. Enable the unit, by setting the UCPDEN bit.
3. Enable the analog Rx filter of either CC line, via the RXAFILTEN bit of the UCPD_CFGR2 register.

68.5.2 Type-C state machine handling

For the general application cases of source, sink, or dual-role port (the last alternating the source and the sink), the software must implement a corresponding USB Type-C state machine. The basic coding is in the following table.

Table 760. Coding for ANAMODE, ANASUBMODE and link with TYPEC_VSTATE_CCx

ANAMODE	ANASUBMODE[1:0]	Notes	TYPEC_VSTATE_CCx[1:0]			
			00	01	10	11
0: Source	00: Disabled	Disabled	N/A			
	01: Default USB Rp	-	vRa[Def]	vRd[Def]	vOPEN[Def]	N/A
	10: 1.5A Rp	-	vRa[1.5]	vRd[1.5]	vOPEN[1.5]	
	11: 3.0A Rp	-	vRa[3.0]	vRd[3.0]	vOPEN[3.0]	
1: Sink	xx	-	vRa	vRd-USB	vRd-1.5	vRd-3.0

The CCENABLE[1:0] bitfield can disable pull-up/pull-downs on one of the CC lines.

Note: The Type-C state machine depends not only on CC line levels, but also on VBUS presence detection (sink mode) and, when in source mode, determines VCONN generation and VBUS state (ON/OFF/+voltage level); discharge). UCPD does not directly control VBUS generation circuitry nor VCONN load switch (enabling VCONN supply generator to be connected to the CC line), but the application needs these inputs and controls, to function correctly.

General programming sequence (with UCPD configured then enabled)

1. Set ANAMODE and ANASUBMODE[1:0] based on the current position in USB Type-C state machine (and also the current advertisement in the case of a source). This turns on the appropriate pull-ups/pull-downs on the CC lines, and defines the voltage levels that the TYPEC_VSTATE fields represent. Note that before programming, the PHY is effectively off.
2. Read TYPEC_VSTATE_CC1/2 to determine the initial Type-C state (for example whether the local source is connected to a remote sink).
3. In the case of no connection, wait for a connection event.
4. Assuming a connection is detected and assuming a local Power Delivery functionality is implemented, start sending/receiving Power Delivery messages.
5. When a new interrupt/event occurs on PHYEVT1/2 indicating a change in stable voltage, re-evaluate the implications and give this input to the Type-C state machine.

Case of a source that needs to change between one of the three possible Rp values (Default-USB / 1.5A / 3.0A) and the sink connected to it:

- [Source] Simply reprogram ANASUBMODE[1:0]
- [Sink behavior from that time] PHYEVT1/2 occurs and the TYPEC_VSTATE1/2 changes accordingly

Programming for a dual-role port (DRP) toggling from source to sink:

- Simply re-program ANAMODE and ANASUBMODE[1:0] to start the new behavior

Detailed programming sequence (example):

Table 761. Type-C sequence (source: 3A); cable/sink connected (Rd on CC1; Ra on CC2)

Type-C state	ANAMODE; ANASUBMODE[1:0]	CCENABLE	PHYCCSEL	RDCH	CC[x] VCONNEN[(1)]	Event => go to next line	Comments
Unattached. SRC	0:Source; 11:Rp3A0	11:both enabled	0 (don't care)	0: [Normal]	00: [neither]	PHYEVT 1: [VRd-3A0]	Wait for sink attach detect ; seen on CC1 [EVT1]
Attachwait. SRC			0 [Rd on CC1]			PHYEVT 2: [VRa]	Attachwait started (100-200 ms) ; now also see the Ra => requesting VCONN
Attached. SRC [VCONN => CC2]	0:Source; 11:Rp3A0 [SinkTxOK]	01: CC2 disable (possible and recommended due to external VCONN switch)			10: [CC2 active]	Timer (100 ms) and no PHYEVTx	Local CC2 disconnected from PHY (VCONN switch connects VCONN source to CC2 externally; Continue to monitor PHYEVT1
	0:Source; 10:Rp1A5 [SinkTxNG]					SW timers (SinkTxNG)	Source wants to initiate message sequence (SinkTxNG condition set first)
	0:Source; 11:Rp3A0 [SinkTxOK]						Source finished message sequence (SinkTxOK condition afterwards)
						PHYEVT 1: [VOpen-3A0]	Wait for Sink disconnected (Vopen on CC1)
Unattached wait. SRC		11:both enabled	0 (do not care)	1: [discharge]	00: [neither]	> 0.8V detection	Discharge VCONN [CC2] actively [Rdch]; to < 0.8V
Unattached. SRC	0:Source; 11:Rp3A0			0: [Normal]			[Details as first line of table]

1. Two GPIOs to enable VCONN through external load switch components

68.5.3 USB PD transmit

On reception of a message from the protocol layer (that is, to be sent), prepare Tx message contents by writing the UCPD_TX_ORDSET and UCPD_TX_PAYSZ registers.

The message transmission is triggered by setting the TXSEND bit, with an appropriate value of the TXMODE bitfield.

When the data byte is transmitted, the TXIS flag is raised to request a new data write to the UCPD_TXDR register.

This re-iterates until the entire payload of data is transmitted.

Upon sending the CRC packet, the TXMSGSENT flag is set to indicate the completion of the message transmission.

Hard Reset transmission

As soon as it is known that a Hard Reset needs to be transmitted, setting the TXHRST bit of the UCPD_CR register forces the internal state machine to generate the correct sequence. The value of UCPD_TX_ORDSET does not require update in this precise case (the correct code for Hard Reset is sent by UCPD).

The USB Power Delivery specification requires that in the case of an ongoing message transmission, the Hard Reset takes precedence. In this case, for example, UCPD truncates the payload of the current message, appending EOP to the end. No notification is available via the registers (for example through the TXMSGSEND flag). This is justified by the fact that the Hard Reset takes precedence over any previous activity (for which it is therefore no longer important to know if it is completed).

Use of DMA for transmission

DMA (Direct Memory Access) can be enabled for transmission by setting the TXDMAEN bit in the UCPD_CR register.

For each message:

- Prepare the whole message in memory (starting with two header bytes)
- Program the DMA operation with a length corresponding to the two header bytes plus a number of data bytes corresponding to the number of data words multiplied by four
- Write TXSEND to initiate the message transfer
- If TXMSGDISC then go back to previous line (TXSEND)
- Wait for DMA transfer complete interrupt (that is, when last Tx byte written to UCPD)
- Double-check subsequent TXMSGSENT interrupt appears

68.5.4 USB PD receive

Notification of start of the receive message sequence is triggered by an interrupt on UCPD_SR (bit RXORDDET).

The information is recovered by reading:

- UCPD_RX_SOP (on interrupt RXORDDET)
- UCPD_RXDR (on interrupt RXNE, repeats for each byte)
- UCPD_RXPAYSZ (on interrupt RXMSGEND)

The data previously read from UCPD_RXDR above must be discarded at this point if the RXERR flag is set.

If the CRC is valid, the received data is transferred to the protocol layer.

For debug purposes, it may be desirable to track statistics of the number of incorrect K-codes received (this is done only when 3/4 K-codes were valid as defined in the specification). This is facilitated through:

- RXSOP3OF4 bit indicating the presence of at least one invalid K-code
- RXSOPKINVALID bitfield identifying the order of invalid K-code in the ordered set

Use of DMA for reception

DMA (Direct Memory Access) can be enabled for reception by setting the RXDMAEN bit in the UCPD_CR register.

Whenever a Rx message is expected:

- Program a DMA receive operation (and spare buffer) a little longer than the maximum possible message (length depends on extended message support).
- After receiving RXORDDET, DMA operation starts working in the background.
- On reception of RXMSGEND interrupt, read RXPAYSZ.
- Double-check RXPAYSZ vs. the number of DMA Rx bytes (must correspond but DMA read of RXDR is slightly after RXDR gets last byte).
- Process the DMA Rx buffer.
- Prepare next Rx DMA buffer as soon as possible in order to be ready.

68.6 UCPD low-power modes

A summary of low-power modes is shown below in *Table 762: Effect of low power modes on the UCPD*.

Table 762. Effect of low power modes on the UCPD

Mode	Description
Sleep	No effect
Stop	Detection of events (Type-C, BMC Rx, FRS detection) remains operational and can wake up the MCU.
Standby	UCPD is not operating, and cannot wake up the MCU. Pull-downs remain active if configured.
Unpowered	Dead battery pull-downs remain active.

The UCPD is able to wake up the MCU from Stop mode when it recognizes a relevant event, either:

- Type-C event relating to a change in the voltage range seen on either of the CC lines, visible in TYPEC_VSTATE_CCx
- Power delivery receive message with an ordered set matching those filtered according to RXORDSETEN[8:0], visible by reading RXORDSET

Wake-up from Stop mode is enabled by setting the WUPEN bit in the UCPD_CFG2 register.

At UCPD level three types of event requiring kernel clock activity may occur during Stop mode:

- Activity on the analog PHY voltage threshold detectors which can later be confirmed to be a stable change between voltage ranges defined in the Type-C specification
- Activity on Power Delivery BMC receiver (coming from the selected CC line) which can potentially generate an Rx message event (that is, RXORDSET) later
- Activity on Power Delivery FRS detector which can potentially generate an FRS signaling detection event (that is, FRSEVT) later

It order to function correctly with the RCC, the clock request signal is activated (conditional on WUPEN) when there is asynchronous activity on:

- Type-C voltage threshold detectors (coming from either CC line)
- Power Delivery receiver signal (from the selected CC line)
- FRS detection signal (from the selected CC line)

68.7 UCPD interrupts

The table below lists the UCPD event flags, with the associated flag clear bits and interrupt enable bits.

Table 763. UCPD interrupt requests

Interrupt event	Event flag	Event flag/Interrupt clearing method	Interrupt enable control bit
FRS detection	FRSEVT	Set FRSEVTCF	FRSEVTIE
Type C voltage level change on CC2	TYPECEVT2	Set TYPECEVT2CF	TYPECEVT2IE
Type C voltage level change on CC1	TYPECEVT1	Set TYPECEVT1CF	TYPECEVT1IE
Rx message received	RXMSGEND	Set RXMSGENDCF	RXMSGENDIE
Rx data overflow	RXOVR	Set RXOVRCF	RXOVR
Rx Hard Reset detected	RXHRSTDET	Set RXHRSTDETCF	RXHRSTDETIE
Rx ordered set (4 K-codes) detected	RXORDDET	Set RXORDDETCF	RXORDDETIE
Receive data register not empty	RXNE	Read data in UCPD_RXDR	RXNEIE
Tx data underrun	TXUND	Set TXUNDCF	TXUNDIE
Hard Reset sent	HRSTSENT	Set HRSTSENTCF	HRSTSENTIE
Hard Reset discarded	HRSTDISC	Set HRSTDISCCF	HRSTDISCIE
Transmit message aborted	TXMSGABT	Set TXMSGABTCF	TXMSGABTIE
Transmit message sent	TXMSGSENT	Set TXMSGSENTCF	TXMSGSENTIE
Transmit message discarded	TXMSGDISC	Set TXMSGDISCCF	TXMSGDISCIE
Transmit data required	TXIS	Write data to the UCPD_TXDR register	TXISIE

When an interrupt from the UCPD is received, then the software has to check what is the source of the interrupt by reading the UCPD_SR register.

Depending on which bit is at 1, the ISR must handle that condition and clear the bit by a write to the appropriate bit of the UCPD_ICR register.

68.8 UCPD registers

68.8.1 UCPD configuration register 1 (UCPD_CFGR1)

Address offset: 0x000

Reset value: 0x0000 0000

General configuration of the peripheral. Writing to this register is only effective when UCPD is disabled (UCPDEN = 0).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UCPDEN	RXDMAEN	TXDMAEN	RXORDSETEN[8:0]									PSC_UCPDCLK[2:0]			Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRANSWIN[4:0]					IFRGAP[4:0]					HBITCLKDIV[5:0]					
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UCPDEN**: UCPD peripheral enable

General enable of the UCPD peripheral.

0: Disable

1: Enable

Upon disabling, the peripheral instantly quits any ongoing activity and all control bits and bitfields default to their reset values. They must be set to their desired values each time the peripheral transits from disabled to enabled state.

Bit 30 **RXDMAEN**: Reception DMA mode enable

When set, the bit enables DMA mode for reception.

0: Disable

1: Enable

Bit 29 **TXDMAEN**: Transmission DMA mode enable

When set, the bit enables DMA mode for transmission.

0: Disable

1: Enable

Bits 28:20 **RXORDSETEN[8:0]**: Receiver ordered set enable

The bitfield determines the types of ordered sets that the receiver must detect. When set/cleared, each bit enables/disables a specific function:

0bXXXXXXXX1: SOP detect enabled

0bXXXXXXX1X: SOP' detect enabled

0bXXXXXX1XX: SOP'' detect enabled

0bXXXXX1XXX: Hard Reset detect enabled

0bXXXX1XXXX: Cable Detect reset enabled

0bXXX1XXXXX: SOP'_Debug enabled

0bXX1XXXXXX: SOP''_Debug enabled

0bX1XXXXXXX: SOP extension#1 enabled

0b1XXXXXXXX: SOP extension#2 enabled

Bits 19:17 **PSC_UCPDCLK[2:0]**: Pre-scaler division ratio for generating ucpd_clk

The bitfield determines the division ratio of a kernel clock pre-scaler producing UCPD peripheral clock (ucpd_clk).

0x0: 1 (bypass)
0x1: 2
0x2: 4
0x3: 8
0x4: 16

It is recommended to use the pre-scaler so as to set the ucpd_clk frequency in the range from 6 to 9 MHz.

Bit 16 Reserved, must be kept at reset value.

Bits 15:11 **TRANSWIN[4:0]**: Transition window duration

The bitfield determines the division ratio (the bitfield value minus one) of a hbit_clk divider producing *tTransitionWindow* interval.

0x00: Not supported
0x01: 2
0x09: 10 (recommended)
0x1F: 32

Set a value that produces an interval of 12 to 20 us, taking into account the ucpd_clk frequency and the HBITCLKDIV[5:0] bitfield setting.

Bits 10:6 **IFRGAP[4:0]**: Division ratio for producing inter-frame gap timer clock

The bitfield determines the division ratio (the bitfield value minus one) of a ucpd_clk divider producing inter-frame gap timer clock (*tInterFrameGap*).

0x00: Not supported
0x01: 2
0x0D: 14
0x0E: 15
0x0F: 16
0x1F: 32

The division ratio 15 is to apply for Tx clock at the USB PD 2.0 specification nominal value. The division ratios below 15 are to apply for Tx clock below nominal, and the division ratios above 15 for Tx clock above nominal.

Bits 5:0 **HBITCLKDIV[5:0]**: Division ratio for producing half-bit clock

The bitfield determines the division ratio (the bitfield value plus one) of a ucpd_clk divider producing half-bit clock (hbit_clk).

0x00: 1 (bypass)
0x1A: 27
0x3F: 64

68.8.2 UCPD configuration register 2 (UCPD_CFGR2)

Address offset: 0x004

Reset value: 0x0000 0000

Configuration of the UCPD Rx signal filtering. Writing to this register is only effective when UCPD is disabled (UCPDEN = 0).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXAFILTEN	Res.	Res.	Res.	Res.	WUPEN	FORCECLK	RXFILT2N3	RXFILTDIS
							rw					rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **RXAFILTEN**: Rx analog filter enable
Setting the bit enables the Rx analog filter required for optimum Power Delivery reception.
0: Disable
1: Enable

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **WUPEN**: Wake-up from Stop mode enable
Setting the bit enables the UCPD_ASYNC_INT signal.
0: Disable
1: Enable

Bit 2 **FORCECLK**: Force ClkReq clock request
0: Do not force clock request
1: Force clock request

Bit 1 **RXFILT2N3**: BMC decoder Rx pre-filter sampling method
Number of consistent consecutive samples before confirming a new value.
0: 3 samples
1: 2 samples

Bit 0 **RXFILTDIS**: BMC decoder Rx pre-filter enable
0: Enable
1: Disable
The sampling clock is that of the receiver (that is, after pre-scaler).

68.8.3 UCPD control register (UCPD_CR)

Address offset: 0x00C

Reset value: 0x0000 0000

Writing to this register is only effective when the peripheral is enabled (UCPDEN = 1).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2TCDIS	CC1TCDIS	Res.	RDCH	FRSTX	FRSRXEN
										rw	rw		rw	rs	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	CCENABLE[1:0]		ANAMODE	ANASUBMODE[1:0]		PHYCCSEL	PHYRXEN	RXMODE	TXHRST	TXSEND	TXMODE[1:0]	
				rw	rw	rw	rw	rw	rw	rw	rw	rs	rs	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **CC2TCDIS**: CC2 Type-C detector disable

The bit disables the Type-C detector on the CC2 line.
0: Enable
1: Disable
When enabled, the Type-C detector for CC2 is configured through ANAMODE and ANASUBMODE[1:0].

Bit 20 **CC1TCDIS**: CC1 Type-C detector disable

The bit disables the Type-C detector on the CC1 line.
0: Enable
1: Disable
When enabled, the Type-C detector for CC1 is configured through ANAMODE and ANASUBMODE[1:0].

Bit 19 Reserved, must be kept at reset value.

Bit 18 **RDCH**: Rdch condition drive

The bit drives Rdch condition on the CC line selected through the PHYCCSEL bit (thus associated with VCONN), by remaining set during the source-only *UnattachedWait.SRC* state, to respect the Type-C state. Refer to *"USB Type-C ECN for Source VCONN Discharge"*. The CCENABLE[1:0] bitfield must be set accordingly, too.
0: No effect
1: Rdch condition drive

Bit 17 **FRSTX**: FRS Tx signaling enable.

Setting the bit enables FRS Tx signaling.
0: No effect
1: Enable
The bit is cleared by hardware after a delay respecting the USB Power Delivery specification Revision 3.1.

Bit 16 **FRSRXEN**: FRS event detection enable

Setting the bit enables FRS Rx event (FRSEVT) detection on the CC line selected through the PHYCCSEL bit. 0: Disable
1: Enable
Clear the bit when the device is attached to an FRS-incapable source/sink.

Bit 15 Reserved, must be kept at reset value.

Bit 14 Reserved, must be kept at reset value.

Bit 13 Reserved, must be kept at reset value.

Bit 12 Reserved, must be kept at reset value.

Bits 11:10 **CCENABLE[1:0]**: CC line enable

This bitfield enables CC1 and CC2 line analog PHYs (pull-ups and pull-downs) according to ANAMODE and ANASUBMODE[1:0] setting.
0x0: Disable both PHYs
0x1: Enable CC1 PHY
0x2: Enable CC2 PHY
0x3: Enable CC1 and CC2 PHY
A single line PHY can be enabled when, for example, the other line is driven by VCONN via an external VCONN switch. Enabling both PHYs is the normal usage for sink/source.

Bit 9 **ANAMODE**: Analog PHY operating mode

0: Source
1: Sink
The use of CC1 and CC2 depends on CCENABLE. Refer to *Table 760: Coding for ANAMODE, ANASUBMODE and link with TYPEC_VSTATE_CCx* for the effect of this bitfield in conjunction with ANASUBMODE[1:0].

Bits 8:7 **ANASUBMODE[1:0]**: Analog PHY sub-mode

Refer to *Table 760: Coding for ANAMODE, ANASUBMODE and link with TYPEC_VSTATE_CCx* for the effect of this bitfield.

Bit 6 **PHYCCSEL**: CC1/CC2 line selector for USB Power Delivery signaling

0: Use CC1 IO for Power Delivery communication
1: Use CC2 IO for Power Delivery communication
The selection depends on the cable orientation as discovered at attach.

Bit 5 **PHYRXEN**: USB Power Delivery receiver enable

0: Disable
1: Enable
Both CC1 and CC2 receivers are disabled when the bit is cleared. Only the CC receiver selected via the PHYCCSEL bit is enabled when the bit is set.

Bit 4 **RXMODE**: Receiver mode

Determines the mode of the receiver.
0: Normal receive mode
1: BIST receive mode (BIST test data mode)
When the bit is set, RXORDSET behaves normally, RXDR no longer receives bytes yet the CRC checking still proceeds as for a normal message. As this mode prevents reception of the header (containing MessageID), software has to auto-increment a received MessageID counter for inclusion in the GoodCRC acknowledge that must still be transmitted during this test.

Bit 3 **TXHRST**: Command to send a Tx Hard Reset

0: No effect
1: Start Tx Hard Reset message
The bit is cleared by hardware as soon as the message transmission begins or is discarded.

Bit 2 **TXSEND**: Command to send a Tx packet

0: No effect
1: Start Tx packet transmission
The bit is cleared by hardware as soon as the packet transmission begins or is discarded.

Bits 1:0 **TXMODE[1:0]**: Type of Tx packet
Writing the bitfield triggers the action as follows, depending on the value:
0x0: Transmission of Tx packet previously defined in other registers
0x1: Cable Reset sequence
0x2: BIST test sequence (BIST Carrier Mode 2)
Others: invalid
From V1.1 of the USB PD specification, there is a counter defined for the duration of the BIST Carrier Mode 2. To quit this mode correctly (after the "tBISTContMode" delay), disable the peripheral (UCPDEN = 0).

68.8.4 UCPD interrupt mask register (UCPD_IMR)

Address offset: 0x010

Reset value: 0x0000 0000

Writing to this register is only effective when the peripheral is enabled (UCPDEN = 1).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRSEVTIE	Res.	Res.	Res.	Res.
											r				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TYPECEVT2IE	TYPECEVT1IE	Res.	RXMSGENDIE	RXOVRIE	RXHRSTDETIE	RXORDDETIE	RXNEIE	Res.	TXUNDIE	HRSTSENTIE	HRSTDISCIE	TXMSGABTIE	TXMSGSENTIE	TXMSGDISCIE	TXISIE
rw	rw		rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **FRSEVTIE**: FRSEVT interrupt enable
0: Disable
1: Enable

Bits 19:16 Reserved, must be kept at reset value.

Bit 15 **TYPECEVT2IE**: TYPECEVT2 interrupt enable
0: Disable
1: Enable

Bit 14 **TYPECEVT1IE**: TYPECEVT1 interrupt enable

Bit 13 Reserved, must be kept at reset value.

Bit 12 **RXMSGENDIE**: RXMSGEND interrupt enable
0: Disable
1: Enable

Bit 11 **RXOVRIE**: RXOVR interrupt enable
0: Disable
1: Enable

Bit 10 **RXHRSTDETIE**: RXHRSTDET interrupt enable
0: Disable
1: Enable

Bit 9 **RXORDDETIE**: RXORDDET interrupt enable
0: Disable
1: Enable

Bit 8 **RXNEIE**: RXNE interrupt enable
0: Disable
1: Enable

Bit 7 Reserved, must be kept at reset value.

Bit 6 **TXUNDIE**: TXUND interrupt enable
0: Disable
1: Enable

Bit 5 **HRSTSENTIE**: HRSTSENT interrupt enable
0: Disable
1: Enable

Bit 4 **HRSTDISCIE**: HRSTDISC interrupt enable
0: Disable
1: Enable

Bit 3 **TXMSGABTIE**: TXMSGABT interrupt enable
0: Disable
1: Enable

Bit 2 **TXMSGSENTIE**: TXMSGSENT interrupt enable
0: Disable
1: Enable

Bit 1 **TXMSGDISCIE**: TXMSGDISC interrupt enable
0: Disable
1: Enable

Bit 0 **TXISIE**: TXIS interrupt enable
0: Disable
1: Enable

68.8.5 UCPD status register (UCPD_SR)

Address offset: 0x014

Reset value: 0x0000 0000

The flags (single-bit status bitfields) are associated with interrupt request. Interrupt is generated if enabled by the corresponding bit of the UCPD_IMR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRSEVT	TYPEC_VSTATE_CC2[1:0]		TYPEC_VSTATE_CC1[1:0]	
											r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TYPECEVT2	TYPECEVT1	RXERR	RXMSGEND	RXOVR	RXHRSTDET	RXORDDET	RXNE	Res.	TXUND	HRSTSENT	HRSTDISC	TXMSGABT	TXMSGSENT	TXMSGDISC	TXIS
r	r	r	r	r	r	r	r		r	r	r	r	r	r	r

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **FRSEVT**: FRS detection event
The flag is cleared by setting the FRSEVTCF bit.
0: No new event
1: New FRS receive event occurred

Bits 19:18 **TYPEC_VSTATE_CC2[1:0]**: CC2 line voltage level
The status bitfield indicates the voltage level on the CC2 line in its steady state.
0x0: Lowest
0x1: Low
0x2: High
0x3: Highest
The voltage variation on the CC2 line during USB PD messages due to the BMC PHY modulation does not impact the bitfield value.

Bits 17:16 **TYPEC_VSTATE_CC1[1:0]**:
The status bitfield indicates the voltage level on the CC1 line in its steady state.
0x0: Lowest
0x1: Low
0x2: High
0x3: Highest
The voltage variation on the CC1 line during USB PD messages due to the BMC PHY modulation does not impact the bitfield value.

Bit 15 **TYPECEVT2**: Type-C voltage level event on CC2 line
The flag indicates a change of the TYPEC_VSTATE_CC2[1:0] bitfield value, which corresponds to a new Type-C event. It is cleared by setting the TYPECEVT2CF bit.
0: No new event
1: A new Type-C event

Bit 14 **TYPECEVT1**: Type-C voltage level event on CC1 line
The flag indicates a change of the TYPEC_VSTATE_CC1[1:0] bitfield value, which corresponds to a new Type-C event. It is cleared by setting the TYPECEVT2CF bit.
0: No new event
1: A new Type-C event

Bit 13 **RXERR**: Receive message error
The flag indicates errors of the last Rx message declared (via RXMSGEND), such as incorrect CRC or truncated message (a line becoming static before EOP is met). It is asserted whenever the RXMSGEND flag is set.
0: No error detected
1: Error(s) detected

Bit 12 **RXMSGEND**: Rx message received
The flag indicates whether a message (except Hard Reset message) has been received, regardless the CRC value. The flag is cleared by setting the RXMSGENDCF bit.
0: No new Rx message received
1: A new Rx message received
The RXERR flag set when the RXMSGEND flag goes high indicates errors in the last-received message.

Bit 11 **RXOVR**: Rx data overflow detection
The flag indicates Rx data buffer overflow. It is cleared by setting the RXOVRCF bit.
0: No overflow
1: Overflow
The buffer overflow can occur if the received data are not read fast enough.

Bit 10 **RXHRSTDET**: Rx Hard Reset receipt detection

The flag indicates the receipt of valid Hard Reset message. It is cleared by setting the RXHRSTDETCF bit.

0: Hard Reset not received

1: Hard Reset received

Bit 9 **RXORDDET**: Rx ordered set (4 K-codes) detection

The flag indicates the detection of an ordered set. The relevant information is stored in the RXORDSET[2:0] bitfield of the UCPD_RX_ORDSET register. It is cleared by setting the RXORDDETCF bit.

0: No ordered set detected

1: A new ordered set detected

Bit 8 **RXNE**: Receive data register not empty detection

The flag indicates that the UCPD_RXDR register is not empty. It is automatically cleared upon reading UCPD_RXDR.

0: Rx data register empty

1: Rx data register not empty

Bit 7 Reserved, must be kept at reset value.

Bit 6 **TXUND**: Tx data underrun detection

The flag indicates that the Tx data register (UCPD_TXDR) was not written in time for a transmit message to execute normally. It is cleared by setting the TXUNDCF bit.

0: No Tx data underrun detected

1: Tx data underrun detected

Bit 5 **HRSTSENT**: Hard Reset message sent

The flag indicates that the Hard Reset message is sent. The flag is cleared by setting the HRSTSENTCF bit.

0: No Hard Reset message sent

1: Hard Reset message sent

Bit 4 **HRSTDISC**: Hard Reset discarded

The flag indicates that the Hard Reset message is discarded. The flag is cleared by setting the HRSTDISCCF bit.

0: No Hard Reset discarded

1: Hard Reset discarded

Bit 3 **TXMSGABT**: Transmit message abort

The flag indicates that a Tx message is aborted due to a subsequent Hard Reset message send request taking priority during transmit. It is cleared by setting the TXMSGABTCF bit.

0: No transmit message abort

1: Transmit message abort

Bit 2 **TXMSGSENT**: Message transmission completed

The flag indicates the completion of packet transmission. It is cleared by setting the TXMSGSENTCF bit.

0: No Tx message completed

1: Tx message completed

In the event of a message transmission interrupted by a Hard Reset, the flag is not raised.

Bit 1 **TXMSGDISC**: Message transmission discarded

The flag indicates that a message transmission was dropped. The flag is cleared by setting the TXMSGDISCCF bit.

0: No Tx message discarded

1: Tx message discarded

Transmission of a message can be dropped if there is a concurrent receive in progress or at excessive noise on the line. After a Tx message is discarded, the flag is only raised when the CC line becomes idle.

Bit 0 **TXIS**: Transmit interrupt status

The flag indicates that the UCPD_TXDR register is empty and new data write is required (as the amount of data sent has not reached the payload size defined in the TXPAYSZ bitfield). The flag is cleared with the data write into the UCPD_TXDR register.

0: New Tx data write not required

1: New Tx data write required

68.8.6 UCPD interrupt clear register (UCPD_ICR)

Address offset: 0x018

Reset value: 0x0000 0000

Writing to this register is only effective when the peripheral is enabled (UCPDEN = 1).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRSEVTCF	Res.	Res.	Res.	Res.
											w				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TYPECEVT2CF	TYPECEVT1CF	Res.	RXMSGENDCF	RXOVRCF	RXHRSTDETCF	RXORDDETCF	Res.	Res.	TXUNDCF	HRSTSENTCF	HRSTDISCCF	TXMSGABTCF	TXMSGSENTCF	TXMSGDISCCF	Res.
w	w		w	w	w	w			w	w	w	w	w	w	

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **FRSEVTCF**: FRS event flag (FRSEVT) clear

Setting the bit clears the FRSEVT flag in the UCPD_SR register.

Bits 19:16 Reserved, must be kept at reset value.

Bit 15 **TYPECEVT2CF**: Type-C CC2 line event flag (TYPECEVT2) clear

Setting the bit clears the TYPECEVT2 flag in the UCPD_SR register

Bit 14 **TYPECEVT1CF**: Type-C CC1 event flag (TYPECEVT1) clear

Setting the bit clears the TYPECEVT1 flag in the UCPD_SR register

Bit 13 Reserved, must be kept at reset value.

Bit 12 **RXMSGENDCF**: Rx message received flag (RXMSGEND) clear

Setting the bit clears the RXMSGEND flag in the UCPD_SR register.

Bit 11 **RXOVRCF**: Rx overflow flag (RXOVR) clear

Setting the bit clears the RXOVR flag in the UCPD_SR register.

Bit 10 **RXHRSTDETCF**: Rx Hard Reset detect flag (RXHRSTDET) clear

Setting the bit clears the RXHRSTDET flag in the UCPD_SR register.

Bit 9 **RXORDDETCF**: Rx ordered set detect flag (RXORDDET) clear
Setting the bit clears the RXORDDET flag in the UCPD_SR register.

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **TXUNDCF**: Tx underflow flag (TXUND) clear
Setting the bit clears the TXUND flag in the UCPD_SR register.

Bit 5 **HRSTSENTCF**: Hard reset send flag (HRSTSENT) clear
Setting the bit clears the HRSTSENT flag in the UCPD_SR register.

Bit 4 **HRSTDISCCF**: Hard reset discard flag (HRSTDISC) clear
Setting the bit clears the HRSTDISC flag in the UCPD_SR register.

Bit 3 **TXMSGABTCF**: Tx message abort flag (TXMSGABT) clear
Setting the bit clears the TXMSGABT flag in the UCPD_SR register.

Bit 2 **TXMSGSENTCF**: Tx message send flag (TXMSGSENT) clear
Setting the bit clears the TXMSGSENT flag in the UCPD_SR register.

Bit 1 **TXMSGDISCCF**: Tx message discard flag (TXMSGDISC) clear
Setting the bit clears the TXMSGDISC flag in the UCPD_SR register.

Bit 0 Reserved, must be kept at reset value.

68.8.7 UCPD Tx ordered set type register (UCPD_TX_ORDSETR)

Address offset: 0x01C

Reset value: 0x0000 0000

Writing to this register is only effective when the peripheral is enabled (UCPDEN = 1) and no packet transmission is in progress (TXSEND and TXHRST bits are both low).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXORDSET[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXORDSET[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **TXORDSET[19:0]**: Ordered set to transmit
The bitfield determines a full 20-bit sequence to transmit, consisting of four K-codes, each of five bits, defining the packet to transmit. The bit 0 (bit 0 of K-code1) is the first, the bit 19 (bit 4 of K-code4) the last.

68.8.8 UCPD Tx payload size register (UCPD_TX_PAYSZR)

Address offset: 0x020

Reset value: 0x0000 0000

Writing to this register is only effective when the peripheral is enabled (UCPDEN = 1).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	TXPAYSZ[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:0 **TXPAYSZ[9:0]**: Payload size yet to transmit

The bitfield is modified by software and by hardware. It contains the number of bytes of a payload (including header but excluding CRC) yet to transmit: each time a data byte is written into the UCPD_TXDR register, the bitfield value decrements and the TXIS bit is set, except when the bitfield value reaches zero. The enumerated values are standard payload sizes before the start of transmission.

0x2: 2 bytes - the size of Control message from the protocol layer
0x6: 6 bytes - the shortest Data message allowed from the protocol layer)
0x1E: 30 bytes - the longest non-extended Data message allowed from the protocol layer
0x106: 262 bytes - the longest possible extended message
0x3FF: 1024 bytes - the longest possible payload (for future expansion)

68.8.9 UCPD Tx data register (UCPD_TXDR)

Address offset: 0x024

Reset value: 0x0000 0000

Writing to this register is only effective when the peripheral is enabled (UCPDEN = 1).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXDATA[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **TXDATA[7:0]**: Data byte to transmit

68.8.10 UCPD Rx ordered set register (UCPD_RX_ORDSETR)

Address offset: 0x028

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXSOPKINVALID[2:0]			RXSOP3OF4	RXORDSET[2:0]		
									r	r	r	r	r	r	r

Bits 31:7 Reserved, must be kept at reset value.

Bits 6:4 **RXSOPKINVALID[2:0]**:

The bitfield is for debug purposes only.
0x0: No K-code corrupted
0x1: First K-code corrupted
0x2: Second K-code corrupted
0x3: Third K-code corrupted
0x4: Fourth K-code corrupted
Others: Invalid

Bit 3 **RXSOP3OF4**:

The bit indicates the number of correct K-codes. For debug purposes only.
0: 4 correct K-codes out of 4
1: 3 correct K-codes out of 4

Bits 2:0 **RXORDSET[2:0]**: Rx ordered set code detected

0x0: SOP code detected in receiver
0x1: SOP' code detected in receiver
0x2: SOP" code detected in receiver
0x3: SOP'_Debug detected in receiver
0x4: SOP"_Debug detected in receiver
0x5: Cable Reset detected in receiver
0x6: SOP extension#1 detected in receiver
0x7: SOP extension#2 detected in receiver

68.8.11 UCPD Rx payload size register (UCPD_RX_PAYSZR)

Address offset: 0x02C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	RXPAYSZ[9:0]									
						r	r	r	r	r	r	r	r	r	r

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:0 **RXPAYSZ[9:0]**: Rx payload size received

This bitfield contains the number of bytes of a payload (including header but excluding CRC) received: each time a new data byte is received in the UCPD_RXDR register, the bitfield value increments and the RXMSGEND flag is set (and an interrupt generated if enabled).
0x2: 2 bytes - the size of Control message from the protocol layer
0x6: 6 bytes - the shortest Data message allowed from the protocol layer)
0x1E: 30 bytes - the longest non-extended Data message allowed from the protocol layer
0x106: 262 bytes - the longest possible extended message
0x3FF: 1024 bytes - the longest possible payload (for future expansion)
The bitfield may return a spurious value when a byte reception is ongoing (the RXMSGEND flag is low).

68.8.12 UCPD receive data register (UCPD_RXDR)

Address offset: 0x030

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXDATA[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **RXDATA[7:0]**: Data byte received

68.8.13 UCPD Rx ordered set extension register 1 (UCPD_RX_ORDEXTR1)

Address offset: 0x034

Reset value: 0x0000 0000

Writing to this register is only effective when the peripheral is disabled (UCPDEN = 0).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXSOPX1[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXSOPX1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **RXSOPX1[19:0]**: Ordered set 1 received

The bitfield contains a full 20-bit sequence received, consisting of four K-codes, each of five bits. The bit 0 (bit 0 of K-code1) is receive first, the bit 19 (bit 4 of K-code4) last.

68.8.14 UCPD Rx ordered set extension register 2 (UCPD_RX_ORDEXTR2)

Address offset: 0x038

Reset value: 0x0000 0000

Writing to this register is only effective when the peripheral is disabled (UCPDEN = 0).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXSOPX2[19:16]			
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXSOPX2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **RXSOPX2[19:0]**: Ordered set 2 received

The bitfield contains a full 20-bit sequence received, consisting of four K-codes, each of five bits. The bit 0 (bit 0 of K-code1) is receive first, the bit 19 (bit 4 of K-code4) last.

68.8.15 UCPD register map

Table 764. UCPD register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	UCPD_CFGR1	UCPDEN	RXDMAEN	TXDMAEN	RXORDSETEN[8:0]									PSC_UCPDCLK[2:0]			Res.	TRANSWIN[4:0]					IFRGAP[4:0]					HBITCLKDIV[5:0]						
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x004	UCPD_CFGR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXAFILTEN	Res.	Res.	Res.	Res.	WUPEN	FORCECLK	RXFILT2N3	RXFILTDIS
	Reset value																								0					0	0	0	0
0x008	Reserved																																
0x00C	UCPD_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2TCDIS	CC1TCDIS	Res.	RDCH	FRSTX	FRSRXEN	Res.	Res.	Res.	Res.	CCENABLE[1:0]		ANAMODE	ANASUBMODE[1:0]		PHYCCSEL	PHYRXEN	RXMODE	TXHRST	TXSEND	TXMODE[1:0]	
	Reset value											0	0		0	0	0					0	0	0	0	0	0	0	0	0	0	0	0

Table 764. UCPD register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x010	UCPD_IMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRSEVTIE	Res.	Res.	Res.	Res.	TYPECEVT2IE	TYPECEVT1IE	Res.	RXMSGENDIE	RXOVRIE	RXHRSTDETIE	RXORDDETIE	RXNEIE	Res.	TXUNDIE	HRSTSENTIE	HRSTDISCIE	TXMSGABTIE	TXMSGSENTIE	TXMSGDISCIE	TXISIE
	Reset value												0					0	0		0	0	0	0	0		0	0	0	0	0	0	0
0x014	UCPD_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRSEVT	TYPEC_VSTATE_CC2[1:0]		TYPEC_VSTATE_CC1[1:0]		TYPECEVT2	TYPECEVT1	RXERR	RXMSGEND	RXOVR	RXHRSTDET	RXORDDET	RXNE	Res.	TXUND	HRSTSENT	HRSTDISC	TXMSGABT	TXMSGSENT	TXMSGDISC	TXIS
	Reset value												0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
0x018	UCPD_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRSEVTCF	Res.	Res.	Res.	Res.	TYPECEVT2CF	TYPECEVT1CF	Res.	RXMSGENDCF	RXOVRCF	RXHRSTDETCF	RXORDDETCF	Res.	Res.	TXUNDCF	HRSTSENTCF	HRSTDISCCF	TXMSGABTCF	TXMSGSENTCF	TXMSGDISCCF	Res.
	Reset value												0					0	0		0	0	0	0			0	0	0	0	0	0	
0x01C	UCPD_TX_ORDSETR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXORDSET[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	UCPD_TX_PAYSZR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXPAYSZ[9:0]									
	Reset value																							0	0	0	0	0	0	0	0	0	0
0x024	UCPD_TXDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXDATA[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x028	UCPD_RX_ORDSETR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXSOPKINVALID[2:0]			RXSOP3OF4	RXORDSET[2:0]		
	Reset value																										0	0	0	0	0	0	0
0x02C	UCPD_RX_PAYSZR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXPAYSZ[9:0]									
	Reset value																							0	0	0	0	0	0	0	0	0	0
0x030	UCPD_RXDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXDATA[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x034	UCPD_RX_ORDEXTR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXSOPX1[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 764. UCPD register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x038	UCPD_RX _ORDEXTR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXSOPX2[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x03C - 0x3FF	Reserved																																

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

69 Ethernet (ETH): media access control (MAC) with DMA controller

69.1 Ethernet introduction

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The Ethernet peripheral enables to transmit and receive data over Ethernet in compliance with the IEEE 802.3-2015 standard.

The peripheral is configurable to meet the needs of a large variety of consumer and industrial applications.

69.2 Ethernet main features

The Ethernet peripheral embeds a dedicated DMA for direct memory interface, a media access controller (MAC) and a PHY interface block supporting several formats.

69.2.1 Standard compliance

The Ethernet peripheral is compliant with the following standards:

- IEEE 802.3-2015 for Ethernet MAC and media independent interface (MII)
- IEEE 1588-2008 for precision networked clock synchronization (PTP)
- IEEE 802.3az-2010 for Energy Efficient Ethernet (EEE)
- AMBA 2.0 for AHB master and AHB slave ports
- RMII specification version 1.2 from RMII consortium

69.2.2 MAC features

MAC Tx and Rx common features

- Separate transmission, reception, and control interfaces to the application
- 10, 100 Mbit/s data transfer rates with the following PHY interfaces:
  - IEEE 802.3-compliant MII interface to communicate with an external Fast Ethernet PHY
  - RMII interface to communicate with an external Fast Ethernet PHY
- Half-duplex operation:
  - CSMA/CD protocol support
  - Flow control using back pressure (based on implementation-specific white papers and UNH Ethernet Clause 4 MAC Test Suite - Annex D)

Note: Ensure that only one queue is active for half-duplex operation.

- Standard IEEE 802.3az-2010 for Energy Efficient Ethernet in MII PHYs

- 32-bit data transfer interface on the application side
- Full-duplex flow control operations (IEEE 802.3x Pause packets and Priority flow control)
- Network statistics with RMON or MIB counters (partial support of RFC2819/RFC2665)
- Ethernet packet timestamping as described in IEEE 1588-2002 and IEEE 1588-2008 (64-bit timestamps given in the Tx or Rx status of PTP packet). Both one-step and two-step timestamping are supported in Tx direction.
- Flexibility to control pulse-per-second (PPS) output signal (eth_ptp_pps_out and ETH_PPS_OUT)
- MDIO (Clause 22 and Clause 45) master interface for PHY device configuration and management

MAC Tx features

- Preamble and start-of-frame data (SFD) insertion
- Separate 32-bit status for each packet transmitted from the application
- Automatic CRC and pad generation controllable on a per-frame basis
- Programmable packet length to support Standard or Jumbo Ethernet packets of up to 16 Kbytes
- Programmable Inter Packet Gap (40–96 bit times in steps of 8)
- IEEE 802.3x Flow Control automatic transmission of zero-quanta Pause packet when flow control input transitions from assertion to de-assertion (in Full-duplex mode)
- Source address field insertion or replacement, and VLAN insertion, replacement, and deletion in transmitted packets with per-packet or static-global control
- Insertion, replacement, or deletion of up to two VLAN tags
- Option to transmit packets with reduced preamble size in Full-duplex mode
- Insert, replace, or delete queue/channel-based VLAN tags

MAC Rx features

- Automatic Pad and CRC stripping options
- Option to disable automatic CRC checking
- Preamble and SFD deletion
- Separate 112-bit or 128-bit status
- Programmable watchdog timeout limit
- Flexible address filtering modes:
  - Four 48-bit perfect (DA) address filters with masks for each byte
  - Four 48-bit SA address comparison check with masks for each byte
  - 64 bit Hash filter for multicast and unicast (DA) addresses
- Option to pass all multicast addressed packets
- Promiscuous mode to pass all packets without any filtering for network monitoring
- Pass all incoming packets (as per filter) with a status report

- Additional packet filtering:
  - VLAN tag-based: Perfect match and Hash-based filtering based either on the outer or inner VLAN tag
  - Layer 3 and Layer 4-based: TCP or UDP over IPv4 or IPv6
- IEEE 802.1Q VLAN tag detection and option to delete the VLAN tags in received packets
- Detection of remote wake-up packets and AMD magic packets
- Optional forwarding of received Pause packets to the application (in Full-duplex mode)
- Layer 3/Layer 4 checksum offload for received packets
- Stripping of up to two VLAN tags and providing the tags in the status

69.2.3 Transaction layer (MTL) features

MTL Tx and Rx common features

- 32-bit transaction layer block (bridges the application and the MAC)
- Optimization for packet-oriented transfers with packets delimiters
- Programmable burst length, up to half the size of the MTL Rx queue or Tx queue size, to support burst data transfer in the EQOS-MTL configuration
- Programmable threshold capability for each queue (default of 64 bytes)

MTL Tx features

- 2048-byte transmit FIFO with programmable threshold capability
- Store-and-forward mechanism or threshold mode (cut-through) for transmission to the MAC
- Automatic retransmission of collision packets in Half-duplex mode
- Discard packets on late collision, excessive collisions, excessive deferral, and under-run conditions with appropriate status
- Module to calculate and insert IPv4 header checksum and TCP, UDP, or ICMP checksum on frames transmitted in Store-and-forward mode
- Statistics by generating pulses for packets dropped (because of underflow) in the Tx FIFO
- Packet-level control for
  - VLAN tag insertion or replacement
  - Ethernet source address insertion
  - Layer 3/Layer 4 checksum insertion control
  - One-step timestamp
  - Timestamp control
  - CRC and pad control

MTL Rx features

- 2048-byte receive FIFO with configurable threshold
- Programmable Rx queue threshold (default fixed at 64 bytes) in threshold (or cut-through) mode
- Option to filter all error packets on reception and not forward them to the application in the store-and-forward mode
- Option to forward the undersized good packets
- Statistics by generating pulses for packets dropped (because of overflow) in the Rx FIFO

69.2.4 DMA block features

The DMA block exchanges data between the peripheral and the system memory. DMA transfers are driven by software descriptors structure. The application can use a set of registers (see *Section 69.11.2: Ethernet DMA registers*) to control the DMA operations. The DMA block supports the following features:

- 32-bit data transfers
- Separate DMA in transmit path and receive paths
- Optimization for packet-oriented DMA transfers with packet delimiters
- Byte-aligned addressing for data buffer support
- Dual-buffer (ring) descriptor support
- Descriptor architecture allowing large blocks of data transfer with minimum CPU intervention (each descriptor can transfer up to 32 Kbytes of data)
- Comprehensive status reporting normal operation and transfer errors
- Individual programmable burst length for Tx DMA and Rx DMA engines for optimal host bus utilization
- Programmable interrupt options for different operational conditions
- Per-packet transmit or receive complete interrupt control
- Round-robin or fixed-priority arbitration between the receive and transmit engines
- Start and Stop modes
- Separate ports for host control (AHB) access and host data interface
- Tx DMA channel with TCP segmentation offload (TSO) feature enabled
- Programmable control for transmit descriptor posted writes to improve the throughput

69.2.5 Bus interface features

AHB master interface

The AHB master interface features are the following:

- Interfaces with the application through AHB
- 32-bit data on the AHB master port
- Split, Retry, and Error AHB responses
- AHB 1-Kbyte boundary burst splitting
- Software-selected type of AHB burst (fixed burst, indefinite burst, or mix of both)

The AHB master interface does not generate the following:

- Wrap burst
- Locked or protected transfers
- 32-bit address width

AHB slave interface

The AHB slave interface supports the following features:

- Interfaces with the application through AHB
- AHB slave interface (32-bit) for CSR access
- All AHB burst types

The AHB slave interface does not generate the following responses:

- Split
- Retry

69.3 Ethernet pins and internal signals

Table 765 lists the Ethernet inputs and output signals connected to package pins or balls. Active pins depend on the PHY type selected (MII or RMII) and on the device configuration.

Table 766 shows the internal Ethernet signals.

Table 765. Ethernet peripheral pins

Port name	Digital port type	Description
ETH_COL	Input	Collision detection signal, MII only.
ETH_CRS	input	Carrier sense signal, MII only
ETH_REF_CLK	Input	RMII reference clock
ETH_RX_CLK	Input	MII timing reference for Rx data transfers
ETH_RXD[3:0]	Input	Receive data. 4 pins for MII, 2 for RMII.
ETH_RX_DV	Input	Receive data valid
ETH_CRS_DV	Input	RMII: Carrier Sense (CRS) and RX_Data Valid (RX_DV) multiplexed on alternate clock cycles. In 10 Mbit/s mode, it alternates every 10 clock cycles.
ETH_RX_ER	Input	Receive error
ETH_TX_CLK	Input	MII timing reference for Tx data transfers
ETH_TXD[3:0]	Output	Transmit data. 4 pins for MII, 2 for RMII.
ETH_TX_EN	Output	Transmit data enable
ETH_TX_ER	Output	Transmit error
ETH_MDC	Output	Management data clock
ETH_MDIO	Input/output	Management data
ETH_PHY_INTN	Input	PHY interrupt

Table 765. Ethernet peripheral pins (continued)

Port name	Digital port type	Description
ETH_PPS_OUT	Output	PTP pulse-per-second output
ETH_PTP_AUX_TS(1)	Input	Trigger input for the auxiliary snapshots of the PTP system time

1. This pin is not available on all devices.

Table 766. Internal Ethernet input/output signals

Signal name	Signal type	Description
eth_hclk	Digital input	AHB clock
eth_sbd_intr_it	Digital output	Main Ethernet interrupt
lpi_intr_o	Digital output	Sideband signal generated when the transmitter or receiver enters or exits the LPI state.
pmt_intr_o	Digital output	Sideband signal generated when a valid remote wake-up packet is received
eth_tx_clk	Digital input	Tx kernel clock
eth_rx_clk	Digital input	Rx kernel clock
eth_rmii_ref_clk	Digital input	RMII reference kernel clock
eth_ptp_pps_out	Digital output	PTP pulse-per-second signal
mac_speed_o[1:0]	Digital output	MAC speed information used by the RCC
clk_ptp_ref_i	Digital input	PTP reference clock input
eth_ptp_aux_ts_trig[3:0]	Digital input	Trigger input for auxiliary snapshots of the PTP system time

Table 767. Ethernet trigger connections

Type	ID	Source	Destination
Internal	eth_ptp_aux_ts_trig[0]	tim2_trgo	-
	eth_ptp_aux_ts_trig[1]	tim3_trgo	-
	eth_ptp_aux_ts_trig[3]	fdcan_tmp	-
	eth_ptp_pps_out (Flexible pulse-per-second output 0)	-	tim2_etr14 tim3_etr14 tim2_ti1_in1 tim3_ti1_in1 tim4_ti1_in1 tim5_ti1_in1
External	Flexible pulse-per-second output 0	-	ETH_PPS_OUT
	eth_ptp_aux_ts_trig[2]	ETH_PTP_AUX_TS	-

69.4 Ethernet architecture

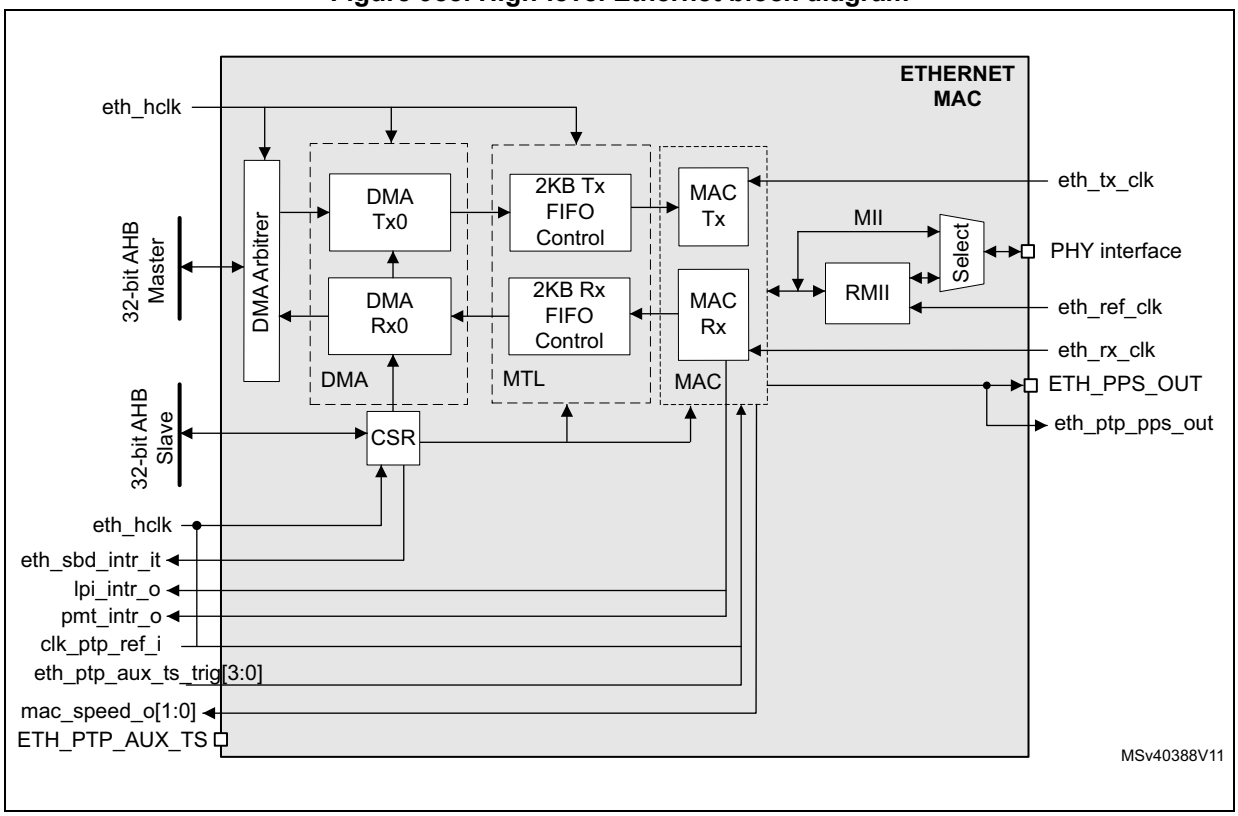
The Ethernet peripheral includes four main functional modules:

- **The control and status register module (CSR)** that controls the registers access through AHB 32-bit slave interface
- The direct memory access interface (DMA)

  This is the logical DMA module with one physical channel for reception and one for transmission. It controls the data transfers between MAC and system memory through the AMBA AHB 32-bit master interface.
- **The media access control module (MAC)** in charge of implementing the Ethernet protocol
- **The MAC transaction layer (MTL)** in charge of controlling the data flow between application and MAC.

A protocol adaption module is added to support the RMII PHY media independent interfaces.

Figure 988. High-level Ethernet block diagram



1. For a definition of the internal signals, refer to *Table 766*.
2. Refer to RCC chapter “Clock distribution for Ethernet” for a detailed description of the Ethernet clock architecture.
3. The ETH_PTP_AUX_TS pin is not available on all devices.

69.4.1 DMA controller

The DMA has independent transmit (Tx) and receive (Rx) engines. The Tx engine transfers data from the system memory to the MAC Transaction Layer (MTL), whereas the Rx engine transfers data from the device port (PHY) to the system memory.

The controller uses descriptors to efficiently move data from source to destination with minimal application CPU intervention. The DMA is designed for packet-oriented data transfers such as packets in Ethernet. The controller can be programmed to interrupt the application CPU for situations such as Packet transmit and receive Transfer completion, and other normal or error conditions.

DMA data structures

The DMA and the application communicate through the following two data structures:

- Control and Status registers (CSR)
- Descriptor lists and data buffers

The DMA transfers the data packets received by the MAC to the Rx buffer in system memory and Tx data packets from the Tx buffer in the system memory. The descriptors that reside in the system memory contain the pointers to these buffers.

The base address of each list is written to the respective Tx and Rx registers: *Channel Tx descriptor list address register (ETH_DMACTXDLAR)*) and *Channel Rx descriptor list address register (ETH_DMACRXDLAR)*.

The descriptor list is forward linked and the next descriptor is always considered at a fixed offset to the current one. The number of descriptors in the list is programmed in the respective Tx/Rx, *Channel Tx descriptor ring length register (ETH_DMACTXRLR)* and *Channel Rx descriptor ring length register (ETH_DMACRXRLR)*.

Once the DMA processes the last descriptor in the list, it automatically jumps back to the descriptor in the List address register to create a descriptor ring. The descriptor lists reside in the physical memory address space of the application. Each descriptor can point to a maximum of two buffers. This enables two buffers to be used and physically addressed, rather than contiguous buffers in memory.

A data buffer resides in the application physical memory space and consists of an entire packet or part of a packet, but cannot exceed a single packet. Buffers contain only data. The buffer status is saved in the descriptor. Data chaining refers to packets that span multiple data buffers. However, a single descriptor cannot span multiple packets. The DMA skips to the data buffer of next packet when EOP is detected.

Descriptors are specified in *Section 69.10: Descriptors*.

DMA arbitration

The DMA module incorporates an arbiter that performs the arbitration between the Tx and Rx channels accesses from the AHB master interface. The following two types of arbitrations are supported and can be selected through *DMA mode register (ETH_DMAMR)*:

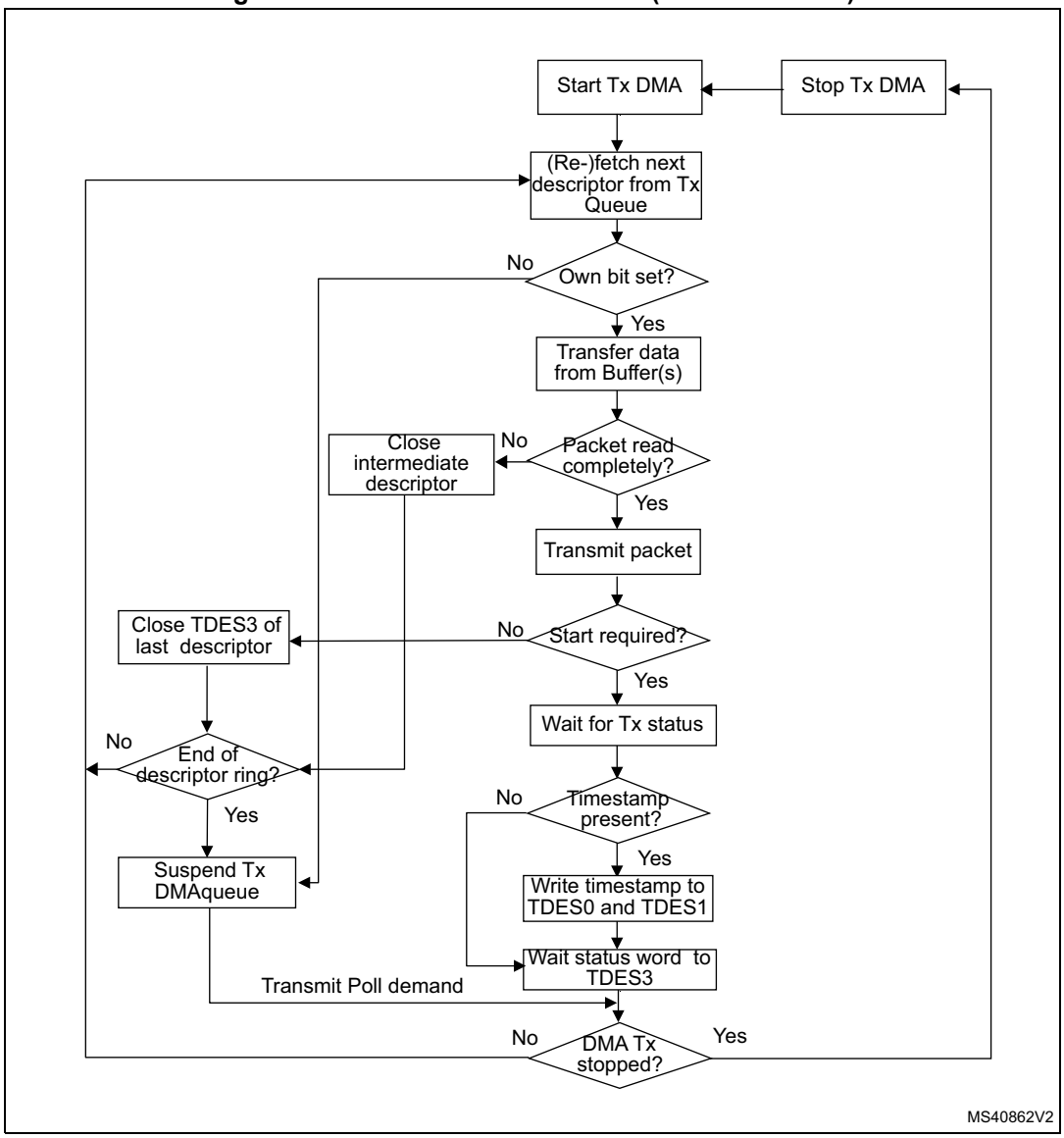
- Round-robin arbitration**:** the arbiter allocates the data bus between Rx and Tx in ratio set by Bits [14:12] of ETH_DMAMR.
- Fixed-priority arbitration**:** by default Rx DMA always gets priority over Tx DMA for data access. Setting bit 11 of ETH_DMAMR register gives priority to the Tx DMA.

DMA transmission in default mode

The Tx DMA engine in default mode proceeds as follows:

1. The application sets up the transmit descriptor (TDES0–TDES3) and sets the Own bit (TDES0[31]) after setting up the corresponding data buffer(s) with Ethernet Packet data.
2. The application shifts the descriptor tail pointer offset value of the transmit channel.
3. The DMA fetches the descriptor from the application memory.
4. If the DMA detects one of the following conditions, the transmission from that channel is suspended, bit 2 and 16 of the corresponding DMA channel Status register are set, and the Tx engine proceeds to step 11:
   - The descriptor is flagged as owned by the application (TDES3 [31] = 0).
   - The descriptor tail pointer is equal to the current descriptor pointer in Ring Descriptor list mode.
   - An error condition occurs.
5. If the acquired descriptor is flagged as owned by the DMA (TDES3[31] = 1), the DMA decodes the Transmit Data Buffer address from the acquired descriptor.
6. The DMA fetches the Transmit data from the system memory and transfers the data to the MTL for transmission.
7. If an Ethernet packet is stored over data buffers in multiple descriptors, the DMA closes the intermediate descriptor and fetches the next descriptor. Steps 3 through 7 are repeated until the end-of-Ethernet-packet data is transferred to the MTL.
8. When packet transmission is complete, if IEEE 1588 timestamp feature was enabled for the packet (as indicated in the Tx status), the timestamp value obtained from MTL is written to the Tx descriptor (TDES0 and TDES1) that contains the EOP buffer. The status information is written to this Tx descriptor (TDES3). The application now owns this descriptor because the Own bit is cleared during this step. If the timestamp feature is disabled for this packet, the DMA does not alter TDES0 and TDES1 contents.
9. Bit 0 of *Channel status register (ETH_DMACSR)*) is set after completing transmission of a packet that has Interrupt on Completion (TDES2[31]) set in its Last Descriptor. The DMA engine returns to step 3.
10. In the Suspend state, the DMA tries to acquire the descriptor again (and thereby return to step 3). A poll demand command is triggered by writing any value to the *Channel Tx descriptor tail pointer register (ETH_DMACTXDTPR)* when it receives a Transmit Poll demand and the underflow interrupt status bit is cleared. If the application stopped the DMA by clearing Bit 0 of Transmit control register of corresponding DMA channel, the DMA enters the Stop state.

Figure 989. DMA transmission flow (standard mode)



DMA transmission in OSP (operate on second packet) mode

In Run state, if bit 4 is set in the *Channel transmit control register (ETH_DMACTXCR)*), the Transmit process can simultaneously acquire two packets without closing the Status descriptor of the first packet. While the Transmit process completes the first packet transfer, it immediately polls the Transmit descriptor list for the second packet. If the second packet is valid, the Transmit process transfers this packet before writing the status information of the first packet.

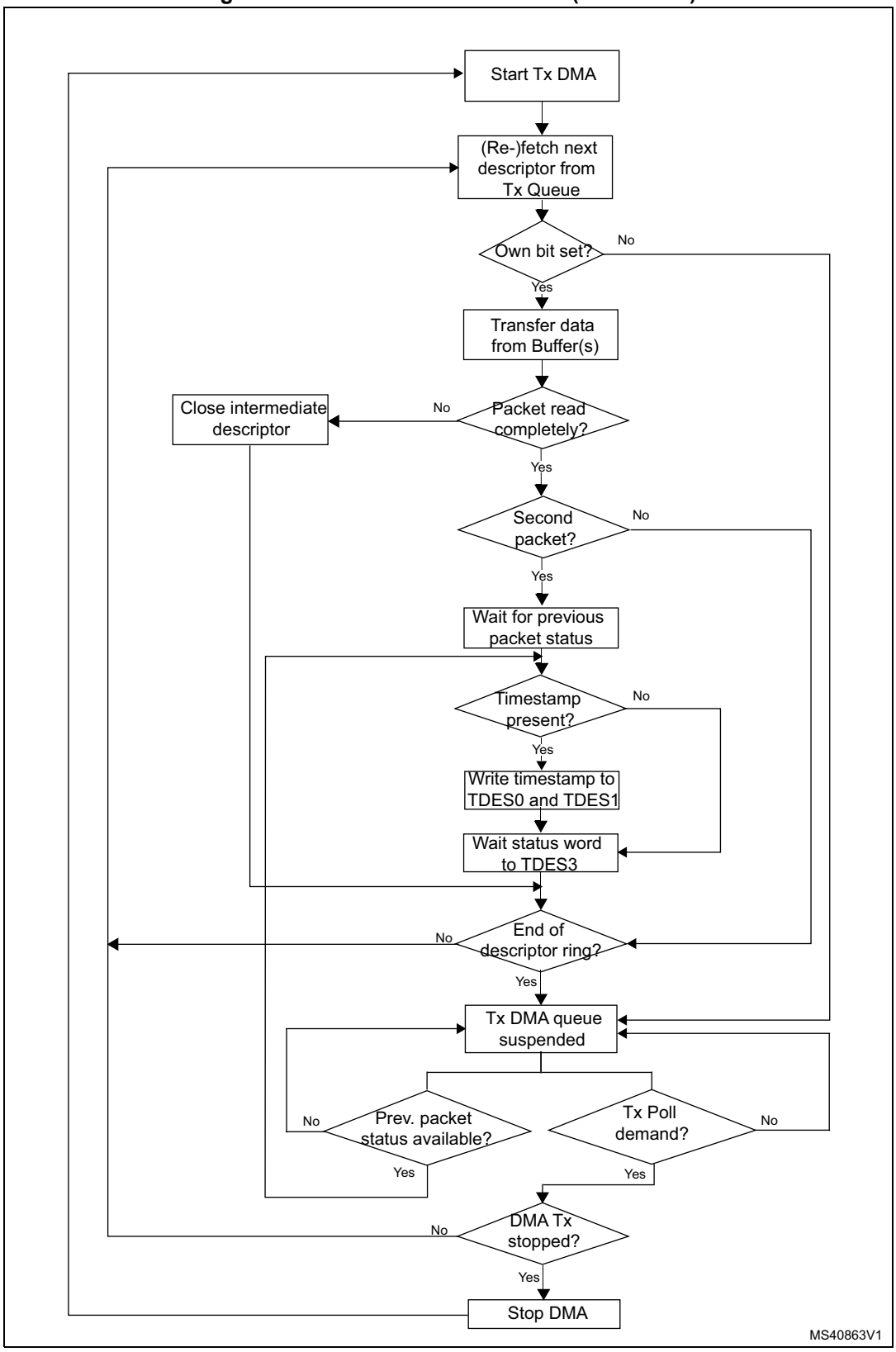
In OSP mode, DMA transmission in the Run state operates as described in the following sequence:

1. The DMA executes steps 1 to 7 of the DMA transmission sequence in default mode (see *Section : DMA transmission in default mode*).
2. The DMA fetches the next descriptor without closing previous packet last descriptor.
3. If the DMA owns the acquired descriptor, the DMA decodes the transmit buffer address in this descriptor. If the DMA does not own the descriptor, the DMA goes into Suspend mode and jumps to step 7.
4. The DMA fetches the Transmit packet from the system memory and transfers the packet to the MTL until the EOP data is transferred, closing the intermediate descriptors if this packet is split across multiple descriptors.
5. The DMA waits for the packet transmission status and timestamp of previous packet. When the status is available, the DMA writes the timestamp to TDES0 and TDES1 if such timestamp was captured (as indicated by a status bit). The DMA writes the status, with a cleared Own bit, to the corresponding TDES3, thus closing the descriptor. If Timestamp feature is not enabled for the previous packet, the DMA does not alter the contents of TDES2 and TDES3.
6. The Transmit interrupt is set (if enabled). The DMA fetches the next descriptor and proceeds to step 3 (when Status is normal). If the previous transmission status shows an underflow error, the DMA goes into Suspend mode (step 7).
7. In Suspend mode, if a pending status and timestamp are received from the MTL, the DMA performs the following operations:
   a) The DMA writes the timestamp (if enabled for the current packet) to TDES2 and TDES3.
   a) The DMA writes the status to the corresponding TDES3.
   a) The DMA sets the relevant interrupts and returns to Suspend mode.

   If no status is pending and the application stopped the DMA by clearing bit 0 of Transmit Control Register of corresponding DMA channel, the DMA enters the Stop state.
8. The DMA can exit Suspend mode and enter the Run state (it goes either to step 1 or to step 2 depending on pending status) only after receiving a Transmit Poll demand in the transmit descriptor tail pointer register of corresponding channel.

A description of the basic DMA transmission flow in OSP mode in given in *Figure 991: Receive DMA flow*.

Figure 990. DMA transmission flow (OSP mode)



DMA reception

In the receive path, the DMA reads a packet from the MTL receive queue and writes it to the packet data buffers of the corresponding DMA channel.

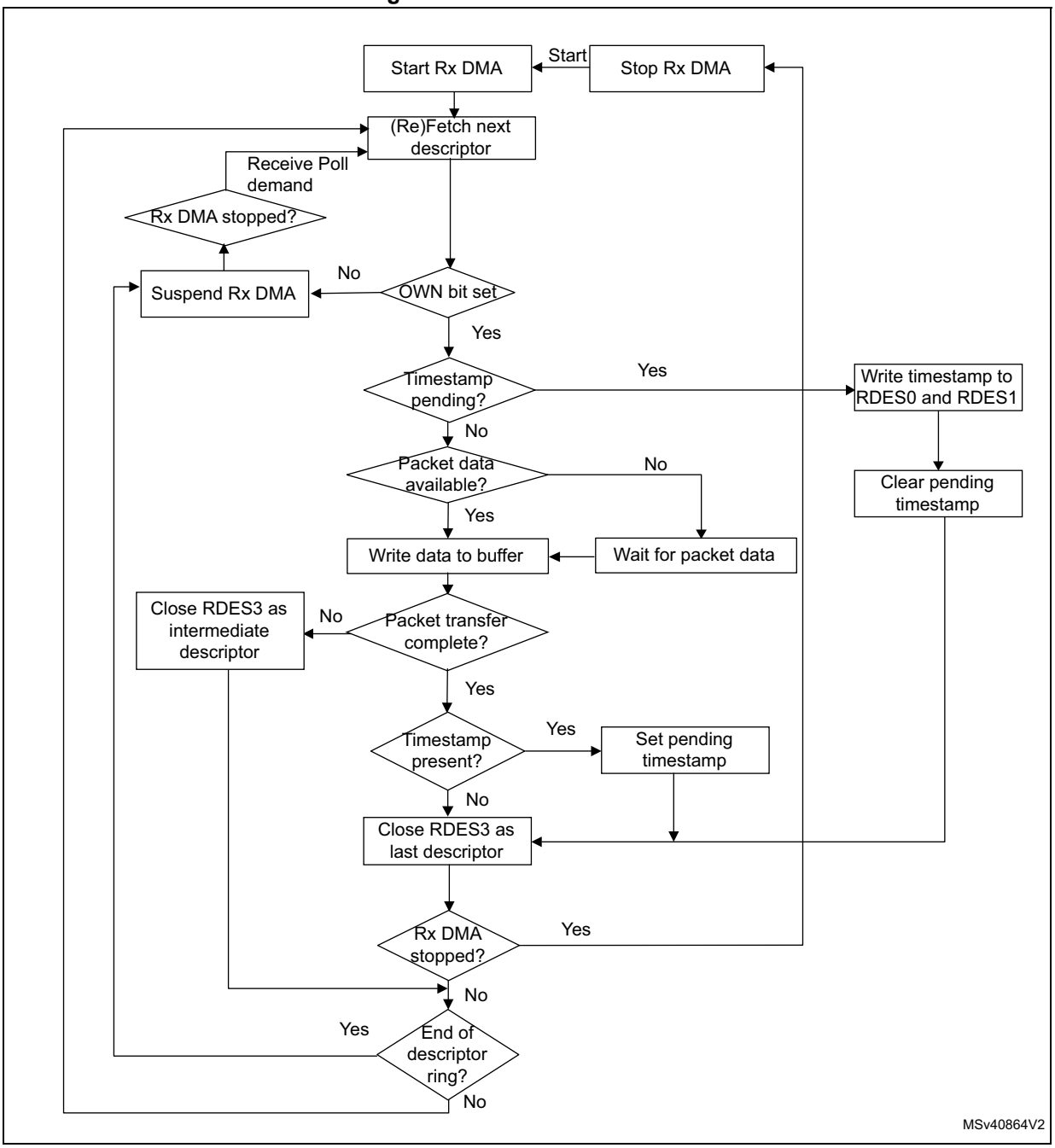
The DMA Rx descriptor ring structure is described in *Section 69.10: Descriptors*.

The reception sequence for Rx DMA engine is as follows (see also *Figure 991: Receive DMA flow*):

1. The application sets up the Rx descriptors (RDES0-RDES3) and the Own bit (RDES3[31]). The application should set the correct value in the receive descriptor tail pointer register of corresponding DMA channel to indicate the location of the last valid descriptor for the DMA. If the tail pointer points to descriptor N, the last valid descriptor for the DMA is descriptor N - 1.
2. When bit 0 of *Channel receive control register (ETH_DMACRXCR)*) is set, the DMA enters the Run state. The DMA looks for free descriptors based on the Rx Current Descriptor and Descriptor tail pointer register values. The descriptors referenced between the current descriptor and the tail pointer registers are available for the DMA. If there are no free descriptors, the DMA channel enters the Suspend state and goes to step 11.
3. The DMA fetches the next available descriptor in the ring and decodes the receive data buffer address from acquired descriptors.
4. If IEEE 1588 timestamping is enabled and the timestamp is available for the previous packet, the DMA writes the timestamp (if available) to the RDES0 and RDES1 of current descriptor and sets the CTXT field (RDES3[30]).
5. The DMA processes the incoming packets and stores them in the data buffers of acquired descriptor.
6. If the current packet transfer is not complete, the DMA closes the current descriptor as intermediate and goes to step 10.
7. The DMA retrieves the status of the receive frame from the MTL and writes the status word to current descriptor with the Own bit cleared and the Last descriptor bit set.
8. The DMA writes the Frame Length to RDES3 and the VLAN tag to RDES0. The DMA also writes the MAC control frame opcode, OAM control frame code, and extended status information (if available) to RDES1 of the last descriptor.
9. The DMA stores the timestamp (if available). The DMA writes the context descriptor after the last descriptor for the current packet (in the next available descriptor).
10. If more descriptors are available in the Rx DMA descriptor ring, go to step 3, otherwise go to the Suspend state (step 11).
11. The receive DMA exits the Suspend state when a receive Poll demand is given, and the application updates the channel receive descriptor tail pointer register to indicate the location of the last valid descriptor for DMA. Then, the engine proceeds to step 2 and fetches again the next descriptor.

Note: Refer to Section : Descriptor tail pointer handling examples for updating the correct value in receive descriptor tail pointer register.

Figure 991. Receive DMA flow



Priority scheme for Tx DMA and Rx DMA

The DMA arbiter performs the arbitration between the Tx and Rx paths of DMA channel 0 to access descriptors and data buffers. The DMA arbiter supports two types of arbitration: fixed priority and weighted round-robin. The DA bit of the *DMA mode register (ETH_DMAMR)* specifies the arbitration scheme (fixed or weighted round-robin) between the Tx and Rx DMA of a given channel.

If the Tx DMA and Rx DMA of a given channel are enabled, the DMA which gets the bus when the channel gets control of the bus must be specified. The priority between the

corresponding Tx DMA and Rx DMA can be configured through the TXPR field of the *DMA mode register (ETH_DMAMR)*. For round-robin arbitration, the weighted priority between the Tx DMA and Rx DMA is configured through the PR field of the *DMA mode register (ETH_DMAMR)*. *Table 768* provides information about the priority scheme between Tx DMA and Rx DMA.

Table 768. Priority scheme for Tx DMA and Rx DMA

DMA mode register (ETH_DMAMR)					Priority scheme
PR[2:0]			TXPR	DA	
x	x	x	0	1	Rx always has priority over Tx
0	0	0	0	0	Tx and Rx have equal priority. Rx gets the access first on simultaneous requests.
0	0	1	0	0	Rx has priority over Tx in ratio 2:1.
0	1	0	0	0	Rx has priority over Tx in ratio 3:1.
0	1	1	0	0	Rx has priority over Tx in ratio 4:1.
1	0	0	0	0	Rx has priority over Tx in ratio 5:1.
1	0	1	0	0	Rx has priority over Tx in ratio 6:1.
1	1	0	0	0	Rx has priority over Tx in ratio 7:1.
1	1	1	0	0	Rx has priority over Tx in ratio 8:1.
x	x	x	1	1	Tx always has priority over Rx.
0	0	0	1	0	Tx and Rx have equal priority. Tx gets the access first on simultaneous requests.
0	0	1	1	0	Tx has priority over Rx in ratio 2:1.
0	1	0	1	0	Tx has priority over Rx in ratio 3:1.
0	1	1	1	0	Tx has priority over Rx in ratio 4:1.
1	0	0	1	0	Tx has priority over Rx in ratio 5:1.
1	0	1	1	0	Tx has priority over Rx in ratio 6:1.
1	1	0	1	0	Tx has priority over Rx in ratio 7:1.
1	1	1	1	0	Tx has priority over Rx in ratio 8:1.

69.4.2 MTL

The MAC Transaction Layer (MTL) provides the FIFO memory interface to buffer and regulate the packets between the application system memory and the MAC. It also enables the data to be transferred between the application clock and MAC clock domains. The MTL layer features two 32-bit wide data paths: the Transmit path and the receive path.

- Transmit path

  The application or internal DMA pushes the Ethernet packets read from the application or system memory into the Tx FIFO. The packet is then popped out and transferred to the MAC when the queue threshold is reached (threshold mode) or complete packet is in the queue (store-and-forward mode). When EOP is transferred, the status of the transmission is taken from the MAC and transferred back to the application or internal DMA. The Tx queue size is 2048 bytes.

- Receive path

  The MTL Rx module receives the packets from the MAC and pushes them into the Rx queue. The status (fill level) of the queue is indicated to the application or to DMA when it crosses the configured receive threshold (RTC bits[1:0] defined in *Rx queue operating mode register (ETH_MTLRXQOMR)*), or when the complete packet was received. The MTL also indicates the queue fill level so that the DMA can initiate preconfigured burst transfers towards the master interface. The Rx queue size is 2048 bytes.

69.4.3 MAC

The MAC is responsible of the Ethernet protocol processing.In Transmission mode, it receives data from MTL before transferring it to the PHY interface. In Reception mode, the MAC receives data from the PHY interface before transferring them to the Rx FIFO of the MTL module.

This section briefly describes transmission and reception sequences.

MAC transmission

The transmission sequence is as follows:

1. Transmission is initiated when the MTL application pushes in data with the SOP (Start of packet) signal asserted.
2. When the SOP signal is detected, the MAC accepts the data and begins the transmission to the MII.
3. When the EOP (End of packet) is transferred to the MAC, the MAC does one of the following:
   - The MAC completes the normal transmission and provides the transmission status to the MTL.
   - If a normal collision (in Half-duplex mode) occurs during transmission, the MAC provides the Transmit status to the MTL, with the Retry bit set. The MAC provides the Retry request till one of the following is true:

     the packet was successfully transmitted;

     the maximum number of Retry requests expires. In this case, the MAC aborts the packet transmission with Excessive Collision Transmit status. The MAC accepts and drops all further data until the next SOP is received. The MTL block should retransmit the same packet from SOP when a Retry request (in the Status) is observed from the MAC.

– If any one of the following event happens, the MAC aborts the packet transmission:

no carrier (Half-duplex mode)

loss of carrier (Half-duplex mode)

excessive deferral (Half-duplex mode)

late collisions (Half-duplex mode)

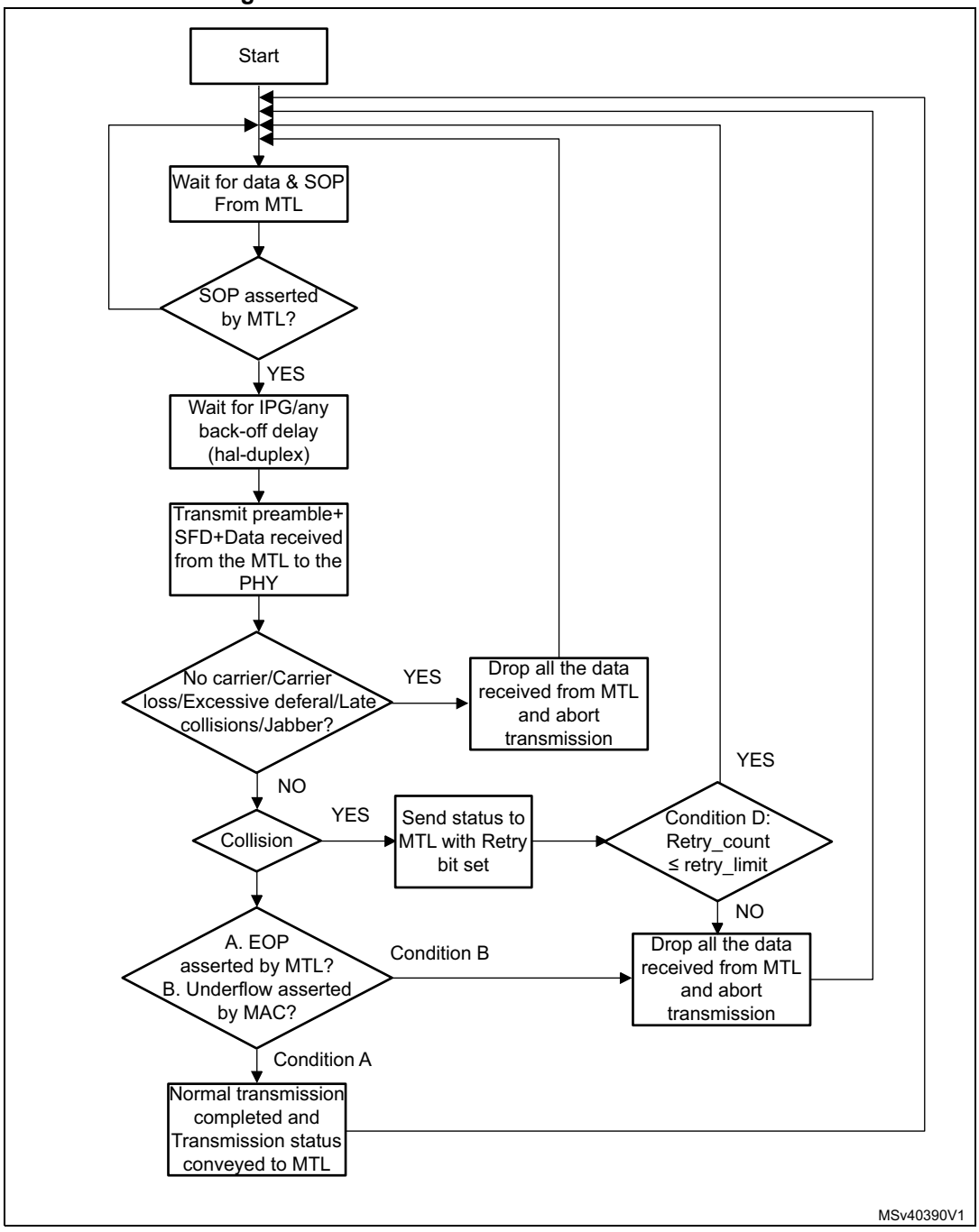
jabber

the MAC accepts and drops all further data until the next SOP is received.

4. The MAC issues an underflow status if the MTL is not able to provide the data continuously during the transmission. The MAC accepts and drops all further data until the next SOP is received.
5. During the normal transfer of a packet from MTL, if the MAC receives a SOP without getting an EOP for the previous packet, it ignores the SOP and considers the new packet as continuation of the previous packet.

Figure 992: Overview of MAC transmission flow illustrates the MAC transmission process flow.

Figure 992. Overview of MAC transmission flow



MAC reception

A receive operation is initiated when the MAC detects an SFD on MII. The MAC strips the preamble and SFD before proceeding to process the packet. The header fields are checked for filtering and the FCS field used to verify the CRC for the packet. The received packet is stored in a shallow buffer until the address filtering is performed. The packet is dropped in the MAC if it fails the address filter.

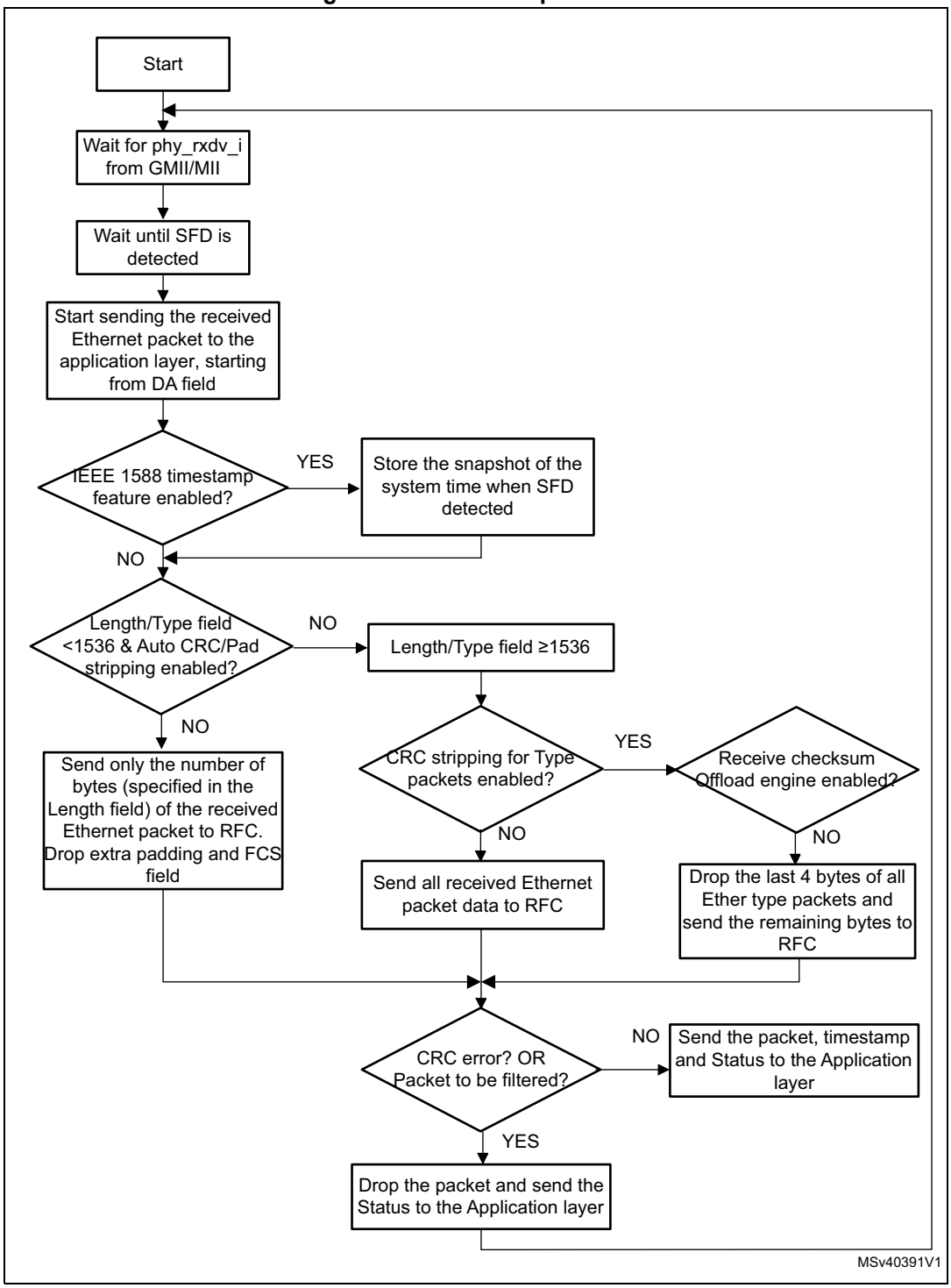
The reception sequence is as follows:

1. When the receive data valid signal (RxDV) of MII becomes active, the receive State Machine (RSM) starts looking for the SFD field (0xD nibble).

   The state machine drops received packets until it detects SFD.
2. When SFD is detected, the state machine starts sending the data of Ethernet packet to the RPC module, beginning with the first byte following the SFD (destination address).
3. If IEEE 1588 timestamp feature is enabled, the MAC takes a snapshot of the system time at which SFD of any packet is detected on MII. If this packet is not dropped during MAC filtering, the timestamp is passed to the application. The MAC converts the received nibble data into bytes and forwards the valid packet data to the RFC module.
4. The receive state machine decodes the Length/Type field of the Ethernet packet being received.

   If the Length/Type field is less than 1,536 and if the MAC is programmed for the Auto CRC/Pad Stripping (bit 20 of the *Operating mode configuration register (ETH_MACCR)*), the state machine sends the packet data up to the count specified in the Length/Type field and starts dropping bytes (including the FCS field). The state machine decodes the Length/Type field and checks for the Length interpretation.
5. If the Length/Type field is greater than or equal to 1,536, the RPE module sends all received Ethernet packet data to the RFC module if you have not enabled the CRC stripping for Type packet in Bit 21 of the *Operating mode configuration register (ETH_MACCR)*. However, if the CRC stripping has been enabled for Type packets and not enabled the receive checksum offload engine, the MAC strips and drops the last 4 bytes of all packets of ether type before forwarding the packets to the application.
6. By default, the MAC is programmed for watchdog timer to be enabled, that is, packets above 2,048 (10,240 if Jumbo Packet is enabled) bytes (DA + SA + LT + DATA + PAD + FCS) are cut off at the RPE module. In addition, you can use a programmable watchdog timer (bit 16 of *Watchdog and jabber timeout register (ETH_MACWJBTR)*) to override the fixed timeout of 2,048 or 10,240 bytes. You can disable the watchdog timer by programming bit 19 of *Operating mode configuration register (ETH_MACCR)*. However, even if the watchdog timer is disabled, a packet greater than 32 Kbytes is cut off and a watchdog timeout status is given.

Figure 993. MAC reception flow



69.5 Ethernet functional description: MAC

69.5.1 Double VLAN processing

The Ethernet peripheral supports the double VLAN (Virtual LAN) tagging feature in which the MAC can process up to two VLAN tags (inner and outer).

The MAC supports the following:

- Insertion, replacement, or deletion of up to two VLAN tags in the Transmit path
- Packet filtering and stripping based on any one of the two VLAN Tags in the receive path. Stripping and providing up to two VLAN Tags in the receive path as a part of the receive status

Transmit path

Table 769: Double VLAN processing features in Tx path describes the features supported by the MAC on the Transmit side.

Table 769. Double VLAN processing features in Tx path

Feature	Description
Support for C-VLAN and S-VLAN tag types	The inner or outer VLAN tag can be of C-VLAN and S-VLAN type. The VLAN type is specified through the CSVL bit of *VLAN inclusion register (ETH_MACVIR)* and *Inner VLAN inclusion register (ETH_MACIVIR)*, respectively. The Ethernet peripheral supports processing of any sequence of outer and inner VLAN tags. However, it does not support the C-VLAN S-VLAN sequence. The MAC does not check whether the packet provided by the application has a valid sequence of the VLAN Tag types or the insertion or replacement operation results in invalid sequence of VLAN Tag type. Therefore, the application must provide correct sequence of VLAN Tag types and program the MAC in such a way that it results in correct sequence of VLAN Tag types in the transmitted packet. The application must ensure the following: – The inner tag should not be S-VLAN when outer C-VLAN Tag insertion is enabled. – The outer tag should not be C-VLAN when inner S-VLAN Tag insertion is enabled. – The inner tag should not be S-VLAN when outer tag should be replaced with C-VLAN. – The outer tag should not be C-VLAN when inner tag should be replaced with S-VLAN.
VLAN tag deletion	VLAN tag deletion can be enabled for outer or inner tag through VLC field in the *VLAN inclusion register (ETH_MACVIR)* or *Inner VLAN inclusion register (ETH_MACIVIR)*, respectively. When VLAN deletion is enabled, the MAC deletes the tag present at the corresponding position. When a packet has only one tag, it is considered as the outer tag. If inner tag deletion is enabled and the packet has only one tag, the MAC does not delete the tag.
VLAN tag insertion or replacement	VLAN tag insertion or replacement can be enabled for outer or inner tag through VLC field in the *VLAN inclusion register (ETH_MACVIR)* or *Inner VLAN inclusion register (ETH_MACIVIR)*, respectively. When VLAN tag insertion or replacement is enabled, the VLTI bit in the previous register is used to determine whether the VLAN tag should be taken from the register or the control word.

Receive path

Table 770: Double VLAN processing in Rx path describes the features supported by the MAC on the receive side and the corresponding bits in the *VLAN tag register (ETH_MACVTR)*.

Table 770. Double VLAN processing in Rx path

Feature	Description
Outer or inner VLAN tag-based filtering	The MAC can filter packets based on the outer or inner VLAN tag through the ERIVLT bit.
C-VLAN or S-VLAN tag-based filtering	The MAC can filter packets based on the C-VLAN or S-VLAN type based on the ERSVLM bit.
Outer and Inner VLAN tag stripping	The MAC can strip the outer and inner VLAN Tags from received frame based on the EVLS and EIVLS bits.
16-bit outer and inner VLAN tag and type in Rx status	The MAC can provide the 16-bit outer and inner VLAN Tag and Type in the Rx status based on the EVLRXS and EIVLRXS bits, respectively.
Disabling or skipping checking of outer VLAN tag type	The MAC can disable or skip checking of outer VLAN Tag type to match C-VLAN or S-VLAN based on the DOVLTC bit.

69.5.2 Source address and VLAN insertion, replacement, or deletion

Source address insertion or replacement

The software can use the SA (source address) insertion or replacement feature to instruct the MAC to do the following for Tx packets:

- Insert the content of the MAC Address registers in the SA field
- Replace the content of the SA field with the content of the MAC Address registers

When SA insertion is enabled, the application must ensure that the packets sent to the MAC do not have the SA field. The MAC does not check whether the SA field is present in the Transmit packet and it inserts the content of MAC Address Registers in the SA field. Similarly, when SA replacement is enabled, the application must ensure that the SA field is present in the packets sent to the MAC. The MAC replaces the six bytes following the Destination Address field in the Transmit packet with the content of the MAC Address Registers.

SA insertion or replacement feature can be enabled for all Transmit packets or selective packets:

- Enabling SA insertion or replacement for all packets

  To enable this feature for all packets, program the SARC field of the *Operating mode configuration register (ETH_MACCR)*.
- Enabling SA insertion or replacement for selective packets

  To enable this feature for selective packets, use the following program the SA Insertion Control field (bits[25:23] of transmit descriptor Word 3/TDES3, refer to *Section 69.10.3: Transmit descriptor*) in the first Transmit descriptor of the packet. When Bit 25 of TDES3 is set, the SA Insertion Control field indicates insertion or replacement by MAC

Address1 registers. When bit 25 of TDES3 is reset, it indicates insertion or replacement by MAC Address 0 registers.

If MAC Address1 registers are not enabled, the MAC Address0 registers are used for insertion or replacement whatever of the value of the most-significant bit of the SA Insertion Control field.

VLAN insertion, replacement, or deletion

The software can use the VLAN insertion, replacement, or deletion feature to instruct the MAC to do the following for Tx packets:

- Delete the VLAN Type and VLAN Tag fields
- Insert or replace the VLAN Type and VLAN Tag fields

  Insertion or replacement is performed based on the setting of VLTI bit in the *VLAN inclusion register (ETH_MACVIR)* as described in *Table 771: VLAN insertion or replacement based on VLTI bit*.

Table 771. VLAN insertion or replacement based on VLTI bit

Condition	Description
VLTI bit is set	The MAC inserts or replaces the following: VLAN Type field (C-VLAN or S-VLAN as indicated by the CSVL bit of *VLAN inclusion register (ETH_MACVIR)*) VLAN Tag field with VT field of Transmit context descriptor of the packet
VLTI bit is reset	The MAC inserts or replaces the following: VLAN Type field (C-VLAN or S-VLAN as indicated by the CSVL bit of *VLAN inclusion register (ETH_MACVIR)*) VLAN Tag field with the VLT field of *VLAN inclusion register (ETH_MACVIR)*

When VLAN replacement or deletion is enabled, the MAC checks if the VLAN Type field (0x8100 or 0x88A8) is present after the DA and SA fields in the Transmit packet. The replace or delete operation does not occur if the VLAN Type field is not detected in two bytes following the DA and SA fields. However, when VLAN insertion is enabled, the MAC does not check the presence of VLAN Type field in the Transmit packet and just inserts the VLAN Type and VLAN Tag fields.

You can enable the VLAN insertion, replacement, or deletion feature for all Tx packets or selective packets:

- To enable this feature for all packets, program the VLC and VLP fields of *VLAN inclusion register (ETH_MACVIR)*.
- To enable this feature for selective packets, program the VTIR field of TDES2 Normal Descriptor (see *Table 804: TDES2 normal descriptor (read format)*).

  In addition, the VLP (VLAN Priority control) bit must be reset in *VLAN inclusion register (ETH_MACVIR)* (for outer VLAN) and *Inner VLAN inclusion register (ETH_MACIVIR)* (in inner VLAN) for the MAC to take the control inputs from the host, depending on the configuration.

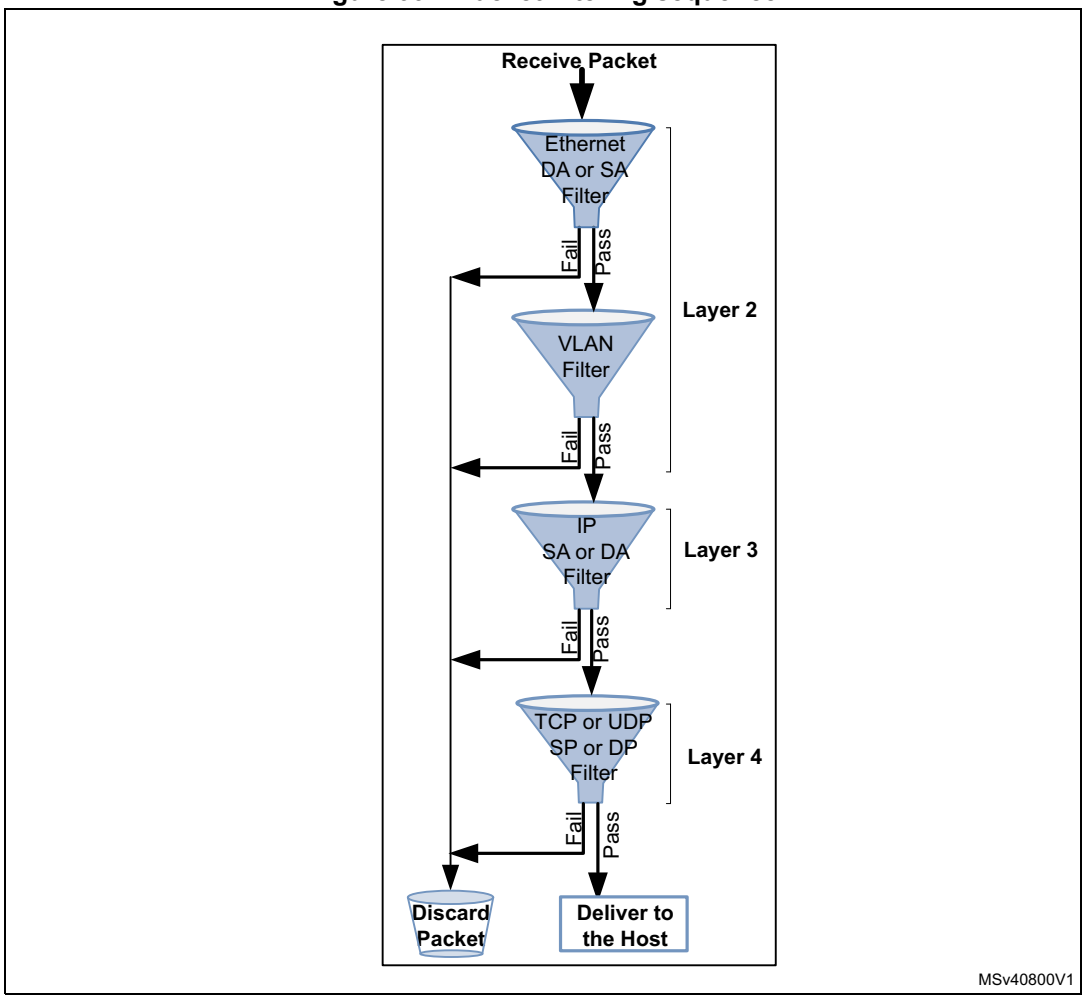
69.5.3 Packet filtering

The MAC supports the following types of filtering for Rx packets:

- *MAC source or destination address filtering*: the Address Filtering Module (AFM) checks the source address and destination address fields of each incoming packet.
- *VLAN filtering*: the MAC supports the VLAN tag-based and VLAN Hash filtering.
- *Layer 3 and Layer 4 filtering*: Layer 3 filtering refers to IP source address and destination address filtering. Layer 4 filtering refers to source port and destination port filtering.

The three filter types can be cascaded. *Figure 994* shows the filtering sequence for Rx packets.

Figure 994. Packet filtering sequence



The sequence shown in *Figure 994* is valid when all the filters (L2, VLAN, L3, L4) are active. If any of the Layer filters are not enabled, that filter is bypassed and the subsequent filter is applied. A packet that fails any of the filters is discarded. However, the discarded packet can be forwarded to the host based on the register control.

For example, when RA bit of *Packet filtering control register (ETH_MACPFR)* is set to 1, all the discarded packets are forwarded to the host but with their packet status indicating the

specific filter failure. If RA bit is cleared to 0, VTFE and IPFE bits of *Packet filtering control register (ETH_MACPFR)* control if the packets that fail the VLAN filter and Layer 3-4 filter should be discarded or forwarded to the host.

MAC source or destination address filtering

The MAC address filtering module checks the source address (SA) and destination address (DA) fields of each incoming packet.

Unicast destination address filtering

The MAC supports 4 MAC addresses for unicast perfect filtering. If perfect filtering is selected (HUC bit of *Packet filtering control register (ETH_MACPFR)* is reset), the MAC compares all 48 bits of received unicast address with the programmed MAC address for any match. The default MacAddr0 is always enabled.

The MacAddr1 to MacAddr3 addresses are selected with an individual enable bit. You can mask each byte during comparison with corresponding received DA byte by setting the corresponding Mask Byte Control bit in *MAC address x high register (ETH_MACAxHR)*. This enables group address filtering for the DA.

In Hash filtering mode (when HUC bit is set), the MAC performs imperfect filtering for unicast addresses using a 64-bit Hash table. For Hash filtering, the MAC uses the upper 6 bits CRC of the received destination address to index the content of the Hash table. A value of 00000 selects bit 0 of selected register, and a value of 11111 selects bit 63 of Hash Table register. If the corresponding bit (indicated by the 6-bit CRC) is set to 1, the unicast packet is considered to have passed the Hash filter; otherwise, the packet is considered to have failed the Hash filter.

Multicast destination address filtering

To program the MAC to pass all multicast packets, set the PM bit in *Packet filtering control register (ETH_MACPFR)*. If the PM bit is reset, the MAC performs the filtering for multicast addresses based on the HMC bit of the *Packet filtering control register (ETH_MACPFR)*.

In Perfect filtering mode, the multicast address is compared with the programmed MAC destination address registers. Group address filtering is also supported.

In Hash filtering mode, the MAC performs imperfect filtering using a 64-bit Hash table. The MAC uses the upper 6-bits CRC of received multicast address to index the content of the Hash table. A value of 000000 selects bit 0 of selected register and a value of 111111 selects bit 63 of the Hash Table register. If the corresponding bit is set to 1, the multicast packet is considered to have passed the Hash filter. Otherwise, the packet is considered to have failed the Hash filter.

Hash or Perfect address filtering

To configure the DA filter to pass a packet when its DA matches either the Hash filter or the Perfect filter, set the HPF bit and the corresponding HUC or HMC bits in *Packet filtering control register (ETH_MACPFR)*. This is applicable to both unicast and multicast packets. If the HPF bit is reset, only one of the filters (Hash or Perfect) is applied to receive packet.

Broadcast address filtering

The MAC does not filter any broadcast packets by default. To program the MAC to reject all broadcast packets, set the DBF bit in *Packet filtering control register (ETH_MACPFR)*.

Unicast source address filtering

The MAC can perform perfect filtering based on the source address field of received packets. By default, the MAC compares the SA field with the values programmed in the SA registers. You can configure the MAC Address registers to use SA instead of DA for comparison by setting bit 30 of *MAC address x high register (ETH_MACAxHR)*.

The MAC also supports group filtering with SA. You can filter a group of addresses by masking one or more bytes of the address. The MAC drops the packets that fail the SA filter if the SAF bit is set in *Packet filtering control register (ETH_MACPFR)*. Otherwise, the result of the SA filter is given as a status bit in the receive Status word (see *Table 773*). When the SAF bit is set, the SA filter and DA filter result is ANDed to decide whether the packet needs to be forwarded. This means that the packet is dropped if either filter fails. The packet is forwarded to the application only if the packet passes both filters in-order.

Inverse filtering

For DA and SA filtering, you can invert the filter-match result at the final output by setting the DAIF and SAIF bits of *Packet filtering control register (ETH_MACPFR)*. The DAIF bit is applicable for both Unicast and Multicast DA packets. The result of the unicast or multicast destination address filter is inverted in this mode. Similarly, when the SAIF bit is set, the result of unicast SA filter is reversed.

Table 772 and *Table 773* summarize the DA and SA filtering based on the type of packets received.

Note: When the RA bit of Packet filtering control register (ETH_MACPFR) is set, all packets are forwarded to the system along with the correct result of the address filtering in the Rx status.

Table 772. Destination address filtering

Packet type	PR	HPF	HUC	DAIF	HMC	PM	DBF	DA filter operation
Broadcast	1	X	X	X	X	X	X	Pass
	0	X	X	X	X	X	0	Pass
	0	X	X	X	X	X	1	Fail
Unicast	1	X	X	X	X	X	X	Pass all packets
	0	X	0	0	X	X	X	Pass on Perfect/Group filter match
	0	X	0	1	X	X	X	Fail on Perfect/Group filter match
	0	0	1	0	X	X	X	Pass on Hash filter match
	0	0	1	1	X	X	X	Fail on Hash filter match
	0	1	1	0	X	X	X	Pass on Hash or Perfect/Group filter match
	0	1	1	1	X	X	X	Fail on Hash or Perfect/Group filter match

Table 772. Destination address filtering (continued)

Packet type	PR	HPF	HUC	DAIF	HMC	PM	DBF	DA filter operation
Multicast	1	X	X	X	X	X	X	Pass all packets
	X	X	X	X	X	1	X	Pass all packets
	0	X	X	0	0	0	X	Pass on Perfect/Group filter match and drop Pause packets if PCF = 0x
	0	0	X	0	1	0	X	Pass on Hash filter match and drop Pause packets if PCF = 0x
	0	1	X	0	1	0	X	Pass on Hash or Perfect/Group filter match and drop Pause packets if PCF = 0x
Multicast	0	X	X	1	0	0	X	Fail on Perfect/Group filter match and drop Pause packets if PCF = 0x
	0	0	X	1	1	0	X	Fail on Hash filter match and drop Pause packets if PCF = 0x
	0	1	X	1	1	0	X	Fail on Hash or Perfect/Group filter match and drop Pause packets if PCF = 0x

Table 773. Source address filtering

Packet type	PR	SAIF	SAF	SA filter operation
Unicast	1	X	X	Pass all packets.
	0	0	0	Pass status on Perfect or Group filter match but do not drop packets that fail
	0	1	0	Fail status on Perfect or Group filter match but do not drop packet
	0	0	1	Pass on Perfect or Group filter match and drop packets that fail
	0	1	1	Fail on Perfect or Group filter match and drop packets that fail

VLAN filtering

The MAC supports Perfect and Hash VLAN filtering. Refer to *Section 69.9.15: Programming guidelines to perform VLAN filtering on the receiver* for detailed programming steps.

VLAN tag Perfect filtering

In VLAN tag Perfect filtering, the MAC compares the VLAN tag of received packet and provides the VLAN packet status to the application. Based on the programmed mode, the MAC compares the lower 12 bits or all 16 bits of received VLAN tag to determine the perfect match.

If VLAN tag Perfect filtering is enabled, the MAC forwards the VLAN-tagged packets along with VLAN tag match status and drops the VLAN packets that do not match. You can also enable the inverse matching for VLAN packets by setting the VTIM bit of *VLAN tag register (ETH_MACVTR)*. In addition, you can enable matching of S-VLAN tagged packets along with the default C-VLAN tagged packets by setting the ESVL bit of *VLAN tag register (ETH_MACVTR)*. The VLAN packet status bit (bit 10 of RDES0) indicates the VLAN tag match status for the matched packets.

Note: The source or destination address (if enabled) has precedence over the VLAN tag filters. This means that a packet that fails the source or destination address filter is dropped irrespective of the VLAN tag filter results.

VLAN tag Hash filtering

The 16-bit VLAN Hash Table is used for group address filtering based on the VLAN tag. The VLAN tag Hash filtering feature can be enabled using the VTHM (VLAN tag Hash Table match enable) bit of the *VLAN tag register (ETH_MACVTR)*. If the VTHM bit is set, the most significant four bits of CRC-32 of VLAN tag are used to index the content of the VLAN Hash Table register. A value of 1 in the VLAN Hash Table register, corresponding to the index, indicates that the VLAN tag of the packet matched and the packet should be forwarded. A value of 0 indicates that VLAN-tagged packet should be dropped.

Note: The 16 or 12 bits of VLAN Tag are considered for CRC-32 computation based on ETV bit in ETH_MACVTR register.

When ETV bit is reset, most significant four bits of CRC-32 of VLAN Tag are inverted and used to index the content of VLAN Hash table register (ETH_MACVHTR).

When ETV bit is set, most significant four bits of CRC-32 of VLAN Tag are directly used to index the content of VLAN tag register (ETH_MACVTR).

The MAC also supports the inverse matching for VLAN packets. In the inverse matching mode, when the VLAN tag of a packet matches the Perfect or Hash filter, the packet should be dropped. If the VLAN perfect and VLAN Hash match are enabled, a packet is considered as matched if either the VLAN Hash or the VLAN perfect filter matches. When inverse match is set, a packet is forwarded only when both perfect and Hash filters indicate mismatch.

Table 774 shows the different possibilities for VLAN matching and the final VLAN match status. When the RA bit of *Packet filtering control register (ETH_MACPFR)* is set, all packets are received and the VLAN match status is indicated in the VF bit of *RDES2 normal descriptor (write-back format)*. When the RA bit is not set and the VTFE bit is set in *Packet filtering control register (ETH_MACPFR)*, the packet is dropped if the final VLAN match status is Fail. In *Table 774*, value *X* means that this column can have any value.

When VLAN VID is programmed to 0 in the VL field of *VLAN tag register (ETH_MACVTR)*, all VLAN-tagged packets are considered as perfect matched but the status of the VLAN Hash match depends on the VTHM and VTIM bits in *VLAN tag register (ETH_MACVTR)*.

Table 774. VLAN match status(1)

VID	VLAN perfect filter match result	VTHM bit	VLAN hash filter match result	VTIM bit	Final VLAN match status
VID = 0	Pass	0	X	X	Pass
	Pass	1	X	0	Pass
	Pass	1	Fail	1	Pass
	Pass	1	Pass	1	Fail

Table 774. VLAN match status(1) (continued)

VID	VLAN perfect filter match result	VTHM bit	VLAN hash filter match result	VTIM bit	Final VLAN match status
VID!= 0	Pass	X	X	0	Pass
	Fail	0	X	0	Fail
	Fail	1	Fail	0	Fail
	Fail	1	Pass	0	Pass
	Fail	0	X	1	Pass
	Pass	X	X	1	Fail
	Fail	1	Pass	1	Fail
	Fail	1	Fail	1	Pass

1. In this table, 'X' represents any value.

Layer 3 and Layer 4 filtering

The MAC supports Layer 3 and Layer 4 based packet filtering. The Layer 3 filtering refers to the IP Source or Destination Address filtering in the IPv4 or IPv6 packets whereas Layer 4 filtering refers to the Source or Destination Port number filtering in TCP or UDP.

The Layer 3 and Layer 4 packet filtering feature automatically enables the IPC Full Checksum Offload Engine on the receive side. For Layer 3 or Layer 4 filtering operation, you must set the IPC bit of the *Operating mode configuration register (ETH_MACCR)* to enable the Rx Checksum Offload engine.

When Layer 3 and Layer 4 filtering is enabled, the packets are filtered in the following way:

- Matched packets

  The MAC forwards the packets that match all enabled fields to the application along with the status. The MAC gives the matched field status only if the IPC bit of *Operating mode configuration register (ETH_MACCR)* is set and one of the following conditions is true:

  – All enabled Layer 3 and Layer 4 fields match.

  – At least one of the enabled field matches and other fields are bypassed or disabled

  When multiple Layer 3 and Layer 4 filters are enabled, any filter match is considered as a match. If more than one filter matches, the MAC provides the status of the lowest filter where Filter 0 is the lowest filter and Filter 3 is the highest filter. For example, if Filter 0 and Filter 1 match, the MAC gives the status corresponding to filter 0.

Note: The source or destination address and VLAN tag filters (if enabled) have precedence over Layer 3 and Layer 4 filter. This means that a packet which fails the source or destination address or VLAN tag filter is dropped irrespective of the Layer 3 and Layer 4 filter results.

- Unmatched packets

  The MAC drops the packets that do not match any of the enabled fields. You can use the inverse match feature to block or drop a packet with specific TCP or UDP over IP fields and forward all other packets.The aborted or partial packets are dropped in the MTL Rx FIFO. If the Rx FIFO operates in the Threshold (cut-through) mode and the threshold is programmed to a small value. Such packet transfer to the application starts before the failed Layer 3 and Layer 4 filter results are available, the application may receive a partial packet with appropriate abort status.
- Non-TCP or UDP IP Packets

  By default, all non-TCP or UDP IP packets are bypassed from the Layer 3 and Layer 4 filters. You can optionally program the MAC to drop all non-TCP or UDP over IP packets.

Layer 3 filtering

The MAC supports perfect matching or inverse matching for IP Source Address and Destination Address. In addition, you can match the complete IP address or mask the lower bits matching, that is, compare all bits of the address except the specified lower mask bits.

For IPv6 packets filtering, you can enable the last four data registers of a register set to contain the 128-bit IP Source Address or IP Destination Address. The IP Source Address or Destination Address should be programmed in the order defined in the IPv6 specification, that is, the first byte of the IP Source Address or Destination Address in the received packet is in the higher byte of the register and the subsequent registers follow the same order.

For IPv4 packet filtering, you can enable the second and third data registers of a register set to contain the 32-bit IP Source Address and IP Destination Address. The remaining two data registers are reserved. The IP Source Address or Destination Address should be programmed in the order defined in the IPv4 specification, that is, the first byte of IP Source Address and Destination Address in the received packet in the higher byte of the respective register.

Layer 4 filtering

The MAC supports perfect matching or inverse matching for TCP or UDP Source and Destination Port numbers. However, you can program only one type (TCP or UDP) at a time. The first data register contains the 16-bit Source and Destination Port numbers of TCP or UDP, that is, the lower 16 bits for Source Port number and higher 16 bits for Destination Port number.

The TCP or UDP Source and Destination Port numbers should be programmed in the order defined in the TCP or UDP specification, that is, the first byte of TCP or UDP Source and Destination Port number in the received packet is in the higher byte of the register.

Layer 3 and Layer 4 filters register set

The MAC implements two sets of registers for Layer 3 and Layer 4 based packet filtering. In a register set, there is a control register, such as *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, to control the packet filtering. In addition, there are five address registers to program the Layer 3 and Layer 4 fields to be matched, such as:

- *Layer4 address filter 0 register (ETH_MACL4A0R)*
- *Layer3 address 0 filter 0 register (ETH_MACL3A00R)*
- *Layer3 address 1 filter 0 register (ETH_MACL3A10R)*
- *Layer3 address 2 filter 0 register (ETH_MACL3A20R)*
- *Layer3 address 3 filter 0 register (ETH_MACL3A30R)*

The second independent set of registers includes: *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, *Layer 4 address filter 1 register (ETH_MACL4A1R)*, *Layer3 address 0 filter 1 Register (ETH_MACL3A01R)*, *Layer3 address 1 filter 1 register (ETH_MACL3A11R)*, *Layer3 address 2 filter 1 Register (ETH_MACL3A21R)* and *Layer3 address 3 filter 1 register (ETH_MACL3A31R)*.

69.5.4 IEEE 1588 timestamp support

The IEEE 1588 standard defines a precision time protocol (PTP) which allows precise synchronization of clocks in measurement and control systems implemented with technologies such as network communication, local computing, and distributed objects. The PTP applies to systems communicating by local area networks supporting multicast messaging, including (but not limited to) Ethernet. This protocol enables heterogeneous systems that include clocks of varying inherent precision, resolution, and stability to synchronize. The protocol supports system-wide synchronization accuracy in the submicrosecond range with minimal network and local clock computing resources.

This chapter contains the following sections:

- *IEEE 1588 timestamp support*
- *IEEE 1588 system time source*
- *IEEE 1588 auxiliary snapshots*
- *Flexible pulse-per-second output*
- *PTP timestamp offload function*
- *One-step timestamp*”

IEEE 1588 timestamp support

The Ethernet peripheral supports the IEEE 1588-2002 (version 1) and IEEE 1588-2008 (version 2). The IEEE 1588-2002 supports PTP transported over UDP/IP. The IEEE 1588 2008 supports PTP transported over Ethernet. The peripheral provides programmable support for both standards. It supports the following features:

- Support of both timestamp formats
- Optional snapshot of all packets or only PTP type packets
- Optional snapshot of only event messages
- Optional snapshot based on the clock type: ordinary, boundary, end-to-end transparent, and peer-to-peer transparent
- Optional selection of the node to act as master or slave for ordinary and boundary clock
- Identification of the PTP message type, version, and PTP payload in packets sent directly over Ethernet and sends the status
- Optional measurement subsecond time in digital or binary format

Clock types

The MAC supports the following clock types defined in the IEEE 1588-2008 specifications:

- Ordinary clock

  The ordinary clock of a domain supports a single copy of the protocol. It has a single PTP state and a single physical port. In typical industrial automation applications, an ordinary clock is associated with an application device such as a sensor or an actuator. In telecom applications, the ordinary clock can be associated with a timing demarcation device.

The ordinary clock can be a grandmaster or a slave clock. It supports the following features:

– Transmission and reception of PTP messages. The timestamp snapshot can be controlled as described in *Timestamp control register (ETH_MACTSCR)*.

– Maintenance of the data sets such as timestamp values.

The table below shows the messages for which you can take the timestamp snapshot on the receive side for master and slave nodes.

Table 775. Ordinary clock: PTP messages for snapshot

Master	Slave
Delay_Req	SYNC

For an ordinary clock, you can take the snapshot of either of the following PTP message types: version 1 or version 2. You cannot take the snapshots for both PTP message types. You can take the snapshot by setting the TSVER2ENA bit and selecting the snapshot mode in *Timestamp control register (ETH_MACTSCR)*.

- Boundary clock

  The boundary clock typically has several physical ports which communicate with the network. The messages related to synchronization, master-slave hierarchy, and signaling end in the protocol engine of the boundary clock. Such messages are not forwarded. The PTP message type status given by the MAC helps to identify the type of message and take appropriate action.

  The boundary clock is similar to the ordinary clock except for the following features:

  – The clock data sets are common to all ports of the boundary clock.

  – The local clock is common to all ports of the boundary clock.

- End-to-end transparent clock

  The end-to-end transparent clock supports the end-to-end delay measurement mechanism between the slave clocks and the master clock. The end-to-end transparent clock forwards all messages like normal bridge, router, or repeater. The residence time of a PTP packet is the time taken by the PTP packet from the ingress port to the egress port.

  The residence time of a SYNC packet inside the end-to-end transparent clock is updated in the correction field of the associated Follow_Up PTP packet before it is transmitted. Similarly, the residence time of a Delay_Req packet, inside the end-to-end transparent clock, is updated in the correction field of the associated Delay_Resp PTP packet before it is transmitted. Therefore, the snapshot needs to be taken at both ingress and egress ports only for the messages mentioned in *Table 776*. You can take the snapshot by setting the SNAPTYPSEL bits to 10 in the *Timestamp control register (ETH_MACTSCR)*.

Table 776. End-to-end transparent clock: PTP messages for snapshot

PTP messages
SYNC
Delay_Req

- Peer-to-peer transparent clock

  In the peer-to-peer transparent clock, the computation of the link delay is based on an exchange of Pdelay_Req, Pdelay_Resp, and Pdelay_Resp_Follow_Up messages with the link peer.

  The peer-to-peer transparent clock differs from the end-to-end transparent clock in the way it corrects and handles the PTP timing messages. In all other aspects, it is identical to the end-to-end transparent clock.

  The residence time of the Pdelay_Req and the associated Pdelay_Resp packets is added and inserted into the correction field of the associated Pdely_Resp_Followup packet. Therefore, support for taking snapshot for the event messages related to Pdelay is added as shown in *Table 784*.

Table 777. Peer-to-peer transparent clock: PTP messages for snapshot

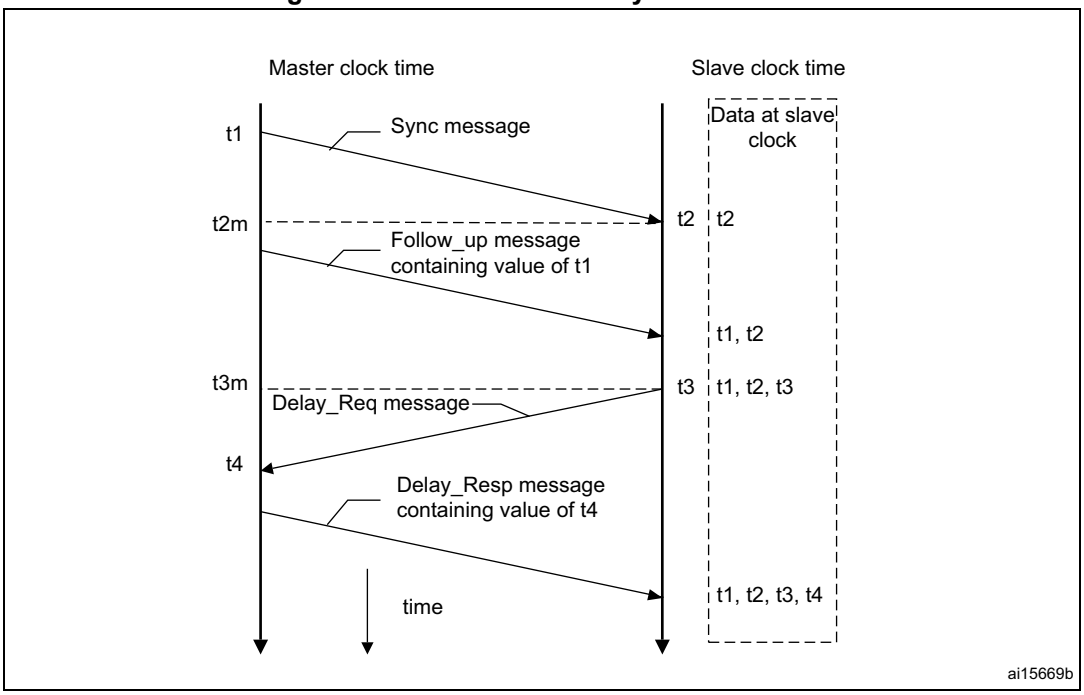
PTP messages
SYNC
Pdelay_Req
Pdelay_Resp

You can take the snapshot by setting the SNAPTYPESEL bit to 11 in *Timestamp control register (ETH_MACTSCR)*.

Delay request-response mechanism

The system or network is classified into the master and slave nodes for distributing the timing and clock information. *Figure 995* shows the process that PTP uses for synchronizing a slave node with a master node by exchanging PTP messages.

Figure 995. Networked time synchronization



As shown in *Figure 995*, the PTP uses the following process:

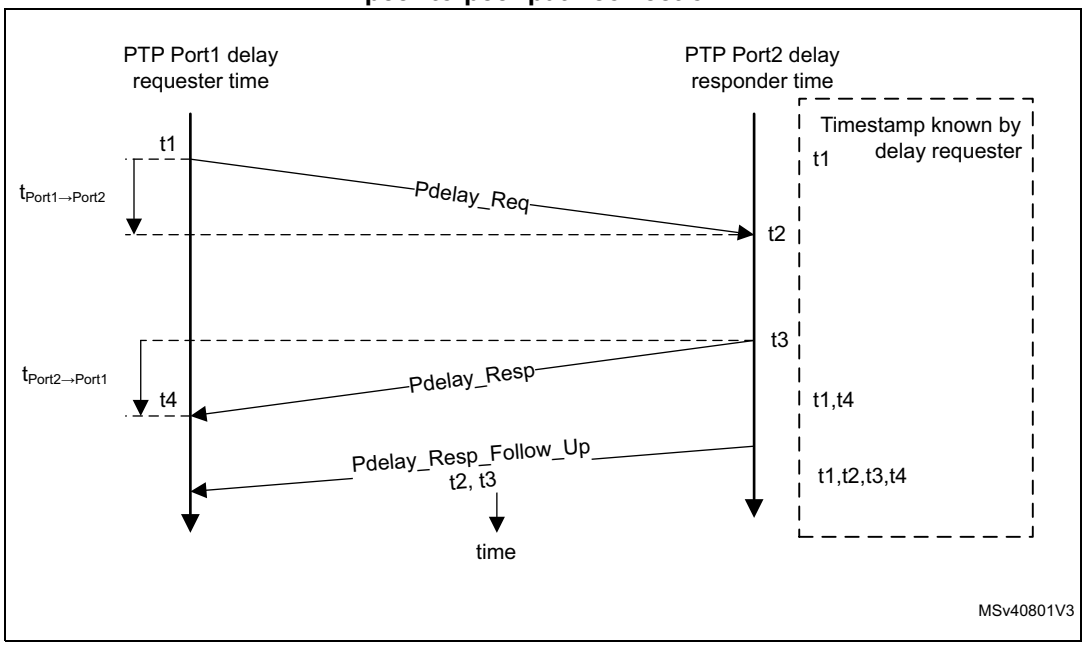
1. The master broadcasts the PTP Sync messages to all its nodes. The Sync message contains the reference time information of the master. This message leaves the system of the master at t_1. This time must be captured for Ethernet ports at MII.
2. The slave receives the SYNC message and also captures the exact time, t_2, using its timing reference.
3. The master sends a Follow_up message to the slave, which contains t_1 information for later use.
4. The slave sends a Delay_Req message to the master and notes the exact time, t_3, at which this packet leaves the MII interface.
5. The master receives the message, capturing the exact time t_4, at which the message enters its system.
6. The master sends the t_4 information to the slave in the Delay_Resp message.
7. The slave uses the four values of t_1, t_2, t_3, and t_4 to synchronize its local timing reference with the timing reference of the master.

Most of the PTP implementation is done in the software above the UDP layer. However, the hardware support is required to capture the exact time when specific PTP packets enter or leave the Ethernet port at the MII interface. This timing information must be captured and returned to the software for proper implementation of PTP with high accuracy.

Peer-to-peer PTP transparent clock (P2P TC) message support

The IEEE 1588-2008 standard supports peer-to-peer PTP (Pdelay) message in addition to the Sync, Delay Request, Follow_up, and Delay Response messages. *Figure 996* shows the method to calculate the propagation delay in clocks supporting peer-to-peer path correction.

Figure 996. Propagation delay calculation in clocks supporting peer-to-peer path correction



As shown in *Figure 996*, the propagation delay is calculated as follows:

1. Port 1 issues a Pdelay_Req message and generates a timestamp (t_1) for the Pdelay_Req message.
2. Port 2 receives the Pdelay_Req message and generates a timestamp (t_2) for this message.
3. Port 2 returns a Pdelay_Resp message and generates a timestamp (t_3) for this message.

   To minimize errors caused by frequency offset between the two ports, Port 2 returns the Pdelay_Resp message as quickly as possible after the receipt of the Pdelay_Req message. Port 2 returns any one of the following:

   – Difference between the timestamps t_2 and t_3 in the Pdelay_Resp message
   – Difference between the timestamps t_2 and t_3 in the Pdelay_Resp_Follow_Up message
   – Timestamps t_2 and t_3 in the Pdelay_Resp and Pdelay_Resp_Follow_Up messages, respectively
4. Port 1 generates a timestamp (t_4) on receiving the Pdelay_Resp message.
5. Port 1 uses all four timestamps to compute the mean link delay.

Timestamp correction

According to the IEEE 1588 specifications, a timestamp must be captured when the message timestamp point (leading edge of the first bit of the octet immediately following the Start Frame Delimiter octet) crosses the boundary between the node and the network.

As the MAC takes the timestamp at an internal point far from the actual boundary of the node and network, this captured timestamp is corrected/updated for the ingress/egress path latency (including the delay in the PHY layers). Further correction is done for the inaccuracies/errors introduced due to the clock (MII Tx, Rx clock) being different at the capture point as compared to the PTP clock (clk_ptp_ref_i) that is used to generate the time. The resultant CDC (clock domain crossing) circuits add an error the depends on the clock period of the MII and PTP clocks.

Ingress correction

In the receive side, the timestamp captured at the internal snapshot point is delayed (later in time) as compared to the time at which that packet SFD bit is received at the port boundary. Therefore, the captured timestamp must be reduced by the ingress latency and the errors in CDC sampling. This correction value must be determined/calculated by the software and written into the *Timestamp ingress correction nanosecond register (ETH_MACTSICNR)*.

The correction value consists of the following three components:

1. External latency in the PHY layer between boundary point and the input of the core

   If the PHY is compliant with the IEEE 802.3 Clause 45 MMD registers, it has registers indicating the maximum and minimum ingress latency. The software can read these registers and determine the average ingress latency in the PHY. Alternatively (if the PHY does not support these registers), the ingress latency must be determined from the PHY datasheet or timing characteristics.
2. Internal latency from the input of the core to the internal capture point

   The internal ingress latency can be read from the *Timestamp ingress latency register (ETH_MACTSILR)*. This is a read-only register that gives the latency in scaledNanoseconds format as defined in IEEE 1588 Clause 5.3.2. The latency differs

based on the active PHY interface (such as MII or RMII) and the operating speed. Therefore, the software must read this register after any speed change in the MAC, to determine the current internal latency.

3. CDC synchronization

   The CDC synchronization error is almost equal to twice the clock-period of the PTP clock (clk_ptp_ref_i).

The values determined from these three components should be added by the software and must be written into the TSIC field of the *Timestamp ingress correction nanosecond register (ETH_MACTSICNR)*.

Note: The value written to the register must be negative (two's complement), because it has to be subtracted from the captured timestamp. The MAC receiver adds the value in this register to the captured timestamp and then gives the resultant value as the timestamp of the received packet.

When TSCTRLSSR bit in *Timestamp control register (ETH_MACTSCR)* is set, the nanoseconds field of the captured timestamp is in decimal format with a granularity of 1 ns. So bit 31 of TSIC must be set to 1 (for negative value) and bits 30 to 0 must be programmed with "10^9 – total ingress_correction_value[nanosecond part]" represented in binary. For example, if the required correction value is –5 ns, then the value is 0xBB9A C9FB.

When TSCTRLSSR bit in *Timestamp control register (ETH_MACTSCR)* is reset, the nanoseconds field of the captured timestamp is in binary format with a granularity of ~0.466 ns. Therefore, bits[30:0] must be written with "2^{31} – total ingress_correction_value" represented in binary with bit[31] = 1.

Egress correction

In the Transmit side, the timestamp captured at the internal snapshot point is earlier (advanced in time) as compared to the time at which that packet SFD bit is output at the port boundary. Therefore, the captured timestamp must be compensated by the egress latency and the errors in CDC sampling. This correction value must be determined/calculated by the software and written into the *Timestamp egress correction nanosecond register (ETH_MACTSECNR)*.

The correction value consists of the following three components:

1. External latency in the PHY layer between the output of the core and the boundary of the port and the network

   If the PHY is compliant with the IEEE 802.3 Clause 45 MMD registers, it has registers indicating the maximum and minimum egress latency. The software can read these registers and determine the average egress latency in the PHY. Alternatively (if the PHY does not support these registers), the egress latency must be determined from the PHY datasheet or timing characteristics.

2. Internal latency from the internal capture point and the output of the core

   This internal egress latency can be read from the *Timestamp egress latency register (ETH_MACTSELR)*. This is a read-only register that gives the latency in scaledNanoseconds format as defined in IEEE 1588 Clause 5.3.2. The latency differs based on the active PHY interface and the operating speed. Therefore, the software

must read this register after any speed change in the MAC, to determine the current internal latency.

3. CDC synchronization error

   The timestamp correction because of synchronization is compensated by adding

$$\text{EGRESS_SYNC_CORR} = (1 \times \text{PTP_CLK_PER} + 4 \times \text{TX_CLK_PER})$$

Table 778 lists the egress and ingress latency values for various PHY interfaces:

Table 778. Egress and ingress latency for PHY interfaces

PHY interface		Egress latency	Ingress latency
RMII	100 Mbit/s	40	120
RMII	10 Mbit/s	400	800

Frequency range of reference timing clock

The timestamp information are transferred across asynchronous clock domains, from the MAC clock domain to the application clock domain. Therefore, a minimum delay is required between two consecutive timestamp captures. This delay is four clock cycles of MII and three clock cycles of PTP clocks. If the delay between two timestamp captures is less than this delay, the MAC does not take a timestamp snapshot for the second packet.

The PTP clock frequency limitations are the following:

- Maximum PTP clock frequency

  The maximum PTP clock frequency is limited by the maximum resolution of the reference time (10 ns at 100 MHz). In addition, the resolution or granularity of the reference time source determines the accuracy of the synchronization. Therefore, a higher PTP clock frequency gives better system performance.

- Minimum PTP clock frequency

  The minimum PTP clock frequency depends on the time required between two consecutive SFD bytes and the time taken for synchronizing the time with the MII clock domain. This relationship is given by the following equation:

  3 × PTP clock period + 4 × MII clock period ≤ Minimum gap between two SFDs

  The MII clock frequency is fixed by IEEE specifications. Therefore, the minimum PTP clock frequency required for proper operation depends on the operating mode and operating speed of the MAC as shown in *Table 779*.

Table 779. Minimum PTP clock frequency example

Mode	Minimum gap between two SFDs	Minimum PTP frequency with internal timestamp
10 Mbit/s full-duplex	168 MII clocks (128 clocks for a 64-byte packet + 24 clocks of min IFG + 16 clocks of preamble)	5 MHz
10 Mbit/s half-duplex	48 MII clocks (8 clocks for a JAM pattern sent just after SFD because of collision + 24 IFG + 16 preamble)	5 MHz

Table 779. Minimum PTP clock frequency example (continued)

Mode	Minimum gap between two SFDs	Minimum PTP frequency with internal timestamp
100 Mbit/s full duplex	168 MII clocks (128 clocks for a 64-byte packet + 24 clocks of min IFG + 16 clocks of preamble)	5 MHz
100 Mbit/s half-duplex	48 MII clocks (8 clocks for a JAM pattern sent just after SFD because of collision + 24 IFG + 16 preamble)	5 MHz

PTP processing and control

Table 780 shows the common message header for the PTP messages. This format is taken from the IEEE 1588-2008 specifications.

Table 780. Message format defined in IEEE 1588-2008

Bits								Octet	Offset
7	6	5	4	3	2	1	0		
transportSpecific				messageType				1	0
Reserved				versionPTP				1	1
messageLength								2	2
domainNumber								1	4
Reserved								1	5
flagField								2	6
correctionField								8	8
Reserved								4	16
sourcePortIdentity								10	20
sequenceId								2	30
controlField(1)								1	32
logMessageInterval								1	33

1. The controlField is used in version 1. In version 2, the messageType field is used for detecting different message types.

Some fields of the Ethernet payload can be used to detect the PTP packet type and control the snapshot to be taken. These fields are different for the following PTP packets:

- PTP packets over IPv4
- PTP frames over IPv6
- PTP packets over Ethernet

PTP packets over IPv4

Table 781 provides information about the fields that are matched to control the snapshot for the PTP packets sent over UDP over IPv4 for IEEE 1588 version 1 and 2. The octet positions for the tagged packets are offset by 4. This is based on the IEEE 1588-2008, Annex D and the message format defined in *Table 780*.

Table 781. Message format defined in IEEE 1588-2008

Matched field	Octet position	Matched value	Description
MAC packet type	12, 13	0x0800	IPv4 datagram
IP version and header length	14	0x45	IP version is IPv4
Layer 4 protocol	23	0x11	UDP
IP multicast address (IEEE 1588 version 1)	30, 31, 32, 33	0xE0, 0x00, 0x01, 0x81 (or 0x82 or 0x83 or 0x84)	Multicast IPv4 addresses allowed: 224.0.1.129 224.0.1.130 224.0.1.131 224.0.1.132
IP multicast address (IEEE 1588 version 2)	30, 31, 32, 33	0xE0, 0x00, 0x01, 0x81 (Hex) 0xE0, 0x00, 0x00, 0x6B (Hex)	PTP Primary multicast address: 224.0.1.129 PTP Pdelay multicast address: 224.0.0.107
UDP destination port	36, 37	0x013F, 0x0140	0x013F: PTP event messages(1) 0x0140: PTP general messages
PTP control field (IEEE 1588 version 1)	74	0x00, 0x01, 0x02, 0x03, 0x04	0x00: SYNC 0x01: Delay_Req 0x02: Follow_Up 0x03: Delay_Resp 0x04: Management
PTP message type field (IEEE 1588 version 2)	42 (nibble)	0x0, 0x1, 0x2, 0x3, 0x8, 0x9, 0xB, 0xC, 0xD	0x0: SYNC 0x1: Delay_Req 0x2: Pdelay_Req 0x3: Pdelay_Resp 0x8: Follow_Up 0x9: Delay_Resp 0xA: Pdelay_Resp_Follow_Up 0xB: Announce 0xC: Signaling 0xD: Management
PTP version	43 (nibble)	0x1 or 0x2	0x1: Supports PTP version 1 0x2: Supports PTP version 2

1. PTP event messages are SYNC, Delay_Req (IEEE 1588 version 1 and 2) or Pdelay_Req, Pdelay_Resp (IEEE 1588 version 2 only)

PTP frames over IPv6

Table 782 provides information about the fields that are matched to control the snapshots for the PTP packets sent over UDP over IPv6 for IEEE 1588 version 1 and 2. The octet positions for the tagged packets are offset by 4. This is based on the IEEE 1588-2008, Annex D and the message format defined in *Table 780*.

Table 782. IPv6-UDP PTP packet fields required for control and status

Matched field	Octet position	Matched value	Description
MAC packet type	12, 13	0x86DD	IP datagram
IP version	14 (bits [7:4])	0x6	IP version is IPv6
Layer 4 protocol	20(1)	0x11	UDP
PTP multicast address	38 – 53	FF0x:0:0:0:0:0:0:181 (Hex) FF02:0:0:0:0:0:0:6B (Hex)	PTP primary multicast address: FF0x:0:0:0:0:0:0:0:181 (Hex) PTP Pdelay multicast address: FF02:0:0:0:0:0:0:0:6B (Hex)
UDP destination port	56, 57a	0x013F, 0x140	0x013F: PTP event message 0x0140: PTP general messages
PTP control field (IEEE 1588 version 1)	94a	0x00, 0x01, 0x02, 0x03, or 0x04	0x00: SYNC 0x01: Delay_Req 0x02: Follow_Up 0x03: Delay_Resp 0x04: Management (version1)
PTP message type field (IEEE 1588 version 2)	62a (nibble)	0x0, 0x1, 0x2, 0x3, 0x8, 0x9, 0xB, 0xC, or 0xD	0x0: SYNC 0x1: Delay_Req 0x2: Pdelay_Req 0x3: Pdelay_Resp 0x8: Follow_Up 0x9: Delay_Resp 0xA: Pdelay_Resp_Follow_Up 0xB: Announce 0xC: Signaling 0xD: Management
PTP Version	63 (nibble)	0x1 or 0x2	0x1: Supports PTP version 1 0x2: Supports PTP version 2

1. The Extension header is not defined for PTP packets.

PTP packets over Ethernet

Table 783 provides information about the fields that are matched to control the snapshots for the PTP packets sent over Ethernet for IEEE 1588 version 1 and 2. The octet positions for the tagged packets are offset by 4. This is based on the IEEE 1588-2008, Annex D and the message format.

Table 783. Ethernet PTP packet fields required for control and status

Matched field	Octet position	Matched value	Description
MAC destination multicast address(1)	0–5	01-1B-19-00-00-00 01-80-C2-00-00-0E	All PTP messages can use any of the following multicast addresses(2): 01-1B-19-00-00-00 01-80-C2-00-00-0E(3)
MAC packet type	12, 13	0x88F7	PTP Ethernet packet
PTP control field (IEEE 1588 version 1)	46	0x00, 0x01, 0x02, 0x03, or 0x04	0x00: SYNC 0x01: Delay_Req 0x02: Follow_Up 0x03: Delay_Resp 0x04: Management
PTP message type field (IEEE 1588 version 2)	14 (nibble)	0x0, 0x1, 0x2, 0x3, 0x8, 0x9, 0xB, 0xC, or 0xD	0x0: SYNC 0x1: Delay_Req 0x2: Pdelay_Req 0x3: Pdelay_Resp 0x8: Follow_Up 0x9: Delay_Resp 0xA: Pdelay_Resp_Follow_Up 0xB: Announce 0xC: Signaling 0xD: Management
PTP version	15 (nibble)	0x1 or 0x2	0x1: Supports PTP version 1 0x2: Supports PTP version 2

1. The unicast address match of destination addresses (DA), programmed in MAC address 0 to 31, is used if the TSENMACADDR bit of *Timestamp control register (ETH_MACTSCR)* is set.
2. IEEE 1588-2008, Annex F
3. The MAC does not consider the PTP version 1 messages with Peer delay multicast address (01-80-C2-00-00-0E) as valid PTP messages.

Transmit path functions

The MAC captures a timestamp when the start packet delimiter (SFD) of a packet is sent on the MII interface. The packets, for which a timestamp has to be captured, can be controlled on per-packet basis. Each Transmit packet can be marked to indicate whether a timestamp should be captured for it.

The MAC does not process the transmitted packets to identify the PTP packets. The packets for which a timestamp has to be captured must be specified. The packets can be defined by using the control bits in the transmit descriptor (see *Section 69.10.3: Transmit descriptor*). The MAC returns the timestamp to the software inside the corresponding

Transmit descriptor, thus automatically connecting the timestamp to the specific PTP packet.

The 64-bit timestamp information is written to the TDES0 and TDES1 fields. The TDES0 field holds the 32 least significant bits of the timestamp.

Receive path functions

The MAC can be programmed to capture the timestamp of all packets received on the MII interface or to process packets to identify the valid PTP messages. The snapshot of the time to be sent to the application can be controlled by using the following options of the *Timestamp control register (ETH_MACTSCR)*:

- Enable snapshot for all packets
- Enable snapshot for IEEE 1588 version 1 or version 2 timestamp
- Enable snapshot for PTP packets transmitted directly over Ethernet or UDP-IP-Ethernet
- Enable timestamp snapshot for the received packet for IPv4 or IPv6
- Enable timestamp snapshot only for EVENT messages (SYNC, DELAY_REQ, PDELAY_REQ, or PDELAY_RESP)
- Enable the node to be a master or slave and select the snapshot type

  This feature controls the type of messages for which snapshots are taken.

Note: The peripheral also supports the PTP messages over VLAN packets.

Table 784 indicates the PTP messages for which a snapshot is taken depending on the SNAPTYPSEL field in *Timestamp control register (ETH_MACTSCR)*.

Table 784. Timestamp snapshot dependency on ETH_MACTSCR bits

SNAPTYPSEL	TSMSTRENA	TSEVNTENA	PTP messages
00	X	0	SYNC, Follow_Up, Delay_Req, Delay_Resp
00	0	1	SYNC
00	1	1	Delay_Req
01	X	0	SYNC, Follow_Up, Delay_Req, Delay_Resp, Pdelay_Req, Pdelay_Resp, Pdelay_Resp_Follow_Up
01	0	1	SYNC, Pdelay_Req, Pdelay_Resp
01	1	1	Delay_Req, Pdelay_Req, Pdelay_Resp
10	X	X	SYNC, Delay_Req
11	X	X	Pdelay_Req, Pdelay_Resp

The DMA returns the timestamp to the software application inside the corresponding receive descriptor. The extended status, containing the timestamp message status and the IPC status, is written in the RDES1 normal descriptor and the snapshot of the timestamp is written in RDES0 and RDES1 fields of the context descriptor. The RDES0 field holds the 32 least significant bits of the timestamp.

Programming guidelines for IEEE 1588 timestamping (system time correction)

See *Section : System time correction* in *Section 69.9.9: Programming guidelines for IEEE 1588 timestamping on page 3579*.

IEEE 1588 system time source

To get a snapshot of the time, the MAC requires a reference time in 64-bit format as defined in the IEEE 1588-2002 (80-bit format as defined in the IEEE 1588-2008).

Description of IEEE 1588 system time source

The peripheral uses the reference clock input and uses it to internally generate the Reference time (also called the system time) and capture timestamps.

The timestamp has the following fields:

- UInteger48 seconds field

  The seconds field is the integer portion of the timestamp in units of seconds. It is 48-bit wide. For example, 2.000000001 seconds are represented as seconds Field = 0x0000 0000 0002.
- UInteger32 nanosecondsField

  The nanoseconds field is the fractional portion of the timestamp in units of nanoseconds. For example, 2.000000001 seconds are represented as nanoSeconds = 0x0000 0001.

  The nanoseconds field supports the following two modes:
  - **Digital rollover mode**: In this mode, the maximum value in the nanoseconds field is 0x3B9A C9FF, that is, (10e9-1) nanoseconds.
  - **Binary rollover mode**: In this mode, the nanoseconds field rolls over and increments the seconds field after value 0x7FFF FFFF. Accuracy is ~0.466 ns per bit.

    These modes can be set through TSCTRLSSR bit in *Timestamp control register (ETH_MACTSCR)*.

System time register module

The 64-bit PTP time is updated using the PTP input reference clock, clk_ptp_ref_i. This PTP time is used as a source to take snapshots (timestamps) of the Ethernet frames being transmitted or received at the MII.

The system time counter can be initialized or corrected using either the coarse or the fine correction method.

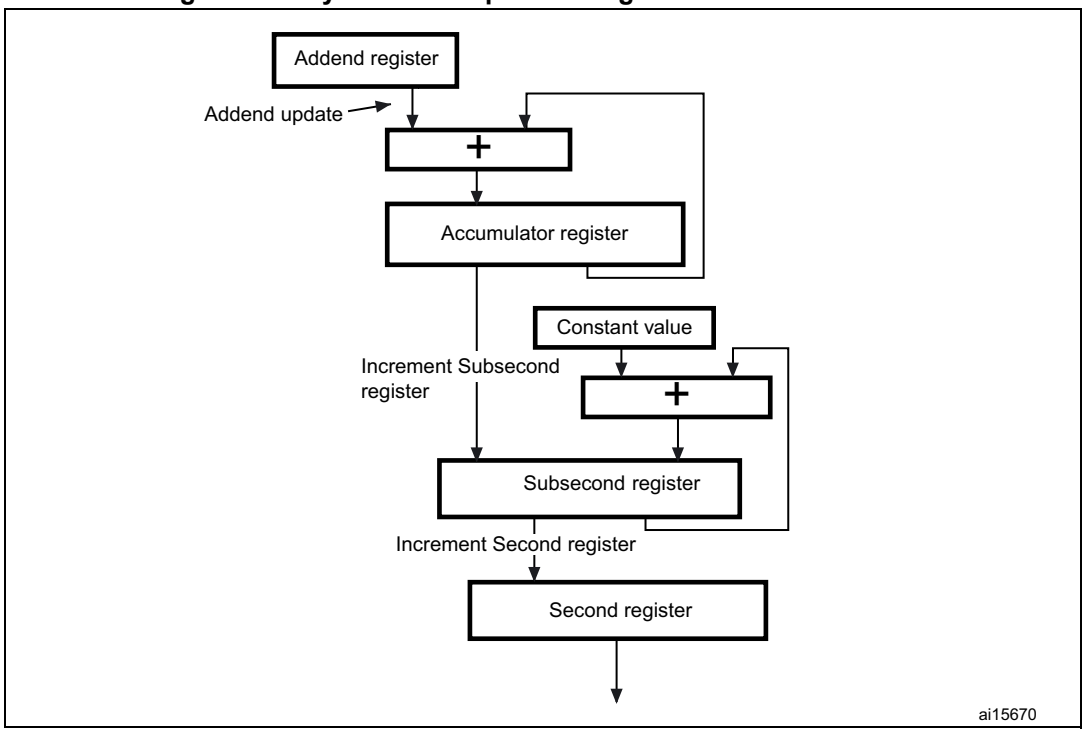
In the coarse correction method, the initial value or the offset value is written to the timestamp update register. For initialization, the system time counter is programmed with the value in the timestamp update registers, whereas for system time correction the offset value (timestamp update register) is added to or subtracted from the system time.

In the fine correction method, the slave clock (reference clock) frequency drift with respect to the master clock (as defined in IEEE 1588-2002 specifications) is corrected over a period of time, unlike in the coarse correction method where it is corrected in a single clock cycle. The longer correction time helps maintain linear time and does not introduce drastic changes (or a large jitter) in the reference time between PTP Sync message intervals. In this method, an accumulator sums up the contents of the Addend register as shown in *Figure 997*. The arithmetic carry that the accumulator generates is used as a pulse to

increment the system time counter. The accumulator and the addend are 32-bit registers. The accumulator acts as a high-precision frequency multiplier or divider.

This system time update algorithm is shown in *Figure 997*.

Figure 997. System time update using fine correction method



The system time update logic requires a 50 MHz clock frequency to achieve 20 ns accuracy. The frequency division is the ratio of the reference clock frequency to the required clock frequency. For example, if the reference clock (clk_ptp_ref_i) is 66 MHz, this ratio is calculated as 66 MHz/50 MHz = 1.32. Therefore, the default addend value to be set in the register is 2^{32} / 1.32, 0xC1F07C1F.

If the reference clock drifts lower, for example, to 65 MHz, the ratio is 65 / 50, that is 1.3 and the value to set in the addend register is 2^{32} / 1.30, or 0xC4EC 4EC4.

If the clock drifts higher, for example to 67 MHz, the addend register must be set to 0xBF0B 7672. When there is not clock drift, the default addend value of 0xC1F0 7C1F (2^{32} / 1.32) must be programmed.

In *Figure 997*, the constant value used to accumulate the subsecond register is decimal 43, which achieves a system time accuracy of 20 ns (in other words, it is incremented in 20 ns steps).

The software must calculate the drift in frequency based on the SYNC messages and accordingly update the Addend register.

Initially, the slave clock is set with FreqCompensationValue0 in the Addend register. This value is as follows:

$$\text{FreqCompensationValue}_0 = 2^{32} / \text{FreqDivisionRatio}$$

If MasterToSlaveDelay is initially assumed to be the same for consecutive Sync messages, the algorithm given in this section must be applied. After a few Sync cycles, frequency lock occurs. The slave clock can then determine a precise MasterToSlaveDelay value and re-synchronize with the master using the new value.

The algorithm is as follows:

1. At time $MasterSyncTime_n$ the master sends the slave clock a SYNC message. The slave receives this message when its local clock is $SlaveClockTime_n$ and computes $MasterClockTime_n$ as follows:

$$MasterClockTime_n = MasterSyncTime_n + MasterToSlaveDelay_n$$

2. The master clock counts for current Sync cycle, $MasterClockCount_n$ is

$$MasterClockCount_n = MasterClockTime_n - MasterClockTime_{n-1}$$

(assuming that MasterToSlaveDelay is the same for Sync cycles n and n – 1)

3. The slave clock count for current Sync cycle, $SlaveClockCount_n$ is

$$SlaveClockCount_n = SlaveClockTime_n - SlaveClockTime_{n-1}$$

4. The difference between master and slave clock counts for current Sync cycle, $ClockDiffCount_n$ is

$$ClockDiffCount_n = MasterClockTime_n - SlaveClockTime_n$$

5. The frequency-scaling factor for slave clock, $FreqScaleFactor_n$ is

$$FreqScaleFactor_n = (MasterClockCount_n + ClockDiffCount_n) / SlaveClockCount_n$$

6. The frequency compensation value for Addend register, $FreqCompensationValue_n$ is

$$FreqCompensationValue_n = FreqScaleFactor_n \times FreqCompensationValue_{n-1}$$

In theory, this algorithm achieves the lock in one Sync cycle. However, it may take several cycles, because of changing network propagation delays and operating conditions. This algorithm is self-correcting. If the slave clock is initially set to an incorrect value by the master, the algorithm corrects it at the cost of additional Sync cycles.

Refer to *Section 69.9.9: Programming guidelines for IEEE 1588 timestamping* for detailed programming steps.

IEEE 1588 auxiliary snapshots

The auxiliary snapshot feature enables to store a snapshot of the system time based on an external event. The event is considered to be the rising edge of the eth_ptp_trgx (where x = 0 to 3) sideband signal.

Up to four auxiliary snapshot inputs can be configured and up to four snapshots can be stored. A FIFO is accessible through registers: *Auxiliary timestamp seconds register (ETH_MACATSSR)* and *Auxiliary timestamp nanoseconds register (ETH_MACATSNR)*.

The snapshots taken for any input are stored in a common FIFO; only 64 bits are kept. The application can read the *Timestamp status register (ETH_MACTSSR)* to know the timestamp of which input is available for reading at the top of this FIFO.

When a snapshot is stored, the MAC indicates this to the application with an interrupt. The value of the snapshot is read through a FIFO register access. If the FIFO becomes full and an external trigger to take the snapshot is asserted, a snapshot trigger-missed status (ATSSTM) is set in the *Timestamp status register (ETH_MACTSSR)*. This indicates that the latest auxiliary snapshot of the timestamp is not stored in the FIFO. The latest snapshot is not written to the FIFO when it is full.

When an application reads the 64-bit timestamp from the FIFO, the space becomes available to store the next snapshot. You can clear a FIFO by setting the ATSFC bit in *Auxiliary control register (ETH_MACACR)*. When multiple snapshots are present in the FIFO, the count is indicated in bits[27:25] of *Timestamp status register (ETH_MACTSSR)*.

Flexible pulse-per-second output

The MAC supports either a fixed pulse-per-second output mode (also called fixed mode) or a flexible pulse-per-second output mode for the ETH_PPS_OUT and eth_ptp_pps_out outputs:

- Fixed pulse-per-second output

  In this mode, only the frequency of the PPS output can be changed by setting the PPSCTRL0 field in the *PPS control register (ETH_MACPPSCR)*.
- Flexible pulse-per-second output

  In this mode, the software has the flexibility to program the start or stop time, width, and interval of the pulse generated on the eth_ptp_pps_out output:

  The start and stop times are programmed through *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*.

  The PPS width and interval are programmed in terms of granularity of system time (number of the units of subsecond increment value) through *PPS width register (ETH_MACPPSWR)* and *PPS interval register (ETH_MACPPSIR)*, respectively.

Note: By default, the peripheral is in Fixed mode and indicates one second interval. When Fixed mode is selected by clearing PPSEN0 to 0 in the PPS control register (ETH_MACPPSCR):

- *the output on all PPS outputs is controlled by the value programmed in the PPSCTRL_PPSCMD field. Independent control of individual PPS output is not supported in Fixed mode.*
- *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR) are used only for generating target time reached interrupt; they are not used for PPS output generation.*
- *TRGTMODSEL0/1/2/3 must be programmed to 0.*
- *the frequency of the PPS output can be changed by setting the PPSCTRL0 field in the PPS control register (ETH_MACPPSCR).*

Description of flexible pulse-per-second (PPS) output

The peripheral supports the following features with the flexible PPS outputs:

- Programming the start or stop time in terms of system time.
- Programming the start point of the single pulse and start and stop points of the pulse train in terms of 64-bit system time. The Target Time registers are used to program the start and stop time.
- Programming the stop time in advance, that is, the stop time can be programmed before the actual start time has elapsed.
- Programming the width between the rising edge and corresponding falling edge of PPS signal output in terms of number of units of subsecond increment value programmed in the *Subsecond increment register (ETH_MACSSIR)*. The pulse width can be programmed from 1 to 232–1 units of subsecond increment value.
- Programming the interval, between the rising edges of PPS signal, in terms of number of units of subsecond increment value. You can program the interval between pulses from 1 to 232–1 units of subsecond increment value.
- Option to cancel the programmed PPS start or stop request.
- Error if the start or stop time being programmed has already elapsed.

Note: The PTP reference clock mentioned in the following sections is the clock at which the system time is updated. When the TSCFUPDT bit of Timestamp control register (ETH_MACTSCR) is set to 0, this clock is similar to the clk_ptp_ref_i clock. In Fine correction mode, this is the clock tick at which the system time is updated (using Subsecond increment register (ETH_MACSSIR) (as shown in Figure 997).

Refer to *Section 69.9.12: Programming guidelines for flexible pulse-per-second (PPS) output* for further details on how configuring flexible pulse output.

PPS start and stop times

The initial start time can be programmed in the Target Time registers.

If required, the start or stop time can be programmed again. However, this can be done only after the earlier programmed value is synchronized with the PTP clock domain. Bit 31 of *PPS target time nanoseconds register (ETH_MACPPSTTNR)* indicates that the synchronization is complete. This enables to program the start or stop time in advance even before the earlier stop or start time has elapsed.

To ensure proper PPS signal output, it is recommended to program advanced system time for the start or stop time. If the application programs a start or stop time that has already elapsed, the MAC sets an error status bit indicating the programming error. If enabled, the MAC also sets the Target Time Reached interrupt event. The application can cancel the start or stop request only if the corresponding start or stop time has not elapsed. If the time has elapsed, the cancel command has no effect.

PPS width and interval

The PPS width and interval are programmed in terms of granularity of system time, that is, number of the units of subsecond increment value. For example, to obtain a PPS pulse width of 40 ns and an interval of 100 ns with a PTP reference clock of 50 MHz, program the width and interval to values 2 and 5, respectively. Smaller granularity can be achieved by using a faster PTP reference clock.

Before giving the command to trigger a pulse or pulse train on the PPS output, program or update the interval and width of the PPS signal output.

PTP timestamp offload function

This feature enables the automatic generation of specific PTP packets to be performed, when the MAC operates as a specific node in the PTP network.

These packets can be generated periodically or triggered by the host software. In other modes, this feature can parse the incoming PTP packets on the receiver, and automatically generate and respond to the required PTP packets. It helps to offload certain PTP node functions with better accuracy and lower response latency.

The PTP offload feature is selected through *PTP offload control register (ETH_MACPOCR)*. 80-bit PTP node identity is configured through the following three registers: *PTP source port identity 0 register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)*.

Description of PTP offload function

Depending on the programmed mode, the MAC generates PTP Ethernet messages periodically or from the application, or based on reception of a particular PTP message. *Table 785* indicates the PTP message generation criteria.

Table 785. PTP message generation criteria

Programming			Mode	Criteria for generation of PTP messages	PTP message type generated
SNAPTYPSEL	TSMSTRENA	TSEVNTENA			
00	0	1	Ordinary or Boundary Slave	SYNC message reception	Delay_Req
00	1	1	Ordinary or Boundary Master	Periodic or on trigger from application	SYNC
				Delay_Req message reception	Delay_Resp
01	0	1	Transparent Slave	Periodic or on trigger from application	Pdelay_Req
				Pdelay_Req message reception	Pdelay_Resp
				SYNC message reception	Delay_Req

Table 785. PTP message generation criteria (continued)

Programming			Mode	Criteria for generation of PTP messages	PTP message type generated
SNAPTYPSEL	TSMSTRENA	TSEVNTENA			
01	1	1	Transparent Master	Periodic or on trigger from application	Pdelay_Req
				Pdelay_Req message reception	Pdelay_Resp
				Periodic or on trigger from application	SYNC
				Delay_Req message reception	Delay_Resp
11	X	X	Peer-to-Peer Transparent	Periodic or on trigger from application	Pdelay_Req
				Pdelay_Req message reception	Pdelay_Resp
All other programming combinations are invalid for the PTP offload feature.					

Note: Clocks supporting peer delay mechanism must not generate delay request/delay response messages, according to IEEE 1588-2008 specifications. However, the peripheral controller supports this for flexibility, with a programmable control bit (DRRDIS) in the PTP offload control register (ETH_MACPOCR).

The DRRDIS bit can be used to control the response generation for delay request/delay response message. For example, in transparent slave mode, delay request is generated in response to received SYNC *only when the bit is reset.*

When the MAC is set as an Ordinary or Boundary Slave clock in the PTP network, it can respond to the reception of SYNC messages with an automatic generation and transmission of the corresponding Delay_Req message. Similarly, various other modes of operation are explained in *Table 785*.

The MAC supports the multicast communication model for the generation of SYNC and Pdelay_Req PTP messages. For instance, the Destination Address field of the generated PTP over Ethernet packet is the defined special multicast addresses (0x011B 1900 0000 for all except peer delay mechanism messages and 0x0180 C200 000E for peer delay mechanism messages).

When the MAC responds to received SYNC, Delay_Req and Pdelay_Req PTP messages with special multicast destination address, it also uses the corresponding special multicast address in the DA field of the automatically generated Delay_Req, Delay_Resp, and Pdelay_Resp PTP messages, respectively.

When the MAC responds to received SYNC, Delay_Req and Pdelay_Req PTP messages with unicast destination address, it takes the SA field of the received packets and makes

them as the DA field of the automatically generated Delay_Req, Delay_Resp, and Pdelay_Resp PTP messages, respectively.

At the same time, all the received PTP messages are forwarded to the application along with Rx status, indicating whether the response was generated by the MAC, if it satisfies the packet filtering logic of the MAC receiver

When the MAC automatically generates a PdelayReq or responds with a Delay_Req, the egress timestamp of these two PTP messages are provided in the Tx TS status (Tx Timestamp Status register and interrupt generated).

In addition to messageType and versionPTP fields match for basic PTP over Ethernet message detection, the following additional fields are matched to qualify the received PTP message type:

1. The domainNumber field is checked for a match against the value programmed in the CSR.
2. The twoStepFlag in flagField field is checked for one-step indication (0b0).
3. The transportSpecific field is checked for Default PTP over Ethernet (0b0000) or 802.1AS mode (0b1111) when enabled.

PTP packet generation

This section explains the format and content of the automatically generated PTP packets by the MAC when this mode is enabled. It provides the template of the common PTP message header, as well as the detailed description of the fields of the specific PTP packets generated.

Table 786. Common PTP message header fields

Bits								Octets	Offset
7	6	5	4	3	2	1	0		
transportSpecific				messageType				1	0
Reserved				versionPTP				1	1
messageLength								2	2
domainNumber								1	4
Reserved								1	5
flagField								2	6
correctionField								8	8
Reserved								4	16
sourcePortIdentity								10	20
sequenceId								2	30
sequenceId								2	30
controlField								1	32
logMessageInterval								1	33

PTP message header fields

- **messageType**

  The following encoded values are used for PTP message types:
  - SYNC: 0000
  - Delay_Req: 0001
  - Pdelay_Req: 0010
  - Pdelay_Resp: 0011
  - Delay_Resp: 1001
- **transportSpecific**

  The following transport protocol encoding is used:
  - Default PTP over Ethernet: 0000
  - 802.1AS mode: 0001
- **versionPTP**

  It is always set to 2 because PTP version 2 is supported.
- **domainNumber**

  This field contains the value from the *PTP offload control register (ETH_MACPOCR)*.
- **flagField**

  The following values are used:
  - alternateMasterFlag (Octet 0 bit 0): 0 for SYNC and Delay_Resp
  - twoStepFlag (Octet 0 bit 1): 0 for SYNC and Pdelay_Resp
  - unicastFlag (Octet 0 bit 2): 0 for Multicast Address, 1 for Unicast Address
- **correctionField**

  For more information, see *Table 787*.
- **sourcePortIdentity**

  This field takes the value programmed in the *PTP source port identity 0 register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)*.
- **sequenceId**

  Pdelay_Resp and Delay_Resp use the same sequenceId field from received Pdelay_Req and Delay_Req PTP messages. For SYNC/Delay_Req, Pdelay_Req, a separate sequenceId counter is maintained. These sequenceId counters get incremented by 1 every time the corresponding message is generated and transmitted.
- **controlField**

  The following encoded values are used for controlField:
  - SYNC: 0000 0000
  - Delay_Req: 0000 0001
  - Pdelay_Req: 0000 0010
  - Pdelay_Resp: 0000 0101
  - Delay_Resp: 0000 0011
- **logMessageInterval**
  - SYNC:

    This field contains logSyncInterval from the corresponding MAC_Log_Message_Interval register.

– Delay_Resp:

This field contains the sum of DRSYNCR and logSyncInterval value taken from the *Log message interval register (ETH_MACLMIR)* for a multicast PTP message and 0111 1111 for unicast PTP message.

– Delay_Req, Pdelay_Req and Pdelay_Resp: 0111 1111

where logSyncInterval = log2 (Mean Value of Interval in seconds)

The MAC supports values of –15 to 15 for logSyncInterval fields, which translates to a range from 32.768 micro second (2–15) to 215 second. For a given value of log sync interval (N), the time interval between two SYNC packets is given by the following:

- $2^{(30+N)}$ ns, when N is negative (–1 to –15)
- 2^{N} seconds, when N is positive (0 to 15)

For example:

- When logSyncInterval is programmed to 1, the interval is 2^{1}; therefore, the SYNC message is sent once every 2 seconds.
- When logSyncInterval is programmed to -1, the interval is 2^{-1} = 0.536 seconds; therefore, the SYNC message is sent once every 536 milliseconds. The value is 0.536 seconds, because 2^{-30} = 1 ns.
- When logSyncInterval is programmed to –-5, the interval is 2^{-5} = 33.55 ms; therefore, the SYNC message is sent once every 33.55 ms.

Note: The MAC uses the PTP system time to generate the intervals for periodic packet transmission. For negative values of log message interval programmed, the generated period may deviate from the value given by the equation $2^{(30+N)}$, because of the non-binary nature of the nanoseconds field of the system time.

PTP message-specific fields

The message-specific fields are the following:

- **messageLength**

  There is no suffix supported, so this field contains the length of the PTP message that includes 34-byte PTP common header and the body specific to the message type.

  For SYNC and Delay_Req packets, this field contains 44, whereas for Delay_Resp, Pdelay_Req and Pdelay_Resp, it contains 54.

- **originTimestamp**

  This field is the captured egress timestamp for SYNC, Delay_Req, and Pdelay_Req PTP messages.

- **receiveTimestamp**

  For Delay_Resp PTP message, this is the ingress timestamp of the corresponding received Delay_Req PTP message.

- **requestingPortIdentity**

  For Delay_Resp and Pdelay_Resp PTP messages, this is the sourcePortIdentity field taken from the corresponding received Delay_Req and Pdelay_Req PTP messages.

- **requestReceiptTimestamp**

  For the Pdelay_Resp PTP message, this field is set to 0.

One-step timestamp

The MAC supports the one-step timestamp feature that enables to identify the offset in the packet and inserts the timestamp received from the application at that offset.

MAC Transmit PTP mode for one-step timestamp

Depending upon the type of message and its mode, the MAC updates the following fields of Transmit PTP packets:

- correctionField in the PTP header of messages
- originTimestamp in SYNC, Delay_Req, and Pdelay_Req messages

Table 787 shows how the PTP mode is selected based on the settings of SNAPTYPSEL, TSMSTRENA, and TSEVNTENA bits of the *Timestamp control register (ETH_MACTSCR)* and the fields that are updated for the incoming PTP packets based on the message type in that mode, during the one-step timestamping operation.

Table 787. MAC transmit PTP mode and one-step timestamping operation

Programming			Mode	Per packet control(1)			Messages processed on transmission
SNAPTYPSEL	TSMSTRENA	TSEVNTENA		TTSE (2)	OSTC (3)	TTS(4)	
X	X	X	N/A	1	X	X	Timestamp is captured and returned to application
X	X	X	N/A	X	0	X	OST operation is not performed (PTP packet is not modified)
00	X	0	End-to-end transparent	0	1	Ingress TS	Sync (correction field for residence time and ingress asymmetric correction)
							Delay_Req (correction field for residence time and egress asymmetric correction)
00	0	1	Ordinary or Boundary Slave	1	1	X	Delay_Req (originTimestamp field) Delay_Req (correction field for egress asymmetric correction)
00	1	1	Ordinary or Boundary Master	0	1	X	Sync (originTimestamp field) Sync (correction field for subnanosecond correction)
01	X	0	End-to-end Transparent with support for peer delay mechanism	0	1	Ingress TS	Sync (correction field for residence time and ingress asymmetric correction)
						Ingress TS	Pdelay_Req (correction field for residence time and egress asymmetric correction)
						Ingress TS	Pdelay_Resp (correction field for residence time and ingress asymmetric correction)

Table 787. MAC transmit PTP mode and one-step timestamping operation (continued)

Programming			Mode	Per packet control[1]			Messages processed on transmission
SNAPTYPSEL	TSMSTRENA	TSEVNTENA		TTSE[2]	OSTC[3]	TTS[4]	
01	0	1	Ordinary or Boundary Slave with support for peer delay mechanism or Peer-to-peer transparent	0	1	Ingress TS	Sync (correction field for residence time and ingress asymmetric correction) (applicable only for Peer to Peer transparent clock operation)
				1	1	X	Delay_Req (originTimestamp field) Delay_Req (correction field for egress asymmetric correction)
				1	1	X	Pdelay_Req (originTimestamp field) Pdelay_Req (correction field for egress asymmetric correction)
				0	1	Ingress TS for Pdelay_Req	Pdelay_Resp (correction field for turnaround time and ingress asymmetric correction)
01	1	1	Ordinary or Boundary Master with support for peer delay mechanism	0	1	X	Sync (originTimestamp field) Sync (correction field for subnanosecond correction)
				1	1	X	Pdelay_Req (originTimestamp field) Pdelay_Req (correction field for egress asymmetric correction)
				0	1	Ingress TS for Pdelay_Req	Pdelay_Resp (correction field for turnaround time and ingress asymmetric correction)
10	X	X	End-to-end transparent	0	1	Ingress TS	Sync (correction field for residence time and ingress asymmetric correction)
						Ingress TS	Delay_Req (correction field for residence time and egress asymmetric correction)

Table 787. MAC transmit PTP mode and one-step timestamping operation (continued)

Programming			Mode	Per packet control(1)			Messages processed on transmission
SNAPTYPSEL	TSMSTRENA	TSEVNTENA		TTSE (2)	OSTC (3)	TTS(4)	
11	X	X	Peer-to-peer transparent	0	1	Ingress TS	Sync (correction field for residence time and ingress asymmetric correction)
				1	1	X	Pdelay_Req (originTimestamp field) Pdelay_Req (correction field for egress asymmetric correction)
				0	1	Ingress TS for Pdelay_Req	Pdelay_Resp (correction field for turnaround time and ingress asymmetric correction)

1. The per-packet control values provided here are the recommended settings used by devices in typical PTP operation and for the programmed mode.
2. TTSE represents TTSE bit of TDES2 transmit normal descriptor. The TTSE function is independent from the OST function and the programmed operation mode for OST. The MAC captures and returns the timestamp when the TTSE bit is set.
3. OSTC represents OSTC bit of TDES3 transmit context descriptor
4. TTS represents the timestamp value provided in the TTSH, TTSL fields of TDES0 and TDES1 transmit normal descriptor (write-back format).

Note: Residence time/ turnaround time is calculated as the difference between the captured timestamp (egress timestamp) and the ingress timestamp. Clocks supporting peer delay mechanism do not use delay request or response, but it is included in OST for flexibility.

Enabling one-step timestamp

The one-step timestamp feature can be enabled for a given packet by setting bit 20 (OSTC) in TDES3 context descriptor. To update the correction field in certain PTP packets, the ingress timestamp must be given in the TSSL and TSSH fields.

The one-step timestamp feature is supported only for the PTP over Ethernet packets. It is not supported for PTP over IPv4/IPv6 packets.

69.5.5 Checksum offload engine

Communication protocols such as TCP and UDP implement checksum fields, which help determine the integrity of data transmitted over a network. The most widespread use of Ethernet is to encapsulate TCP and UDP over IP datagrams. The MAC has a Checksum Offload Engine (COE) to support checksum calculation and insertion in the Transmit path, as well as error detection in the receive path.

Transmit checksum offload engine

In the transmit path, the MAC calculates the checksum and inserts it in the Tx packet. This feature helps reducing the load on the software and can improve the overall system throughput.

The COE module supports two types of checksum calculation and insertion. The checksum engine can be controlled for each packet by setting the CIC bits (TDES3 bits[17:16]).

Note: The checksum for TCP, UDP, or ICMP is calculated over a complete packet, and then inserted into its corresponding header field. Because of this requirement, the Tx FIFO automatically operates in the Store-and-forward mode even if the MAC is configured in Threshold (cut-through) mode.

Make sure that the Tx FIFO is deep enough to store a complete packet before that packet is transferred to the MAC transmitter, the reason being that when space is not available to accept the programmed burst length of data, then the MTL Tx FIFO starts reading to avoid deadlock. In such a case, the COE fails as the start of the packet header is read out before the payload checksum can be calculated and inserted. Therefore, the checksum insertion must be enabled only in the packets that are less than the number of bytes, given by the following equation:

$$\text{Packet size} < \text{TxQSize} - (\text{PBL} + 7) \times 4$$

where

TxQSize corresponds to the TQS bitfield of *Tx queue operating mode register (ETH_MTLTXQOMR)*

PBL corresponds to the TxPBL bitfield of *Channel transmit control register (ETH_DMACTXCR)*

Refer to IETF specifications RFC 791, RFC 793, RFC 768, RFC 792, RFC 2460, and RFC 4443 for IPv4, TCP, UDP, ICMP, IPv6, and ICMPv6 packet header specifications, respectively.

IP header checksum engine

In IPv4 datagrams, the integrity of the header fields is indicated by the 16-bit Header Checksum field (the eleventh and twelfth bytes of the IPv4 datagram). The COE detects an IPv4 datagram when the Type field of Ethernet packet has the value 0x0800 and the Version field of IP datagram has the value 0x4. The checksum field of the input packet is ignored during calculation and replaced with the calculated value.

Note: IPv6 headers do not have a checksum field. Therefore, the COE does not modify the IPv6 header fields.

The result of this IP header checksum calculation is indicated by the IP Header Error status it in the Transmit status (bit 0 in *Table 809: TDES3 normal descriptor (write-back format)*).

This status bit is set whenever the values of the Ethernet Type field and the Version field of IP header are not consistent, or when the Ethernet packet does not have enough data, as indicated by the IP header Length field. In other words, this bit is set when an IP header error is asserted under the following circumstances:

- For IPv4 datagrams:
  - The received Ethernet type is 0x0800, but the Version field of IP header is not equal to 0x4.
  - The IPv4 Header Length field indicates a value less than 0x5 (20 bytes).
  - The total packet length is less than the value given in the IPv4 Header Length field.

- For IPv6 datagrams:
  - The Ethernet type is 0x86DD but the IP header Version field is not equal to 0x6.
  - The packet ends before the IPv6 header (40 bytes) or extension header (as given in the corresponding Header Length field in an extension header) is completely received.

TCP/UDP/ICMP checksum engine

The TCP/UDP/ICMP Checksum Engine processes the IPv4 or IPv6 header (including extension headers) and determines whether the encapsulated payload is TCP, UDP, or ICMP. The checksum is calculated for the TCP, UDP, or ICMP payload and inserted into its corresponding field in the header. The Tx COE can work in the following two modes:

- The TCP, UDP, or ICMPv6 pseudo-header is not included in the checksum calculation and is assumed to be present in the Checksum field of the input packet. This engine includes the Checksum field in the checksum calculation, and then replaces the Checksum field with the final calculated checksum.
- The engine ignores the Checksum field, includes the TCP, UDP, or ICMPv6 pseudo-header data into the checksum calculation, and overwrites the checksum field with the final calculated value.

Note: For ICMP-over-IPv4 packets, the Checksum field in the ICMP packet must always be 0x0000 in both modes, because pseudo-headers are not defined for such packets. If it does not equal 0x0000, an incorrect checksum may be inserted into the packet.

The result of this operation is indicated by the Payload Checksum Error status bit in the Transmit Status vector (bit 12 in *Table 809: TDES3 normal descriptor (write-back format)*). This engine sets the Payload Checksum Error status bit when it detects that the packet has been forwarded to the MAC transmitter engine in the store-and-forward mode without the end of packet (EOP) being written to the FIFO, or when the packet ends before the number of bytes indicated by the Payload Length field in the IP Header is received. When the packet is longer than the indicated payload length, the COE ignores them as stuff bytes, and no error is reported. When this engine detects the first type of error, it does not modify the TCP, UDP, or ICMP header. For the second error type, it still inserts the calculated checksum into the corresponding header field.

Table 788 describes the functions supported by Transmit Checksum Offload engine based on the packet type. When the MAC does not insert the checksum, it is indicated as “No” in the table.

Note: Do not enable checksum insertion for IPv4 or IPv6 packets that are greater than the frame size constraint specified in Section : Transmit checksum offload engine because it might result in incorrect checksum insertion or unexpected behavior.

Table 788. Transmit checksum offload engine functions for different packet types

Packet type	Hardware IP header checksum insertion	Hardware TCP/UDP checksum insertion
Non-IPv4 or IPv6 packet	No	No
IPv4 packet is greater than 1,522 bytes (2,000 bytes when IEEE 802.3ad support for 2K packets is enabled in the MAC) but less than or equal to the frame size constraint specified in *Section : Transmit checksum offload engine*.	Yes	Yes

Table 788. Transmit checksum offload engine functions for different packet types (continued)

Packet type	Hardware IP header checksum insertion	Hardware TCP/UDP checksum insertion
IPv6 packet is greater than 1,522 bytes (2,000 bytes when IEEE 802.3ad support for 2K packets is enabled in MAC) but less than or equal to the frame size constraint specified in *Section : Transmit checksum offload engine*.	Not applicable	Yes
IPv4 with TCP, UDP, or ICMP	Yes	Yes
IPv4 packet has IP options (IP header is longer than 20 bytes)	Yes	Yes
Packet is an IPv4 fragment	Yes	No
IPv6 packet with the following next header fields in main or extension headers: – Hop-by-hop options (in IPv6 main header) – Hop-by-hop options (in IPv6 extension header) – Destinations options – Routing (with segment left 0) – Routing (with segment left > 0) – TCP, UDP, or ICMP – Authentication – Any other next header field in main or extension headers	 – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable	 – Yes – No – Yes – No – No – Yes – No – No
IPv4 packet has TCP header with Options fields	Yes	Yes
IPv4 Tunnels: – IPv4 packet in an IPv4 tunnel – IPv6 packet in an IPv4 tunnel	 – Yes (IPv4 tunnel header) – Yes (IPv4 tunnel header)	 – No – No
IPv6 Tunnels: – IPv4 packet in an IPv6 tunnel – IPv6 packet in an IPv6 tunnel	 – Not applicable – Not applicable	 – No – No
IPv4 packet has 802.3ac tag (with C-VLAN tag or S-VLAN Tag when enabled).	Yes	Yes
IPv6 packet has 802.3ac tag (with C-VLAN tag or S-VLAN Tag when enabled).	Not applicable	Yes
IPv4 frames with security features (such as encapsulated security payload)	Yes	No
IPv6 frames with security features (such as encapsulated security payload)	Not applicable	No

Receive checksum offload engine

The receive checksum offload engine is used to detect errors in IP packets by calculating the header checksum and further matching it with the received header checksum. This engine also identifies a TCP, UDP, or ICMP payload in received IP packets and calculates the checksum of such payloads appropriately.

The receive checksum offload engine (Rx COE) can be enabled by setting the IPC bit of *Operating mode configuration register (ETH_MACCR)*. When this bit is set, both IPv4 and IPv6 packet in the received Ethernet packets are detected and processed for data integrity. The MAC receiver identifies IPv4 or IPv6 packets by checking for value 0x0800 or 0x86DD, respectively, in the Type field of the received Ethernet packet. This identification is applicable to single VLAN-tagged packets. It is also applicable to double VLAN-tagged packets when the EDVLP bit of the *VLAN tag register (ETH_MACVTR)* is set.

The Rx COE calculates the IPv4 header checksums and checks that they match the received IPv4 header checksums. The result of this operation (pass or fail) is given to the RFC module for insertion into the receive status word. The IP Header Error bit is set for any mismatch between the indicated payload type (Ethernet Type field) and the IP header version, or when the received packet does not have enough bytes, as indicated by the Length field of the IPv4 header (or when fewer than 20 bytes are available in an IPv4 or IPv6 header).

Packets with TCP/IP errors (header or payload) are dropped in MTL when DIS_TCP_EF bit of the *Rx queue operating mode register (ETH_MTLRXQOMR)* is reset and FEP bit is set.

This engine also identifies a TCP, UDP, or ICMP payload in the received IP datagrams (IPv4 or IPv6) and calculates the checksum of such payloads properly, as defined in the TCP, UDP, or ICMP specifications. This engine includes the TCP, UDP, or ICMPv6 pseudo-header bytes for checksum calculation and checks whether the received checksum field matches the calculated value. The result of this operation is given as a Payload Checksum Error bit in the receive status word. This status bit is also set if the length of the TCP, UDP, or ICMP payload does not match the expected payload length given in the IP header.

Table 789: Receive checksum offload engine functions for different packet types describes the functions supported by the Rx COE based on the packet type. When the payload of an IP packet is not processed (indicated as "No" in the table), the information (whether the checksum engine is bypassed or not) is given in the receive status.

Note: The MAC does not append any payload checksum bytes to the received Ethernet packets.

Table 789. Receive checksum offload engine functions for different packet types

Packet type	Hardware IP header checksum checking	Hardware TCP/UDP/ICMP checksum checking
Non-IPv4 or IPv6	No	No
IPv4 packet is greater than 1,522 bytes (2,000 bytes when IEEE 802.3ad support for 2K packets is enabled in the MAC)	Yes	Yes
IPv6 packet is greater than 1,522 bytes (2,000 bytes when IEEE 802.3ad Support for 2K packets is enabled in the MAC)	Not applicable	Yes
IPv4 with TCP, UDP, or ICMP	Yes	Yes
IPv4 header's protocol field contains a protocol other than TCP, UDP, or ICMP	Yes	No
IPv4 packet has IP options (IP header is longer than 20 bytes)	Yes	Yes
Packet is an IPv4 fragment	Yes	No
IPv6 packet with the following next header fields in main or extension headers: – Hop-by-hop options (in IPv6 main header) – Hop-by-hop options (in IPv6 extension header) – Destinations options – Routing (with segment left 0) – Routing (with segment left > 0) – TCP, UDP, or ICMP – Any other next header field in main or extension headers	 – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable	 – Yes – No – Yes – Yes – No – Yes – No
IPv4 packet has TCP header with Options fields	Yes	Yes
IPv4 Tunnels: – IPv4 packet in an IPv4 tunnel – IPv6 packet in an IPv4 tunnel	 – Yes (IPv4 tunnel header) – Yes (IPv4 tunnel header)	 – No – No
IPv6 Tunnels: – IPv4 packet in an IPv6 tunnel – IPv6 packet in an IPv6 tunnel	 – Not applicable – Not applicable	 – No – No
IPv4 packet has 802.3ac tag (with C-VLAN Tag or S-VLAN Tag when enabled).	Yes	Yes
IPv6 packet has 802.3ac tag (with C-VLAN Tag or S-VLAN Tag when enabled).	Not applicable	Yes
IPv4 frames with security features (such as encapsulated security payload)	Yes	No
IPv6 frames with security features (such as encapsulated security payload)	Not applicable	No

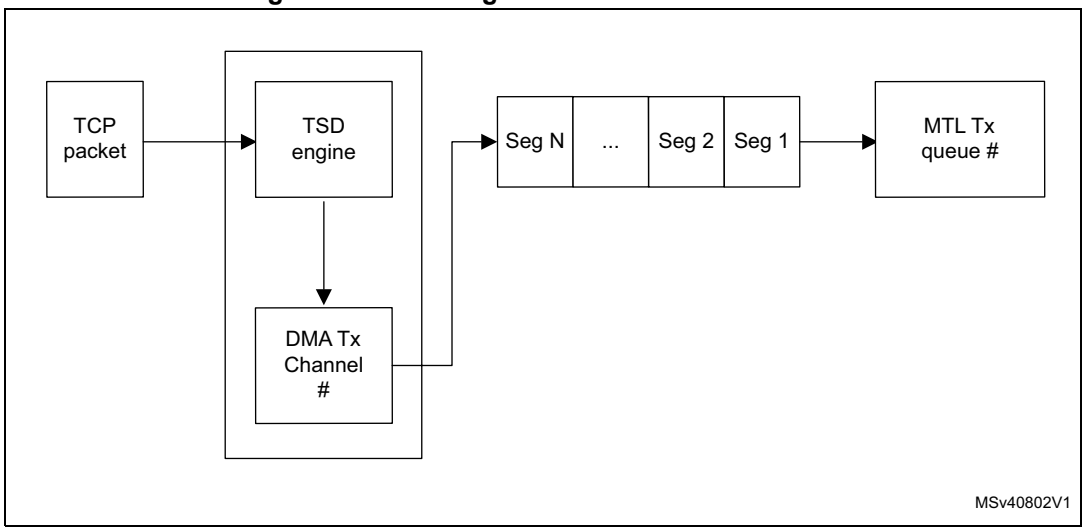
69.5.6 TCP segmentation offload

The MAC supports the TCP segmentation offload (TSO) feature in which the DMA splits a large TCP packet into multiple small packets and passes these packets to the MTL as shown in *Figure 998*.

This feature is enabled by programming the TSE bit of corresponding ETH_DMACTXCR register (see *Channel transmit control register (ETH_DMACTXCR)*). It is only supported when the MAC operates in Full-duplex mode.

For detailed programming steps, refer to *Section 69.9.14: Programming guidelines for TSO*.

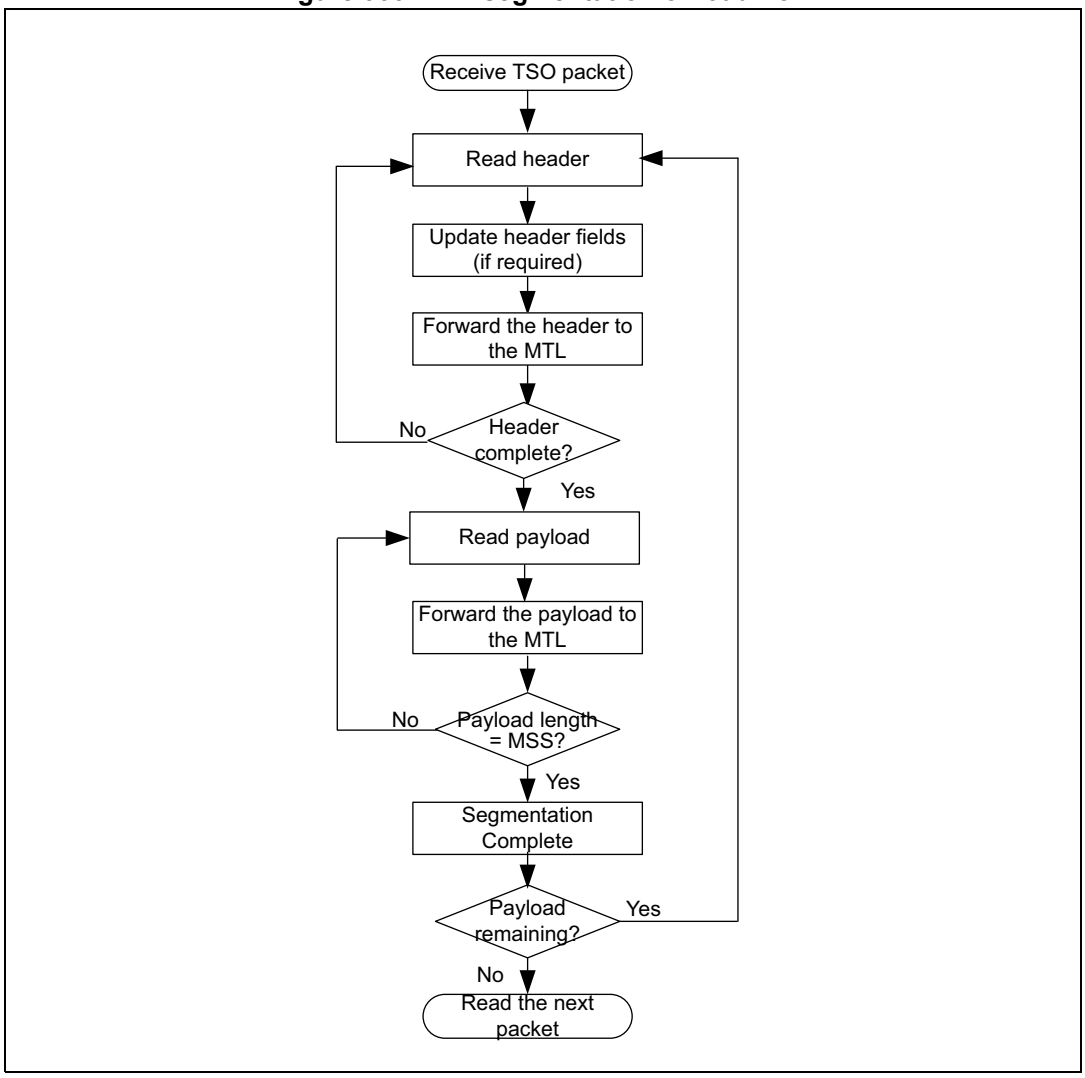
Figure 998. TCP segmentation offload overview



DMA operation with TSO feature

Figure 999 shows the TSO flow.

Figure 999. TCP segmentation offload flow



For the TSO feature, the Tx DMA operation is as follows:

1. The application sets up the Transmit descriptor (TDES0-TDES3) and sets the Own bit (TDES3[31]) after setting up the corresponding data buffer(s) with Ethernet packet data.
2. The application increases the offset value of the descriptor tail pointer of the DMA Tx channel.
3. While in the Run state, the DMA fetches the next available descriptor and performs one of the following actions:
   - If the descriptor is a context descriptor and the context is not between the first and last descriptors of a packet, the DMA stores the context values.
   - If the descriptor is a context descriptor and the context is between the first and last descriptors of a packet, the DMA closes the context descriptor indicating a Context Descriptor Error (TDES3[23]) and fetches the next descriptor.

– If the descriptor is a normal descriptor, the DMA checks the TSE bit. If the TSE bit is not set, the DMA continues with the default mode of operation or OSF operation (if enabled).

4. The DMA calculates the number of segments from the TCP payload length (TDES3[17:0]) and the MSS value.
5. The DMA goes through channel arbitration to fetch the data buffers. The DMA fetches the header and payload separately.
6. For the first segment, the DMA fetches the header from the system memory and stores it in the TSO memory (if present and when the length of header is not greater than the TSO memory size). If the current segmented packet is not the first segment, it fetches again the header buffer in system memory, as done for the first segment. In such cases, the DMA does not close the first descriptor containing the header buffer until the header for last segment is fetched.
7. The required fields in the header bytes are modified/updated as per the segmentation requirements and written into the corresponding MTL Tx queue.
8. The DMA then takes the payload buffer pointer, fetches the MSS number of payload bytes from the system memory, and directly pushes it into the MTL Tx queue. If the buffer(s) in the descriptor do(es) not have enough data for the MSS payload (except for the last segment), the DMA closes this descriptor.
9. The DMA jumps to Step 3 and repeats the process until the last segment is written into the Tx queue.
10. The DMA closes the last descriptor and the first descriptor (containing the header buffer when it is not stored in TSO memory), and then moves on to the next packet transfer.

The DMA repeats all these steps if more descriptors are available. When no more descriptor are available, the DMA enters the suspend state.

Note: The TSO engine determines whether to perform TSO or USO operation based on the THL field (TCP Header Length) in TDES3 of first Normal Tx descriptor for the packet. The value of 2 indicates USO and any value greater than or equal to 5 indicates TSO.

TCP/IP header fields

While segmenting a TCP packet, the DMA automatically updates the TCP/IP header fields. *Table 790* describes how the TCP and IP headers are updated.

Table 790. TSO: TCP and IP header fields

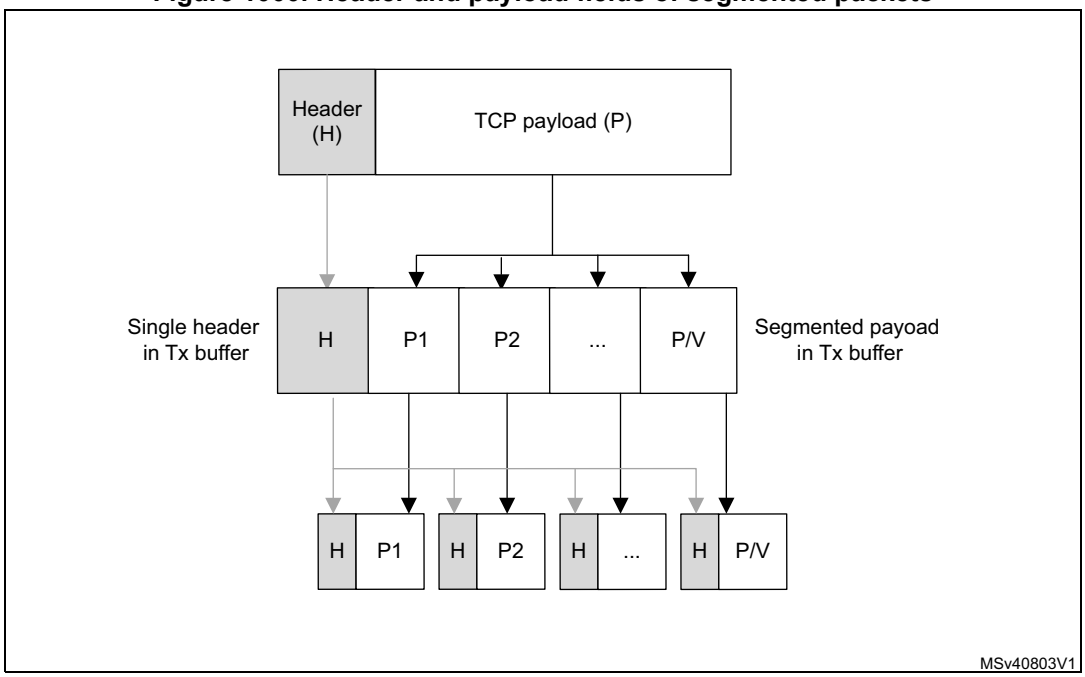
Packet sequence	TCP header	IP header
First packet	1. The sequence number is not updated. The value provided in the header is used. 2. If set, the FIN and PSH flags are cleared. 3. The TCP checksum is calculated again.	IPv4 Header – Total Length = MSS + TCP Header Length + IP Header Length – Identification field is not modified. It is sent as per the header provided by the software. – IPv4 Header Checksum is recalculated. IPv6 Header – Payload Length = MSS + TCP Header Length + IP Extension Header Length
Subsequent packets	1. The sequence number is updated. The MSS value is added to the sequence number value of previous segment. 2. If set, the FIN and PSH flags are cleared. 3. The TCP checksum is calculated again.	IPv4 Header – Total Length = MSS + TCP Header Length + IP Header Length – Identification field = Previous Identification Field + 1 – IPv4 Header Checksum is recalculated IPv6 Header – Payload Length = MSS + TCP Header Length + IP Extension Header Length
Last packet	1. The sequence number is updated. The MSS value is added to the sequence number value of previous segment. 2. If FIN and PSH flags were set in original header, these flags are set. 3. The TCP checksum is calculated again.	IPv4 Header – Total Length = Remaining Payload + TCP Header Length + IP Header Length – Identification Field = Previous Identification Field + 1 – IPv4 header Checksum is recalculated IPv6 Header – Payload Length = Remaining Payload Length + TCP Header Length + IP Extension Header Length

Header and payload fields of segmented packets

After segmentation, the split packets use the same header as the parent TCP packet for header fields other than the ones described in *Table 790: TSO: TCP and IP header fields*. *Figure 1000: Header and payload fields of segmented packets* shows how same header is used for the header fields of segmented packets.

The application must create the header in Buffer 1 of the first descriptor of the packet to be segmented and provide the header length in TDES2 of the first descriptor (FD = 1). When the FD bit is set, the DMA reads the header from the header buffer to which the TDES0 is pointing. Buffer 2 of the first descriptor can be used for payload and TDES0 and TDES1 of subsequent descriptors. For subsequent descriptors (FD = 0), the address to which the TDES0 and TDES1 are pointing is treated as payload buffer address of the same packet.

Figure 1000. Header and payload fields of segmented packets



Context descriptor sequence

The context descriptor can provide the maximum segment size (MSS) value for segmentation. The application must provide the context descriptor before the normal descriptor to be used for the corresponding TCP packet. If the application needs to provide a new MSS, it must create the context descriptor in the descriptor list before the first normal descriptor of the packet to be segmented with the new MSS value. The MSS value in the context descriptor is valid only if the TCMSSV bit of TDES3 in context descriptor is set and the OSTC bit is reset (refer to *Section 69.10.3: Transmit descriptor*).

When the application provides a context descriptor with a valid MSS value, the DMA internally stores the MSS value and uses this value for all subsequent packets for which the TSO is enabled through the TSE bit of TDES3 normal descriptor.

If the application places a context descriptor in the middle of a packet (between the first and last descriptors of a packet), the DMA does the following:

1. The DMA ignores the context and closes the descriptor.
2. The DMA indicates the error in descriptor status.
3. The DMA generates an interrupt if the CDEE bit is set in the Interrupt enable register corresponding to a DMA channel (see *Channel interrupt enable register (ETH_DMACIER)*).

The application can read the interrupt status through CDE bit of Status register corresponding to a DMA channel (see *Channel status register (ETH_DMACSR)*).

Building the Descriptor and the packet for the TSO feature

To enable segmentation for a packet, the application must set the TSE bit of TDES3 of first normal descriptor (see *Section 69.10.3: Transmit descriptor*). If the TSE bit is set in TDES3 for a non TCP/IP packet, the DMA behavior is unpredictable.

The application must program the length of the TCP packet payload in TDES3[17:0] and the TCP header in TDES3[22:19]. The maximum length of TCP packet payload that can be segmented is 256 Kbytes.

The header of the packet including Ethernet header, L3 header and L4 header should be provided in Buffer1 of the first normal descriptor of the TSO packet. Only buffer 1 of the first normal descriptor of a packet enabled for TSO is taken as the buffer containing the header.

The TCP payload can begin from buffer 2 of the first normal descriptor and continue to buffer1 and buffer 2 of second normal descriptor and subsequent descriptors.

The TCP payload may span across multiple buffers and multiple descriptors. The size of buffers containing the TCP payload should add up to be equal to the TCP payload length provided in TDES3[17:0] of the first normal descriptor.

The MAC always calculates and appends CRC and inserts Padding (if required) for all packets segmented by the DMA. If the TSE bit of TDES3 is enabled, the CRC PAD Control (CPC) field of TDES3 is reserved. To determine the size of a TCP packet after segmentation, the DMA uses the Maximum Segment Size (MSS) provided by the application through context descriptor. The DMA segments only those packets which have payload size greater than MSS. The application must provide the MSS by either programming the MSS value in ETH_DMACCR (see *Channel control register (ETH_DMACCR)*) or by providing a context descriptor. The DMA uses the last programmed value of MSS or the last MSS value provided through context (whichever is provided later).

The header length plus the MSS size (which is equal to the size of each TCP segment) should not exceed 16383 bytes otherwise the MAC transmitter truncates the packet after 16383 bytes causing a CRC error.

The header length plus MSS size plus programmed PBL value in ETH_DMACTXCR register (see *Channel transmit control register (ETH_DMACTXCR)*) should be lesser than the Tx queue size programmed in TQS field of ETH_MTLTXQOMR register (see *Tx queue operating mode register (ETH_MTLTXQOMR)*). A MSS plus header equal to half the programmed Tx queue size is recommended.

The DMA also supports segmentation of VLAN-tagged TCP/IP frames. If the TCP packet has a VLAN tag, then the same tag is used for all the segments irrespective of the VLAN tag type provided (C-VLAN or S-VLAN). The VLAN tag insert/replace control bits are used for all segments.

If the Double VLAN feature is selected, then the DMA passes both tags for all segments irrespective of the VLAN tag types provided (C-VLAN or S-VLAN). The VLAN tag Insert/Replace control bits for both tags is applicable to all segments. If the Double VLAN feature is not selected, then the application must not set the TSE bit in TDES3 for a TCP/IP packet with two tags. The DMA behavior in this scenario is unpredictable.

If the TSE bit is set in TDES3 for the packet and TCP header length provided is less than 5 (meaning this is an invalid TCP header because it is less than 20 bytes), the DMA does not perform segmentation, instead it transmits the entire packet as a single packet. In this scenario, the CRC pad control bits are forced by DMA to 00 (MAC does CRC and padding) and checksum insertion control bits are forced to 11 (hardware does the checksum calculation for both header and payload).

69.5.7 IPv4 ARP offload

The MAC supports the Address Recognition Protocol (ARP) Offload for IPv4 packets. This feature allows to process the IPv4 ARP request packet in the receive path and to generate the corresponding ARP response packet in the transmit path.

The MAC generates the ARP reply packets for appropriate ARP request packets**.** ARP packets for IPv4 are L2 layer packets with Length/Type of 0x0806.

The ARP offloading sequence is as follows:

1. The MAC receiver gets an ARP request if the request Target Protocol Address matches the IPv4 address programmed in the MAC L3 register.
2. The MAC generates an ARP reply packet.
3. The MAC copies the Sender Hardware Address field in the ARP request to the following fields:
   – DA field of the Ethernet packet header
   – Target Hardware Address field of the ARP reply packet
4. The MAC copies the Sender Protocol Address field in the ARP request to the Target Protocol Address field in the ARP reply packet.
5. The MAC places its MAC address in the following fields:
   – SA field of the Ethernet packet header
   – Sender Hardware Address field of the ARP reply packet
6. The MAC copies the Target Protocol Address field in the ARP request to the Sender Protocol Address field in the ARP reply packet.
7. The MAC sets the opcode field in ARP reply packet to 2 indicating ARP reply.
8. The MAC recalculates the CRC and performs padding for the generated ARP reply packet.
9. The MAC transmitter sends the ARP reply

The MAC processes only one ARP request at a time. It does not store the fields of multiple ARP requests. If the MAC receives an ARP request when it is already processing an earlier ARP request, the MAC does not generate the ARP reply for new ARP request. The MAC forwards the new ARP request packet to the application with ARP Reply Not Generated status bit set (bit 34). However, in power-down mode, if the MAC receives an ARP request when it is already processing an earlier ARP request, the MAC drops the new ARP request. If the Disable CRC check (DCRCC) bit of the *Extended operating mode configuration register (ETH_MACECR)* is set, then the MAC does not check for valid CRC of a ARP

request packet. It can generate an ARP response packet if the other conditions are valid. The ARP request packet must always have a valid CRC.

Note: When the received ARP request is less than the 64-byte packet length, the MAC does not send an ARP response. It is treated as a normal packet and forwarded to the application based on the MAC filter settings.

69.5.8 Loopback

The MAC supports loopback of transmitted packets to its receiver.

Guidelines for using loopback mode

Below some guidelines for using the loopback mode:

- Enable loopback only with the Full-duplex mode. In Half-duplex mode, the carrier sense signal or collision signal inputs get sampled which may result into issues such as packet dropping.
- If the loopback mode is enabled without connecting a PHY chip, externally generate the Tx and Rx clocks and provide these clocks to the MAC.
- Do not loop back big packets since they may get corrupted in the loopback FIFO.

The transmit and receive clocks can have an asynchronous timing relationship. Therefore, an asynchronous FIFO is used to make the loopback path of the transmitted data to the receive path. The FIFO is free-running to write on the write clock (eth_tx_clk) and read on every read clock (eth_rx_clk). At the start of each packet read from the FIFO, the write and read pointers are reinitialized to have an offset of four (in 10/100 Mbit/s mode). This avoids overflow or underflow during a packet transfer, and ensures that the overflow or underflow occurs only during the IPG period between the packets. The FIFO depth of five or nine is sufficient to prevent data corruption for packet sizes up to 9,022 bytes with a difference of 200 ppm between MII transmit and receive clock frequencies.

Therefore, bigger packets should not be looped back because they may get corrupted in this loopback FIFO.

At the end of every received packet, the receive Protocol Engine module generates received packet status and sends it to the receive Packet Controller module. The control, missed packet, and filter fail status are added to the receive status in the receive Packet Controller module. The MAC does not process ARP or PMT packets that are looped back.

Enabling loopback mode

To enable this feature, program the LM bit of the *Operating mode configuration register (ETH_MACCR)*. Loopback can be enabled for all PHY interfaces. The data is always looped back through internal asynchronous FIFO on to the internal receive MII interface, irrespective of which PHY interface is selected.

The loopback data is also passed through the corresponding transmit PHY interface block, onto the Ethernet line.

Note: During loopback, the data/packet is reflected on the mii_txd signal.

69.5.9 Flow control

The transmit flow control involves transmitting Pause packets in Full-duplex mode and back-pressure in Half-duplex mode to control the flow of packets from the remote end. This section describes the flow control for transmit and receive paths.

Flow control in Full-duplex mode

In Full-duplex mode, the MAC uses IEEE 802.3x Pause packets for flow control. *Table 791* describes the fields of a Pause packet.

Table 791. Pause packet fields

Field	Description
DA	Contains the special multicast address
SA	Contains the MAC address 0
Type	Contains 8808
MAC Control opcode	Contains 0001 for IEEE 802.3x Pause Control packets
PT	Contains Pause time specified in the PT field of the *Tx Queue flow control register (ETH_MACQTXFCR)*

When the FCB bit is set, the MAC generates and transmits a single Pause packet. If the FCB bit is set again after the Pause packet transmission is complete, the MAC sends another Pause packet irrespective of whether the pause time is complete or not. To extend the pause or terminate the pause prior to the time specified in the previously-transmitted Pause packet, the application should program the Pause Time register with appropriate value and then again set the FCB bit.

Flow control in Half-duplex mode

In Half-duplex mode, the MAC uses the deferral mechanism for the flow control (backpressure). When the application requests to stop receiving packets, the MAC sends a JAM pattern of 32 bytes when it senses a packet reception, provided the transmit flow control is enabled. This results in a collision and the remote station backs off. If the application requests a packet to be transmitted, it is scheduled and transmitted even when the backpressure is activated. If the backpressure is kept activated for a long time (and more than 16 consecutive collision events occur), the remote stations abort the transmission because of excessive collisions.

Table 792 describes the flow control in the Tx path based on the setting of the following bits:

- TFE bit of *Tx Queue flow control register (ETH_MACQTXFCR)*
- DM bit of *Operating mode configuration register (ETH_MACCR)*

Flow control is similar for all queues.

Table 792. Tx MAC flow control

TFE	DM	Description
0	X	The MAC transmitter does not perform the flow control or backpressure operation.
1	0	The MAC transmitter performs backpressure when Bit 0 of *Tx Queue flow control register (ETH_MACQTXFCR)* is set.
1	1	The MAC transmitter sends the Pause packet when Bit 0 of *Tx Queue flow control register (ETH_MACQTXFCR)* is set.

Transmit flow control

The transmit flow control is enabled when TFE bit is set in *Tx Queue flow control register (ETH_MACQTXFCR)*.

Flow control trigger

The application can request the MAC to send a Pause packet or initiate back-pressure by setting the FCB bit in the corresponding *Tx Queue flow control register (ETH_MACQTX-FCR)*.

Receive flow control

In the receive path, the flow control is functional only in full-duplex mode. If any Pause packet is received in half-duplex mode, the packet is considered as a normal control packet.

Description of receive flow control

Table 793 describes the flow control in the Rx path based on the setting of the following bits:

- RFE bit of *Rx flow control register (ETH_MACRXFCR)*
- DM bit of *Operating mode configuration register (ETH_MACCR)*

Table 793. Rx MAC flow control

RFE	DM	Description
0	x	The MAC receiver does not detect the received Pause packets.
1	0	The MAC receiver does not detect the received Pause packets but recognizes such packets as Control packets.
1	1	The MAC receiver detects or processes the Pause packets and responds to such packets by stopping the MAC transmitter.

The following sequence describes the Rx flow control:

1. The MAC checks the destination address (DA) of the received Pause packet for either of the following:
   - Multicast destination address: the DA matches the unique multicast address specified for the control packet (0x0180 C200 0001).
   - Unicast destination address: the DA matches the content of the MAC Address 0 registers (*MAC address 0 high register (ETH_MACA0HR)* and *MAC address x low register (ETH_MACAxLR)*) and the UP bit of *Rx flow control register (ETH_MACRXFCR)* is set.

If the UP bit is set, the MAC processes Pause packets with unicast destination address in addition to the unique multicast address.

2. The MAC decodes the following fields of the received packet:
   - Type field: this field is checked for 0x8808.
   - Opcode field: this field is checked for 0x0001 (Pause packet).
   - Pause time: the Pause time (for Pause packet) is captured to determine the time for which the transmitter needs to be blocked.
3. If the byte count of the status indicates 64 bytes and there is no CRC error, the MAC transmitter pauses the transmission of any data packet for the duration of the decoded Pause Time value multiplied by the slot time (64 byte times).

If subsequent Pause packets are received before the earlier Pause Time expires, the MAC updates the Pause Timer with new value.

Enabling receive flow control

Set the RFE bit in the *Rx flow control register (ETH_MACRXFCR)* to enable the Pause flow control.

69.5.10 MAC management counters

The peripheral supports storing the statistics about the received and transmitted packets in registers that are accessible through the application.

The counters in the MAC management counters (MMC) module can be viewed as an extension of the register address space of the CSR module. The MMC module maintains a set of registers for gathering statistics on the received and transmitted packets. The register set includes a control register for controlling the behavior of the registers, two 32-bit registers containing interrupts generated (receive and transmit), and two 32-bit registers containing masks for the Interrupt register (receive and transmit). These registers are accessible from the Application through the AHB slave interface in the same way the CSR registers are accessed. The organization of these registers is shown in *Section 69.11.4: Ethernet MAC and MMC registers*.

The MMC counters are free running. There is no separate enable for the counters to start. A particular MMC counter starts counting when corresponding packet is received or transmitted.

The receive MMC counters are updated for packets that are passed by the Address Filter (AFM) block. The statistics of packets dropped by the AFM module, are not updated unless they are runt packets of less than 6 bytes (DA bytes are not received fully). To get statistics of all packets, set bit 0 in the *Packet filtering control register (ETH_MACPFR)*. The MMC module gathers statistics on encapsulated IPv4, IPv6, TCP, UDP, or ICMP payloads in received Ethernet packets.

In addition to control registers, two sets of registers are implemented:

- Six registers used for collision, error, and good packet counters:
  - *Tx single collision good packets register (ETH_TX_SINGLE_COLLISION_GOOD_PACKETS)*
  - *Tx multiple collision good packets register (ETH_TX_MULTIPLE_COLLISION_GOOD_PACKETS)*
  - *Tx packet count good register (ETH_TX_PACKET_COUNT_GOOD)*
  - *Rx CRC error packets register (ETH_RX_CRC_ERROR_PACKETS)*
  - *Rx alignment error packets register (ETH_RX_ALIGNMENT_ERROR_PACKETS)*
  - *Rx unicast packets good register (ETH_RX_UNICAST_PACKETS_GOOD)*
- Four registers to record LPI mode transition:
  - *Tx LPI microsecond timer register (ETH_TX_LPI_USEC_CNTR)*
  - *Tx LPI transition counter register (ETH_TX_LPI_TRAN_CNTR)*
  - *Rx LPI microsecond counter register (ETH_RX_LPI_USEC_CNTR)*
  - *Rx LPI transition counter register (ETH_RX_LPI_TRAN_CNTR)*

Definitions

The following terminology is used in MMC register descriptions:

- Transmitted packets are considered “good” if transmitted successfully. In other words, a transmitted packet is good if the packets transmission is not aborted because of any of the following errors:
  - Jabber timeout
  - No carrier or loss of carrier
  - Late collision
  - Packet underflow
  - Excessive deferral
  - Excessive collision
- Received packets are considered “good” if none of the following errors exists:
  - CRC error
  - Runt packet (shorter than 64 bytes)
  - Alignment error (in 10/100 Mbit/s only)
  - Length error (non-Type packet only)
  - Out of range (non-Type packet only, longer than 1518 bytes)
- The maximum transmit frame size depends on the frame type, as follows:
  - Untagged frame maxsize = 1,518
  - VLAN frame maxsize = 1,522
  - Jumbo frame maxsize = 9,018
  - JumboVLAN frame maxsize = 9,022
- The maximum receive packet size depends on the packet type and control bits (JE, S2KP, GPSLCE and EDVLP), as shown in the *Table 794*.

Table 794. Size of the maximum receive packet

JE	S2KP	GPSLCE	EDVLP	Untagged frame maximum size in bytes	Single VLAN frame maximum size in bytes	Double VLAN Frame maximum size in bytes
1	X	X	1	9018	9022	9026
0	1	X	X	2000	2000	2000
0	0	1	1	GPSL	GPSL+4	GPSL+8
0	0	0	1	1518	1522	1526
1	X	X	0	9018	9022	9022
0	0	1	0	GPSL	GPSL+4	GPSL+4
0	0	0	0	1518	1522	1522

69.5.11 Interrupts generated by the MAC

Interrupts can be generated from the MAC as a result of various events. These interrupt events are combined with the events in the DMA on the eth_sbd_intr_it signal. The MAC interrupts are of level type, that is, the interrupt remains asserted (high) until it is cleared by the application or software.

The *Interrupt status register (ETH_MACISR)* describes the events that can cause an interrupt from the MAC. The MAC interrupts are enabled by default. Each event can be prevented from asserting the interrupt on the eth_sbd_intr_it signals by setting the corresponding mask bits in the *Interrupt enable register (ETH_MACIER)*.

The interrupt register bits only indicate the block from which the event is reported. You must read the corresponding status registers and other registers to clear the interrupt.

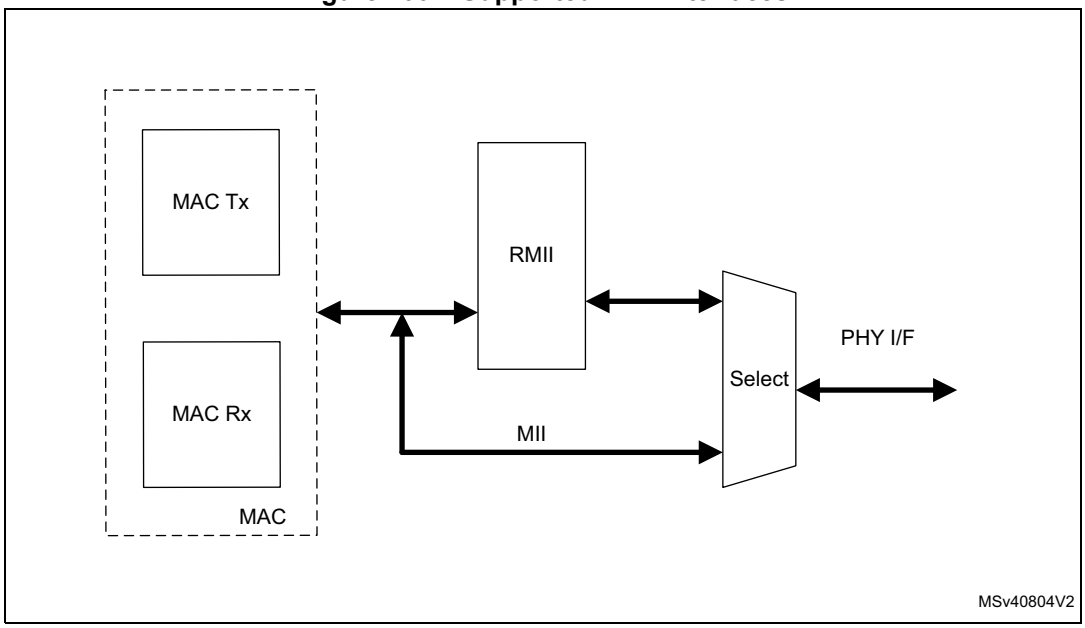
69.5.12 MAC and MMC register descriptions

Refer to *Section 69.11.4: Ethernet MAC and MMC registers*.

69.6 Ethernet functional description: PHY interfaces

The Ethernet peripheral support several PHY interfaces. The root interface is the MII one. All other interfaces are derived from it as shown in *Figure 1001*.

Figure 1001. Supported PHY interfaces



This section describes the SMA module used for PHY control and different PHY interfaces. It contains the following sections:

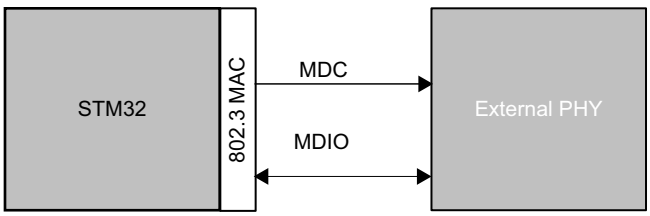
- *Station management agent (SMA)*
- *Media independent interface (MII)*
- *Reduced media independent interface (RMII)*

69.6.1 Station management agent (SMA)

The application can access the PHY registers through the station management agent (SMA) module. The SMA includes a two-wire station management interface (MIM).

The SMA module supports accessing up to 32 PHYs. The application can address one of the 32 registers from any 32 PHYs. Only one register in one PHY can be addressed at a time. The application sends the control data to the PHY and receives status information from the PHY through the SMA module, as shown in *Figure 1002*.

Figure 1002. SMA Interface block



SMA functional overview

The MAC initiates the management write or read operation with respect to the MDC clock. The MDC clock is derived from the CSR clock (eth_hclk). The maximum operating frequency of the ETH_MDC pin is 2.5 MHz, as specified in IEEE 802.3 specifications. However, a different divider can be selected if the system supports higher clock frequencies. The division factor depends on the clock range setting through CR[3:0] in the *MDIO address register (ETH_MACMDIOAR)* register. The MDC clock is selected as follows:

Table 795. MCD clock selection

Selection	MDC clock
0000	eth_hclk/42
0001	eth_hclk/62
0010	eth_hclk/16
0011	eth_hclk/26
0100	eth_hclk/102
0101	eth_hclk/124
0110	eth_hclk/204
0111	eth_hclk/324
1000	eth_hclk/4
1001	eth_hclk/6
1010	eth_hclk/8
1011	eth_hclk/10
1100	eth_hclk/12
1101	eth_hclk/14
1110	eth_hclk/16
1111	eth_hclk/18

The data exchange between the MAC and the PHY is performed through a three-state buffer and brought out as ETH_MDIO line connected to the PHY.

Figure 1003 shows the structure of a Clause 45 MDIO packet, while *Table 796* provides a detailed description of the packet fields.

Figure 1003. MDIO packet structure (Clause 45)

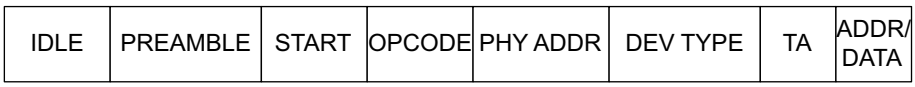
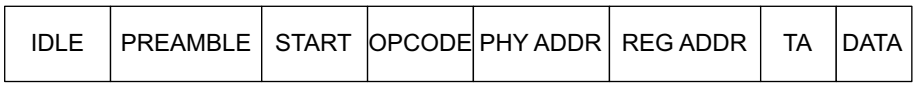


Table 796. MDIO Clause 45 frame structure

Field	Description
IDLE	The ETH_MDIO line is three-state; there is no clock on ETH_MDC.
PREAMBLE	32 continuous bits of value 1
START	Start of packet is 0b00
OPCODE	– 0b00: Address – 0b01: Write – 0b10: Read+ Address – 0b11: Read
PHY ADDR	5-bit address select for one of 32 PHYs
DEV TYPE	5-bit device type
TA	Turnaround – 0bZ0: Read and post-read increment address – 0b10: Write and address MDIO accesses where Z is the tri-state level
DATA	16-bit value: for an address cycle (OPCODE = 0b00), this frame contains the address of the register to be accessed on the next cycle. For the data cycle of a write frame, this field contains the data to be written to the register. For read or post-read increment address frames, this field contains the contents of the register read from the PHY. – In address and data write cycles, the peripheral drives the ETH_MDIO line during the transfer of these 16 bits. – In read and post-read increment address cycles, the PHY drives the ETH_MDIO line during the transfer of these 16 bits.

The frame structure for Clause 22 frames is also supported. The C45E bit in *MDIO address register (ETH_MACMDIOAR)* can be programmed to enable Clause 22 or Clause 45 mode of operation. *Figure 1004* shows the structure of a Clause 22 MDIO packet, while *Table 797* provides a detailed description of the packet fields.

Figure 1004. MDIO packet structure (Clause 22)



MSv40806V1

Table 797. MDIO Clause 22 frame structure

Field	Description
IDLE	The ETH_MDIO line is three-state; there is no clock on ETH_MDC.
PREAMBLE	32 continuous bits of value 1
START	Start of packet is 0b01
OPCODE	0b10 for Read and 0b01 for Write
PHY ADDR	5-bit address select for one of 32 PHYs
REG ADDR	Register address in the selected PHY
TA	Turnaround – 0bZ0: Read and post-read increment address – 0b10: Write and address MDIO accesses where Z is the tri-state level
DATA	Any 16-bit value. In a Write operation, the MAC drives ETH_MDIO. In a Read operation, the PHY drives it.

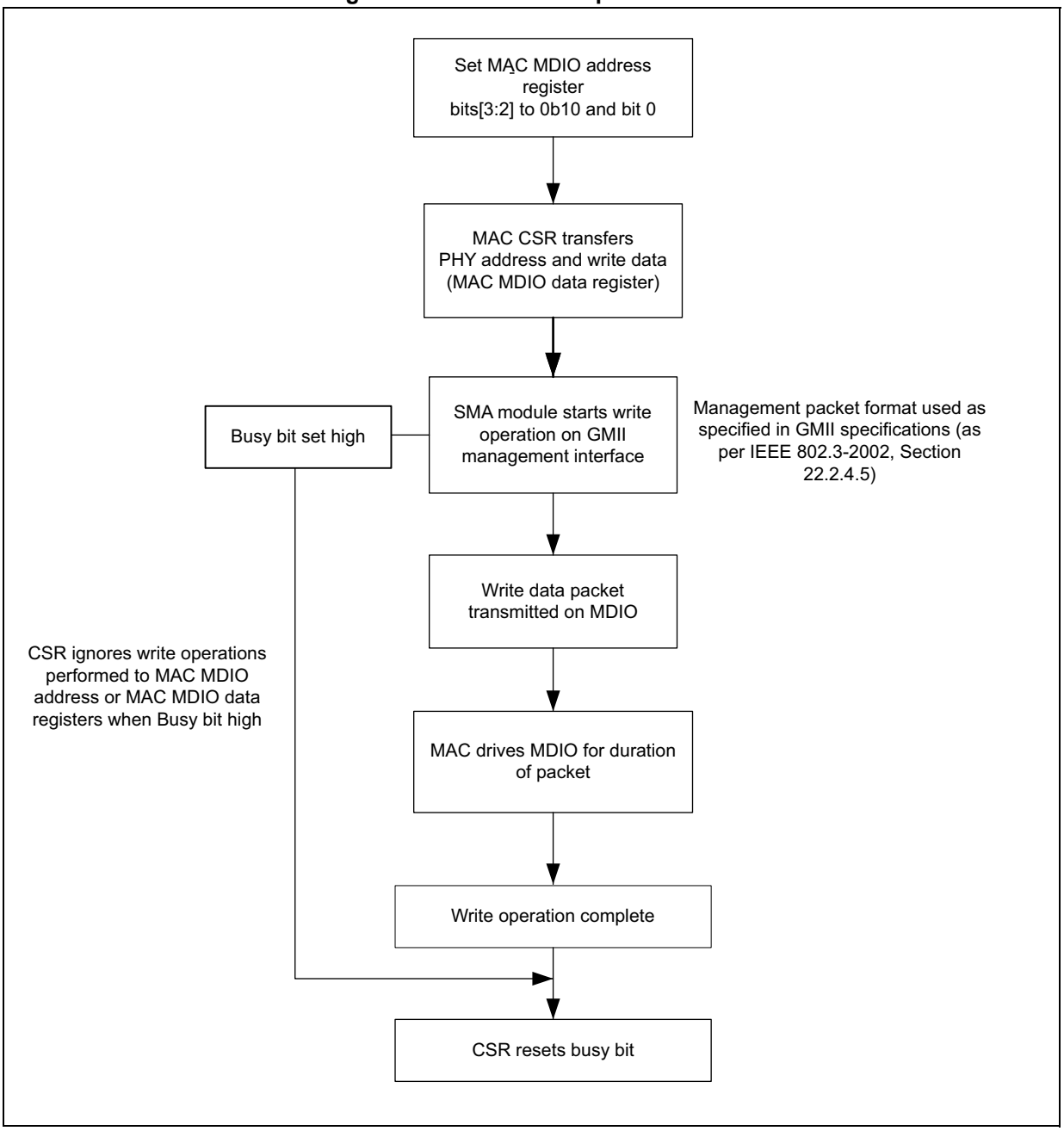
In addition to normal read and write operations, the SMA also supports post-read increment address while operating in Clause 45 mode.

MII management write operations

After the station management agent receives the PHY address and the write data from the MAC CSR module, the SMA starts a write operation to the PHY registers.

Figure 1005 illustrates the flow for a write operation from the SMA module to the PHY registers.

Figure 1005. SMA write operation flow



When bits[3:2] are set to 01 and bit 0 to 1 in the *MDIO address register (ETH_MACMDIOAR)*, the MAC CSR module transfers the PHY address, the register address in PHY, and the write data (*MDIO data register (ETH_MACMDIODR)*) to the SMA to initiate a Write operation into the PHY registers. At this point, the SMA module starts a Write operation on the MII management Interface using the management packet format specified in the MII specifications (as per IEEE 802.3-2002 specifications, *Section 22.2.4.5*).

When the SMA module starts a Write operation, the write data packet is transmitted on the MDIO line. The MAC drives the MDIO line for complete duration of the packet. The Busy bit is set high until the write operation is complete. The CSR ignores the Write operations performed to the *MDIO address register (ETH_MACMDIOAR)* or the *MDIO data register*

(ETH_MACMDIODR) during this period (the Busy bit is high). When the Write operation is complete, the SMA module indicates this to the CSR, and the CSR resets the Busy bit. The packet format for the Write operation is as follows:

Figure 1006. Write data packet

IDLE	PREAMBLE	START	OPCODE	PHY ADDR	REG ADDR	TA	DATA	IDLE
Z	1111..11	01	01	AAAAA	RRRRR	10	DDD...DDD	Z

MSv40807V1

MII management read operation

When bits[3:2] are set to 11 and bit 0 to 1 in the *MDIO address register (ETH_MACMDIOAR)*, the MAC CSR module transfers the PHY address and the register address in PHY to the SMA to initiate a Read operation in the PHY registers. At this point, the SMA module starts a Read operation on the MII management interface using the management packet format specified in the MII specifications (as per IEEE 802.3-2002 specifications, *Section 22.2.4.5*).

When the SMA module starts a Read operation on the MDIO, the CSR ignores the Write operations to the *MDIO address register (ETH_MACMDIOAR)* or *MDIO data register (ETH_MACMDIODR)* register during this period (the Busy bit is high) and the transaction is completed without any error on the MCI interface. When the Read operation is complete, the SMA indicates this to the CSR. The CSR resets the Busy bit and updates the *MDIO data register (ETH_MACMDIODR)* with the data read from the PHY. The MAC drives the MDIO line for the complete duration of the frame except during the Data fields when the PHY is driving the MDIO line. For more information about the communication from the application to the PHYs, see the Reconciliation Sublayer and Media Independent Interface Specifications sections of the IEEE 802.3z, 1000BASE Ethernet.

The packet format for the Read operation is as follows:

Figure 1007. Read data packet

IDLE	PREAMBLE	START	OPCODE	PHY ADDR	REG ADDR	TA	DATA	IDLE
Z	1111..11	01	10	AAAAA	RRRRR	Z0	DDD...DDD	Z

MSv40808V1

Preamble suppression

The IEEE standard specifies 32-bit preamble (all-ones) for the MDIO frames. The peripheral provides controls to support preamble suppression. It transmits MDIO frames with only 1 preamble bit. The preamble suppression can be enabled by setting the PSE bit in *MDIO address register (ETH_MACMDIOAR)*.

Trailing clocks and back-to-back transactions

The peripheral drives the ETH_MDC clock for the duration of the MDIO frame. There is no clock driven during the idle period. The trailing clock feature can be used if the PHY needs the ETH_MDC clock to be active for some cycles after the MDIO frame. The NTC[2:0] bitfield in *MDIO address register (ETH_MACMDIOAR)* allows the programming of trailing clocks from 0 to 7.

The peripheral supports back-to-back transactions which allow starting the next MDIO frame even before the trailing clocks are complete for previous MDIO frame. This feature can be enabled by setting BTB bit in *MDIO address register (ETH_MACMDIOAR)* when the trailing clock feature is also enabled. When back-to-back transactions are enabled, the GMII busy bit (GB) is cleared immediately after MDIO frame completion. This allows the software to issue the next command, which is executed by the peripheral while trailing clocks are still on for the previous MDIO frame. When (GB) transactions are not enabled, the GMII busy bit is cleared after the trailing clocks are complete for the MDIO frame.

Interrupt for MDIO transaction completion

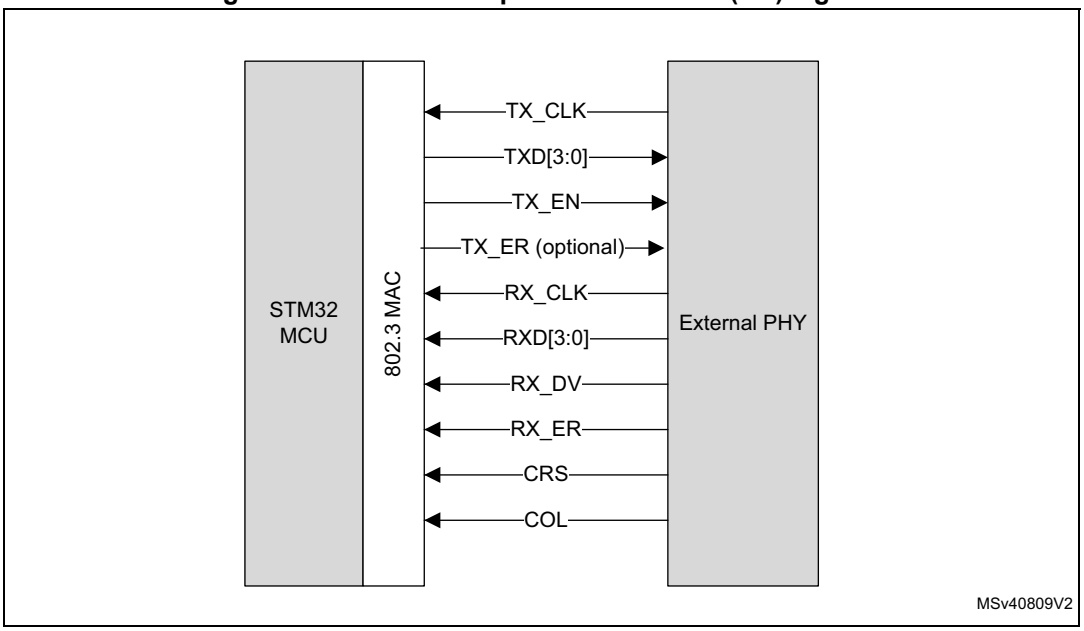
The peripheral can generate an interrupt on completion of MDIO read or write transactions. Therefore, the application need not poll the GMII busy bit of the *MDIO address register (ETH_MACMDIOAR)* to know the completion of MDIO commands.

69.6.2 Media independent interface (MII)

The media-independent interface (MII) defines the interconnection between the MAC sublayer and the PHY for data transfer at 10 Mbit/s and 100 Mbit/s.

MII signals are given in *Figure 1008: Media independent interface (MII) signals*.

Figure 1008. Media independent interface (MII) signals



- TX_CLK: continuous clock that provides the timing reference for Tx data transfers. The nominal frequency is 2.5 MHz at 10 Mbit/s and 25 MHz at 100 Mbit/s.
- TXD[3:0]: transmit data.

  TXD is a bundle of 4 data signals driven synchronously by the MAC sublayer and qualified (valid data) on the assertion of the TX_EN signal. TXD[0] is the least significant bit, TXD[3] is the most significant bit. While TX_EN is deasserted, the transmit data must have no effect upon the PHY.
- TX_EN: transmission enable signal indicating that the MAC is presenting nibbles on the MII for transmission. It must be asserted synchronously (TX_CLK) with the first nibble of the preamble and must remain asserted while all nibbles to be transmitted are presented to the MII.
- TX_ER (optional): required only for Energy Efficient Ethernet (EEE). The transmit error is indicated by inverting the CRC. The remote station can detect the Transmit error through incorrect CRC.
- RX_CLK: continuous clock that provides the timing reference for Rx data transfers. The nominal frequency is 2.5 MHz at 10 Mbit/s, 25 MHz at 100 Mbit/s.
- RXD[3:0]: receive data

  RXD is a bundle of 4 data signals driven synchronously by the PHY and qualified (valid data) on the assertion of the RX_DV signal. RXD[0] is the least significant bit, RXD[3] is the most significant bit. While RX_EN is deasserted and RX_ER is asserted, a specific RXD[3:0] value is used to transfer specific information from the PHY.

- RX_DV: receive data valid

  This signal indicates that the PHY is presenting recovered and decoded nibbles on the MII for reception. It must be asserted synchronously (RX_CLK) with the first recovered nibble of the frame and must remain asserted through the final recovered nibble. It must be deasserted prior to the first clock cycle that follows the final nibble. In order to receive the frame correctly, the RX_DV signal must encompass the frame, starting no later than the SFD field.

- RX_ER: receive error

  This signal must be asserted for one or more clock periods (RX_CLK) to indicate to the MAC sublayer that an error was detected somewhere in the frame. This error condition must be qualified by RX_DV assertion.

- CRS: carrier sense.

  This signal is asserted by the PHY when either the transmit or receive medium is non idle. It is deasserted by the PHY when both transmit and receive media are idle. The PHY must ensure that the CS signal remains asserted throughout the duration of a collision condition. This signal is not required to transition synchronously with respect to the Tx and Rx clocks. In Full-duplex mode the state of this signal is don't care for the MAC sublayer.

- COL: collision detection signal

  This signal must be asserted by the PHY upon detection of a collision on the medium and must remain asserted while the collision condition persists. This signal is not required to transition synchronously with respect to the Tx and Rx clocks. In Full-duplex mode, the state of this signal is don't care for the MAC sublayer.

69.6.3 Reduced media independent interface (RMII)

The reduced media independent interface (RMII) specification reduces the pin count between Ethernet PHYs and STM32 MCU. According to the IEEE 802.3u, an MII contains 16 pins for data and control. RMII specification reduces the pin count to 7.

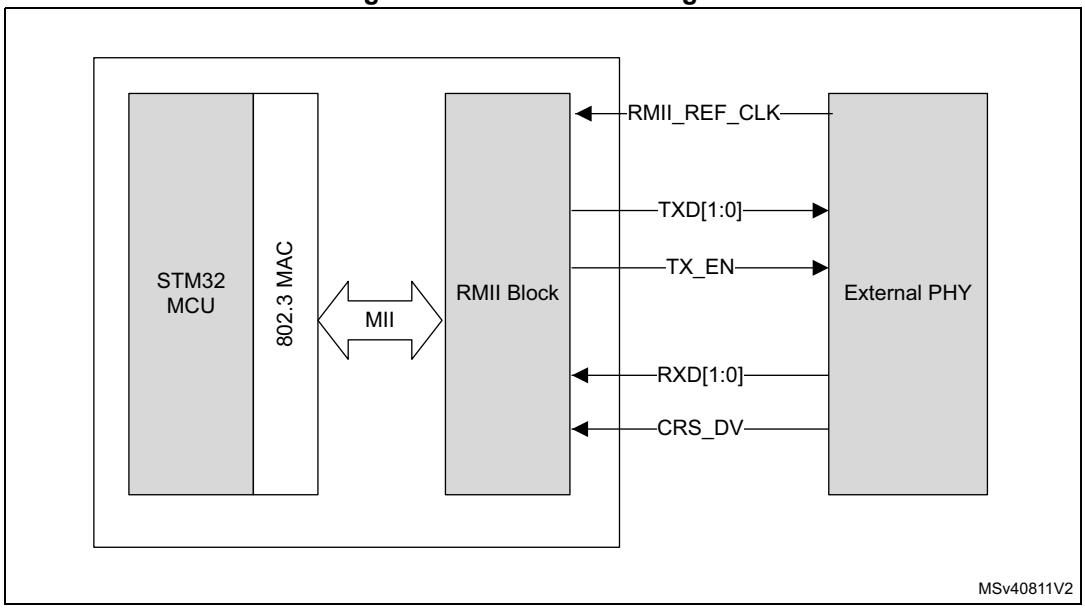
Part of the Ethernet peripheral, the RMII module is instantiated at the MAC output. This helps in translating the MII of the MAC into the RMII. The RMII block has the following characteristics:

- Supports 10 Mbit/s and 100 Mbit/s operating rates. It does not support the 1000 Mbit/s operation.
- Provides independent 2-bits wide transmit and receive paths by sourcing two clock references externally.

RMII block diagram

Figure 1009: RMII block diagram shows the position of the RMII block relative to the MAC and RMII PHY. The RMII block is placed in front of the MAC to translate the MII signals to RMII signals.

Figure 1009. RMII block diagram

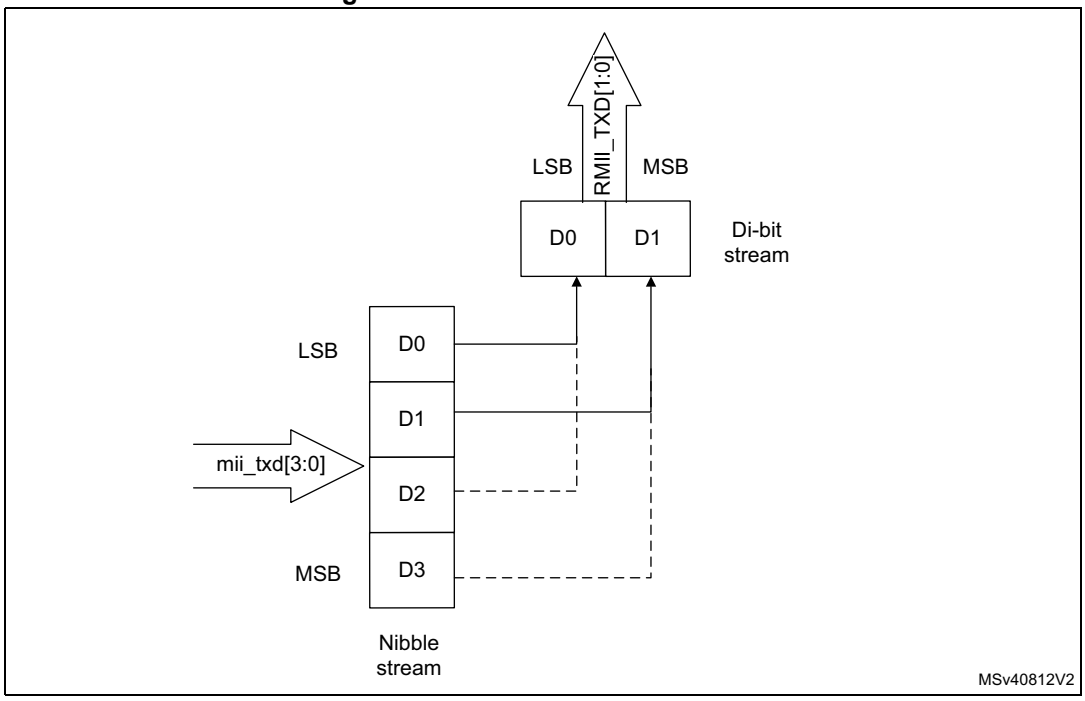


- RMII_REF_CLK: continuous 50 MHz reference clock input
- TXD[1:0]: transmit data
- TX_EN: transmit data enable.
  When high, this bit indicates that valid data are being transmitted on TXD[1:0].
- RXD[1:0]: receive data
- CRS_DV: carrier Sense (CRS) and RX_Data Valid (RX_DV) multiplexed on alternate clock cycles. In 10 Mbit/s mode, it alternates every 10 clock cycles.

Transmit bit order

Each nibble from the MII interface must be transmitted on the RMII interface di-bit at a time with the order of di-bit transmission shown in *Figure 1010: Transmission bit order*. The lower order bits (D1 and D0) are transmitted first followed by higher order bits (D2 and D3).

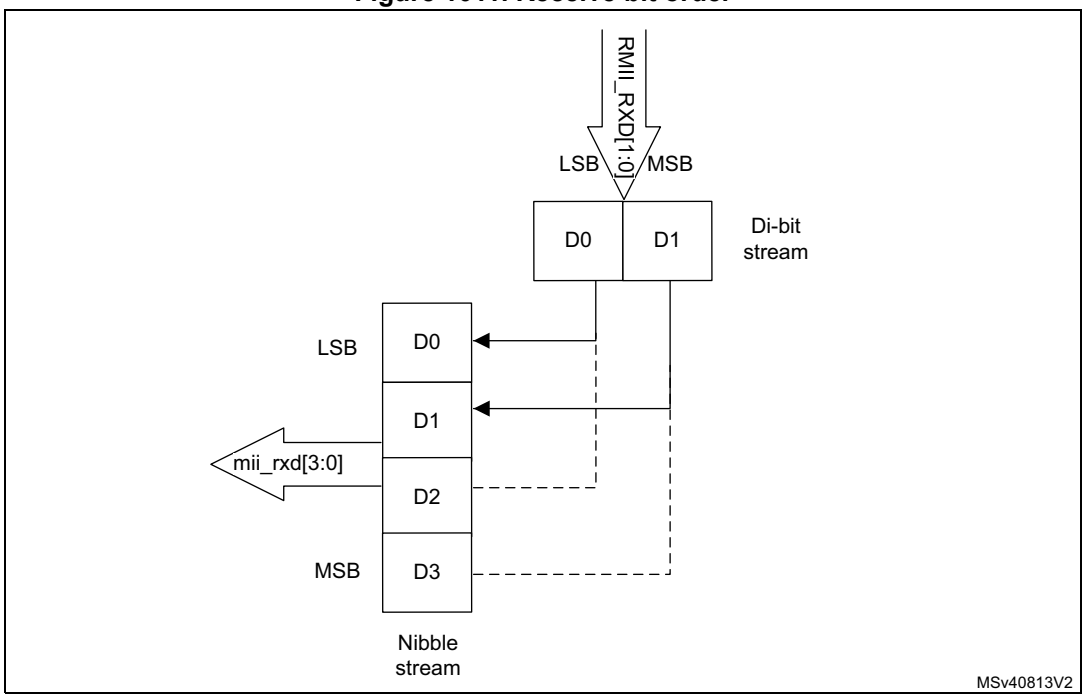
Figure 1010. Transmission bit order



Receive bit order

Each nibble is transmitted to the MII interface from the di-bit received from the RMII interface in the nibble transmission order shown in *Figure 1011: Receive bit order*. The lower order bits (D0 and D1) are received first, followed by the higher order bits (D2 and D3).

Figure 1011. Receive bit order



69.7 Ethernet low-power modes

69.7.1 Low-power management

The Ethernet peripheral supports the following techniques to save power:

- Magic packet
- Remote wake-up

The magic packet and remove wake-up techniques are used to save power in the host system when it is in low-power mode, and has to be woken up only at the reception of specific packets from the Ethernet network. In low-power mode, the clocks on most of the host logic, along with the majority of the peripherals (except the MAC receiver logic), can be disabled. On receiving the specific packets from the network, the MAC generates the trigger to wake up the host system and come back to normal state. Refer to the power control (PWR) section of the reference manual for the list of the system operating modes that support Ethernet low-power modes.

The Energy Efficient Ethernet (EEE) mode is compliant with the IEEE 802.3az-2010 standard. It is primarily targeted to save power in the Ethernet port when there is no traffic on the line. In this mode, the host indicates to the far-end that it does not have any packets to transmit in the near future and puts the transmitter port (MAC controller, PCS and PHY layers) in low-power mode. Similarly, the receiver port can also be put in low-power mode

when the far-end host indicates that it does not have any traffic to transfer. This allows significant saving of power in the Ethernet port (mainly in the PHY) with intermittent and burst traffic profile. The triggering of entry and exit out of the EEE mode is controlled by the MAC and is supported within the peripheral.

Simultaneous operation of the EEE mode along with any or both the other power saving modes is also supported.

Description of magic packet mode

This section describes how to save power through magic packet detection.

Note: The magic packet feature is based on the magic packet technology white paper from Advanced Micro Device (AMD).

The watchdog timeout limit for a magic packet is 2,048 bytes irrespective of the value programmed in WD bit in Operating mode configuration register (ETH_MACCR) and PWE bit in Watchdog and jabber timeout register (ETH_MACWJBTR).

In the magic-packet-based power saving mode, the reception of a valid magic packet by the MAC receiver triggers an exit from low-power mode. The MAC enters power saving mode when PWRDWN bit of *PMT control status register (ETH_MACPCSR)* is programmed to 1. Exit from the magic-packet-based power saving mode is enabled by setting the MGKPKTEN bit of *PMT control status register (ETH_MACPCSR)* to 1.

The magic packet contains a unique pattern at any offset after the Destination address, Source address, and Length/Type fields. In addition to the unique pattern matching, the MAC receiver also checks for the following, to detect the received packet as a valid magic packet:

- The packet must be addressed to it (Destination Address of the received packet should perfect match the *MAC address 0 high register (ETH_MACA0HR)* and *MAC Address 0 low register (ETH_MACA0LR)*) or with multicast/broadcast address.
- The packet must not have any length error, FCS error, dribble bit error, GMII error, and collision.
- The packet must not be runt (length including Ethernet header and FCS is at least 64 bytes).

Magic packet data format

The content of the unique pattern in magic packets is described as follows:

- Six bytes of all-ones (0xFF FF FF FF FF FF) called synchronization stream. There can be more than six bytes of 0xFF, but only the last six are considered.
- The synchronization stream is immediately followed by 16 repetitions of the Destination address field of the packet (*MAC address 0 high register (ETH_MACA0HR)* and the *MAC Address 0 low register (ETH_MACA0LR)*) or multicast/broadcast address.
- No break or interruption between synchronization stream and first repetition of Destination address field or within its 16 repetitions.

If the MAC address of a node is 0x00 11 22 33 44 55, the MAC scans for the following data sequence:

Destination Address Source Address Length/Type…… FF FF FF FF FF FF
00 11 22 33 44 55 00 11 22 33 44 55 00 11 22 33 44 55 00 11 22 33 44 55
00 11 22 33 44 55 00 11 22 33 44 55 00 11 22 33 44 55 00 11 22 33 44 55
00 11 22 33 44 55 00 11 22 33 44 55 00 11 22 33 44 55 00 11 22 33 44 55
00 11 22 33 44 55 00 11 22 33 44 55 00 11 22 33 44 55 00 11 22 33 44 55
…CRC

Description of remote wake-up packet mode

This section describes the power saving mode based on remote wake-up packet.

Note: The remote wake-up packet feature implementation is based on the Device Class Power Management Reference Specification and various implementation-specific white papers.

The watchdog timeout limit for a magic packet is 2,048 bytes irrespective of the value programmed in WD bit in Operating mode configuration register (ETH_MACCR) and PWE bit in Watchdog and jabber timeout register (ETH_MACWJBTR).

In the remote-wake-up-magic-packet-based power saving mode, the reception of expected remote wake-up packet by the MAC receiver triggers the exit from low-power mode. The MAC enters power saving mode when PWRDWN bit in *PMT control status register (ETH_MACPCSR)* is programmed to 1. Exit from the remote-wake-up-magic-packet-based power saving mode is enabled by programming RWKPKTEN bit of *PMT control status register (ETH_MACPCSR)* to 1.

The MAC implements a filter lookup table (programmed through *Remote wake-up packet filter register (ETH_MACRWKPFR)* in which CRC, offset, and byte mask of the pattern embedded in remote wake-up packet and the filter operation commands are programmed.

The pattern embedded in the remote wake-up packet is located at any offset after the Destination address and Source address fields. In addition to the CRC match for the pattern, the MAC receiver also checks the following, to detect the received packet as a valid remote wake-up packet:

- The packet must be addressed to it (Destination Address of the received packet should perfect match the *MAC address 0 high register (ETH_MACA0HR)* and *MAC Address 0 low register (ETH_MACA0LR)*) or with multicast/broadcast address.
- The packet must not have any length error, FCS error, dribble bit error, GMII error, and collision.
- The packet must not be runt (length including Ethernet header and FCS is at least 64 bytes).

When a valid remote wake-up packet is received, the MAC receiver sets the RWKPRCVD bit in *PMT control status register (ETH_MACPCSR)* and triggers the interrupt on pmt_intr_o output port. The PMTIS bit in *Interrupt status register (ETH_MACISR)* is set when power-gating is not enabled in low-power mode. An interrupt is triggered to the application on the sbd_intr_o output port when interrupt is enabled (PMTIE bit in *Interrupt enable register (ETH_MACIER)* is set) and CSR clock is not gated off in low-power mode.

Remote wake-up packet filters

When the remote-wake-up-based power saving mode is enabled, four remote wake-up filters can be selected. The structure of the remote wake-up filters is shown in *Table 798: Remote wake-up packet filter register*.

Table 798. Remote wake-up packet filter register

ETH_MACRWKPFR value	Field							
0	Filter 0 byte mask							
1	Filter 1 byte mask							
2	Filter 2 byte mask							
3	Filter 3 byte mask							
4	Reserved	Filter 3 command	Reserved	Filter 2 command	Reserved	Filter 1 command	Reserved	Filter 0 command
5	Filter 3 offset		Filter 2 offset		Filter 1 offset		Filter 0 offset	
6	Filter 1 CRC - 16				Filter 0 CRC - 16			
7	Filter 3 CRC - 16				Filter 2 CRC - 16			

The remote wake-up filter fields are described in *Table 799: Description of the remote wake-up filter fields*.

Table 799. Description of the remote wake-up filter fields

Register	Description
Filter *i* Byte mask	The filter *i* byte mask register defines the bytes of the packet that are examined by filter *i* (0, 1, 2 or 3) to determine whether or not a packet is a wake-up packet. – The MSB (31st bit) must be zero. – Bit j[30:0] is the byte mask. – If Bit j (byte number) of the byte mask is set, the CRC block processes the Filter *i* Offset + j of the incoming packet; otherwise Filter *i* Offset + j is ignored.
Filter *i* Command	The 4-bit filter *i* command controls the filter *i* operation. – Bit 3 specifies the address type, defining the destination address type of the pattern. When the bit is set, the pattern applies to only multicast packets; when the bit is reset, the pattern applies only to unicast packet. – Bit 2 (Inverse mode), when set, reverses the logic of the CRC16 Hash function signal, to reject a packet with matching CRC_16 value. Bit 2, along with Bit 1, allows a MAC to reject a subset of remote wake-up packets by creating filter logic such as "Pattern 1 AND NOT Pattern 2". – Bit 1 (And_Previous) implements the Boolean logic(1). When set, the result of the current entry is logically ANDed with the result of the previous filter. This AND logic allows a filter pattern longer than 32 bytes by splitting the mask among two, three, or four filters. This depends on the number of filters that have the And_Previous bit set. – Bit 0 is the enable for filter *i*. If Bit 0 is not set, filter *i* is disabled.

Table 799. Description of the remote wake-up filter fields (continued)

Register	Description
Filter *i* Offset	This filter *i* offset register defines the offset (within the packet) from which the filter *i* examines the packets. – This 8-bit pattern-offset is the offset for the filter *i* first byte to be examined. – The minimum allowed offset is 12, which refers to the 13th byte of the packet. – The offset value 0 refers to the first byte of the packet.
Filter *i* CRC-16	This filter *i* CRC-16 register contains the CRC_16 value calculated from the pattern and also the byte mask programmed to the wake-up filter register block. – The 16-bit CRC calculation uses the following polynomial: $G(x) = x^{16} + x^{15} + x^2 + 1$ Each mask, used in the Hash function calculation, is compared with a 16-bit value associated with that mask. Each filter has the following: – 32-bit Mask: Each bit in this mask corresponds to one byte in the detected packet. If the bit is 1', the corresponding byte is taken into the CRC16 calculation. – 8-bit Offset Pointer: Specifies the byte to start the CRC16 computation. The pointer and the mask are used together to locate the bytes to be used in the CRC16 calculations.

1. The And_Previous bit setting is applicable within a set of four filters.
Setting And_Previous bit of a filter that is not enabled has no effect, that is setting And_Previous bit of lowest number filter in the set of four filters has no effect. For example, setting And_Previous bit of Filter 0 has no effect.
If And_Previous bit is set for a given filter to form an AND chained filter, the AND chain breaks when it finds a disabled filter. For example: If Filter 2 And_Previous bit is set (bit 1 in Filter 2 command is set) but Filter 1 is not enabled (bit 0 in Filter 1 command is reset), then only Filter 2 result is considered. If Filter 2 And_Previous bit is set (bit 1 in Filter 2 command is set), Filter 3 And_Previous bit is set (bit 1 in Filter 3 command is set), but Filter 1 is not enabled (bit 0 in Filter 1 command is reset), then only Filter 2 result ANDed with Filter 3 result is considered. If Filter 2 And_Previous bit is set (bit 1 in Filter 2 command is set), Filter 3 And_Previous bit is set (bit 1 in Filter 3 command is set), but Filter 2 is not enabled (bit 0 in Filter 2 command is reset), then since setting Filter 2 And_Previous bit has no effect, only Filter 1 result ORed with Filter 3 result is considered.
If filters chained by And_Previous bit setting have complementary programming, then a frame may never pass the AND chained filter. For example, if Filter 2 And_Previous bit is set (bit 1 in Filter 2 command is set), Filter 1 Address_Type bit is set (bit 3 in Filter 1 command is set) indicating multicast detection and Filter 2 Address_Type bit is reset (bit 3 in Filter 2 command is reset) indicating unicast detection or vice versa, then a remote wake-up frame does not pass the AND chained filter as a remote wake-up frame cannot be of both unicast and multicast address types.

The remote wake-up filter registers are implemented as eight indirect access registers (wkuppktfilter_reg#i) for four remote wake-up filters, and accessed by the application through *Remote wake-up packet filter register (ETH_MACRWKPFR)*. The entire set of wkuppktfilter_reg registers must be written to program the remote wake-up filters. The wkuppktfilter_reg register is programmed by sequentially writing the eight register values in *Remote wake-up packet filter register (ETH_MACRWKPFR)* for wkuppktfilter_reg0 to wkuppktfilter_reg3, respectively. The wkuppktfilter_reg register is read in a similar way. The MAC updates the wkuppktfilter_reg register current pointer value in RWKPTR field of *PMT control status register (ETH_MACPCSR)*.

Note: If the Remote wake-up packet filter register (ETH_MACRWKPFR) is accessed in byte or half-word mode, the internal counter to access the appropriate wkuppktfilter_reg is incremented when the CPU accesses Lane 3.

When Remote wake-up packet filter register (ETH_MACRWKPFR) is written, the content is transferred from CSR clock domain to PHY receive clock domain after the write operation. There should not be any further write to the Remote wake-up packet filter register (ETH_MACRWKPFR) until the first write is updated in PHY receive clock domain. Otherwise, the second write operation does not get updated to the PHY receive clock domain. Therefore, the delay between two write operations to the Remote wake-up packet filter register (ETH_MACRWKPFR) should be at least 4 cycles of the PHY receive clock.

PMT interrupt

The PMT interrupt signal is asserted when a valid remote wake-up packet is received.

Table 800 lists the remote wake-up scenarios in which PMT interrupt is generated.

Table 800. Remote wake-up packet and PMT interrupt generation(1)

Filter i Command			Frame Type and CRC Status		Interrupt Generation
CAST	INV	EN	Received Frame Cast Type	CRC Status	RWK INTR
0	0	1	Unicast	MATCH	Remote Wake-up packet is detected and PMT interrupt is generated
0	1	1	Unicast	MISMATCH	Remote Wake-up packet is detected and PMT interrupt is generated
1	0	1	Multicast	MATCH	Remote Wake-up packet is detected and PMT interrupt is generated
1	1	1	Multicast	MISMATCH	Remote Wake-up packet is detected and PMT interrupt is generated

1. In all other combinations, the Remote Wake-up packet is not detected and PMT interrupt is not generated.

In addition to sbd_intr_o signal, the pmt_intr_o (synchronous to Rx clock) signal is asserted. The pmt_intr_o signal, synchronous to the Rx clock domain, is provided so that the application clock can be stopped by software when the MAC is in the power-down mode. It is ORed with lpi_intr_o signal (see *Section : LPI interrupt*) and tied to the EXTI peripheral.

As the pmt_intr_o signal is generated in the PHY Rx clock domain, it is not cleared immediately when the *PMT control status register (ETH_MACPCSR)* is read. This is because the resultant clear signal has to cross to the PHY Rx clock domain, and then clear the interrupt source. This delay is at least 4 clock cycles of Rx clock and can be significant when the peripheral is operating in the 10 Mbit/s mode. When the application clears the PWRDWN bit in *Remote wake-up packet filter register (ETH_MACRWKPFR)*, the MAC comes out of the power-down mode, but this event does not generate the PMT interrupt.

Power-down sequence

The software must perform the following tasks to initiate the power-down sequence:

- Disable the Transmit DMA (if applicable) by clearing the ST bit of the *Channel transmit control register (ETH_DMACTXCR)*.
- Wait for any previous frame transmissions to complete. You can check this by reading TFCSTS[1:0] and TPESTS bits in the *Debug register (ETH_MACDR)* and TXQSTS bit in the *Tx queue debug register (ETH_MTLTXQDR)* of all MTL Tx queues.
- Disable the MAC transmitter and MAC receiver by clearing TE and RE bits in *Operating mode configuration register (ETH_MACCR)*.
- Wait until the receive DMA empties all frames from the Rx FIFO. To check this, read PRXQ[13:0] in the *Rx queue debug register (ETH_MTLRXQDR)*. If this bit is zero, the Rx FIFO is empty.
- Configure the magic packet (MGKPKTEN) and/or remote wake-up (RWKPKTEN) detection in the *PMT control status register (ETH_MACPCSR)*.
- Set bit 31 (ARPEN) in the *Operating mode configuration register (ETH_MACCR)*.
- Enable the MAC receiver by setting RE bit and then set PWRDWN bit in the *PMT control status register (ETH_MACPCSR)* to initiate the power-down sequence in MAC.

Note: If the feature is enabled and the MAC transmitter is in the LPI mode when it is put into the power-down mode, then the MII interface gets clamped to assert the LPI pattern. If the MAC transmitter is not in the LPI mode when it is put into the power-down mode, the GMII or MII interface gets clamped to all-zero.

Power-up sequence

The MAC wakes up on receiving the magic packet or remote wake-up frame. The power-up sequence is as follows:

- The MAC asserts pmt_intr_o. When only clock-gating is employed in low-power mode, the pmt_intr_o signal can be used to start the clocks that were gated-off after entering low-power mode.
- The software performs the following tasks:
  - De-assert the pmt_intr_o by reading the *PMT control status register (ETH_MACPCSR)*.
  - Perform a write operation (with reset values) to the *PMT control status register (ETH_MACPCSR)* and the *Remote wake-up packet filter register (ETH_MACRWKPFR)* so that the corresponding values in the always-on block gets synchronized. Otherwise, the values of these registers are different.
  - Perform write operations to the *Operating mode configuration register (ETH_MACCR)*, *MAC address 0 high register (ETH_MACA0HR)* and *MAC Address 0 low register (ETH_MACA0LR)* to synchronize the values in the CSR module and the respective bits in the always-on block. Otherwise, the MAC receiver is on even though the Receive Enable bit is set to 0.

After completing these steps, the software must initialize all registers, enable the transmitter, and program the DMA (in DMA configurations) to resume the normal operation.

69.7.2 Energy-efficient Ethernet (EEE)

EEE is an operational mode that enables the IEEE 802.3 Media Access Control (MAC) sublayer along with a family of physical layers to operate in Low-power idle (LPI) mode. The

EEE operational mode supports the IEEE 802.3 MAC operation at 100 Mbit/s. The peripheral supports the IEEE 802.3az-2010 for EEE.

The LPI mode allows saving power by switching off the parts of the communication device functionality when there is no data to be transmitted and received. The systems on both sides of the link can disable some functionalities to save power during the periods of low-link utilization. The MAC controls whether the system should enter or exit the LPI mode and communicates this to the PHY.

The EEE specifies the capabilities negotiation methods that the link partners can use to determine whether EEE is supported, and then select the set of parameters that are common to both devices.

Transmit path functions

The transmit path functions include tasks that the MAC must perform to make the PHY enter the LPI state.

In the transmit path, the software must set the LPIEN bit of the *LPI control and status register (ETH_MACLCSR)* to indicate to the MAC to stop transmission and initiate the LPI protocol. The MAC completes the transmission in progress, generates its transmission status, and starts transmitting the LPI pattern instead of the IDLE pattern if the link status has been up continuously for a period specified in the LPI LS TIMER LST[9:0] bitfield of *LPI timers control register (ETH_MACLTCR)*. The PHY Link Status PLS bit of the *LPI control and status register (ETH_MACLCSR)* indicates the link status of the PHY.

Note: The EEE feature is not supported when the MAC is configured to use the RMII.

According to the standard (IEEE 802.3az-2010), the PHY must not stop the TxCLK clock during the LPI state in the MII (10 or 100) mode.

To make the PHY enter the LPI state, the MAC performs the following tasks:

1. De-asserts TX_EN.
2. Asserts TX_ER.
3. Sets TXD[3:0] to 0x1 (for 100 Mbit/s)
4. Updates the status (TLPIEN bit of *LPI control and status register (ETH_MACLCSR)*) and generates an interrupt.

Note: The MAC maintains the same state of the TX_EN, TX_ER, and TXD signals for the entire duration during which the PHY remains in the LPI state.

To bring the PHY out of the LPI state, that is when the software resets the LPIEN bit, the MAC performs the following tasks:

1. Stops transmitting the LPI pattern and starts transmitting the IDLE pattern.
2. Starts the LPI TW TIMER:

   The MAC cannot start the transmission until the wake-up time specified for the PHY expires. The auto-negotiated wake-up interval is programmed in the TWT field of the *LPI timers control register (ETH_MACLTCR)*.
3. Updates the LPI exit status (TLPIEX bit of the *LPI control and status register (ETH_MACLCSR)*) and generates an interrupt.

Figure 1012 shows the behavior of TX_EN, TX_ER, and TXD[3:0] signals during the LPI mode transitions.

Note: The MAC does not stop the TX_CLK clock. The application can stop this clock (as shown in Figure 1012) if the PHY supports it and when the MAC sets the sbd_tx_clk_gating_ctrl_o

signal to 1. The sbd_tx_clk_gating_ctrl_o signal is asserted after nine Tx Clock Cycles, one Pulse Synchronizer delay, and one CSR clock cycle. The assertion of the sbd_tx_clk_gating_ctrl_o signal depends on the LPITCSE bit of the LPI control and status register (ETH_MACLCSR) and can be done automatically as shown on Figure 1013.

If RGMII Interface is selected, the Tx clock is required for transmitting the LPI pattern and so the Tx Clock cannot be gated.

If the MAC is in the Tx LPI mode and the Tx clock is stopped, the application should not write to CSR registers that are synchronized to Tx clock domain.

If the MAC is in the LPI mode and the application issues a soft reset or hard reset, the MAC transmitter comes out of the LPI mode.

Figure 1012. LPI transitions (Transmit, 100 Mbds)

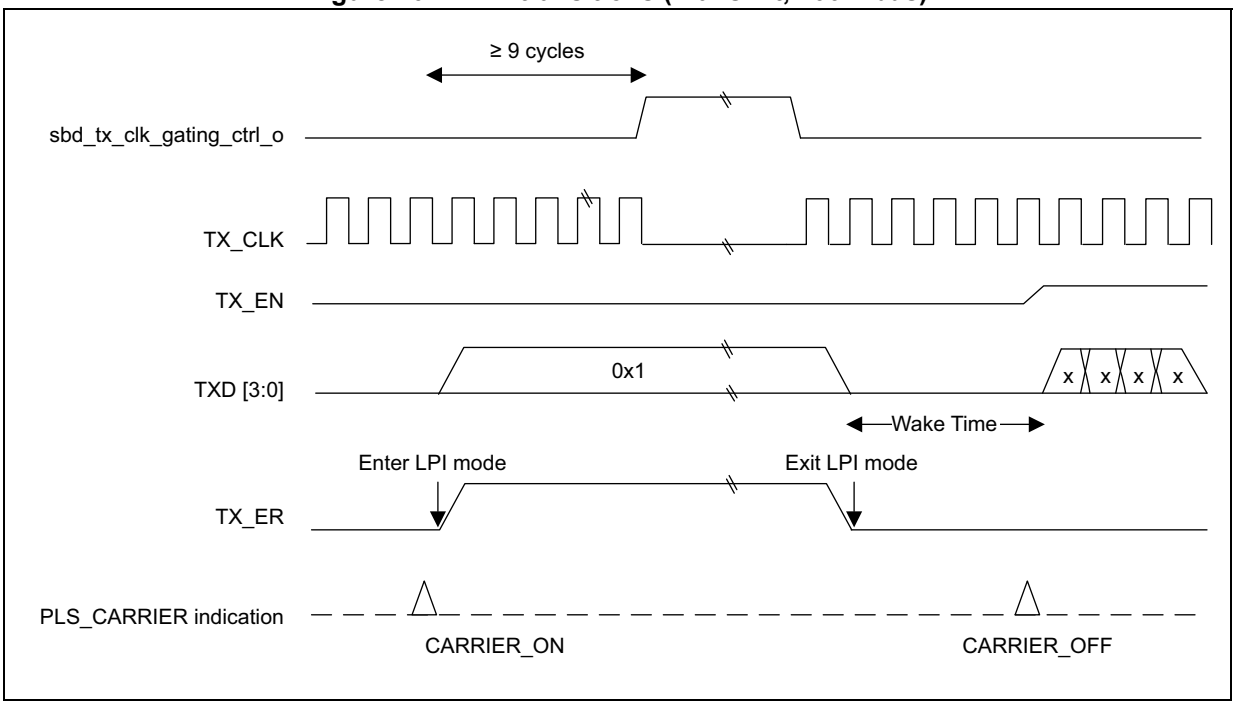
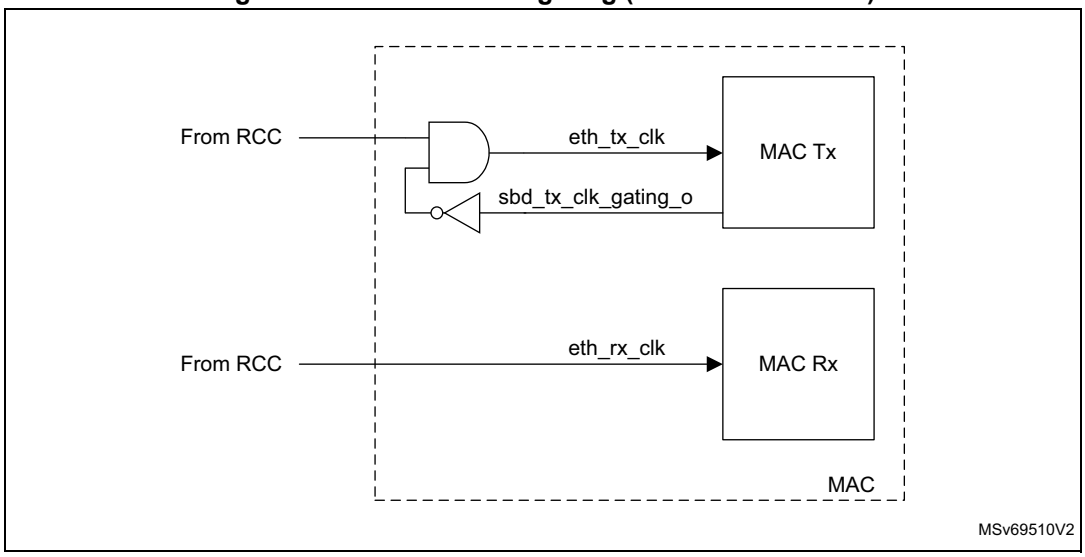


Figure 1013. LPI Tx clock gating (when LPITCSE = 1)



Automated entry/exit from LPI mode in transmit path

The MAC transmitter can be programmed to enter and exit LPI Idle mode automatically based on whether it is Idle for a specific period of time or has a packet to transfer. These modes are enabled and controlled by the *LPI control and status register (ETH_MACLCSR)*.

When LPITXA and LPIEN of *LPI control and status register (ETH_MACLCSR)* are set, the MAC transmitter enters LPI Idle state when the MAC transmit path (including the MTL layers and DMA layers) are idle. The MAC transmitter exits the LPI Idle state and clears the LPITXEN bit as soon as any of functions in the TX path (DMA, MTL or MAC) becomes non-idle due to initiation of a packet transfer.

In addition, when LPITE is also set, the MAC transmitter enters LPI Idle state only if the Transmit path remains in idle state (no activity) for the time period indicated by the value in *LPI entry timer register (ETH_MACLETR)*. In this mode also, the MAC transmitter exits the LPI Idle state as soon as any of the functions becomes non-idle. However, the LPIEN bit is not cleared but remains active so that reentry to LPI Idle state is possible without any software intervention when the MAC becomes idle again.

When both LPITE and LPITXA bits are cleared, the application can directly control the entry and exit of LPI Idle state by programming the LPIEN bit.

Receive path functions

The receive path functions include the tasks that the PHY and MAC must perform when the PHY receives signals from the link partner to exit the LPI state.

In the receive path, when the PHY receives the signals from the link partner to enter into the LPI state, the PHY and MAC perform the following tasks:

1. The PHY asserts RX_ER.
2. The PHY sets RXD[3:0] to 0x1 (for 100 Mbit/s).
3. The PHY de-asserts RX_DV.
4. The MAC updates the RLPIEN bit of the *LPI control and status register (ETH_MACLCSR)* and immediately generates an interrupt.

Note: The PHY maintains the same state of the RX_ER, RXD, and RX_DV signals for the entire duration during which it remains in the LPI state.

If the LPI pattern is detected for a very short duration (that is, less than two cycles of Rx clock), the MAC does not enter the Rx LPI mode.

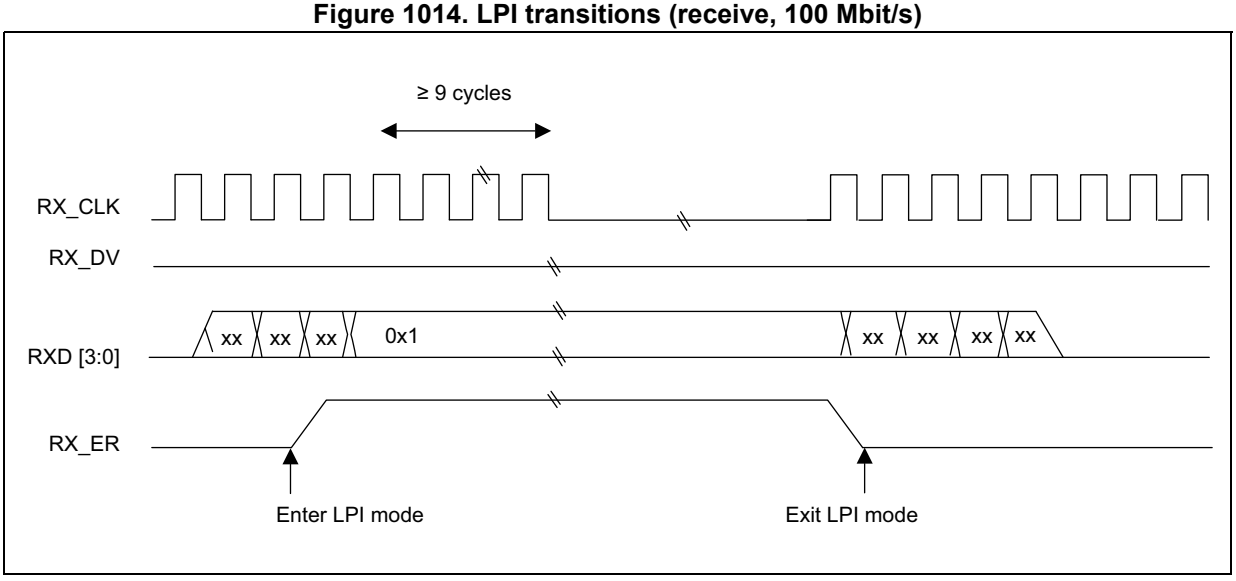
If the duration between the end of the current Rx LPI pattern and the start of the next Rx LPI pattern is very short (that is, less than two Rx clock cycles), then the MAC exits and enters again the Rx LPI mode. The MAC does not trigger the Rx LPI Exit and Entry interrupts.

When the PHY receives signals from the link partner to exit the LPI state, the PHY and MAC perform the following tasks:

1. The PHY de-asserts RX_ER and returns to a normal inter-packet state.
2. The MAC updates the RLPIEX bit of the *LPI control and status register (ETH_MACLCSR)* and generates an interrupt immediately. The sideband signal lpi_intr_o (synchronous to Rx clock) is also asserted.

Figure 1014 shows the behavior of RX_ER, RX_DV, and RXD[3:0] signals during the LPI mode transitions.

Figure 1014. LPI transitions (receive, 100 Mbit/s)



Note: If the RX_CLK_stoppable bit (in the PHY register written through MDIO) is asserted when the PHY is indicating LPI to the MAC, the PHY may halt the RX_CLK at any time more than nine clock cycles after the start of the LPI state as shown in Figure 1014.

If the MAC is in LPI mode and the application issues a soft reset or hard reset, the MAC receiver exits from LPI mode during reset. If the LPI pattern is still received after the reset is de-asserted, the MAC receiver enters again the LPI state.

If the RX clock is stopped in the RX LPI mode, the application should not write to the CSR registers that are being synchronized to the RX clock domain.

When the PHY sends the LPI pattern, if EEE feature is enabled, the MAC automatically enters the LPI state. There is no software control to prevent the MAC from entering the LPI state.

LPI timers

The transmitter maintains the LPI LS TIMER, LPI TW TIMER, and LPI AUTO ENTRY TIMER timers.

The following LPI timers are loaded with the respective values from the *LPI timers control register (ETH_MACLTCR)* and *LPI entry timer register (ETH_MACLETR)*:

- LPI LS TIMER

  The LPI LS TIMER counts, in milliseconds, the time expired since the link status is up.

  This timer is cleared every time the link goes down. It starts to increment when the link is up again and continues to increment until the value of the timer becomes equal to the terminal count. Once the terminal count is reached, the timer remains at the same value as long as the link is up. The terminal count is the value programmed in the LST[9:0] bitfield in the *LPI timers control register (ETH_MACLTCR)*. The LPI LS TIMER is 10-bit wide. The software can program up to 1023 milliseconds.
- LPI TW TIMER

  The LPI TW TIMER counts, in microseconds, the time expired since the de-assertion of LPI. The terminal count should be programmed in Bit[15:0] of *LPI timers control register (ETH_MACLTCR)*. The terminal count of the timer is the value of resolved Transmit TW that is the auto-negotiated time after which the MAC can resume the normal transmit operation. After exiting the LPI mode, the MAC resumes its normal operation after the TW timer reaches the terminal count.

  The MAC supports the LPI TW TIMER in units of microsecond. The LPI TW TIMER is 16-bit wide. Therefore, the software can program up to 65535 micro seconds.
- LPI AUTO ENTRY TIMER

  This timer counts in steps of eight microseconds, the time for which the MAC transmit path has to remain in idle state (no activity), before the MAC transmitter enters the LPI IDLE state and starts transmitting the LPI pattern. This timer is enabled when LPITE bit in *LPI control and status register (ETH_MACLCSR)* is set.

LPI interrupt

The MAC generates the LPI interrupt when the Tx or Rx side enters or exits the LPI state. The interrupt sbd_intr_o is asserted when the LPI interrupt status is set. The LPI interrupt can be cleared by reading the *LPI control and status register (ETH_MACLCSR)*.

When the MAC exits the Rx LPI state, then in addition to the sbd_intr_o, the sideband signal lpi_intr_o (synchronous to Rx clock) is asserted. The lpi_intr_o signal can be used to trigger the external clock-gating circuitry to restore the application clock to the MAC. The lpi_intr_o signal, synchronous to the Rx clock domain, is provided so that the application clock can be stopped by software when the MAC is in the LPI state. It is ORed with pmt_intr_o signal (see *Section : PMT interrupt*) and tied to the EXTI peripheral.

The lpi_intr_o signal is generated in the Rx clock domain. It may not be cleared immediately after the *LPI control and status register (ETH_MACLCSR)* is read. This is because the clear signal, generated in CSR clock domain, has to cross the Rx clock domain, and then clear the interrupt source. This delay is at least four clock cycles of Rx clock and can be significant when the peripheral is operating in the 10 Mbit/s mode.

Programming guidelines for Energy Efficient Ethernet

For detailed guidelines on the programming guidelines, see *Section 69.9.11: Programming guidelines for Energy Efficient Ethernet (EEE) on page 3584*.

69.8 Ethernet interrupts

The Ethernet peripheral generates a single interrupt signal (eth_sbd_intr_it). This signal can be raised as a result of various events. These events are captured in status registers and interrupt enables are provided for each source of interrupt such that the interrupt signal is asserted for an event only when the corresponding interrupt enable is set.

The interrupt status and corresponding enable registers are organized in a hierarchical manner so that it is easier for software to traverse and identify the source of interrupt event quickly. When interrupt is asserted, the *Interrupt status register (ETH_DMAISR)* register is first level that indicates the major blocks for the interrupt event source. This register is read-only, and it contains bits corresponding to each DMA channel (TX & RX pair), the MTL, and the MAC. The software application must then read one (or more) of the following registers corresponding to the bits that are set:

- ETH_DMACSR: channel status (see *Channel status register (ETH_DMACSR)*))
- ETH_MTLISR: interrupt status (see *Interrupt status register (ETH_MTLISR)*)
- ETH_MACISR: interrupt status (see *Interrupt status register (ETH_MACISR)*)

69.8.1 DMA interrupts

Interrupt registers description

The ETH_DMACSR: Channel status register (see *Channel status register (ETH_DMACSR)*) captures all the interrupt events of that TxDMA and RxDMA channel. The ETH_DMACIER: Channel interrupt enable register (see *Channel interrupt enable register (ETH_DMACIER)*) contains the corresponding enable bits for each of the interrupt event.

There are two groups of interrupts in the DMA channel namely Normal and Abnormal interrupts.They are indicated by Bits[15:14] of ETH_DMACSR register respectively. The normal group is for events that happen during the normal transfer of packets (TI: transmit interrupt, RI: receive interrupt, TBU: Transmit buffer unavailable) while the abnormal interrupt events are for error events.

Interrupts are not queued. If the same interrupt event occurs again before the driver responds to the previous one, no additional interrupts are generated. An interrupt is generated only once for multiple events. The driver must scan the *Interrupt status register (ETH_DMAISR)* for the cause of the interrupt and clear the source in the respective Status register. The interrupt is cleared only when all the bits of *Interrupt status register (ETH_DMAISR)* are cleared.

Receive idle timer

The Receive DMA provides multiple options to generate and regulate the occurrence of a Receive interrupt (RI) in the *Channel status register (ETH_DMACSR)*, after an ingress packet is transferred to the host memory.

Among these is an option to generate an RI event when the Receive DMA receives and transfers a receive packet after a long gap or time interval.

The option is enabled by writing a nonzero value to the ITW[4:0] bitfield of the*Channel Rx interrupt watchdog timer register (ETH_DMACRXIWTR)*. The time interval depends on the programming of this bitfield.

When the option is enabled, this timer restarts when an RI event occurs for which the following apply:

- The RIE bit is set and the RI status bit is cleared.
- The RI status bit is cleared and RIE is programmed.

Equally, the timer stops and is cleared, and no further action is taken if a new packet is received before the timer expiry due.

If the timer expires before the next Receive packet is completely transferred to the host memory, then an RI event is logged and the interrupt is asserted irrespective of the setting of the IOC bit. The other timers in the *Channel Rx interrupt watchdog timer register (ETH_DMACRXIWTR)* continue to operate as specified. The timer starts only after a packet is transferred without a corresponding RI event.

For programming guidelines on the Receive idle timer, see *Section 69.9.16: Programming guidelines for receive idle and receive interrupt watchdog timers*

Descriptor refetch when the OWN bit is cleared

By default, the DMA engine checks the OWN bit (xDES3[31]) of the descriptor to confirm whether the descriptor content is valid and can be processed. If the OWN bit is cleared, it drops the descriptor.

If, however, bit 26 of the *Channel control register (ETH_DMACCR)* is set, the automatic refetch operation is enabled. In this case, when the DMA engine determines that the OWN bit is cleared, it attempts to refetch the same descriptor. If the OWN bit is still cleared, the DMA engine enters Suspend mode and waits for the software to wake it up by writing into or by updating the tail pointer register, which generates the xBU interrupt.

The description refetch operation may also be required to ensure that the synchronization of the descriptor field update by the application does not generate any error.

For programming guidelines on the descriptor refetch, see *Programming guidelines for descriptor refetch when the OWN bit is cleared*.

Periodic scheduling of transmit and receive interrupt

It is not preferable to generate interrupts for every packet transferred by DMA (RI and TI) for system throughput performance reasons. The Ethernet peripheral gives the flexibility to schedule the interrupt at regular intervals using two methods:

1. Set Interrupt on Completion bit in Transmit descriptor (TDES2[31] in *Table 804: TDES2 normal descriptor (read format)*) once for every “required” number of packets to be transmitted.
2. Similarly, set the IOC (RDES3[30] in*Table 817: RDES3 normal descriptor (read format)*) bit only at some specific intervals of Receive descriptors. This way, whenever a received packet transfer to system memory is complete and any of the descriptors used for that packet transfer has the IOC bit set, only then the RI event is generated.

In addition to above, an interrupt timer called *Channel Rx interrupt watchdog timer register (ETH_DMACRXIWTR)* is given for flexible control and periodic scheduling of the receive interrupt. When this interrupt timer is programmed with a nonzero value, it gets activated as soon as the Rx DMA completes a transfer of a received packet to system memory without asserting the Receive interrupt because the corresponding interrupt of completion IOC bit (RDES3[30] in*Table 817: RDES3 normal descriptor (read format)*) is not set. When this timer runs out as per the programmed value, RI bit is set and the interrupt is asserted if the corresponding RIE is enabled in ETH_DMACIER register (see *Channel interrupt enable*

register (ETH_DMACIER)). The timer is stopped and cleared before it expires, if the RI is set for a packet transfer whose descriptor's IOC was set. The timer is reactivated automatically after the next packet transfer is complete without the RI event being generated.

Receive interrupt watchdog timer

When the DMA channel receives a packet and an SOP is detected, an internal timer starts.

This timer accumulates the packet size extracted from the received packet status (expressed in bytes) over the number of packets received, starting with the packet for which the Receive DMA does not assert the Receive interrupt (RI) because the corresponding interrupt of completion (IOC), namely the DES3[30]bit, is not set.

When the number of accumulated bytes per packet equals or exceeds the programmed value, if the corresponding RIE is enabled in the *Channel interrupt enable register (ETH_DMACIER)*, then the RI bit is set and the interrupt is asserted.

If the RI bit is set for a packet transfer whose descriptor IOC was set, or if the interrupt timer expires, the timer is stopped and cleared. The timer is reactivated automatically after the next packet transfer for which the RI event is not generated is complete.

For programming guidelines on the Receive interrupt watchdog timer, see *Section 69.9.16: Programming guidelines for receive idle and receive interrupt watchdog timers*.

Channel transfer complete interrupt

The transmit transfer complete interrupt (TI) and receive transfer complete interrupt (RI) is reflected in the channel status register (*Channel status register (ETH_DMACSR)*). The TI bit is set whenever the Tx DMA channel closes the descriptor in which the IOC bit is set (Interrupt On Completion - TDES2[31]). Similarly, the RI bit is set whenever the Rx DMA channel closes the descriptor with the LD bit set and, in any of the descriptors used for transferring that packet, IOC bit is set (Interrupt Enable on completion - RDES3[30])).

The interrupt signal is asserted for the Transfer complete interrupts only when the corresponding interrupts are enabled in the channel interrupt enable register (*Channel interrupt enable register (ETH_DMACIER)*).

The behavior of the RI/TI interrupts changes depending on the settings of INTM field (bits[17:16]) in the ETH_DMAMR register (*DMA mode register (ETH_DMAMR)*). *Table 801* explains the behavior of the Transfer Complete interrupt.

Table 801. Transfer complete interrupt behavior

Interrupt mode	Behavior of TI/RI and interrupt signal
INTM=0	The TI/RI status signals are set whenever the Transfer complete event is detected. These bits are cleared whenever the software driver writes 1 to these bits. The interrupt signal is asserted whenever the corresponding interrupts are also enabled in the ETH_DMACIER register.

Table 801. Transfer complete interrupt behavior

Interrupt mode	Behavior of TI/RI and interrupt signal
INTM=1	The TI/RI is set as explained above. However, the interrupt is not asserted for any RI/TI event.
INTM=2	The RI/TI status bits are set whenever the Transfer Complete event is detected and are reset whenever software driver clears them by writing 1. However, if another Transfer complete event is detected before it is cleared (serviced) by the software, then these status bits are automatically set again. However, the interrupt is not generated based on TI/RI.

69.8.2 MTL interrupts

MTL interrupt events are combined with the events in the DMA to generate the interrupt signal.

The register *Interrupt status register (ETH_MTLISR)* report the queue number responsible for the event. ETH_MTLQICSR: Queue interrupt control status must be read for event description.

The MTL interrupts are enabled by default. Each event can be prevented from asserting the interrupt by setting the corresponding mask bits in the *Interrupt status register (ETH_MTLISR)* register.

MTL interrupt signal is driven by one of these events:

- Receive queue overflow interrupt
- Transmit queue underflow

69.8.3 MAC interrupts

MAC interrupt events are combined with the events in the DMA to generate the interrupt signal.

The MAC interrupts are of level type, that is, the interrupt remains asserted (high) until it is cleared by the application or software.

The *Interrupt status register (ETH_MACISR)* describes the events that can cause an interrupt from the MAC. The MAC interrupts are enabled by default. Each event can be prevented from asserting the interrupt by setting the corresponding mask bits in the *Interrupt status register (ETH_MACISR)*.

The interrupt register bits only indicate the block from which the event is reported. You must read the corresponding status registers and other registers to clear the interrupt.

MAC interrupt signal is driven by one of these events:

- Receive status interrupt
- Transmit status interrupt
- Timestamp interrupt status
- MMC interrupt status
  - MMC receive checksum offload interrupt status
  - MMC transmit interrupt status
  - MMC Receive interrupt status
- LPI interrupt status
- PMT interrupt status
- PHY interrupt

Note: Two sidebands signals are generated together with LPI and PMT interrupts: lpi_intr_o and pmt_intr_o. They are used for wake-up event detection at EXTI level.

69.9 Ethernet programming model

This chapter provides the instructions for initializing the DMA or MAC registers in the proper sequence. It contains the following sections:

- DMA initialization (see *Section 69.9.1*)
- MTL initialization (see *Section 69.9.2*)
- MAC initialization (see *Section 69.9.3*)
- Performing normal receive and transmit operation (see *Section 69.9.4*)
- Stopping and starting transmission (see *Section 69.9.5*)
- Programming guidelines for MII link state transitions (see *Section 69.9.8*)
- Programming guidelines for IEEE 1588 timestamping (see *Section 69.9.9*)
- Programming guidelines for energy-efficient Ethernet (see *Section 69.9.11*)
- Programming guidelines for flexible pulse-per-second (PPS) output (see *Section 69.9.12*)
- Programming guidelines for IEEE 1588 auxiliary snapshot (see *Section 69.9.13*)
- Programming guidelines for TSO (see *Section 69.9.14*)
- Programming guidelines for VLAN filtering on the receiver (see *Section 69.9.15*)
- Programming guidelines for receive idle and receive interrupt watchdog timers (see *Section 69.9.16*)

69.9.1 DMA initialization

Complete the following steps to initialize the DMA:

1. Provide a software reset to reset all MAC internal registers and logic (bit 0 of *DMA mode register (ETH_DMAMR)*).
2. Wait for the completion of the reset process (poll bit 0 of the *DMA mode register (ETH_DMAMR)*, which is cleared when the reset operation is completed).
3. Program the following fields to initialize the *System bus mode register (ETH_DMASBMR)*:
   a) AAL
   b) Fixed burst or undefined burst
   c) Burst mode values in case of AHB bus interface.
4. Create a transmit and a receive descriptor list. In addition, ensure that the receive descriptors are owned by the DMA (set bit 31 of TDES3/RDES3 descriptor). For more information on descriptors, refer to *Section 69.10: Descriptors*.

Note: Descriptor address from start to end of the ring should not cross the 4GB boundary.

5. Program ETH_DMACTXRLR and ETH_DMACRXRLR registers (see *Channel Tx descriptor ring length register (ETH_DMACTXRLR)* and *Channel Rx descriptor ring length register (ETH_DMACRXRLR)*). The programmed ring length must be at least 4.
6. Initialize receive and transmit descriptor list address with the base address of transmit and receive descriptor (*Channel Tx descriptor list address register (ETH_DMACTXDLAR)*, *Channel Rx descriptor list address register (ETH_DMACRXDLAR)*). In addition, program the transmit and receive tail pointer registers that inform the DMA about the available descriptors (see *Channel Tx descriptor tail pointer register (ETH_DMACTXDTPR)* and *Channel Rx descriptor tail pointer register (ETH_DMACRXDTPR)*).
7. Program ETH_DMACCR, ETH_DMACTXCR and ETH_DMACRXCR registers (see *Channel control register (ETH_DMACCR)*, *Channel transmit control register (ETH_DMACTXCR)* and *Channel receive control register (ETH_DMACRXCR)*) to configure the parameters such as the maximum burst-length (PBL) initiated by the DMA, descriptor skip lengths, OSP for TxDMA, RBSZ[13:0] for RxDMA, and so on.
8. Enable the interrupts by programming the ETH_DMACIER register (see *Channel interrupt enable register (ETH_DMACIER)*).
9. Start the receive and transmit DMAs by setting SR (bit 0) of *Channel receive control register (ETH_DMACRXCR)* and ST (bit 0) of the ETH_DMACTXCR (see *Channel transmit control register (ETH_DMACTXCR)*).

69.9.2 MTL initialization

Complete the following steps to initialize the MTL registers:

1. Program the following fields to initialize the operating mode in *Tx queue operating mode register (ETH_MTLTXQOMR)*.
   a) Transmit store and forward (TSF) or transmit threshold control (TTC) if the Threshold mode is used.
2. Program the following fields to initialize the operating mode in the ETH_MTLRXQOMR register (see *Rx queue operating mode register (ETH_MTLRXQOMR)*):
   a) Receive store and forward (RSF) or RTC if Threshold mode is used.
   b) Flow control activation and deactivation thresholds for MTL Receive FIFO (RFA and RFD).
   c) Error packet and undersized good packet forwarding enable (FEP and FUP).
   d) Receive queue size (RQS).

69.9.3 MAC initialization

The MAC configuration registers establish the operating mode of the MAC. If possible, these registers must be initialized before initializing the DMA. The following MAC Initialization operations can also be performed after DMA initialization. If the MAC initialization is complete before the DMA is configured, enable the MAC receiver (last step in the following sequence) only after the DMA is active. Otherwise, received frames fill the Rx FIFO and overflow.

1. Provide the MAC address registers: *MAC address x low register (ETH_MACAxLR)*, *MAC address 0 high register (ETH_MACA0HR)* and *MAC address x high register (ETH_MACAxHR)*.
2. Program the following fields to set the appropriate filters for the incoming frames in the *Packet filtering control register (ETH_MACPFR)*:
   a) Receive All.
   b) Promiscuous mode.
   c) Hash or Perfect Filter.
   d) Unicast, multicast, broadcast, and control frames filter settings.
3. Program the following fields for proper flow control in the *Tx Queue flow control register (ETH_MACQTXFCR)*:
   a) Pause time and other Pause frame control bits.
   b) Transmit Flow control bits.
   c) Flow Control Busy.
4. Program the *Interrupt enable register (ETH_MACIER)* as required, if it is applicable for your configuration.
5. Program the appropriate fields in the *Operating mode configuration register (ETH_MACCR)* register. For example, Inter-packet gap while transmission and jabber disable.
6. Set bit 0 and 1 in *Operating mode configuration register (ETH_MACCR)* register to start the MAC transmitter and receiver.

To support Jumbo Transmit/Receive packets, follow these steps:

- In the *Operating mode configuration register (ETH_MACCR)*
  a) Set JE bit to 1.
  b) Set JD and WD bits to 0 to avoid giant packet error reporting.
  c) Set GPSLCE bit to 1
  d) Set GPSL bitfield of the *Extended operating mode configuration register (ETH_MACECR)* to a value > 9026

To support Transmit/Receive packets, up to 16K, follow these steps:

- In the *Operating mode configuration register (ETH_MACCR)*
  a) Set JD and WD bits to 1 to avoid giant packet error reporting.
  b) Set GPSLCE bit to 1.
  c) Set GPSL bitfield of the *Extended operating mode configuration register (ETH_MACECR)* to 16383.

69.9.4 Performing normal receive and transmit operation

For normal operation, complete the following steps:

1. For normal transmit and receive interrupts, read the interrupt status. Then, poll the descriptor by reading the status of the descriptor owned by the Host (either transmit or receive).
2. Set the descriptors to appropriate values. Make sure that transmit and receive descriptors are owned by the DMA to resume the transmission and reception of data.
3. If the descriptors are not owned by the DMA (or no descriptor is available), the DMA goes into Suspend state. The transmission or reception can be resumed by freeing the descriptors and writing the ETH_DMACTXDTPR (see *Channel Tx descriptor tail pointer register (ETH_DMACTXDTPR)* and ETH_DMACRXDTPR (see *Channel Rx descriptor tail pointer register (ETH_DMACRXDTPR)*).
4. In debug mode, the values of the current host transmitter or receiver descriptor address pointer can be read in ETH_DMACCATXDR and ETH_DMACCARXDR registers (see *Channel current application transmit descriptor register (ETH_DMACCATXDR)* and *Channel current application receive descriptor register (ETH_DMACCARXDR)*).
5. In debug mode, the values of the current host transmit buffer address pointer and receive buffer address pointer can be read in ETH_DMACCATXDR and ETH_DMACCARXDR registers (see *Channel current application transmit descriptor register (ETH_DMACCATXDR)* and *Channel current application receive descriptor register (ETH_DMACCARXDR)*).

69.9.5 Stopping and starting transmission

Complete the following steps to pause the transmission for some time:

1. Disable the Transmit DMA (if applicable) by clearing Bit 0 (ST) of ETH_DMACTXCR register (see *Channel transmit control register (ETH_DMACTXCR)*).
2. Wait for any previous frame transmissions to complete. You can check this by reading the appropriate bits of *Tx queue debug register (ETH_MTLTXQDR)* (TRCSTS[1:0] is not 01 and TXQSTS = 0).
3. Disable the MAC transmitter and MAC receiver by clearing RE and TE bits of the *Operating mode configuration register (ETH_MACCR)* Register.
4. Disable the Receive DMA (if applicable), after making sure that the data in the Rx FIFO is transferred to the system memory (by reading the appropriate bits of *Tx queue debug register (ETH_MTLTXQDR)*, PRXQ=0 and RXQSTS[1:0] = 00).
5. Make sure that both Tx queue and Rx queue are empty (TXQSTS is 0 in *Tx queue debug register (ETH_MTLTXQDR)* and RXQSTS[1:0] is set to 00.
6. To restart the operation, first start the DMAs, and then enable the MAC transmitter and receiver.

Note: Do not change the configuration (such as duplex mode, speed, port, or loopback) when the MAC is actively transmitting or receiving. These parameters are changed by software only when the MAC transmitter and receiver are not active.

Similarly, do not change the DMA-related configuration when transmit and receive DMA are active.

69.9.6 Programming guidelines for switching to new descriptor list in RxDMA

Switching to a new descriptor list is different in the Rx DMA compared to the Tx DMA. Switching to a new descriptor list is permitted when the RxDMA is in Suspend state, as explained below:

- Generally, RxDMA prepares the descriptors in advance.
- If the RxDMA goes to Suspend state due to descriptors not being available, a major failure occurs (software is not able to free the filled-up descriptors/buffers). If this issue is not rectified immediately, frames are lost because of an RxFIFO overflow. Therefore, the software is allowed to create a new descriptor list and program the RxDMA to start using it immediately, without going into Stop state.

69.9.7 Programming guidelines for switching the AHB clock frequency

To dynamically change the AHB clock frequency (without applying soft reset or hard reset), follow these steps:

1. Disable the Transmit DMA (if applicable) and wait for any previous frame transmissions to complete. When the frame transmissions is complete, the Tx FIFO becomes empty and the Tx DMA enters Stop state. The Tx FIFO status is given in the *Tx queue debug register (ETH_MTLTXQDR)* and the status of DMA is given in *Debug status register (ETH_DMADSR)*.
2. Disable the MAC transmitter and the MAC receiver by clearing the appropriate bits in *Operating mode configuration register (ETH_MACCR)*.

3. Disable the Receive DMA (if applicable) after making sure that the data in the Rx FIFO is transferred to the system memory. The Rx FIFO empty status is given in *Rx queue debug register (ETH_MTLRXQDR)*.
4. Ensure that the application does not perform any register read or write operation.
5. Change the frequency of the AHB clock.
6. Enable the MAC transmitter or the MAC receiver and the Transmit or Receive DMA. These steps ensure that no valid data is present in the Tx FIFO or Rx FIFO at the time of clock frequency switching and prevent any data corruption.

69.9.8 Programming guidelines for MII link state transitions

Transmit and receive clocks are running when the link is down

Complete the following steps when the link is down while the transmit and receive clocks are running:

1. Disable the Transmit DMA (if applicable) by clearing bit 0 (ST) of *Channel control register (ETH_DMACCR)*.
2. Disable the MAC receiver by clearing RE bit of *Operating mode configuration register (ETH_MACCR)*.
3. Wait for any previous frame transmissions to complete. You can check this by reading the appropriate bits of *Tx queue debug register (ETH_MTLTXQDR)* (TRCSTS[1:0] is not 01).

   or

   Flush the Tx FIFO for faster empty operation.
4. Disable the MAC transmitter by clearing TE bit of the *Operating mode configuration register (ETH_MACCR)* Register.
5. Make sure that both Tx and Rx queues are empty (TXQSTS is set to 0 in *Tx queue debug register (ETH_MTLTXQDR)* and RXQSTS[1:0] to 00 in *Rx queue debug register (ETH_MTLRXQDR)*).
6. After the link is up, read the PHY registers to identify the latest configuration and program the MAC registers accordingly.
7. Restart the operation by starting the Tx DMA. Then enable the MAC transmitter and receiver.

   The Rx DMA does not need to be enabled: since the receiver is disabled, there are no data in the Rx FIFO.

Transmit and receive clocks are stopped when the link is down

Complete the following steps when the link is down and the transmit and receive clocks are stopped:

1. Disable the MAC transmitter and receiver by clearing RE and TE bits in the *Operating mode configuration register (ETH_MACCR)*. This does not take immediate effect as the clocks are absent.
2. Wait till the link is up and the clocks are restored.
3. Wait until the transfer of any partial frame is complete if any was ongoing when the Transmit/Receive clock is stopped. This can be checked by reading the *Debug register (ETH_MACDR)* (all bits should be set to 0). Some old packets may still remain in the TXFIFO as the MAC transmitter is stopped.

4. Read the PHY registers to identify the latest operating mode and program the MAC registers accordingly.
5. Restart the MAC transmitter and receiver by setting RE and TE bits.

69.9.9 Programming guidelines for IEEE 1588 timestamping

Initializing the System time generation

The timestamp feature can be enabled by setting bit 0 of the *Timestamp control register (ETH_MACTSCR)*. However, it is essential that the timestamp counter is initialized after this bit is set. Complete the following steps to perform the peripheral initialization:

1. Mask the Timestamp Trigger interrupt by clearing bit 12 of *Interrupt enable register (ETH_MACIER)*.
2. Set bit 0 of *Timestamp control register (ETH_MACTSCR)* to enable timestamping.
3. Program *Subsecond increment register (ETH_MACSSIR)* based on the PTP clock frequency.
4. If you use the Fine Correction method, program *Timestamp addend register (ETH_MACTSAR)* and set bit 5 of *Timestamp control register (ETH_MACTSCR)*.
5. Poll the *Timestamp control register (ETH_MACTSCR)* until bit 5 is cleared.
6. Program bit 1 of *Timestamp control register (ETH_MACTSCR)* to select the Fine Update method (if required).
7. Program *System time seconds update register (ETH_MACSTSUR)* and *System time nanoseconds update register (ETH_MACSTNUR)* with the appropriate time value.
8. Set bit 2 in *Timestamp control register (ETH_MACTSCR)*.

   The timestamp counter starts as soon as it is initialized with the value written in the timestamp update registers. If one-step timestamping is required:

   a) Enable one-step timestamping by programming bit 27 of the TDES3 Context Descriptor.

   b) Program *Timestamp ingress asymmetric correction register (ETH_MACTSIACR)* to update the correction field in PDelay_Req PTP messages.
9. Enable the MAC receiver and transmitter for proper timestamping.

Note: If timestamp operation is disabled by clearing bit 0 of Timestamp control register (ETH_MACTSCR), repeat all these steps to restart the timestamp operation.

System time correction

To synchronize or update the system time in one shot (coarse correction method), complete the following steps:

1. Set the offset (positive or negative) in the timestamp update registers (*System time seconds update register (ETH_MACSTSUR)* and *System time nanoseconds update register (ETH_MACSTNUR)*).
2. Set bit 3 (TSUPDT) of the *Timestamp control register (ETH_MACTSCR)*.

   The value in the timestamp update registers is added to or subtracted from the system time when the TSUPDT bit is cleared.

To synchronize or update the system time to reduce system-time jitter (fine correction method), complete the following steps:

1. With the help of the algorithm described in *Section : System time register module*, calculate at which rate you intend to increment or decrement the system time.
2. Update the *Timestamp addend register (ETH_MACTSAR)* with the new value and set bit 5 of the *Timestamp control register (ETH_MACTSCR)* Register.
3. Wait for the time during which you want the new value of the Addend register to be active. This can be done by enabling the Timestamp Trigger interrupt after the system time reaches the target value.
4. Program the required target time in *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*.
5. Enable the Timestamp interrupt in bit 12 of *Interrupt enable register (ETH_MACIER)*.
6. Set bit 3 in Register *Timestamp control register (ETH_MACTSCR)*.
7. When this trigger generates an interrupt, read *Interrupt status register (ETH_MACISR)*.
8. Reprogram *Timestamp addend register (ETH_MACTSAR)* with the old value and set bit 5 again.

69.9.10 Programming guidelines for PTP offload feature

Programming guidelines to enable automatic periodic generation of PTP sync messages

Follow these steps to enable automatic periodic generation of PTP sync messages:

1. Program SNAPTYPSEL, TSMSTRENA, and TSEVNTENA fields of *Timestamp control register (ETH_MACTSCR)* to 0, 1, and 1 respectively, to configure the node as Ordinary or Boundary Master (1, 1, and 1 for Transparent Master).
2. Program the PTOEN bit and DN field of *PTP offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain number to send in egress PTP Sync message.
3. Program the ASYNCEN bit of *PTP offload control register (ETH_MACPOCR)* to enable periodic generation of PTP Sync messages.
4. Program the 80-bit Source Port Identity in *PTP source port identity 0 register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to send in egress PTP Sync message.
5. Program the LSI field of *Log message interval register (ETH_MACLMIR)* to program the periodicity of the PTP Sync messages.

   For example, a value of 1 corresponds to 2^1 which translates to PTP Sync message every 2 seconds, and a value of 0xFF (twos complement of -1) corresponds to 2^{-1} which translates to PTP Sync message every 0.536 seconds.
6. Program the TSIE bit of *Interrupt enable register (ETH_MACIER)* to enable generation of Timestamp interrupt.
7. Wait for sbd_intr_o interrupt generated by setting TXTSSIS bit in *Timestamp status register (ETH_MACTSSR)*. It indicates that the timestamp for PTP Sync message is captured in *Tx timestamp status seconds register (ETH_MACTXTSSSR)* and *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)*.

Programming guidelines to enable periodic generation of PTP Pdelay_Req messages

Follow these steps to enable automatic periodic generation of PTP Pdelay_Req messages

1. Program SNAPTYPSEL, TSMSTRENA and TSEVNTENA fields of *Timestamp control register (ETH_MACTSCR)* to 1, 0, and 1 respectively to configure the node as Transparent Slave (1, 1, and 1 for Transparent Master OR 3, X, and X for Peer-to-Peer Transparent).
2. Program the PTOEN bit and DN field of *PTP offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain number to send in egress PTP Pdelay_Req message.
3. Program the APDREQEN bit of *PTP offload control register (ETH_MACPOCR)* to enable periodic generation of PTP Pdelay_Req messages.
4. Program the 80-bit Source Port Identity in *PTP source port identity 0 register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to send in egress PTP Pdelay_Req message.
5. Program the LMPDRI field of *Log message interval register (ETH_MACLMIR)* to program the periodicity of the PTP Pdelay_Req messages.

   For example, a value of 1 corresponds to 2^1 which translates to PTP Pdelay_Req message every 2 seconds, and a value of 0xFF (twos complement of -1) corresponds to 2^{-1} which translates to PTP Pdelay_Req message every 0.536 seconds.
6. Program the TSIE bit of *Interrupt enable register (ETH_MACIER)* to enable generation of Timestamp interrupt.
7. Wait for sbd_intr_o interrupt generated by setting TXTSSIS bit in *Timestamp status register (ETH_MACTSSR)*. It indicates that the timestamp for PTP Sync message is captured in *Tx timestamp status seconds register (ETH_MACTXTSSSR)* and *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)*.

Programming guidelines to enable the generation of PTP response messages for Ordinary or Boundary Master mode

Follow these steps to enable the generation of PTP response messages for Ordinary or Boundary Master mode (Periodic PTP Sync messages generated and PTP Delay_Resp message generated in response to PTP Delay_Req message):

1. Program SNAPTYPSEL, TSMSTRENA and TSEVNTENA fields of *Timestamp control register (ETH_MACTSCR)* to 0, 1, and 1 respectively.
2. Program the PTOEN bit and DN field of *PTP offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain number to match with ingress PTP Delay_Req message and send in egress PTP Delay_Resp message.
3. Program the 80-bit Source Port Identity in *PTP source port identity 0 register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to match with ingress PTP Delay_Req message and send in egress PTP Delay_Resp message.
4. Program the DRSYNCR and LSI fields in *Log message interval register (ETH_MACLMIR)*. The sum of both fields is updated in logMinDelayReqInterval field of PTP Delay_Resp message.

Programming guidelines to enable the generation of PTP response messages for Ordinary or Boundary Slave mode

Follow these steps to enable generation of PTP response messages for Ordinary or Boundary Slave mode (PTP Delay_Req message generated in response to PTP Sync message):

1. Program SNAPTYPSEL, TSMSTRENA and TSEVNTENA fields of *Timestamp control register (ETH_MACTSCR)* to 0, 0, and 1 respectively.
2. Program the PTOEN bit and DN field of *PTP offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain Number to match with ingress PTP Sync message and send in egress PTP Delay_Req message.
3. Program the 80-bit Source Port Identity in *PTP source port identity 0 register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to match with ingress PTP Sync message and send in egress PTP Delay_Req message.
4. Program the DRSYNCR field in *Log message interval register (ETH_MACLMIR)* to indicate one PTP Delay_Req message is generated in response to how many received PTP Sync messages.

Programming guidelines to enable the generation of PTP response messages for Transparent Slave mode

Follow these steps to enable generation of PTP response messages for Transparent Slave mode (PTP Delay_Req message generated in response to PTP Sync message, PTP Pdelay_Resp message generated in response to PTP Pdelay_Req message and Periodic PTP Pdelay_Req messages generated)

1. Program SNAPTYPSEL, TSMSTRENA and TSEVNTENA fields of *Timestamp control register (ETH_MACTSCR)* to 1, 0, and 1 respectively.
2. Program the PTOEN bit and DN field of *PTP offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain Number to match with ingress PTP Sync or Pdelay_Req message and send in egress PTP Delay_Req or Pdelay_Resp or Pdelay_Req message.
3. Program the 80-bit Source Port Identity in *PTP source port identity 0 register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to match with ingress PTP Sync or Pdelay_Req message and send in egress PTP Delay_Req or Pdelay_Resp or Pdelay_Req message.
4. Program the DRSYNCR and LMPDRI fields in *Log message interval register (ETH_MACLMIR)* to indicate one PTP Delay_Req message is generated in response to how many received PTP Sync messages and periodicity of the PTP Pdelay_Req messages.
5. Program the TSIE bit of *Interrupt enable register (ETH_MACIER)* to enable generation of Timestamp interrupt.
6. Wait for sbd_intr_o interrupt generated by setting TXTSSIS bit in *Timestamp status register (ETH_MACTSSR)*. It indicates that the timestamp for PTP Sync message is captured in *Tx timestamp status seconds register (ETH_MACTXTSSSR)* and *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* for egress PTP Pdelay_Req and Pdelay_Resp messages.

Programming guidelines to enable the generation of PTP response messages for Transparent Master mode

Follow these steps to enable generation of PTP response messages for Transparent Master mode (PTP Delay_Resp message generated in response to PTP Delay_Req message, PTP Pdelay_Resp message generated in response to PTP Pdelay_Req message and Periodic PTP Pdelay_Req or Sync messages generated):

1. Program SNAPTYPSEL, TSMSTRENA and TSEVNTENA fields of *Timestamp control register (ETH_MACTSCR)* to 1, 1, and 1 respectively.
2. Program the PTOEN bit and DN field of *PTP offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain number to match with ingress PTP Delay_Req or Pdelay_Req message and send in egress PTP Delay_Resp or Pdelay_Resp or Pdelay_Req or Sync message.
3. Program the 80-bit Source Port Identity in *PTP source port identity 0 register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to match with ingress PTP Delay_Req or Pdelay_Req message and send in egress PTP Delay_Resp or Pdelay_Resp or Pdelay_Req or Sync message.
4. Program the DRSYNCR, LSI and LMPDRI fields in *Log message interval register (ETH_MACLMIR)*, the sum of DRSYNCR and LSI is updated in logMinDelayReqInterval field of PTP Delay_Resp message and periodicity of the PTP Sync or Pdelay_Req messages.
5. Program the TSIE bit of *Interrupt enable register (ETH_MACIER)* to enable generation of Timestamp interrupt.
6. Wait for sbd_intr_o interrupt generated by setting TXTSSIS bit in *Timestamp status register (ETH_MACTSSR)*. It indicates that the timestamp for PTP Sync message is captured in *Tx timestamp status seconds register (ETH_MACTXTSSSR)* and *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* for egress PTP Sync, Pdelay_Req and Pdelay_Resp messages.

Programming guidelines to enable the generation of PTP response messages for Peer-to-Peer Transparent mode

Follow these steps to enable generation of PTP response messages for Peer-to-Peer Transparent mode (PTP Pdelay_Resp message generated in response to PTP Pdelay_Req message and Periodic PTP Pdelay_Req messages generated):

1. Program the SNAPTYPSEL, TSMSTRENA and TSEVNTENA fields of *Timestamp control register (ETH_MACTSCR)* to 3, X, and X respectively.
2. Program the PTOEN bit and DN field of *PTP offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain Number to match with ingress PTP Pdelay_Req message and send in egress PTP Pdelay_Resp message.
3. Program the 80-bit Source Port Identity in *PTP source port identity 0 register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to match with ingress PTP Pdelay_Req message and send in egress PTP Pdelay_Resp message.
4. Program the LMPDRI field in *Log message interval register (ETH_MACLMIR)* to indicate periodicity of the PTP Pdelay_Req messages

5. Program the TSIE bit of *Interrupt enable register (ETH_MACIER)* to enable generation of Timestamp interrupt
6. Wait for sbd_intr_o interrupt generated by setting TXTSSIS bit in *Timestamp status register (ETH_MACTSSR)*. It indicates that the timestamp for PTP Sync message is captured in *Tx timestamp status seconds register (ETH_MACTXTSSSR)* and *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* for egress PTP Pdelay_Req and Pdelay_Resp messages.

69.9.11 Programming guidelines for Energy Efficient Ethernet (EEE)

Entering and exiting Tx LPI mode

EEE enables the IEEE 802.3 Media Access Control (MAC) sublayer along with a family of physical layers to operate in the Low-power idle (LPI) mode. In the Transmit path, the software must set the LPIEN bit of the *LPI control and status register (ETH_MACLCSR)* to indicate to the MAC to stop transmission and initiate the LPI protocol.

Complete the following steps during MAC initialization:

1. Read the PHY register through the MDIO interface and check if the remote end has the EEE capability. Then negotiate the timer values.
2. Program the PHY registers through the MDIO interface (including the RX_CLK_stoppable bit that indicates to the PHY whether to stop Rx clock in LPI mode or not).
3. Program bits 25 to 16 and bits 15 to 0 in *LPI timers control register (ETH_MACLTCR)*.
4. Read the PHY link status by using the MDIO interface and update bit 17 of *LPI control and status register (ETH_MACLCSR)*.

   Update *LPI control and status register (ETH_MACLCSR)* accordingly. This update should be done whenever the link status in the PHY chip changes.
5. Program *One-microsecond-tick counter register (ETH_MAC1USTCR)* as per the frequency of the clock used for accessing the CSR slave port.
6. Program the LPIET bit in the *LPI entry timer register (ETH_MACLETR)* with the IDLE time for which the MAC should wait before entering the LPI state on its own.
7. Set LPITE and LPITXA (bits 20 to 19) of *LPI control and status register (ETH_MACLCSR)* to enable LPI auto-entry and MAC auto-exit from LPI state.
8. Set bit 16 of *LPI control and status register (ETH_MACLCSR)* to put the MAC transmitter in LPI state.

   The MAC enters the LPI state when all scheduled packets are completed. It remains IDLE for the time indicated by LPIET bits. It sets the TLPIEN (bit 0) after entering LPI state.
9. When a packet transmission is scheduled (when the TxDMA exits IDLE state or when a packet is presented at ATI or MTI interface), the MAC transmitter automatically exits LPI state. It waits for TWT time before setting the TLPIEX interrupt status bit and then resume the packet transmission.
10. The MAC transmitter enters again LPI state if it remains IDLE for LPIET time. It then sets the TLPIEN bit and the entry-exit cycle continues.
11. Reset LPIEN bit if the application needs to override the auto-entry/exit modes and directly exit the MAC transmitter from LPI state.

Note: To make sure the MAC enters the LPI state only after the transmission of all the queued frames in the Tx FIFO is complete, set LPITXA bit in LPI control and status register (ETH_MACLCSR).

To switch off the CSR clock or power to the rest of the system during the LPI state, wait for the TLPIEN interrupt of LPI control and status register (ETH_MACLCSR) to be generated. Restore the clocks before performing step 6 when you want to come out of the LPI state.

Gating Off the CSR Clock in the LPI mode

You can gate off the CSR clock to save the power when the MAC is in the Low-Power Idle (LPI) mode.

Gating off the CSR clock in the Rx LPI mode

The following operations are performed when the MAC receives the LPI pattern from the PHY:

1. The MAC RX enters the LPI mode and the Rx LPI entry interrupt status (RLPIEN interrupt of *LPI control and status register (ETH_MACLCSR)*) is set.
2. The interrupt pin (sbd_intr_o) is asserted. The sbd_intr_o interrupt is cleared when the host reads the *LPI control and status register (ETH_MACLCSR)*.

After the sbd_intr_o interrupt is asserted and the MAC Tx is also in the LPI mode, the CSR clock can be gated off. If the MAC TX is not in LPI mode when the CSR clock is gated off, the events on the MAC transmitter do not get reported or updated in the CSR. To restore the CSR clock, wait for the LPI exit indication from the PHY after which the MAC asserts the LPI exit interrupt on lpi_intr_o (synchronous to clk_rx_i). The lpi_intr_o interrupt is cleared when *LPI control and status register (ETH_MACLCSR)* is read.

Gating off the CSR clock in the Tx LPI mode

The following operations are performed when bit 16 (LPIEN) of *LPI control and status register (ETH_MACLCSR)* is set:

1. The Transmit LPI Entry interrupt (TLPIEN bit of *LPI control and status register (ETH_MACLCSR)*) is set.
2. The interrupt pin (sbd_intr_o) is asserted. The sbd_intr_o interrupt is cleared when the host reads the *LPI control and status register (ETH_MACLCSR)*.

After the sbd_intr_o interrupt is asserted and the MAC RX is also in the LPI mode, the CSR clock can be gated off. If the MAC RX is not in LPI mode when the CSR clock is gated off, the events on the MAC receiver do not get reported or updated in the CSR. To restore the CSR clock, switch on the CSR clock when the MAC has exited TX LPI mode. After the CSR clock is resumed, reset bit 16 (LPIEN) of *LPI control and status register (ETH_MACLCSR)* to exit the MAC from LPI mode.

69.9.12 Programming guidelines for flexible pulse-per-second (PPS) output

Generating a single pulse on PPS

To generate a single pulse on PPS:

1. Program TRGTMODSEL[1:0] bit to 11 or 10 (for interrupt) in *PPS control register (ETH_MACPPSCR)*. This instructs the MAC to use the Target Time registers (*PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*) as start time of PPS signal output.
2. Program the start time value in the target time registers (register *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*).
3. Program the width of the PPS signal output in *PPS width register (ETH_MACPPSWR)* Register.
4. Program PPSCMD[3:0] of *PPS control register (ETH_MACPPSCR)* to 0001. This instructs the MAC to generate a single pulse on the PPS signal output at the time programmed in the Target Time registers.

Generating next pulse on PPS

When the PPSCMD is executed (PPSCMD bits = 0), you can cancel the pulse generation by giving the Cancel Start Command (PPSCMD=0011) before the programmed start time has elapsed. You can also program the behavior of the next pulse in advance. To program the next pulse:

1. Program the start time for the next pulse in the Target Time registers. This time should be higher than the time at which the falling edge occurs for the previous pulse.
2. Program the width of the next PPS signal output in *PPS width register (ETH_MACPPSWR)*.
3. Program PPSCMD[3:0] bits of *PPS control register (ETH_MACPPSCR)* to generate a single pulse after the previous pulse is deasserted. This instructs the MAC to generate a single pulse on the PPS signal output at the time programmed in Target Time registers.

   If this command is given before the previous pulse becomes low, then the new command overwrites the previous command and the peripheral may generate only 1 extended pulse.

Generating a pulse train on PPS

To generate a pulse train on PPS:

1. Program TRGTMODSEL[1:0] bits to 11 or 10 (for interrupt) in *PPS control register (ETH_MACPPSCR)*. This instructs the MAC to use the Target Time registers (*PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*) for start time of the PPS signal output.
2. Program the start time value in the Target Time registers (register *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*).
3. Program the interval value between the train of pulses on the PPS signal output in *PPS interval register (ETH_MACPPSIR)*.
4. Program the width of the PPS signal output in *PPS width register (ETH_MACPPSWR)*.

5. Program PPSCMD[3:0] bits in *PPS control register (ETH_MACPPSCR)* to 0010. This instructs the MAC to generate a train of pulses on the PPS signal output at the start time programmed in Target Time registers.

   By default, the PPS pulse train is free-running unless it is stopped by issuing a 'STOP Pulse train at time' or 'STOP Pulse Train immediately' commands.
6. Program the stop value in the Target Time registers. Ensure that TSTRBUSY bit in *PPS target time nanoseconds register (ETH_MACPPSTTNR)* is reset before programming the Target Time registers again.
7. Program the PPSCMD[3:0] bits in *PPS control register (ETH_MACPPSCR)* to 0100 to stop the train of pulses on PPS signal output after the programmed stop time specified at step 6 has elapsed.

The pulse train can be stopped at any time by programming 0101 in the PPSCMD[3:0] field.

Similarly, the Stop Pulse train command (given in Step 7) can be canceled by programming PPSCMD[3:0] bits to 0110 before the time (programmed at step 6) has elapsed.

The pulse train generation can be stopped by programming PPSCMD[3:0] to 0011 before the start time programmed at step 2) has elapsed.

Generating an interrupt without affecting the PPS

TRGTMODSEL[1:0] bits in *PPS control register (ETH_MACPPSCR)* enable you to program the Target Time registers (*PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*) to do any one of the following:

- Generate only interrupts.
- Generate interrupts and the PPS start and stop time.
- Generate only PPS start and stop time.

To program the Target Time registers to generate only interrupt event:

1. Program TRGTMODSEL[1:0] bits of *PPS control register (ETH_MACPPSCR)* to 00 (for interrupt). This instructs the MAC to use the Target Time registers for target time interrupt.
2. Program a target time value in the Target Time registers. This instructs the MAC to generate an interrupt when the target time elapses.

   If TRGTMODSEL[1:0] bits are changed (for example, to control the PPS), then the interrupt generation is overwritten with the new mode and new programmed Target Time register value.

Note: The TSTRGTERR0 bit in Timestamp status register (ETH_MACTSSR) is set when the programmed target time is smaller (that is corresponds to a time in the past) compared to the system time in the System time seconds register (ETH_MACSTSR) and System time nanoseconds register (ETH_MACSTNR).

An interrupt is generated (sbd_intr_o) if the TSIE bit in the Interrupt enable register (ETH_MACIER) is set.

Therefore, to avoid unwanted interrupts, the correct writing order is as follows:

1. *PPS target time nanoseconds register (ETH_MACPPSTTNR).*
2. *PPS target time seconds register (ETH_MACPPSTTSR).*
3. *PPS interval register (ETH_MACPPSIR).*
4. *PPS width register (ETH_MACPPSWR).*
5. *PPSCTRL[3:0] and PPSCTRL[3:0] and PPSEN0 bitfields of PPS control register (ETH_MACPPSCR).*

69.9.13 Programming guidelines for IEEE 1588 auxiliary snapshot

The IEEE 1588 auxiliary snapshot function is used to capture the auxiliary snapshot for a trigger event received on the eth_ptp_aux_ts_trig_i input.

To program the IEEE 1588 auxiliary snapshot function, complete the following steps:

1. Program the TSIE bit in the *Interrupt enable register (ETH_MACIER)* to enable interrupt generation when the auxiliary snapshot is captured in the FIFO.
2. Program the ATSENx bit of the *Auxiliary control register (ETH_MACACR)* to enable the capture of the auxiliary snapshot based on the respective trigger input.
3. If the software does not want the captured auxiliary snapshot to be read, program the ATSFC bit of *Auxiliary control register (ETH_MACACR)* anytime to clear the auxiliary snapshot FIFO.
4. When TSIS is set or an interrupt is generated (due to TSIE programmed to 1), read the *Timestamp status register (ETH_MACTSSR)*, *Tx timestamp status seconds register (ETH_MACTXTSSSR)*, and *Auxiliary timestamp nanoseconds register (ETH_MACATSNR)* to access the captured auxiliary snapshot.

Note: When the auxiliary snapshot is captured in the FIFO for a trigger event, the following bitfields are updated:

- *AUXTSTRIG (status bit indicating that an auxiliary snapshot has been captured), ATSSTN (trigger event input source identifying the first available entry in the FIFO), and ATSNS (indicating the number of auxiliary snapshots available in the FIFO) bitfields of the Timestamp status register (ETH_MACTSSR).*
- *TSIS (indicating that an interesting event occurred in the IEEE 1588 timestamp function) bitfield in the Interrupt status register (ETH_DMAISR).*

The AUXTSTRIG bit is cleared on read (or set when the RCWE bit of the CSR software control register (ETH_MACCSRSWCR) is set).

Note: When the captured auxiliary snapshot is ignored because that the FIFO is full, the ATSSTM bit, which indicates that a trigger has been missed, is set.

69.9.14 Programming guidelines for TSO

The TCP segmentation offload (TSO) engine is used to offload the TCP segmentation functions to the hardware. To program the TSO, set the TSE bit to enable TCP packet segmentation, and program descriptor fields to enable TSO for the current packet.

Follow the steps below to program TSO:

1. Program TSE bit of the corresponding *Channel transmit control register (ETH_DMACTXCR)* to enable TCP packet segmentation in that DMA.
2. In addition to the normal transfer descriptor setting, the following descriptor fields must be programmed to enable TSO for the current packet:
   a) Enable TSE of TDES3 (bit 18).
   b) Program the length of the unsegmented TCP/IP packet payload in bits 17 to 0 of TDES3, and the TCP header in bits 22 to 19 of TDES3.
   c) Program the maximum size of the segment in:
   – MSS[13:0] of *Channel control register (ETH_DMACCR)*
   – or MSS in the context descriptor

   If MSS[13:0] field is programmed in both *Channel control register (ETH_DMACCR)* and in the context descriptor, the latest software programmed sequence is considered.
3. The unsegmented TCP/IP packet header should be stored in Buffer 1 of the first descriptor. This buffer must not hold any payload bytes. The payload is allocated to Buffer 2 and the buffers of the subsequent descriptors.

Caution: If TSE is enabled in TDES3 for a non-TCP-IP packet, the result is unpredictable.

69.9.15 Programming guidelines to perform VLAN filtering on the receiver

Follow the sequence below to perform VLAN filtering on the receiver:

1. Program *VLAN tag register (ETH_MACVTR)* for the following bit to select the filtering method:
   – ETV: Enable 12-bit VLAN Tag Comparison or 16-bit VLAN Tag comparison.
   – VTHM: VLAN Tag Hash Table Match Enable.
   – ERIVLT: Enable inner VLAN Tag or outer VLAN Tag (to enable the inner or outer VLAN Tag filtering, Double VLAN Processing should enabled by setting EDVLP)
   – ERSVLM: Enable Receive S-VLAN Match or C-VLAN match (for S-VLAN processing to be enabled, set ESVL)
   – DOVLTC: Ignores VLAN Type for Tag Match
   – VTIM: to enable VLAN Tag Inverse Match instead of the normal VLAN Tag matching
2. Program VL bit in *VLAN tag register (ETH_MACVTR)* for the 12-bit or 16-bit VLAN tag.
3. If VLAN tag Hash filtering is enabled, program *VLAN Hash table register (ETH_MACVHTR)*.
   – When the ETV bit is reset, the upper 4 bits of the calculated CRC-32 of VLAN tag are inverted and used to index the content of the *VLAN Hash table register (ETH_MACVHTR)*.
   – When ETV bit is set, the upper 4 bits of the calculated CRC-32 of VLAN tag are used to index the content of *VLAN Hash table register (ETH_MACVHTR)*.

   For example, when ETV bit is set, a hash value of 0b1000 selects bit 8 of the VLAN Hash table. When ETV bit is reset, a hash value of 0b1000 selects bit 7 of the VLAN Hash table.

69.9.16 Programming guidelines for receive idle and receive interrupt watchdog timers

Programming guidelines for the receive idle timer

Follow these steps to enable the receive idle timer.

1. Program the ITW[4:0] bitfield of the *Channel Rx interrupt watchdog timer register (ETH_DMACRXIWTR)* with a nonzero value to enable the Idle timer.
2. Use the ITCU[1:0] bitfield of the *Channel Rx interrupt watchdog timer register (ETH_DMACRXIWTR)* to define the number of application clock cycles per unit in the ITW[4:0] bitfield.
3. Program the ITW[4:0] bitfield of the *Channel Rx interrupt watchdog timer register (ETH_DMACRXIWTR)* for a given channel to check the trigger condition for the Idle timer.
4. Program the RIE bit of the *Channel interrupt enable register (ETH_DMACIER)* to a timer value of ITW × ITCU application clock cycles.

Programming guidelines for the receive interrupt watchdog timer

Follow these steps to enable the receive interrupt watchdog timer.

1. Set the PSEL bit of the *Channel Rx interrupt watchdog timer register (ETH_DMACRXIWTR)* to set the receive watchdog timer to operate in received packet counter mode.
2. Clear the PSEL bit of the *Channel Rx interrupt watchdog timer register (ETH_DMACRXIWTR)* to set the timer to operate in received byte counter mode.
3. Program the RBCT[9:0] bitfield of the *Channel Rx interrupt watchdog timer register (ETH_DMACRXIWTR)* with a nonzero value to set the byte-per-packet threshold for the receive watchdog timer.

Programming guidelines for descriptor refetch when the OWN bit is cleared

The descriptor refetch checks the value of the OWN bit twice before the DMA engine enters Suspend mode.

To enable the refetch on both the transmit and receive sides, set the DRO bit of the *Channel control register (ETH_DMACCR)*.

69.10 Descriptors

69.10.1 Descriptor overview

In the Ethernet peripheral, the DMA transfers data based on a linked list of descriptors. The application creates the descriptors in the system memory (SRAM). The following two types of descriptors are supported:

- **Normal descriptors**

  The normal descriptors are used for packet data and to provide control information applicable to the packets to be transmitted.

- **Context descriptors**

  The context descriptors are used to provide control information applicable to the packet to be transmitted.

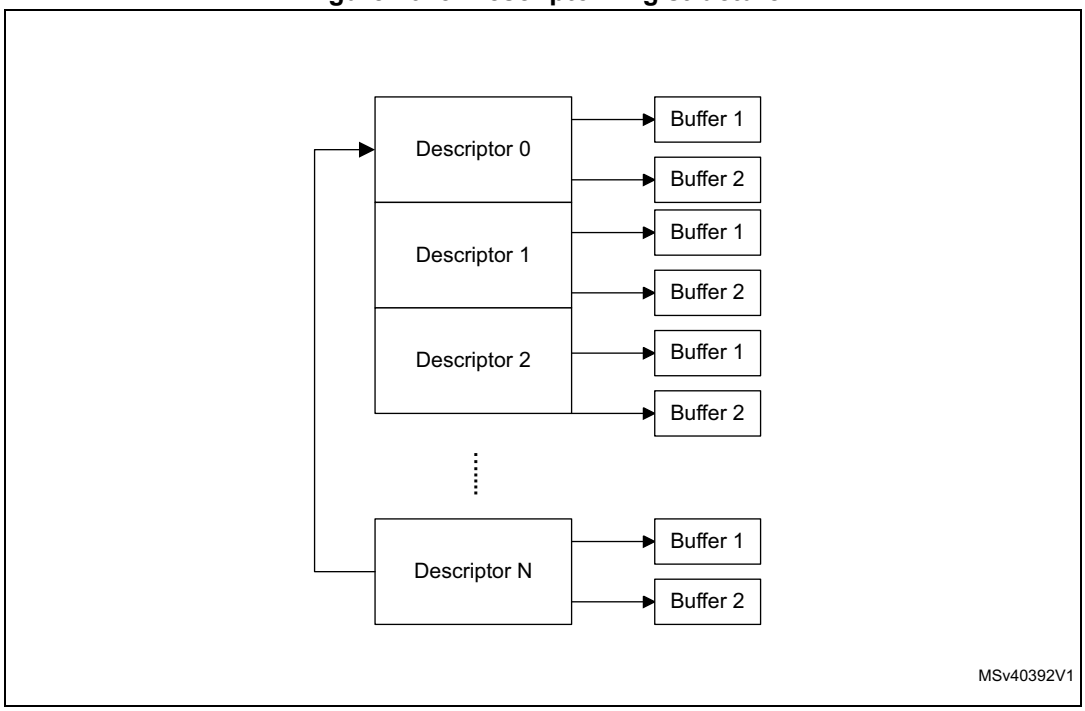
Each normal descriptor contains two buffers and two address pointers. These buffers enable the adapter port to be compatible with various types of memory management schemes.

There is no limit to the number of descriptors that can be used for a single packet.

69.10.2 Descriptor structure

The Ethernet peripheral supports the ring structure for DMA descriptors.

Figure 1015. Descriptor ring structure



In a ring structure, descriptors are separated by the 32-bit word number programmed in the DSL field of the *Channel control register (ETH_DMACCR)*). The application needs to program the total ring length, that is the total number of descriptors in ring span, in the following registers of a DMA channel:

- *Channel Tx descriptor ring length register (ETH_DMACTXRLR)*)
- *Channel Rx descriptor ring length register (ETH_DMACRXRLR)*)

The *Channel Tx descriptor tail pointer register (ETH_DMACTXDTPR)* or *Channel Rx descriptor tail pointer register (ETH_DMACRXDTPR)* contains the pointer to the descriptor address (*N*). The base address and the current descriptor pointer decide the address of the current descriptor that the DMA can process. The descriptors up to one location less than the one indicated by the descriptor tail pointer (*N* – 1) are owned by the DMA. The DMA continues to process the descriptors until the following condition occurs:

```
Current Descriptor Pointer == Descriptor Tail Pointer;
```

The DMA enters the Suspend state when this condition occurs. The application must perform a write operation to the descriptor tail pointer register and update the tail pointer so that the following condition is met:

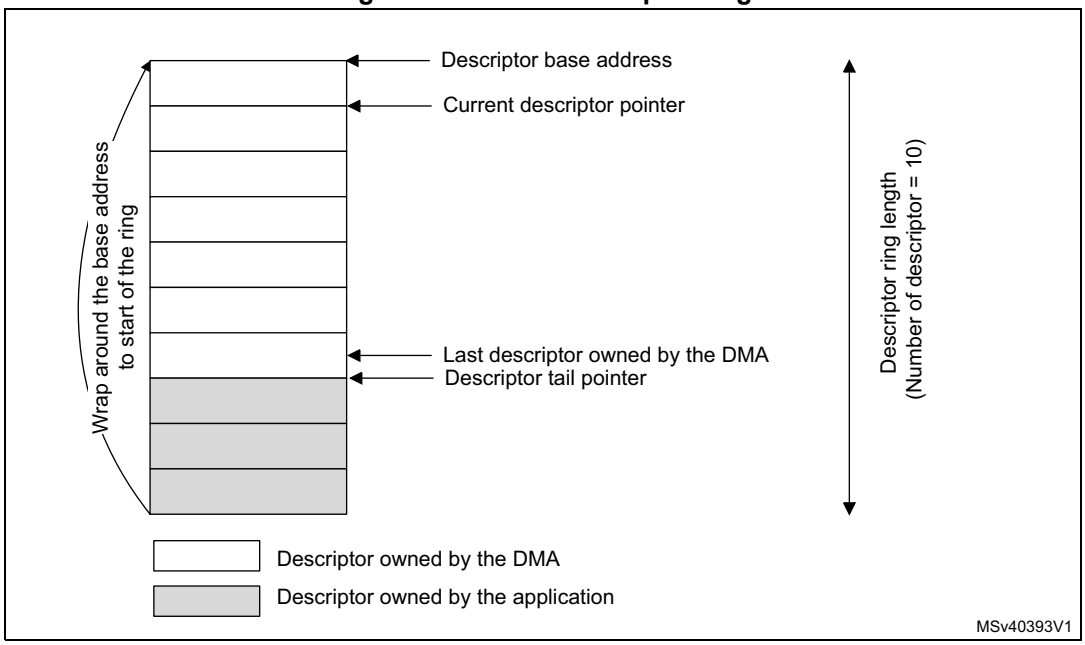
```
Descriptor Tail Pointer > Current Descriptor Pointer;
```

Note: When the application sets the descriptors into the end-of-descriptor ring, continues setting from the start of the descriptor list and updating the descriptor tail pointer, the above condition is not satisfied. The DMA detects such a case, processes the descriptors until the end of the ring and then continues processing from the start of the descriptor list until the current descriptor pointer is equal to the descriptor tail pointer.

When the application programs the descriptor tail pointer beyond the end of the descriptor ring, the DMA interprets this as the availability of one more complete ring of descriptors, and after processing the last descriptor in the ring continues to process descriptors from the start of the descriptor list. If this is not intended, the application must program the descriptor tail pointer to the start of the descriptor list after setting the last descriptor in the ring.

The DMA automatically wraps around the base address when the end of ring is reached, as shown in *Figure 1016: DMA descriptor ring*.

Figure 1016. DMA descriptor ring



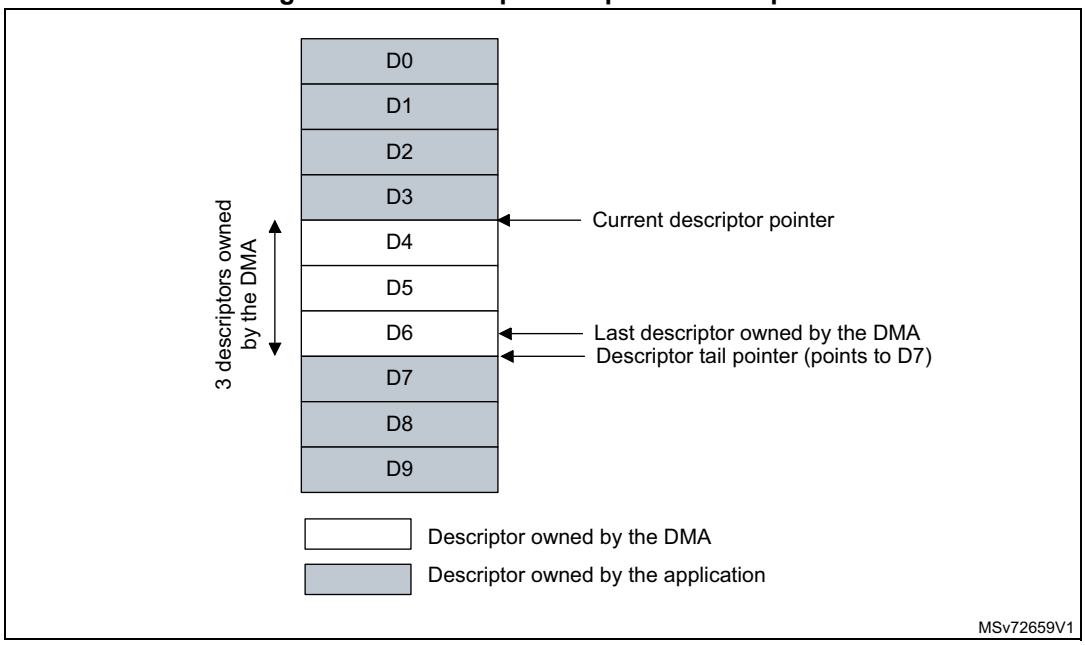
For descriptors owned by the application, the OWN bit of DES3 is reset to 0.

For descriptors owned by the DMA, the OWN bit is set to 1.

At the beginning, if the application has only one descriptor, it sets the last descriptor address (tail pointer) to Descriptor Base Address + 1. The DMA then processes the first descriptor and waits for the application to increment the tail pointer.

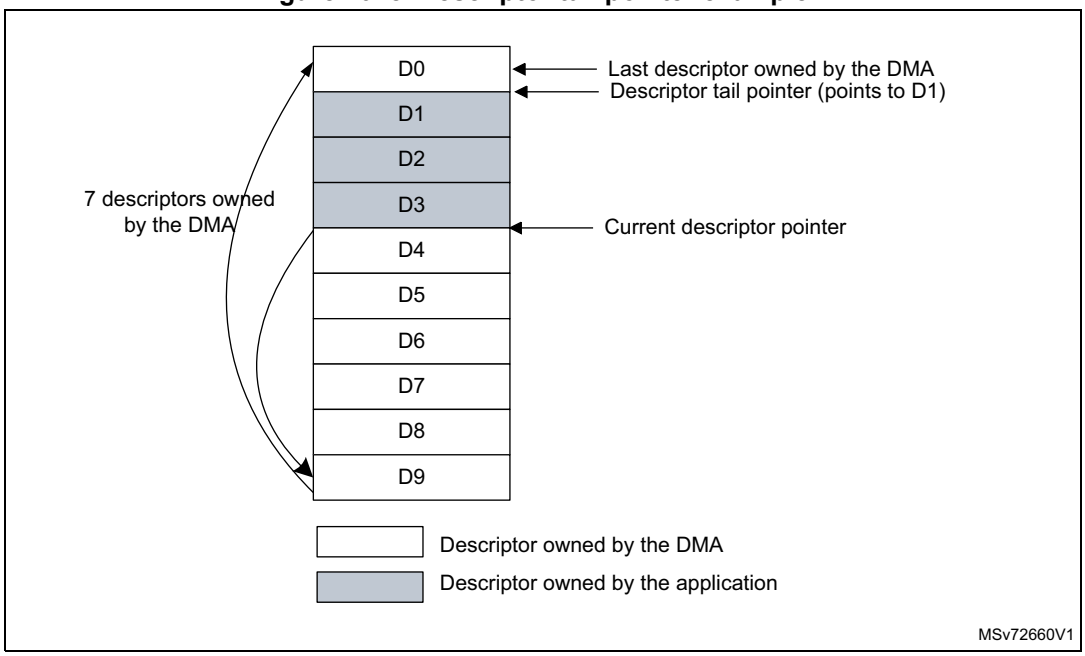
Descriptor tail pointer handling examples

Figure 1017. Descriptor tail pointer example 1



When the current descriptor pointer points to descriptor 4 (D4) and the descriptor tail pointer points to descriptor 7 (D7), the last descriptor owned by the DMA is descriptor 6 (D6) and there are three descriptors (D4, D5, D6) available for the DMA, as shown in *Figure 1017: Descriptor tail pointer example 1*.

Figure 1018. Descriptor tail pointer example 2



As shown in *Figure 1018: Descriptor tail pointer example 2*, the application frees four descriptors (D7, D8, D9 and D0) and updates the descriptor tail pointer to point to descriptor 1 (D1). The last descriptor owned by the DMA is descriptor 0 (D0). The descriptors referenced between the current descriptor pointer (D4) and the descriptor tail pointer (D1) are available to the DMA.

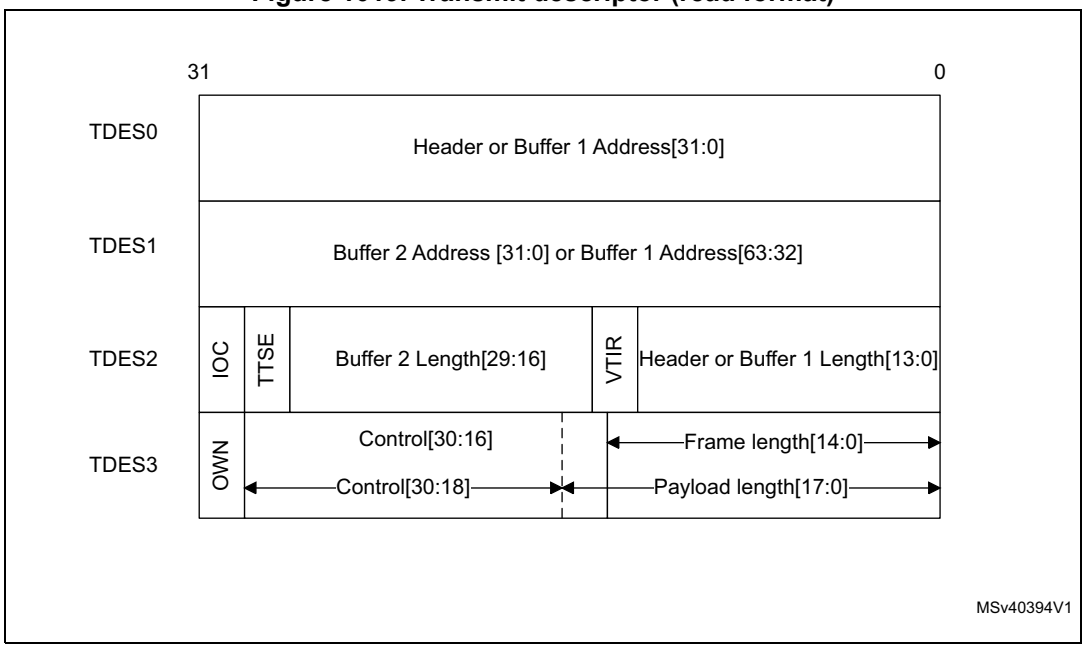
69.10.3 Transmit descriptor

The Ethernet peripheral DMA requires at least one descriptor for a transmit packet. In addition to two buffers, two byte-count buffers, and two address pointers, the transmit descriptor features control fields which can be used to manage the MAC operation on per-transmit packet basis. The Transmit normal descriptor has the following two formats: Read format and Write-back format.

Transmit normal descriptor (read format)

Figure 1019 shows the Read format for Transmit normal descriptor. *Table 802* to *Table 805* provide a detailed description of all Transmit normal descriptors (read format).

Figure 1019. Transmit descriptor (read format)



- TDES0 normal descriptor (read format)

Table 802. TDES0 normal descriptor (read format)

Bit	Name	Description
31:0	BUF1AP	**Buffer 1 address pointer or TSO header(1) address pointer** These bits indicate either the physical address of buffer 1 or the TSO header address pointer when the following bits are set: – TSE bit of TDES3 – FD bit of TDES3

1. TSO header means from the Ethernet source address to the end of the TCP header.

- TDES1 normal descriptor (read format)

Table 803. TDES1 normal descriptor (read format)

Bit	Name	Description
31:0	BUF2AP	**Buffer 2 or buffer 1 address pointer:** These bits indicate the physical address of buffer 2 when a descriptor ring structure is used. There is no limitation to the buffer address alignment.

- TDES2 normal descriptor (read format)

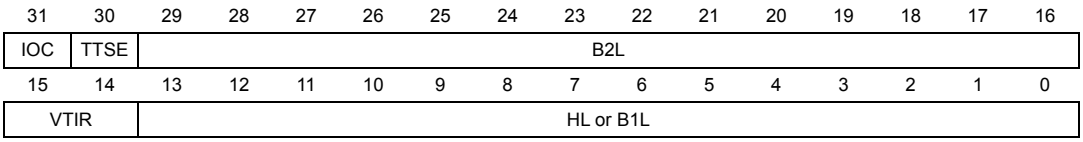


Table 804. TDES2 normal descriptor (read format)

Bits	Name	Description
31	IOC	**Interrupt on completion:** This bit sets the TI bit in the *Channel status register (ETH_DMACSR)*) when the present packet transmission is complete.
30	TTSE	**Transmit timestamp enable** This bit enables the IEEE1588 timestamping for the transmit packet referenced by the descriptor.
29:16	B2L	**Buffer 2 length** The driver sets this field. When set, this field indicates the buffer 2 length.
15:14	VTIR	**VLAN tag insertion or replacement:** These bits request the MAC to perform VLAN tagging or untagging before transmitting the packets. The application must set the CRC Pad Control bits appropriately when VLAN tag insertion, replacement, or deletion is enabled for the packet. The values of these bits are as follows: 00: Do not add a VLAN tag. 01: Remove the VLAN tag from the packets before transmission. This option should be used only with the VLAN packets. 10: Insert a VLAN tag with the tag value programmed in the *VLAN inclusion register (ETH_MACVIR)* or context descriptor. 11: Replace the VLAN tag in packets with the tag value programmed in the *VLAN inclusion register (ETH_MACVIR)* or context descriptor. This option should be used only with the VLAN packets.

Table 804. TDES2 normal descriptor (read format) (continued)

Bits	Name	Description
13:0	HL or B1L	**Header length or buffer 1 length** For Header length, only bits [9:0] are taken into account. Bits 13 to 0 are applicable only to buffer 1 length. If the TCP Segmentation Offload feature is enabled through the TSE bit of TDES3, this field is equal to the header length. When the TSE bit is set in TDES3, the header length includes the length (expressed in bytes) from the Ethernet source address until the end of the TCP header (Ethernet frame header, IP header, and TCP header). The maximum header length supported for TSO feature is 1023 bytes. If the TCP Segmentation Offload feature is not enabled, this field is equal to Buffer 1 length.

- TDES3 normal descriptor (read format)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OWN	CTXT	FD	LD	CPC		SAIC			THL				TSE	TPL	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FT/L															

Table 805. TDES3 normal descriptor (read format)

Bits	Name	Description
31	OWN	**Own bit** 1: the DMA owns the descriptor. 0: the application owns the descriptor. The DMA clears this bit after it completes the transfer of data given in the associated buffer(s).
30	CTXT	**Context Type** This bit should be set to 0 for normal descriptor.
29	FD	**First Descriptor** When this bit is set, it indicates that the buffer contains the first segment of a packet.
28	LD	**Last Descriptor** When this bit is set, it indicates that the buffer contains the last segment of the packet. B1L or B2L field should have a non-zero value.

Table 805. TDES3 normal descriptor (read format) (continued)

Bits	Name	Description
27:26	CPC	**CRC pad control** This field controls the CRC and Pad Insertion for Tx packet. It is valid only when the first descriptor bit (TDES3[29]) is set. The values of bits[27:26] are the following: 00: CRC and pad insertion The MAC appends the cyclic redundancy check (CRC) at the end of the transmitted packets whose length greater than or equal to 60 bytes. The MAC automatically appends padding and CRC to a packet with length less than 60 bytes. 01: CRC insertion (disable pad insertion) The MAC appends the CRC at the end of the transmitted packet but it does not append padding. The application should ensure that the padding bytes are present in the packet being transferred from the Transmit buffer, that is, the packet being transferred from the Transmit Buffer is of length greater than or equal to 60 bytes. 10: Disable CRC insertion The MAC does not append the CRC at the end of the transmitted packet. The application should ensure that the padding and CRC bytes are present in the packet being transferred from the Transmit Buffer. 11: CRC replacement The MAC replaces the last four bytes of the transmitted packet with recalculated CRC bytes. The application should ensure that the padding and CRC bytes are present in the packet being transferred from the transmit buffer. When the TSE bit is set, the MAC ignores this field because the CRC and pad insertion is always done for segmentation.
25:23	SAIC	**SA insertion control** These bits request the MAC to add or replace the Source Address field in the Ethernet packet with the value given in the MAC Address 0 register. The application must appropriately set the CRC Pad Control bits when SA Insertion Control is enabled for the packet. Bit 25 specifies the MAC address register (1 or 0) value that is used for source address insertion or replacement. The following list describes the values of Bits[24:23]: 00: Do not include the source address 01: Include or insert the source address. For reliable transmission, the application must provide frames without source addresses. 10: Replace the source address. For reliable transmission, the application must provide frames with source addresses. 11: Reserved These bits are valid when the First Segment control bit (TDES3 [29]) is set.
22:19	THL	**TCP header length** (in words) If the TSE bit is set, this field contains the length of the TCP/UDP header. The minimum value of this field must be 5 for TCP header. THL value must be equal to 2 for UDP header. This field is valid only for the first descriptor.
18	TSE	**TCP segmentation enable** When this bit is set, the DMA performs the TCP/UDP segmentation for a packet. This bit is valid only if the FD bit is set.

Table 805. TDES3 normal descriptor (read format) (continued)

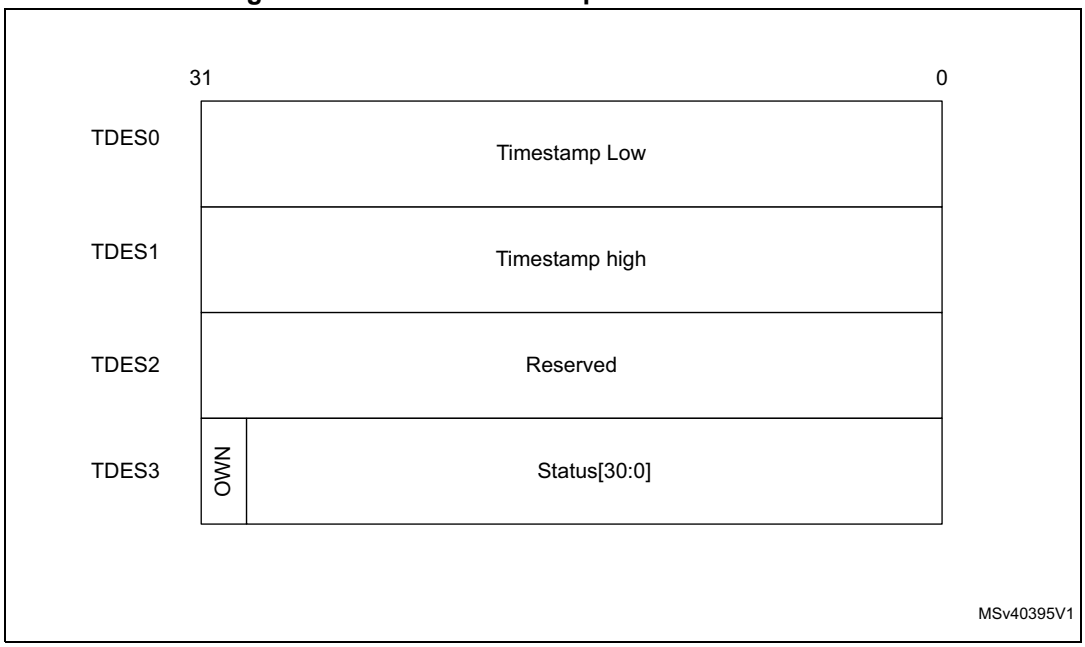
Bits	Name	Description
17:16	CIC/TPL	**Checksum insertion control or TCP payload length** These bits control the checksum calculation and insertion. They can take the following values: 00: Checksum insertion disabled. 01: Only IP header checksum calculation and insertion are enabled. 10: IP header checksum and payload checksum calculation and insertion are enabled, but pseudo-header checksum is not calculated in hardware. 11: IP header checksum and payload checksum calculation and insertion are enabled, and pseudo-header checksum is calculated in hardware. This field is valid when the TSE bit is reset.When the TSE bit is set, it contains the upper bits [17:16] of the TCP Payload length. This allows the TCP packet length field to be spanned across TDES3[17:0] to provide 256 Kbyte packet length support.
15	TPL	**Reserved or TCP payload length** When the TSE bit is reset, this bit is reserved. When the TSE bit is set, this is bit 15 of the TCP payload length [17:0].
14:0	FL/TPL	**Reserved or TCP payload length** When the TSE bit is set, this field is equal to the lower 15 bits of the TCP payload length. This length does not include Ethernet header or TCP/UDP/IP header length. When the TSE bit is reset, this bit is reserved.

Transmit normal descriptor (write-back format)

The write-back format is applicable only for the last descriptor of the corresponding packet. The LD bit (TDES3[28]) is set in the descriptor where the DMA writes back the status and timestamp information for the corresponding Transmit packet.

Figure 1020 shows the write-back format for Transmit normal descriptors. *Table 806* to *Table 809* provide a detailed description of all Transmit Normal descriptors (Write-Back Format).

Figure 1020. Transmit descriptor write-back format



- TDES0 normal descriptor (write-back format)

Table 806. TDES0 normal descriptor (write-back format)(1)

Bit	Name	Description
31:0	TTSL	**Transmit Packet Timestamp Low** The DMA updates this field with least significant 32 bits of the timestamp captured for the corresponding Transmit packet. The DMA writes the timestamp only if TTSE bit of TDES2 is set in the first descriptor of the packet. This field holds the timestamp only if the Last Segment bit (LS) in the descriptor is set and the Timestamp status (TTSS) bit is set.

1. This format is only applicable to the last descriptor of a packet.

- TDES1 normal descriptor (write-back format)

Table 807. TDES1 normal descriptor (write-back format)(1)

Bit	Name	Description
31:0	TTSH	**Transmit Packet Timestamp High** The DMA updates this field with the most significant 32 bits of the timestamp captured for corresponding receive packet. The DMA writes the timestamp only if the TTSE bit of TDES2 is set in the first descriptor of the packet. This field has the timestamp only if the Last Segment bit (LS) in the descriptor is set and Timestamp status (TTSS) bit is set.

1. This format is only applicable to the last descriptor of a packet.

- TDES2 normal descriptor (write-back format)

Table 808. TDES2 normal descriptor (write-back format)(1)

Bit	Description
31:0	Reserved

1. This format is only applicable to the last descriptor of a packet.

- TDES3 normal descriptor (write-back format)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OWN	CTXT	FD	LD	Reserved										TTSS	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ES	JT	FF	PCE	LoC	NC	LC	EC	CC				ED	UF	DB	IHE

Table 809. TDES3 normal descriptor (write-back format)(1)

Bit	Name	Description
31	OWN	**Own bit** When this bit is set, it indicates that the DMA owns the descriptor. The DMA clears this bit when it completes the packet transmission. After the write-back is complete, this bit is set to 0.
30	CTXT	**Context Type** This bit should be set to 0 for normal descriptors.
29	FD	**First Descriptor** This bit indicates that the buffer contains the first segment of a packet.
28	LD	**Last Descriptor** This bit is set 1 for last descriptor of a packet. The DMA writes the status fields only in the last descriptor of the packet.
27:24	Reserved	
23	DE	**Descriptor Error** When this bit is set, it indicates that the descriptor content is incorrect. The DMA sets this bit during write-back while closing the descriptor. Descriptor errors can be: – Incorrect sequence from the context descriptor, such as a location after the first descriptor for a packet. – All 1s. – CTXT is set to 1 along with LD or FD bits set to 1. *Note: When a Descriptor error occurs due to All 1s or CTXT, LD, and FD bits set to 1, the Transmit DMA closes the transmit descriptor with DE and LD bits set to 1. When IOC bit in TDES2 of corresponding first descriptor is set to 1, Transmit DMA sets the TI bit in the Channel status register (ETH_DMACSR).* *Based on CTXT, LD, and FD bits of the transmit descriptor, the subsequent descriptor might be considered as the First Descriptor (even if FD bit is not set) and partial packet is sent.*
22:18	Reserved	

Table 809. TDES3 normal descriptor (write-back format)(1) (continued)

Bit	Name	Description
17	TTSS	**Tx Timestamp Status** This status bit indicates that a timestamp has been captured for the corresponding transmit packet. When this bit is set, TDES0 and TDES1 have timestamp values that were captured for the Transmit packet. This field is valid only when the Last Segment control bit (TDES3 [28]) in a descriptor is set.
16	Reserved	
15	ES	**Error Summary** This bit indicates the logical OR of the following bits: TDES3[0]: IP Header Error TDES3[14]: Jabber timeout TDES3[13]: Packet Flush TDES3[12]: Payload Checksum Error TDES3[11]: Loss of Carrier TDES3[10]: No Carrier TDES3[9]: Late Collision TDES3[8]: Excessive Collision TDES3[3]: Excessive Deferral TDES3[2]: Underflow Error
14	JT	**Jabber timeout** This bit indicates that the MAC transmitter has experienced a jabber timeout. This bit is set only when the JD bit of the *Operating mode configuration register (ETH_MACCR)* is not set.
13	FF	**Packet Flushed** This bit indicates that the DMA or MTL flushed the packet because of a software flush command given by the CPU.
12	PCE	**Payload Checksum Error** This bit indicates that the Checksum Offload engine had a failure and did not insert any checksum into the encapsulated TCP, UDP, or ICMP payload. This failure can be either caused by insufficient bytes, as indicated by the Payload Length field of the IP Header, or by the MTL starting to forward the packet to the MAC transmitter in Store-and-Forward mode without the checksum having been calculated yet. This second error condition only occurs when the Transmit FIFO depth is less than the length of the Ethernet packet being transmitted to avoid deadlock, the MTL starts forwarding the packet when the FIFO is full, even in the store-and-forward mode. This error can also occur when a Bus error is detected during packet transfer.
11	LoC	**Loss of Carrier** This bit indicates that Loss of Carrier occurred during packet transmission (that is, the ETH_CRS signal was inactive for one or more transmit clock periods during packet transmission). This is valid only for the packets transmitted without collision and when the MAC operates in the Half-duplex mode.

Table 809. TDES3 normal descriptor (write-back format)(1) (continued)

Bit	Name	Description
10	NC	**No Carrier** This bit indicates that the carrier sense signal form the PHY was not asserted during transmission.
9	LC	**Late Collision** This bit indicates that packet transmission was aborted because a collision occurred after the collision window (64 byte times including Preamble in MII mode). This bit is not valid if Underflow Error is set.
8	EC	**Excessive Collision** This bit indicates that the transmission was aborted after 16 successive collisions while attempting to transmit the current packet. If the DR bit is set in the *Operating mode configuration register (ETH_MACCR)*, this bit is set after first collision and the transmission of the packet is aborted.
7:4	CC	**Collision Count** This 4-bit counter value indicates the number of collisions occurred before the packet was transmitted. The count is not valid when the EC bit is set.
3	ED	**Excessive Deferral** This bit indicates that the transmission ended because of excessive deferral of over 24,288 bit times if DC bit is set in the *Operating mode configuration register (ETH_MACCR)*.
2	UF	**Underflow Error** This bit indicates that the MAC aborted the packet because the data arrived late from the system memory. The underflow error can occur because of either of the following conditions: The DMA encountered an empty Transmit Buffer while transmitting the packet The application filled the MTL Tx FIFO slower than the MAC transmit rate The transmission process enters the Suspend state and sets the underflow bit corresponding to a queue in the ETH_MTLISR register.
1	DB	**Deferred Bit** This bit indicates that the MAC deferred before transmitting because of presence of carrier. This bit is valid only in the Half-duplex mode.
0	IHE	**IP Header Error** When IP Header Error is set, this bit indicates that the Checksum Offload engine detected an IP header error. If COE detects an IP header error, it still inserts an IPv4 header checksum if the Ethernet Type field indicates an IPv4 payload.

1. This format is only applicable to the last descriptor of a packet.

Transmit context descriptor

The Transmit context descriptor can be provided any time before a packet descriptor. The context is valid for the current packet and subsequent packets. The context descriptor is used to provide the timestamps for one-step timestamp correction, and VLAN Tag ID for VLAN insertion feature. Write-back is only done on a context descriptor to reset the OWN bit.

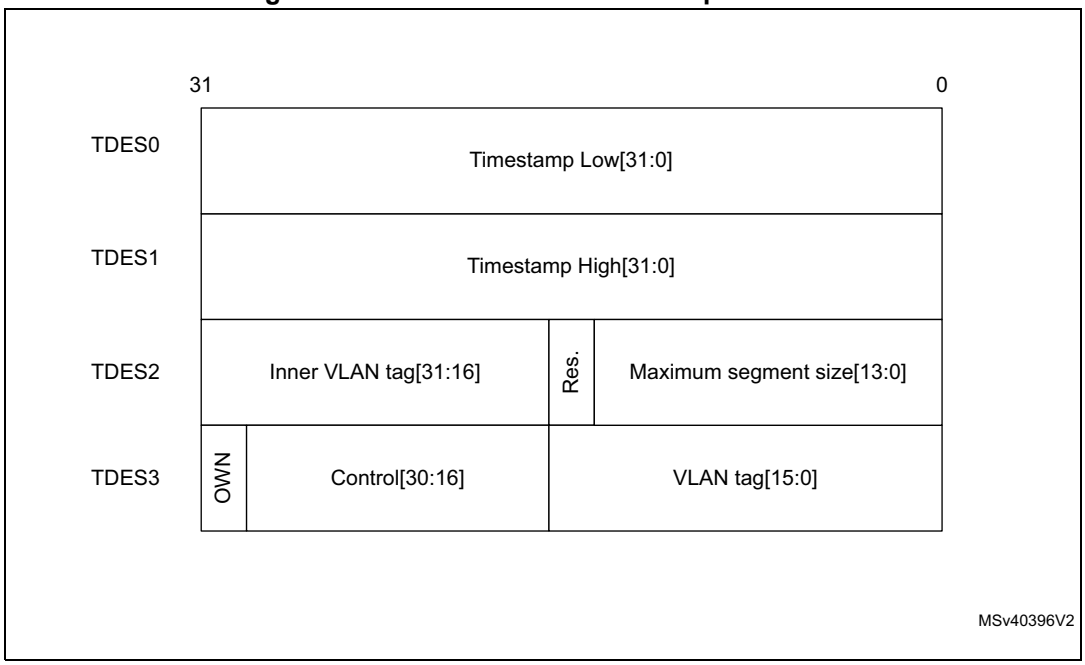
Note: The VLAN tag IDs and MSS values, which are provided by the application in a context descriptor with their corresponding Valid bits set, are stored internally by the DMA.

When the outer or inner VLAN tag is provided with the Valid bit set, the DMA always passes the last valid VLAN tag to the MTL. The application cannot invalidate the valid VLAN tag stored by the DMA. The VLAN tag is inserted or replaced based on the control inputs provided for the packet.

The Inner VLAN Tag Control input is used only for the packet that immediately follows the context descriptor. The application must provide a context descriptor before the normal descriptor of each packet for which the DMA should use the inner VLAN tag control input.

Figure 1021 shows the format for transmit context descriptors. *Table 810* to *Table 813* provide a detailed description of all transmit context descriptors.

Figure 1021. Transmit context descriptor format



- TDES0 context descriptor (read format)

Table 810. TDES0 context descriptor

Bit	Name	Description
31:0	TTSL	**Transmit Packet Timestamp Low** For one-step correction, the driver can provide the lower 32 bits of timestamp in this descriptor word. The DMA uses this value as the low word for doing one-step timestamp correction. This field is valid only if the OSTC and TCMSSV bits of TDES3 context descriptor are set.

- TDES1 context descriptor (read format)

Table 811. TDES1 context descriptor

Bit	Name	Description
31:0	TTSH	**Transmit Packet Timestamp High** For one-step correction, the driver can provide the upper 32 bits of timestamp in this descriptor. The DMA uses this value as the high word for doing one-step timestamp correction. This field is valid only if the OSTC and TCMSSV bits of TDES3 context descriptor are set.

- TDES2 context descriptor (read format)

Table 812. TDES2 context descriptor

Bit	Name	Description
31:16	IVT	**Inner VLAN Tag** When the IVLTV bit of TDES3 context descriptor is set and the TCMSSV and OSTC bits of TDES3 context descriptor are reset, TDES2[31:16] contains the inner VLAN Tag to be inserted in the subsequent Transmit packets.
15:14	Reserved	
13:0	MSS	**Maximum Segment Size** This segment size is used while segmenting the TCP/IP payload. This field is valid only if the TCMSSV bit of TDES3 context descriptor is set and the OSTC bit of the TDES3 context descriptor is reset.

- TDES3 context descriptor (read format)

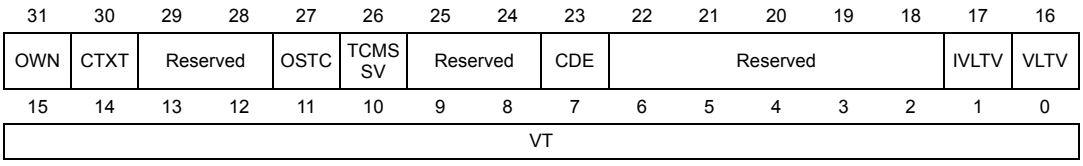


Table 813. TDES3 context descriptor

Bit	Name	Description
31	OWN	**Own bit** 1: the DMA owns the descriptor. 0: the application owns the descriptor. The DMA clears this bit immediately after a read operation.
30	CTXT	**Context Type** This bit should be set to 1 for context descriptor.
29:28	Reserved	
27	OSTC	**One-Step Timestamp Correction Enable** When this bit is set, the DMA performs a one-step timestamp correction with reference to the timestamp values provided in TDES0 and TDES1.
26	TCMSSV	**One-Step Timestamp Correction Input or MSS Valid** When this bit and the OSTC bit are set, it indicates that the Timestamp Correction input provided in TDES0 and TDES1 is valid. When the OSTC bit is reset and this bit and the TSE bit of TDES3 are set in subsequent normal descriptor, it indicates that the MSS input in TDES2 is valid.
25:24	Reserved	
23	CDE	**Context Descriptor Error** When this bit is set, it indicates that the context descriptor is incorrect. The DMA sets this bit during write-back while closing the context descriptor. The Context Descriptor errors can be: – Incorrect sequence from the context descriptor. For example, a location before the first descriptor for a packet. – All 1s. – CD, LD, and FD bits set to 1. *Note: When a Context Descriptor error occurs due to All 1s or CTXT, LD, and FD bits set to 1, the Transmit DMA closes the transmit descriptor with DE and LD bits set to 1. When IOC bit in TDES2 of corresponding first descriptor is set to 1, Transmit DMA sets the TI bit in the Channel status register (ETH_DMACSR).* *Based on CTXT, LD, and FD bits of the transmit descriptor, the subsequent descriptor might be considered as the First Descriptor (even if FD bit is not set) and partial packet is sent.* *This error is categorized as an abnormal event; recovery is only by issuing a software reset (DMA stopping-reconfiguring-restarting recovery mechanism is not supported)*
22:20	Reserved	

Table 813. TDES3 context descriptor (continued)

Bit	Name	Description
19:18	IVTIR	Inner VLAN Tag Insert or Replace When these bits are set, they request the MAC to perform Inner VLAN tagging or untagging before transmitting the packets. If the packet is modified for VLAN tags, the MAC automatically recalculates and replaces the CRC bytes. This bitfield has the following values: 00: Do not add the inner VLAN tag. 01: Remove the inner VLAN tag from the packets before transmission. This option should be used only with the VLAN frames. 10: Insert an inner VLAN tag with the tag value programmed in the *Inner VLAN inclusion register (ETH_MACIVIR)* or context descriptor. 11: Replace the inner VLAN tag in packets with the tag value programmed in the *Inner VLAN inclusion register (ETH_MACIVIR)* or context descriptor. This option should be used only with the VLAN frames.
17	IVLTV	Inner VLAN Tag Valid When this bit is set, it indicates that the IVT field of TDES2 is valid.
16	VLTV	VLAN Tag Valid When this bit is set, it indicates that the VT field of TDES3 is valid.
15:0	VT	VLAN Tag This field contains the VLAN Tag to be inserted or replaced in the packet. This field is used as VLAN Tag only when the VLTI bit of the *VLAN inclusion register (ETH_MACVIR)* is reset.

69.10.4 Receive descriptor

The DMA in the Ethernet peripheral attempts to read a descriptor only if the Tail pointer is different from the Base pointer or current pointer. It is recommended to have a descriptor ring with a length that can accommodate at least two complete packets received by the MAC; otherwise, the performance of the DMA is greatly impacted because of the unavailability of the descriptors. In such a situation, the MTL RxFIFO becomes full and starts dropping packets.

The following receive descriptors are present:

- Normal descriptors with read and write-back formats
- Context descriptors

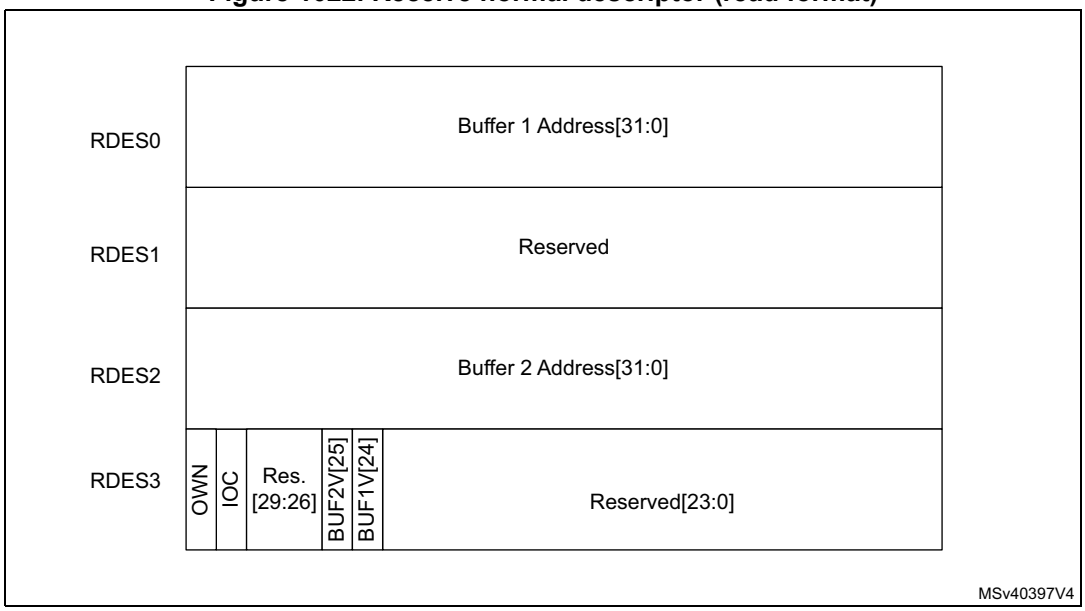
All received descriptors are prepared by the software and given to the DMA as “normal” descriptors (see *Figure 1022: Receive normal descriptor (read format)* for a description of their content). The DMA reads this descriptor and, after transferring a received packet (or part of it) to the buffers indicated by the descriptor, the Rx DMA closes the descriptor with the corresponding packet status. The status format is given in *Figure 1023: Receive normal descriptor (write-back format)*.

For some packets, the normal descriptor bits are not sufficient to write the complete status. For such packets, the Rx DMA writes the extended status to the next descriptor (without processing or using the Buffers pointers embedded in that descriptor). The format and content of this write-back descriptor is described in *Figure 1024: Receive context descriptor*.

Receive normal descriptor (read format)

Figure 1022 shows the read format for receive normal descriptors. *Table 814* to *Table 817* provide a detailed description of all receive normal descriptors (read format).

Figure 1022. Receive normal descriptor (read format)



Note: In the receive descriptor (read format), if the Buffer Address field contains only 0s, the MAC does not transfer data to this buffer and skips to the next buffer or next descriptor.

- RDES0 normal descriptor (read format)

Table 814. RDES0 normal descriptor (read format)

Bit	Name	Description
31:0	BUF1AP	**Buffer 1 Address Pointer** These bits indicate the physical address of Buffer 1. The application can program a byte-aligned address for this buffer, which means that the LS bits of this field can be non-zero. However, while transferring the start of packet, the DMA performs a write operation with RDES2[1:0]=0 in case of 64-/128-bit configuration) as zero. However, the packet data is shifted by the actual offset as given in the buffer address pointer. If the address pointer points to a buffer where the middle or last part of the packet is stored, the DMA ignores the offset address and writes to the full location as indicated by the data-width.

- RDES1 normal descriptor (read format)

Table 815. RDES1 normal descriptor (read format)

Bit	Name	Description
31:0	Reserved	Field reserved.

- RDES2 normal descriptor (read format)

Table 816. RDES2 normal descriptor (read format)

Bit	Name	Description
31:0	BUF2AP	**Buffer 2 Address Pointer** These bits indicate Buffer 2 physical address. The RxDMA uses the LS bits of the pointer address only while transferring the start bytes of a packet. If the BUF2AP is giving the address of a buffer in which the middle or last part of a packet is stored, the DMA ignores RDES2[1:0]=0 and writes to the complete location.

- RDES3 normal descriptor (read format)

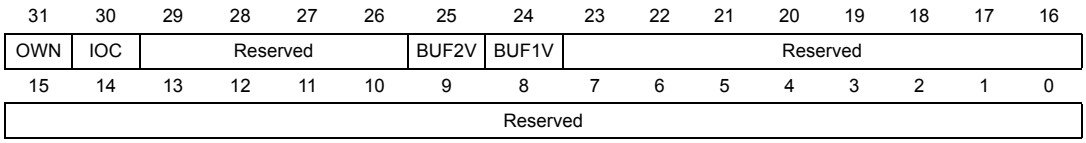


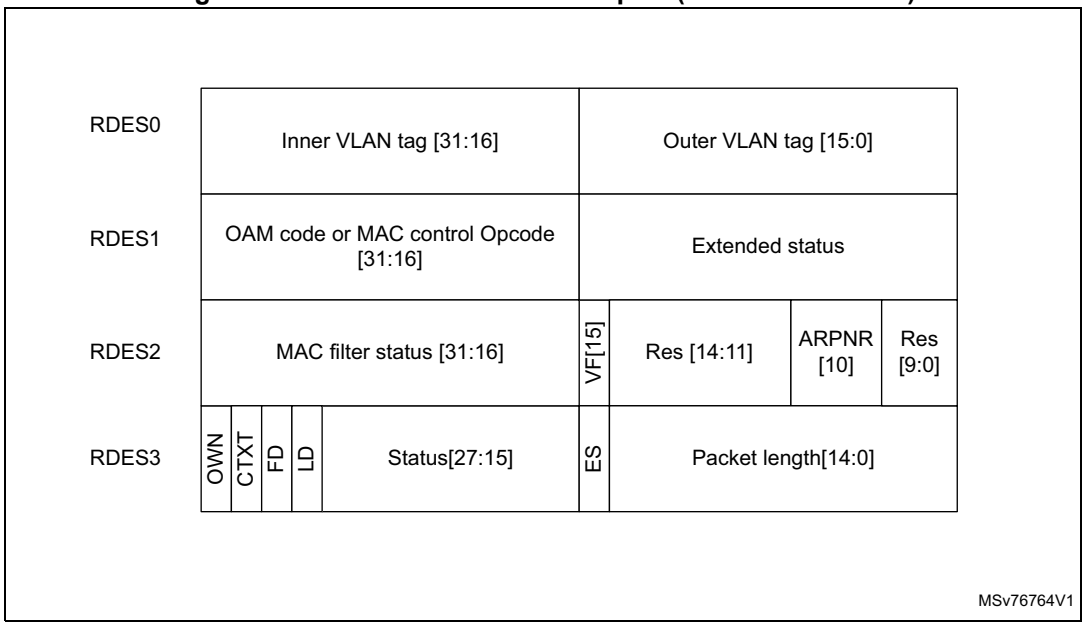
Table 817. RDES3 normal descriptor (read format)

Bit	Name	Description
31	OWN	**Own bit** When this bit is set, it indicates that the DMA owns the descriptor. When this bit is reset, it indicates that the application owns the descriptor. The DMA clears this bit when either of the following conditions is true: – The DMA completes the packet reception – The buffers associated with the descriptor are full
30	IOC	**Interrupt Enabled on Completion** When this bit is set, an interrupt is issued to the application when the DMA closes this descriptor.
29:26	Reserved	
25	BUF2V	**Buffer 2 Address Valid** When this bit is set, it indicates to the DMA that the buffer 2 address specified in RDES2 is valid. The application must set this bit so that the DMA can use the address to which the Buffer 2 address in RDES0 is pointing, to write received packet data.
24	BUF1V	**Buffer 1 Address Valid** When set, this indicates to the DMA that the buffer 1 address specified in RDES0 is valid. The application must set this value if the address to which Buffer 1 address points in RDES0, can be used by the DMA to write received packet data.
23:0	Reserved	

Receive normal descriptor (write-back format)

Figure 1023 shows the write-back format for receive normal descriptors. *Table 818* to *Table 821* provide a detailed description of all receive normal descriptors (write-back format).

Figure 1023. Receive normal descriptor (write-back format)



- RDES0 normal descriptor (write-back format)

Table 818. RDES0 normal descriptor (write-back format)

Bit	Name	Description
31:16	IVT	**Inner VLAN Tag** This field contains the Inner VLAN tag of the received packet if the RS0V bit of RDES3 is set. This is valid only when Double VLAN tag processing and VLAN tag stripping are enabled.
15:0	OVT	**Outer VLAN Tag** This field contains the Outer VLAN tag of the received packet if the RS0V bit of RDES3 is set.

- RDES1 normal descriptor (write-back format)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OPC															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TD	TSA	PV	PFT	PMT				IPCE	IPCB	IPV6	IPV4	IPHE	PT		

Table 819. RDES1 normal descriptor (write-back format)(1)

Bit	Name	Description
31:16	OPC	**OAM Subtype Code, or MAC Control Packet opcode** OAM Subtype Code If bits[18:16] of RDES3 are set to 111, this field contains the OAM subtype and code fields. MAC Control Packet opcode If bits[18:16] of RDES3 are set to 110, this field contains the MAC Control packet opcode field.
15	TD	**Timestamp Dropped** This bit indicates that the timestamp was captured for this packet but got dropped in the MTL Rx FIFO because of overflow.
14	TSA	**Timestamp Available** When Timestamp is present, this bit indicates that the timestamp value is available in a context descriptor word 2 (RDES2) and word 1(RDES1). This is valid only when the Last Descriptor bit (RDES3 [28]) is set. The context descriptor is written in the next descriptor just after the last normal descriptor for a packet.
13	PV	**PTP Version** 1: Received PTP message in IEEE 1588 version 2 format 0: Received PTP message in IEEE 1588 version 1 format
12	PFT	**PTP Packet Type** This bit indicates that the PTP message is sent directly over Ethernet.
11:8	PMT	**PTP Message Type** These bits are encoded to give the type of the message received: 0000: No PTP message received 0001: SYNC (all clock types) 0010: Follow_Up (all clock types) 0011: Delay_Req (all clock types) 0100: Delay_Resp (all clock types) 0101: Pdelay_Req (in peer-to-peer transparent clock) 0110: Pdelay_Resp (in peer-to-peer transparent clock) 0111: Pdelay_Resp_Follow_Up (in peer-to-peer transparent clock) 1000: Announce 1001: Management 1010: Signaling 1011–1110: Reserved 1111: PTP packet with Reserved message type
7	IPCE	**IP Payload Error** When this bit is set, it indicates either of the following: – The 16-bit IP payload checksum (that is, the TCP, UDP, or ICMP checksum) calculated by the MAC does not match the corresponding checksum field in the received segment. – The TCP, UDP, or ICMP segment length does not match the payload length value in the IP Header field. – The TCP, UDP, or ICMP segment length is less than minimum allowed segment length for TCP, UDP, or ICMP. Bit 15 (ES) of RDES3 is not set when this bit is set.

Table 819. RDES1 normal descriptor (write-back format)(1) (continued)

Bit	Name	Description
6	IPCB	**IP Checksum Bypassed** This bit indicates that the checksum offload engine is bypassed.
5	IPV6	**IPv6 header Present** This bit indicates that an IPV6 header is detected.
4	IPV4	**IPV4 Header Present** This bit indicates that an IPV4 header is detected.
3	IPHE	**IP Header Error** – When this bit is set, it indicates either of the following: – The 16-bit IPv4 header checksum calculated by the MAC does not match the received checksum bytes. – The IP datagram version is not consistent with the Ethernet Type value. – Ethernet packet does not have the expected number of IP header bytes. This bit is valid when either bit 5 or bit 4 is set.
2:0	PT	**Payload Type** These bits indicate the type of payload encapsulated in the IP datagram processed by the receive checksum offload engine (COE): 000: Unknown type or IP/AV payload not processed 001: UDP 010: TCP 011: ICMP 100: IGMP if IPV4 Header Present bit is set Others: reserved. If the COE does not process the payload of an IP datagram because there is an IP header error or fragmented IP, it sets these bits to 3'b000.

1. The Status fields in write-back format are valid only for the last descriptor (RDES3[28] is set).

- RDES2 normal descriptor (write-back format)

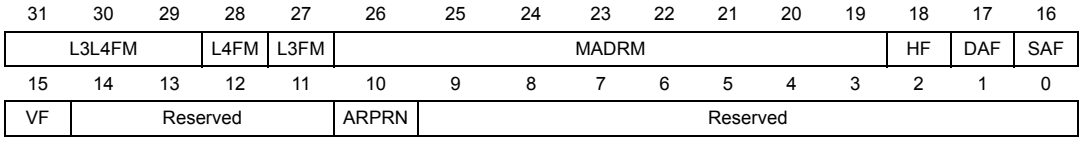


Table 820. RDES2 normal descriptor (write-back format)

Bit	Name	Description
31:29	L3L4FM	**Layer 3 and Layer 4 Filter Number Matched** These bits indicate the number of the Layer 3 and Layer 4 Filter that matched the received packet: – 000: Filter 0 – 001: Filter 1 – 010: Filter 2 – 011: Filter 3 – 100: Filter 4 – 101: Filter 5 – 110: Filter 6 – 111: Filter 7 This field is valid only when bit 28 or bit 27 is set high. When more than one filter matches, these bits give the number of lowest filter.
28	L4FM	**Layer 4 Filter Match** When this bit is set, it indicates that the received packet matches one of the enabled Layer 4 Port Number fields. This status is given only when one of the following conditions is true: – Layer 3 fields are not enabled and all enabled Layer 4 fields match – All enabled Layer 3 and Layer 4 filter fields match When more than one filter matches, this bit gives the layer 4 filter status of filter indicated by bits[31:29].
27	L3FM	**Layer 3 Filter Match** When this bit is set, it indicates that the received packet matches one of the enabled Layer 3 IP Address fields. This status is given only when one of the following conditions is true: – All enabled Layer 3 fields match and all enabled Layer 4 fields are bypassed – All enabled filter fields match When more than one filter matches, this bit gives the layer 3 filter status of filter indicated by bits[31:29].
26:19	MADRM	**MAC Address Match or Hash Value** When the HF bit is reset, this field contains the MAC address register number that matched the Destination address of the received packet. This field is valid only if the DAF bit is reset. When the HF bit is set, this field contains the Hash value computed by the MAC. A packet passes the Hash filter when the bit corresponding to the Hash value is set in the Hash filter register.
18	HF	**Hash Filter Status** When this bit is set, it indicates that the packet passed the MAC address Hash filter. its[26:19] indicate the Hash value.
17	DAF	**Destination Address Filter Fail** When this bit is set, it indicates that the packet failed the DA Filter in the MAC.
16	SAF	**SA Address Filter Fail** When this bit is set, it indicates that the packet failed the SA Filter in the MAC.

Table 820. RDES2 normal descriptor (write-back format) (continued)

Bit	Name	Description
15	VF	**VLAN Filter Status** When this bit is set, it indicates that the VLAN Tag of received packet passed the VLAN filter.
14:11	Reserved	
10	ARPNR	**ARP Reply Not Generated** When this bit is set, it indicates that the MAC did not generate the ARP Reply for received ARP Request packet. This bit is set when the MAC is busy transmitting ARP reply to earlier ARP request (only one ARP request is processed at a time).
9:0	Reserved	

- RDES3 normal descriptor (write-back format)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OWN	CTXT	FD	LD	RS2V	RS1V	RS0V	CE	GP	RWT	OE	RE	DE	LT		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ES	PL														

Table 821. RDES3 normal descriptor (write-back format)

Bit	Name	Description
31	OWN	**Own bit** 1: The DMA owns the descriptor. 0: The application owns the descriptor. The DMA clears this bit when either of the following conditions is true: The DMA completes the packet reception The buffers associated with the descriptor are full
30	CTXT	**Receive Context Descriptor** When this bit is set, it indicates that the current descriptor is a context type descriptor. The DMA writes 0 to this bit for normal receive descriptor. When CTXT and FD bits are used together, {CTXT, FD} possible values are: 00: Intermediate Descriptor 01: First Descriptor 10: Reserved 11: Descriptor error (due to all 1s) *Note: When a Descriptor error occurs, the receive DMA closes the receive descriptor indicating a Descriptor error. This receive descriptor is skipped and the buffer addresses are not used to write the packet data. The receive DMA sets the CDE field of the Channel status register (ETH_DMACSR) but does not set the RI field, even when IOC field is set, as this is not marked as last receive descriptor for the packet. The subsequent valid receive descriptor is used to write the packet data.*

Table 821. RDES3 normal descriptor (write-back format) (continued)

Bit	Name	Description
29	FD	**First Descriptor** When this bit is set, it indicates that this descriptor contains the first buffer of the packet. If the size of the first buffer is 0, the second buffer contains the beginning of the packet. If the size of the second buffer is also 0, the next descriptor contains the beginning of the packet. Refer to the CTXT bit description for details on how to use the CTXT bit and FD bit together.
28	LD	**Last Descriptor** When this bit is set, it indicates that the buffers to which this descriptor is pointing are the last buffers of the packet.
27	RS2V	**Receive Status RDES2 Valid** When this bit is set, it indicates that the status in RDES2 is valid and it is written by the DMA. This bit is valid only when the LD bit of RDES3 is set.
26	RS1V	**Receive Status RDES1 Valid** When this bit is set, it indicates that the status in RDES1 is valid and it is written by the DMA. This bit is valid only when the LD bit of RDES3 is set.
25	RS0V	R**eceive Status RDES0 Valid** When this bit is set, it indicates that the status in RDES0 is valid and it is written by the DMA. This bit is valid only when the LD bit of RDES3 is set.
24	CE	**CRC error** When this bit is set, it indicates that a Cyclic Redundancy Check (CRC) Error occurred on the received packet. This field is valid only when the LD bit of RDES3 is set.
23	GP	**Giant packet** When this bit is set, it indicates that the packet length exceeds the specified maximum Ethernet size of 1518, 1522, or 2000 bytes (9018 or 9022 bytes if jumbo packet enable is set). Giant packet indicates only the packet length. It does not cause any packet truncation.
22	RWT	**Receive watchdog timeout** When this bit is set, it indicates that the receive watchdog timer has expired while receiving the current packet. The current packet is truncated after watchdog timeout.
21	OE	**Overflow error** When this bit is set, it indicates that the received packet is damaged because of buffer overflow in Rx FIFO. This bit is set only when the DMA transfers a partial packet to the application. This happens only when the Rx FIFO is operating in the threshold mode. In the store-and-forward mode, all partial packets are dropped completely in Rx FIFO.
20	RE	**Receive error** When this bit is set, it indicates that the ETH_RX_ER signal is asserted while the ETH_RX_DV signal is asserted during packet reception.

Table 821. RDES3 normal descriptor (write-back format) (continued)

Bit	Name	Description
19	DE	**Dribble bit error** When this bit is set, it indicates that the received packet has a non-integer multiple of bytes (odd nibbles). This bit is valid only in the MII Mode.
18:16	LT	**Length/type field** This field indicates if the packet received is a length packet or a type packet. The encoding of the 3 bits is as follows: 000: The packet is a length packet 001: The packet is a type packet. 011: The packet is a ARP Request packet type 100: The packet is a type packet with VLAN Tag 101: The packet is a type packet with Double VLAN tag 110: The packet is a MAC Control packet type 111: The packet is a OAM packet type 010: Reserved
15	ES	**Error Summary** When this bit is set, it indicates the logical OR of the following bits: RDES3[19]: Dribble Error RDES3[20]: Receive Error RDES3[21]: Overflow Error RDES3[22]: Watchdog timeout RDES3[23]: Giant Packet RDES3[24]: CRC Error This field is valid only when the LD bit of RDES3 is set.
14:0	PL	**Packet Length** These bits indicate the byte length of the received packet that was transferred to system memory (including CRC). This field is valid when both the LD bit of RDES3 is set and the Overflow Error bit is reset. The packet length also includes the two bytes appended to the Ethernet packet when IP checksum calculation is enabled and the received packet is not a MAC control packet. When LD bit of RDES3 is reset, this field contains the accumulated number of bytes (partial) that have been transferred for the current packet.

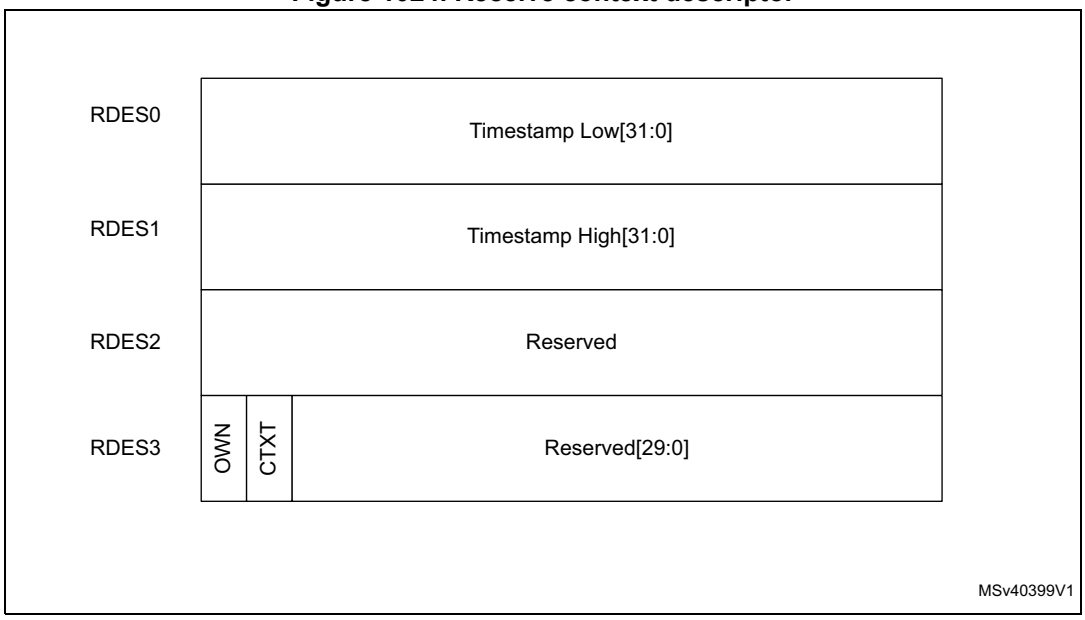
Receive context descriptor

This descriptor is read-only for the application. This descriptor can be written only by the DMA.

The context descriptor provides information about the extended status related to the last received packet. Bit 30 of RDES3 indicates the context type descriptor.

Figure 1024 shows the format for receive context descriptors. *Table 822* to *Table 825* provide a detailed description of all receive context descriptors.

Figure 1024. Receive context descriptor



- RDES0 context descriptor

Table 822. RDES0 context descriptor

Bit	Name	Description
31:0	RTSL	**Receive Packet Timestamp Low** The DMA updates this field with least significant 32 bits of the timestamp captured for corresponding receive packet. When this field and the RTSH field of RDES1 show all-ones value, the timestamp must be considered as corrupt.

- RDES1 context descriptor

Table 823. RDES1 context descriptor

Bit	Field	Description
31:0	RTSH	**Receive Packet Timestamp High** The DMA updates this field with most significant 32 bits of the timestamp captured for corresponding receive packet. When this field and the RTSL field of RDES0 show all-ones value, the timestamp must be considered as corrupt.

- RDES2 context descriptor

Table 824. RDES2 context descriptor

Bit	Description
31:0	Reserved

- RDES3 context descriptor

Table 825. RDES3 context descriptor

Bit	Name	Description
31	OWN	**Own Bit** 1: The DMA owns the descriptor 0: The application owns the descriptor. The DMA clears this bit when either of the following conditions is true: The DMA completes the packet reception The buffers associated with the descriptor are full
30	CTXT	**Receive Context Descriptor** When this bit is set, it indicates that the current descriptor is a context descriptor. The DMA writes 1'b1 to this bit for context descriptor. When CTXT and DE bits are used together, {CTXT, DE} possible values are: 00: Reserved 01: Reserved 10: Context Descriptor 11: Descriptor error When a Descriptor error occurs, the receive DMA closes the receive descriptor indicating a Descriptor error. This receive descriptor is skipped and the buffer addresses are not used to write the packet data The receive DMA sets the CDE bit in *Channel status register (ETH_DMACSR)* but does not set the RI field even when IOC is set, as this is not marked as last receive descriptor for the packet. The subsequent valid receive descriptor is used to write the packet data.
29	DE	**Descriptor Error** Refer to the CTXT bit description for details on how to use the E bit along with CTXT bit.
28:0	Reserved	

69.11 Ethernet registers

69.11.1 Ethernet register maps

This section provides the following register maps:

- DMA registers (see *Section 69.11.2: Ethernet DMA registers*)
- MTL registers (see *Section 69.11.3: Ethernet MTL registers*)
- MAC registers including MMC registers (see *Section 69.11.4: Ethernet MAC and MMC registers*)

69.11.2 Ethernet DMA registers

DMA mode register (ETH_DMAMR)

Address offset: 0x1000

Reset value: 0x0000 0000

The DMA mode register establishes the bus operating modes for the DMA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INTM[1:0]	
														rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	PR[2:0]			TXPR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DA	SWR
	rw	rw	rw	rw										rw	rw

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:16 **INTM[1:0]**: Interrupt Mode

This field defines the interrupt mode of the Ethernet peripheral.
The behavior of the interrupt signal and of the RI/TI bits in the ETH_DMACSR register changes depending on the INTM value (refer to *Table 801: Transfer complete interrupt behavior*).

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **PR[2:0]**: Priority ratio

These bits control the priority ratio in weighted round-robin arbitration between the Rx DMA and Tx DMA. These bits are valid only when the DA bit is reset. The priority ratio is Rx:Tx or Tx:Rx depending on whether the TXPR bit is reset or set.
000: The priority ratio is 1:1
001: The priority ratio is 2:1
010: The priority ratio is 3:1
011: The priority ratio is 4:1
100: The priority ratio is 5:1
101: The priority ratio is 6:1
110: The priority ratio is 7:1
111: The priority ratio is 8:1

Bit 11 **TXPR**: Transmit priority

When set, this bit indicates that the Tx DMA has higher priority than the Rx DMA during arbitration for the system-side bus.

Bits 10:2 Reserved, must be kept at reset value.

Bit 1 **DA**: DMA Tx or Rx Arbitration Scheme

This bit specifies the arbitration scheme between the transmit and receive paths of all channels:

0: Weighted Round-Robin with Rx:Tx or Tx:Rx

The priority between the paths is according to the priority specified in Bits[14:12] and the priority weight is specified in the TXPR bit.

1: Fixed priority

The Tx path has priority over the Rx path when the TXPR bit is set. Otherwise, the Rx path has priority over the Tx path.

Bit 0 **SWR**: Software Reset

When this bit is set, the MAC and the DMA controller reset the logic and all internal registers of the DMA, MTL, and MAC. This bit is automatically cleared after the reset operation is complete in all clock domains. Before reprogramming any register, a value of zero should be read in this bit.

Note: The reset operation is complete only when all resets in all active clock domains are deasserted. Therefore, it is essential that all PHY inputs clocks (applicable for the selected PHY interface) are present for software reset completion. The time to complete the software reset operation depends on the frequency of the slowest active clock.

System bus mode register (ETH_DMASBMR)

Address offset: 0x1004

Reset value: 0x0000 0000

The System bus mode register controls the behavior of the AHB master. It mainly controls burst splitting and number of outstanding requests.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RB	MB	Res.	AAL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FB
r	rw		rw												rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **RB**: Rebuild INCRx Burst

When this bit is set high and the AHB master gets SPLIT, RETRY, or Early Burst Termination (EBT) response, the AHB master interface rebuilds the pending beats of any initiated burst transfer with INCRx and SINGLE transfers. By default, the AHB master interface rebuilds pending beats of an EBT with an unspecified (INCR) burst.

Bit 14 **MB**: Mixed Burst

When this bit is set high and the FB bit is low, the AHB master performs undefined bursts transfers (INCR) for burst length of 16 or more. For burst length of 16 or less, the AHB master performs fixed burst transfers (INCRx and SINGLE).

Bit 13 Reserved, must be kept at reset value.

Bit 12 **AAL**: Address-Aligned Beats

When this bit is set to 1, the master performs address-aligned burst transfers on Read and Write channels.

Bits 11:1 Reserved, must be kept at reset value.

Bit 0 **FB**: Fixed Burst Length

When this bit is set to 1, the AHB master initiates burst transfers of specified length (INCRx or SINGLE).

When this bit is set to 0, the AHB master initiates transfers of unspecified length (INCR) or SINGLE transfers.

Interrupt status register (ETH_DMAISR)

Address offset: 0x1008

Reset value: 0x0000 0000

The application reads this interrupt status register during interrupt service routine or polling to determine the interrupt status of DMA channels, MTL queues, and the MAC.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MACIS	MTLIS
														r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DC0IS
															r

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **MACIS**: MAC interrupt status

This bit indicates an interrupt event in the MAC. To reset this bit to 1'b0, the software must read the corresponding register in the MAC to get the exact cause of the interrupt and clear its source.

Bit 16 **MTLIS**: MTL interrupt status

This bit indicates an interrupt event in the MTL. To reset this bit to 1'b0, the software must read the corresponding register in the MTL to get the exact cause of the interrupt and clear its source.

Bits 15:1 Reserved, must be kept at reset value.

Bit 0 **DC0IS**: DMA channel interrupt status

This bit indicates an interrupt event in DMA channel. To reset this bit to 0, the software must read the corresponding register in DMA channel to get the exact cause of the interrupt and clear its source.

Debug status register (ETH_DMADSR)

Address offset: 0x100C

Reset value: 0x0000 0000

The Debug status register gives the receive and transmit process status for DMA channel for debugging purpose.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TPS0[3:0]				RPS0[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	AXWHSTS
r	r	r	r	r	r	r	r								r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **TPS0[3:0]**: DMA channel Transmit Process State

This field indicates the Tx DMA FSM state for channel:
000: Stopped (Reset or Stop Transmit Command issued)
001: Running (Fetching Tx Transfer Descriptor)
010: Running (Waiting for status)
011: Running (Reading Data from system memory buffer and queuing it to the Tx buffer (Tx FIFO))
100: Timestamp write state
101: Reserved for future use
110: Suspended (Tx Descriptor Unavailable or Tx Buffer Underflow)
111: Running (Closing Tx Descriptor)
The MSB of this field always returns 0. This field does not generate an interrupt.

Bits 11:8 **RPS0[3:0]**: DMA channel receive Process State

This field indicates the Rx DMA FSM state for channel:
000: Stopped (Reset or Stop receive Command issued)
001: Running (Fetching Rx Transfer Descriptor)
010: Reserved for future use
011: Running (Waiting for Rx packet)
100: Suspended (Rx Descriptor Unavailable)
101: Running (Closing the Rx Descriptor)
110: Timestamp write state
111: Running (Transferring the received packet data from the Rx buffer to the system memory)
The MSB of this field always returns 0. This field does not generate an interrupt.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **AXWHSTS**: AHB Master Write channel

When high, this bit indicates that the write channel of the AHB master FMSs are in non-idle state.

Channel control register (ETH_DMACCR)

Address offset: 0x1100

Reset value: 0x0000 0000

The DMA channel control register specifies the MSS value for segmentation, length to skip between two descriptors, and also the features such as header splitting and 8xPBL mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	DRO	Res.	Res.	Res.	Res.	Res.	DSL[2:0]			Res.	PBLX8
					rw						rw	rw	rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	MSS[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **DRO**: Descriptor refetch when OWN bit is 0

When this bit is set and the OWN bit of a descriptor is cleared, an additional attempt is made by the DMA engine to fetch the descriptor. If the OWN bit is still cleared, the transmit/receive buffer unavailable (TBU/RBU) interrupt is generated and the DMA goes into Suspend state until the tail pointer register is updated by the application.

When this bit is cleared, the DMA engine goes into Suspend mode as soon as it finds OWN bit cleared.

Bits 25:21 Reserved, must be kept at reset value.

Bits 20:18 **DSL[2:0]**: Descriptor Skip Length

This bit specifies the 32-bit word number to skip between two unchained descriptors. The address skipping starts from the end of the current descriptor to the start of the next descriptor.

When the DSL value is equal to zero, the DMA takes the descriptor table as contiguous.

Bit 17 Reserved, must be kept at reset value.

Bit 16 **PBLX8**: 8xPBL mode

When this bit is set, the PBL value programmed in Bits[21:16] in *Channel transmit control register (ETH_DMACTXCR)* and in Bits[21:16] in *Channel receive control register (ETH_DMACRXCR)* is multiplied eight times. Therefore, the DMA transfers the data in 8, 16, 32, 64, 128, and 256 beats depending on the PBL value.

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:0 **MSS[13:0]**: Maximum Segment Size

This field specifies the maximum segment size that should be used while segmenting the packet. This field is valid only if the TSE bit of *Channel transmit control register (ETH_DMACTXCR)* is set.

The value programmed in this field must be more than the configured Data width in bytes. It is recommended to use a MSS value of 64 bytes or more.

Channel transmit control register (ETH_DMACTXCR)

Address offset: 0x1104

Reset value: 0x0000 0000

The DMA channel transmit control register controls the Tx features such as PBL, TCP segmentation, and Tx channel weights.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXPBL[5:0]					
										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TSE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OSF	Res.	Res.	Res.	ST
			rw								rw				rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:16 **TXPBL[5:0]**: Transmit Programmable Burst Length

These bits indicate the maximum number of beats to be transferred in one DMA data transfer. This is the maximum value that is used in a single block Read or Write. The DMA always attempts to burst as specified in PBL each time it starts a burst transfer on the application bus. You can program PBL with any of the following values: 1, 2, 4, 8, 16, or 32. Any other value results in undefined behavior.

To transfer more than 32 beats, perform the following steps:

a) Set the PBLx8 mode in ETH_DMACCR.

b) Set the TXPBL[5:0].

Note: The maximum value of TXPBL must be less than or equal to half the Tx Queue size (TQS field of *Tx queue operating mode register (ETH_MTLTXQOMR)*) in terms of beats. This is required so that the Tx Queue has space to store at least another Tx PBL worth of data while the MTL Tx Queue Controller is transferring data to MAC. The total locations in Tx Queue of size 2048 bytes is 512, TXPBL and 8xPBL needs to be programmed to less than or equal to 512/2.

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **TSE**: TCP Segmentation Enabled

When this bit is set, the DMA performs the TCP segmentation for packets in channel x. The TCP segmentation is done only for those packets for which the TSE bit (TDES0[19]) is set in the Tx Normal descriptor. When this bit is set, the TxPBL value must be greater than or equal to 4.

Bits 11:5 Reserved, must be kept at reset value.

Bit 4 **OSF**: Operate on Second Packet

When this bit is set, it instructs the DMA to process the second packet of the Transmit data even before the status for the first packet is obtained.

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **ST**: Start or Stop Transmission Command

When this bit is set, transmission is placed in the Running state. The DMA checks the Transmit list at the current position for a packet to be transmitted.

The DMA tries to acquire descriptor from either of the following positions:

– The current position in the list: this is the base address of the Transmit list set by the ETH_DMACTXDLAR register.

– The position at which the transmission was previously stopped

If the DMA does not own the current descriptor, the transmission enters the Suspended state and the TBU bit of the ETH_DMACSR is set. The Start Transmission command is effective only when the transmission is stopped. If the command is issued before setting the ETH_DMACTXDLAR register, the DMA behavior is unpredictable.

When this bit is reset, the transmission process is placed in the Stopped state after completing the transmission of the current packet. The Next Descriptor position in the Transmit list is saved, and it becomes the current position when the transmission is restarted. To change the list address, you need to program ETH_DMACTXDLAR register with a new value when this bit is reset. The new value is considered when this bit is set again. The stop transmission command is effective only when the transmission of the current packet is complete or the transmission is in the Suspended state.

Channel receive control register (ETH_DMACRXCR)

Address offset: 0x1108

Reset value: 0x0000 0000

The DMA channel receive control register controls the Rx features such as PBL, buffer size, and extended status.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RPF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXPBL[5:0]					
rw										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RBSZ[13:0]														SR
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **RPF**: DMA Rx Channel Packet Flush

When this bit is set to 1, the Ethernet peripheral automatically flushes the packet from the Rx queues destined to DMA Rx channel when the DMA Rx channel is stopped after a system bus error has occurred. When this bit remains set and the DMA is re-started by the software driver, the packets residing in the Rx Queues that were received when this RxDMA was stopped, are flushed out. The packets that are received by the MAC after the RxDMA is restarted are routed to the RxDMA. The flushing happens on the Read side of the Rx queue.

When this bit is set to 0 the Ethernet peripheral does not flush the packet in the Rx queue destined to DMA Rx channel after the DMA is stopped due to a system bus error.

This might cause head-of-line blocking in the corresponding RxQueue.

Note: The stopping of packet flow from a Rx DMA channel to the application by setting RPF works only when there is one-to-one mapping of the Rx queues to the Rx DMA channels. In Dynamic mapping mode, setting the RPF bit in the Channel receive control register (ETH_DMACRXCR) might flush packets from unintended Rx queues, which are destined to the stopped Rx DMA channel.

Bits 30:22 Reserved, must be kept at reset value.

Bits 21:16 **RXPBL[5:0]**: Receive Programmable Burst Length

These bits indicate the maximum number of beats to be transferred in one DMA data transfer. This is the maximum value that is used in a single block Read or Write. The DMA always attempts to burst as specified in PBL each time it starts a burst transfer on the application bus. You can program PBL with any of the following values: 1, 2, 4, 8, 16, or 32. Any other value results in undefined behavior.

To transfer more than 32 beats, perform the following steps:

a) Set the PBLx8 mode in the ETH_DMACCR.

b) Set the RXPBL[5:0].

Note: The maximum value of RXPBL must be less than or equal to half the Rx Queue size (RQS field of Rx queue operating mode register (ETH_MTLRXQOMR)) in terms of beats. This is required so that the Rx Queue has space to store at least another Rx PBL worth of data while the MTL Rx Queue Controller is transferring data to MAC.The total locations in Rx Queue of size 2048 bytes is 512, RXPBL and 8xPBL needs to be programmed to less than or equal to 512/2.

Bit 15 Reserved, must be kept at reset value.

Bits 14:1 **RBSZ[13:0]**: Receive Buffer size

This field indicates the size of the Rx buffers specified in bytes. The maximum buffer size is limited to 16 Kbytes.

Note: The buffer size must be a multiple of 4. This is required even if the value of the buffer address pointer is not aligned to the bus width. If the buffer size is not a multiple of 4, it may result in an undefined behavior.

The LSB bits (1:0) are ignored and the DMA internally takes the LSB bits as all-zero. Therefore, these LSB bits are read-only (RO).

Bit 0 **SR**: Start or Stop receive

When this bit is set, the DMA tries to acquire the descriptor from the receive list and processes the incoming packets.

The DMA tries to acquire descriptor from either of the following positions:

– The current position in the list: this is the address set by the *Channel Rx descriptor list address register (ETH_DMACRXDLAR)*.

– The position at which the Rx process was previously stopped

If the DMA does not own the current descriptor, the reception is suspended and the RBU bit of the ETH_DMACSR is set. The Start Receive command is effective only when the reception is stopped. If the command is issued before setting the *Channel Rx descriptor list address register (ETH_DMACRXDLAR)*, the DMA behavior is unpredictable.

When this bit is reset, the Rx DMA operation is stopped after the transfer of the current packet. The next descriptor position in the receive list is saved, and it becomes the current position after the Rx process is restarted. The Stop Receive command is effective only when the Rx process is in the Running (waiting for Rx packet) or Suspended state.

Channel Tx descriptor list address register (ETH_DMACTXDLAR)

Address offset: 0x1114

Reset value: 0x0000 0000

Channel Tx descriptor list address register points the DMA to the start of the transmit descriptor list. The descriptor lists reside in the physical memory space of the application and must be word-aligned. The DMA internally converts it to bus width aligned address by making the corresponding LSB to low.

Writing to this register is permitted only when the Tx DMA has stopped, that is, the ST bit is cleared in ETH_DMACTXCR register. When stopped, this register can be written with a new

descriptor list address. When the ST bit is set, the DMA takes the newly-programmed descriptor base address. If this register is not changed when ST bit is cleared, the DMA takes the descriptor address where it was stopped earlier.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TDESLA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TDESLA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r

Bits 31:0 **TDESLA[31:0]**: Start of Transmit List

This field contains the base address of the first descriptor in the Transmit descriptor list. The DMA ignores the LSB bits (1:0) for 32-bit bus width and internally takes these bits as all-zero. Therefore, these LSB bits are read-only (RO).

Channel Rx descriptor list address register (ETH_DMACRXDLAR)

Address offset: 0x111C

Reset value: 0x0000 0000

The channel Rx descriptor list address register points the DMA to the start of receive descriptor list.

This register points to the start of the receive descriptor list. The descriptor lists reside in the physical memory space of the application and must be word-aligned. The DMA internally converts it to bus width aligned address by making the corresponding LS bits low. Writing to this register is permitted only when reception is stopped. When stopped, this register must be written to before the receive Start command is given. You can write to this register only when Rx DMA has stopped, that is, SR bit is set to zero in the ETH_DMACRXCR register. When stopped, this register can be written with a new descriptor list address.

When you set the SR bit to 1, the DMA takes the newly programmed descriptor base address.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDESLA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDESLA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r

Bits 31:0 **RDESLA[31:0]**: Start of receive list

This field contains the base address of the first descriptor in the Rx Descriptor list. The DMA ignores the LSB bits (1:0) for 32-bit bus width and internally takes these bits as all-zero. Therefore, these LSB bits are read-only (RO).

Channel Tx descriptor tail pointer register (ETH_DMACTXDTPR)

Address offset: 0x1120

Reset value: 0x0000 0000

The channel Tx descriptor tail pointer register points to an offset from the base and indicates the location of the last valid descriptor.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TDT[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TDT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r

Bits 31:0 **TDT[31:0]**: transmit descriptor tail pointer

This field contains the tail pointer for the Tx descriptor ring. The software writes the tail pointer to add more descriptors to the Tx channel. The hardware tries to transmit all packets referenced by the descriptors between the head and the tail pointer registers.

Channel Rx descriptor tail pointer register (ETH_DMACRXDTPR)

Address offset: 0x1128

Reset value: 0x0000 0000

The channel Rx descriptor tail pointer points to an offset from the base and indicates the location of the last valid descriptor.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDT[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r

Bits 31:0 **RDT[31:0]**: Receive Descriptor Tail Pointer

This field contains the tail pointer for the Rx descriptor ring. The software writes the tail pointer to add more descriptors to the Rx channel. The hardware tries to write all received packets to the descriptors referenced between the head and the tail pointer registers.

Channel Tx descriptor ring length register (ETH_DMACTXRLR)

Address offset: 0x112C

Reset value: 0x0000 0000

The channel Tx descriptor ring length register contains the length of the transmit descriptor ring.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	TDRL[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:0 **TDRL[9:0]**: Transmit descriptor ring length

This 10-bit field sets the maximum number of Tx descriptors in the circular descriptor ring.
TDRL[9:0] corresponds to the number of Tx descriptors minus one.
It can be programmed to any value up to 0x3FF (1024 descriptors).
A minimum ring descriptor length of four is recommended.
For example, program 0x9 to configure 10 descriptors.

Channel Rx descriptor ring length register (ETH_DMACRXRLR)

Address offset: 0x1130

Reset value: 0x0000 0000

The channel Rx descriptor ring length register contains the length of the receive descriptor circular ring.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARBS[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	RDRL[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **ARBS[7:0]**: Alternate receive buffer size

Indicates size in bytes for Buffer 1 when ARBS[7:0] is programmed to a non-zero value.
When ARBS[7:0] = 0, Rx Buffer1 and Rx Buffer2 sizes are based on RBSZ[13:0] field of *Channel receive control register (ETH_DMACRXCR)*.

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:0 **RDRL[9:0]**: Receive Descriptor Ring Length

This 10-bit field sets the maximum number of Rx descriptors in the circular descriptor ring.
RDRL[9:0] corresponds to the number of Rx descriptors minus one. It can be programmed to any value up to 0x3FF (1024 descriptors).
For example, program 0x9 to configure 10 descriptors.

Channel interrupt enable register (ETH_DMACIER)

Address offset: 0x1134

Reset value: 0x0000 0000

The channel interrupt enable register enables the interrupts reported by the Status register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NIE	AIE	CDEE	FBEE	ERIE	ETIE	RWTE	RSE	RBUE	RIE	Res.	Res.	Res.	TBUE	TXSE	TIE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **NIE**: Normal Interrupt Summary Enable

When this bit is set, the normal interrupt summary is enabled. This bit enables the following interrupts in the *Channel status register (ETH_DMACSR)*:
Bit 0: Transmit interrupt
Bit 2: Transmit buffer unavailable
Bit 6: Receive interrupt
Bit 11: Early receive interrupt
When this bit is reset, the normal interrupt summary is disabled.

Bit 14 **AIE**: Abnormal Interrupt Summary Enable

When this bit is set, the abnormal interrupt summary is enabled. This bit enables the following interrupts in the *Channel status register (ETH_DMACSR)*:
Bit 1: Transmit process stopped
Bit 7: Rx buffer unavailable
Bit 8: Receive process stopped
Bit 9: Receive watchdog timeout
Bit 10: Early transmit interrupt
Bit 12: Fatal bus error
Bit 13: Context descriptor error
When this bit is reset, the abnormal interrupt summary is disabled.

Bit 13 **CDEE**: Context descriptor error enable

When this bit is set along with the AIE bit, the Context Descriptor error interrupt is enabled. When this bit is reset, the Context Descriptor error interrupt is disabled.

Bit 12 **FBEE**: Fatal Bus Error enable

When this bit is set along with the AIE bit, the Fatal Bus error interrupt is enabled. When this bit is reset, the Fatal Bus Error error interrupt is disabled.

Bit 11 **ERIE**: Early receive interrupt enable

When this bit is set along with the NIE bit, the Early receive interrupt is enabled. When this bit is reset, the Early receive interrupt is disabled.

Bit 10 **ETIE**: Early Transmit Interrupt enable

When this bit is set along with the AIE bit, the Early Transmit interrupt is enabled. When this bit is reset, the Early Transmit interrupt is disabled.

Bit 9 **RWTE**: Receive watchdog timeout enable

When this bit is set along with the AIE bit, the receive watchdog timeout interrupt is enabled. When this bit is reset, the receive watchdog timeout interrupt is disabled.

Bit 8 **RSE**: Receive Stopped Enable

When this bit is set along with the AIE bit, the Receive Stopped Interrupt is enabled. When this bit is reset, the Receive Stopped interrupt is disabled.

Bit 7 **RBUE**: Receive Buffer Unavailable enable

When this bit is set along with the AIE bit, the Receive Buffer Unavailable interrupt is enabled. When this bit is reset, the Receive Buffer Unavailable interrupt is disabled.

Bit 6 **RIE**: Receive Interrupt enable

When this bit is set along with the NIE bit, the receive interrupt is enabled. When this bit is reset, the receive interrupt is disabled.

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **TBUE**: Transmit Buffer Unavailable enable

When this bit is set along with the NIE bit, the Transmit Buffer Unavailable interrupt is enabled. When this bit is reset, the Transmit Buffer Unavailable interrupt is disabled.

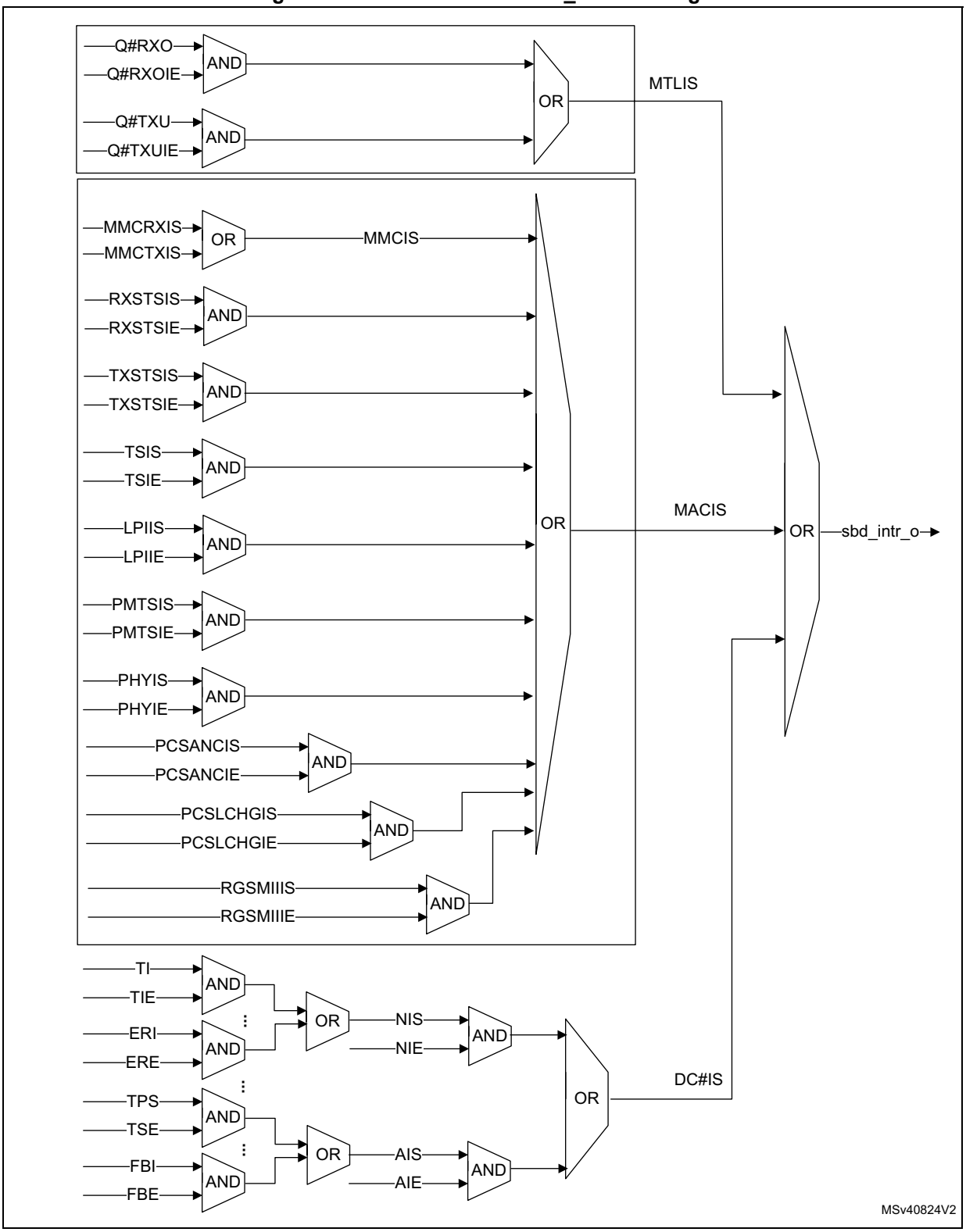
Bit 1 **TXSE**: Transmit Stopped enable

When this bit is set along with the AIE bit, the Transmission Stopped interrupt is enabled. When this bit is reset, the Transmission Stopped interrupt is disabled.

Bit 0 **TIE**: Transmit Interrupt enable

When this bit is set along with the NIE bit, the transmit interrupt is enabled. When this bit is reset, the transmit interrupt is disabled.

Figure 1025. Generation of ETH_DMAISR flags



Channel Rx interrupt watchdog timer register (ETH_DMACRXIWTR)

Address offset: 0x1138

Reset value: 0x0000 0000

The channel receive interrupt watchdog timer register indicates the watchdog timeout for receive interrupt (RI) from the DMA. When this register is written with a non-zero value, it enables the watchdog timer for the RI bit of the *Channel status register (ETH_DMACSR)*.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PSEL	Res.	RBCT[9:0]										ITCU[1:0]		RWTU[1:0]	
rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	ITW[4:0]					RWT[7:0]							
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **PSEL**: Packet Count Interrupt Select

When this bit is set, RBCT[9:0] indicates the number of packet threshold at which the receive interrupt (RI) is activated and the watchdog timer reset.

When this bit is cleared, RBCT[9:0] indicates the number of data byte threshold at which the receive interrupt (RI) is activated and the watchdog timer reset.

1: RBCT[9:0] is used to generate interrupt based on the number of packets received.

0: RBCT[9:0] is used to generate interrupt based on the number of bytes received.

Bit 30 Reserved, must be kept at reset value.

Bits 29:20 **RBCT[9:0]**: Receive Byte Count Threshold

This bitfield sets the limit in number of bytes or number of RX packets (based on PSEL) transferred without the assertion of receive interrupt. Once this limit is crossed, the receive interrupt is asserted and the watchdog timer (corresponding to RWT[7:0] is also reset.

This function is valid only when set to a nonzero value. When RBCT[9:0] = 0x00, RX packet/byte counter is inactive.

When PSEL = 0, this bitfield is multiplied by 1024 to get the actual number of byte threshold. When PSEL = 1, RBCT[9:0) value is directly used. Thus, the maximum limit is 511 packets or 511 x 1024 bytes, respectively.

Bits 19:18 **ITCU[1:0]**: Rx Idle Timer Count Units

This bitfield indicates the number of system clock cycles corresponding to one unit in the ITW[4:0] bitfield.

0b00: 256

0b01: 512

0b10: 1024

0b22: 2048

For example, when ITW[4:0] = 0b01010 and ITCU[1:0] = 0b01, the Rx Idle timer is set for 10 × 512 = 1024 system clock cycles.

Bits 17:16 **RWTU[1:0]**: Receive Interrupt Watchdog Timer Count Units

This bitfield indicates the number of system clock cycles corresponding to one unit in RWT[7:0] bitfield.

00: 256

01: 512

10: 1024

11: 2048

For example, when RWT[7:0] = 2 and RWTU[1:0] = 1, the watchdog timer is set for 2 × 512 = 1024 system clock cycles.

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **ITW[4:0]**: Rx Idle Timer Window

When programmed with a nonzero value, this bitfield enables the Rx Idle timer operation. The timer window is expressed in number of system clock cycles when this bitfield is multiplied by the ITCU unit.

Bits 7:0 **RWT[7:0]**: Receive Interrupt Watchdog Timer Count

This bitfield indicates the number of system clock cycles, multiplied by factor indicated in RWTU field, for which the watchdog timer is set.

The watchdog timer is triggered with the programmed value after the Rx DMA completes the transfer of a packet for which the RI bit is not set in the ETH_DMACSR, because of the setting of Interrupt Enable bit in the corresponding descriptor RDES3[30].

When the watchdog timer runs out, the RI bit is set and the timer is stopped. The watchdog timer is reset when the RI bit is set high because of automatic setting of RI as per the Interrupt Enable bit RDES3[30] of any received packet.

Channel current application transmit descriptor register (ETH_DMACCATXDR)

Address offset: 0x1144

Reset value: 0x0000 0000

The channel current application transmit descriptor register points to the current transmit descriptor read by the DMA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CURTDESAPTR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CURTDESAPTR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CURTDESAPTR[31:0]**: Application transmit descriptor address pointer

The DMA updates this pointer during Tx operation. This pointer is cleared on reset.

Channel current application receive descriptor register (ETH_DMACCARXDR)

Address offset: 0x114C

Reset value: 0x0000 0000

The channel current application receive descriptor register points to the current receive descriptor read by the DMA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CURRDESAPTR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CURRDESAPTR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CURRDESAPTR[31:0]**: Application receive descriptor address pointer
The DMA updates this pointer during Rx operation. This pointer is cleared on reset.

Channel current application transmit buffer register (ETH_DMACCATXBR)

Address offset: 0x1154

Reset value: 0x0000 0000

The channel current application transmit buffer address register points to the current Tx buffer address read by the DMA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CURTBUFAPTR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CURTBUFAPTR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CURTBUFAPTR[31:0]**: Application Transmit Buffer Address Pointer
The DMA updates this pointer during Tx operation. This pointer is cleared on reset.

Channel current application receive buffer register (ETH_DMACCARXBR)

Address offset: 0x115C

Reset value: 0x0000 0000

The channel current application receive buffer address register points to the current Rx buffer address read by the DMA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CURRBUFAPTR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CURRBUFAPTR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CURRBUFAPTR[31:0]**: Application receive buffer address pointer
The DMA updates this pointer during Rx operation. This pointer is cleared on reset.

Channel status register (ETH_DMACSR)

Address offset: 0x1160

Reset value: 0x0000 0000

The software driver (application) reads the status register during interrupt service routine or polling to determine the status of the DMA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REB[2:0]			TEB[2:0]		
										r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NIS	AIS	CDE	FBE	ERI	ETI	RWT	RPS	RBU	RI	Res.	Res.	Res.	TBU	TPS	TI
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rw	rc_w1	rc_w1	rc_w1				rc_w1	rc_w1	rc_w1

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:19 **REB[2:0]**: Rx DMA Error Bits
This field indicates the type of error that caused a bus error. For example, error response on the AHB interface.
Bit [2]: Error during data transfer by Rx DMA when 1, no rror during data transfer by Rx DMA when 0.
Bit[1]: Error during descriptor access when 1, error during data buffer access when 0
Bit[0]: Error during read transfer when 1, error during write transfer when 0
This field is valid only when the FBE bit is set. This field does not generate an interrupt.

Bits 18:16 **TEB[2:0]**: Tx DMA Error Bits
This field indicates the type of error that caused a bus error. For example, error response on the AHB interface.
Bit[2]: Error during data transfer by Tx DMA when 1, no error during data transfer by Tx DMA when 0
Bit[1]: Error during descriptor access when 1, error during data buffer access when 0
Bit[0]: Error during read transfer when 1, Error during write transfer when 0
This field is valid only when the FBE bit is set. This field does not generate an interrupt.

Bit 15 **NIS**: Normal Interrupt Summary
Normal Interrupt Summary bit value is the logical OR of the following bits when the corresponding interrupt bits are enabled in the ETH_DMACIER register:
Bit 0: Transmit interrupt
Bit 2: Transmit buffer unavailable
Bit 6: Receive interrupt
Bit 11: Early receive interrupt
Only unmasked bits (interrupts for which interrupt enable is set in ETH_DMACIER register) affect the Normal Interrupt Summary bit.
This is a sticky bit. You must clear this bit (by writing 1 to this bit) each time a corresponding bit which causes NIS to be set is cleared.

Bit 14 **AIS**: Abnormal Interrupt Summary

Abnormal Interrupt Summary bit value is the logical OR of the following when the corresponding interrupt bits are enabled in the ETH_DMACIER register:
Bit 1: Transmit process stopped
Bit 7: Receive buffer unavailable
Bit 8: Receive process stopped
Bit 10: Early transmit interrupt
Bit 12: Fatal bus error
Bit 13: Context descriptor error
Only unmasked bits affect the Abnormal Interrupt Summary bit.
This is a sticky bit. You must clear this bit (by writing 1 to this bit) each time a corresponding bit, which causes AIS to be set, is cleared.

Bit 13 **CDE**: Context descriptor error

This bit indicates that the DMA Tx/Rx engine received a descriptor error, which indicates invalid context in the middle of packet flow (intermediate descriptor) or all one‘s descriptor in Tx case and on Rx side it indicates DMA has read a descriptor with either of the buffer address as ones which is considered to be invalid.

Bit 12 **FBE**: Fatal bus error

This bit indicates that a bus error occurred (as described in the EB field). When this bit is set, the corresponding DMA channel engine disables all bus accesses.

Bit 11 **ERI**: Early receive interrupt

When set, this bit indicates that the RxDMA has completed the transfer of packet data to the memory. The RI bit of this register automatically clears this bit.

Bit 10 **ETI**: Early transmit interrupt

When set, this bit indicates that the TxDMA has completed the transfer of packet data to the MTL TXFIFO memory.

Bit 9 **RWT**: Receive watchdog timeout

This bit is asserted when a packet with length greater than 2,048 bytes (10,240 bytes when Jumbo Packet mode is enabled) is received.

Bit 8 **RPS**: Receive process stopped

This bit is asserted when the Rx process enters the Stopped state.

Bit 7 **RBU**: Receive buffer unavailable

This bit indicates that the application owns the next descriptor in the receive list, and the DMA cannot acquire it. The Rx process is suspended. To resume processing Rx descriptors, the application should change the ownership of the descriptor and issue a Receive Poll Demand command. If this command is not issued, the Rx process resumes when the next recognized incoming packet is received. In ring mode, the application should advance the receive descriptor tail pointer register of a channel. This bit is set only when the DMA owns the previous Rx descriptor.

Bit 6 **RI**: Receive interrupt

This bit indicates that the packet reception is complete or Rx Idle timer/Rx watchdog timer is timed out. When packet reception is complete, Bit 31 of RDES1 is reset in the last descriptor, and the specific packet status information is updated in the descriptor.
The reception remains in the Running state.

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **TBU**: Transmit buffer unavailable

This bit indicates that the application owns the next descriptor in the Transmit list, and the DMA cannot acquire it. Transmission is suspended. The TPSi field of the *Debug status register (ETH_DMADSR)* register explains the Transmit Process state transitions.

To resume processing the Transmit descriptors, the application should do the following:

1. Change the ownership of the descriptor by setting Bit 31 of TDES3.
2. Issue a Transmit Poll Demand command.

For ring mode, the application should advance the transmit descriptor tail pointer register of a channel.

Bit 1 **TPS**: Transmit process stopped

This bit is set when the transmission is stopped.

Bit 0 **TI**: Transmit interrupt

This bit indicates that the packet transmission is complete. When transmission is complete, Bit 31 of TDES3 is reset in the last descriptor, and the specific packet status information is updated in the descriptor.

Channel missed frame count register (ETH_DMACMFCR)

Address offset: 0x1164

Reset value: 0x0000 0000

This register has the number of packet counter that got dropped by the DMA either due to bus error or due to programing RPF field in *Channel receive control register (ETH_DMACRXCR)* register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MFCO	Res.	Res.	Res.	Res.	MFC[10:0]										
rc_r					rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **MFCO**: Overflow status of the MFC Counter

When this bit is set then the MFC counter does not get incremented further. The bit gets cleared when this register is read.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:0 **MFC[10:0]**: Dropped packet counters

This counter indicates the number of packet counters that are dropped by the DMA either because of bus error or because of programing RPF field in *Channel receive control register (ETH_DMACRXCR)*. The counter gets cleared when this register is read.

Ethernet DMA register map and reset values

Table 826. ETH_DMA common register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x1000	ETH_DMAMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INTM[1:0]		Res.	PR[2:0]			TXPR	Res.	Res.	Res.	Res.	Res.	Res.	Res.			DA	SWR
	Reset value															0	0		0	0	0	0										0	0
0x1004	ETH_DMASBMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RB	MB	Res.	AAL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FB
	Reset value																	0	0		0												0
0x1008	ETH_DMAISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MACIS	MTLIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DC0IS
	Reset value															0	0																0
0x100C	ETH_DMADSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TPS0[3:0]				RPS0[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	AXWHSTS
	Reset value																	0	0	0	0	0	0	0	0								0

Table 827. ETH_DMA_CH register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x1100	ETH_DMACCR	Res.	Res.	Res.	Res.	Res.	DRO	Res.	Res.	Res.	Res.	Res.	DSL[2:0]			Res.	PBLX8	Res.	Res.	MSS[13:0]													
	Reset value						0						0	0	0		0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1104	ETH_DMACTXCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXPBL[5:0]						Res.	Res.	Res.	TSE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OSF	Res.			ST
	Reset value											0	0	0	0	0	0				0								0				0
0x1108	ETH_DMACRXCR	RPF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXPBL[5:0]						Res.	RBSZ[13:0]											Res.	Res.	Res.	SR
	Reset value	0										0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0				0
0x110C - 0x1110	Reserved																																
0x1114	ETH_DMACTXDLAR	TDESLA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1118	Reserved																																
0x111C	ETH_DMACRXDLAR	RDESLA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1120	ETH_DMACTXDTPR	TDT[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1124	Reserved																																

Table 827. ETH_DMA_CH register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x1128	ETH_DMACRXDTPR	RDT[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x112C	ETH_DMACTXRLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDRL[9:0]									
	Reset value																							0	0	0	0	0	0	0	0	0	0
0x1130	ETH_DMACRXRLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARBS[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	RDRL[9:0]									
	Reset value									0	0	0	0	0	0	0	0							0	0	0	0	0	0	0	0	0	0
0x1134	ETH_DMACIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NIE	AIE	CDEE	FBEE	ERIE	ETIE	RWTE	RSE	RBUE	RIE	Res.	Res.	Res.	TBUE	TXSE	TIE
	Reset value																	0	0	0	0	0	0	0	0	0	0				0	0	0
0x1138	ETH_DMACRXIWTR	PSEL	Res.	RBCT[9:0]										ITCU[1:0]		RWTU[1:0]		Res.	Res.	Res.	ITW[4:0]			RWT[7:0]									
	Reset value	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0	0
0x113C-0x1140	Reserved																																
0x1144	ETH_DMACCATXDR	CURTDESAPTR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1148	Reserved																																
0x114C	ETH_DMACCARXDR	CURRDESAPTR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1150	Reserved																																
0x1154	ETH_DMACCATXBR	CURTBUFAPTR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1158	Reserved																																
0x115C	ETH_DMACCARXBR	CURRBUFAPTR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1160	ETH_DMACSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REB[2:0]			TEB[2:0]			NIS	AIS	CDE	FBE	ERI	ETI	RWT	RPS	RBU	RI	Res.	Res.	Res.	TBU	TPS	TI
	Reset value											0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
0x1164	ETH_DMACMFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MFCO	Res.	Res.	Res.	Res.	MFC[10:0]										
	Reset value																	0					0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

69.11.3 Ethernet MTL registers

Operating mode register (ETH_MTLOMR)

Address offset: 0x0C00

Reset value: 0x0000 0000

The operating mode register establishes the transmit and receive operating modes and commands.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CNT CLR	CNT PRST	Res.	Res.	Res.	Res.	Res.	Res.	DTX STS	Res.
						rw	rw							rw	

Bits 31:10 Reserved, must be kept at reset value.

Bit 9 **CNTCLR**: Counters reset

When this bit is set, all counters are reset. This bit is cleared automatically after 1 clock cycle. If this bit is set along with CNTPRST bit, CNTPRST has precedence.

Bit 8 **CNTPRST**: Counters preset

When this bit is set:

- *Tx queue underflow register (ETH_MTLTXQUR)* is initialized/preset to 0x7F0.
- Missed Packet and Overflow Packet counters in *Rx queue missed packet and overflow counter register (ETH_MTLRXQMPOCR)* is initialized/preset to 0x7F0

This bit is cleared automatically.

Bit 7 Reserved, must be kept at reset value.

Bits 6:2 Reserved, must be kept at reset value.

Bit 1 **DTXSTS**: Drop transmit status

When this bit is set, the Tx packet status received from the MAC is dropped in the MTL. When this bit is reset, the Tx packet status received from the MAC is forwarded to the application.

Bit 0 Reserved, must be kept at reset value.

Interrupt status register (ETH_MTLISR)

Address offset: 0x0C20

Reset value: 0x0000 0000

The software driver (application) reads this register during interrupt service routine or polling to determine the interrupt status of MTL queues and the MAC.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Q0IS
															r

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **Q0IS**: Queue interrupt status

This bit indicates that an interrupt has been generated by Queue . To reset this bit, read ETH_MTLQICSR register to identify the interrupt cause and clear the source.

Tx queue operating mode register (ETH_MTLTXQOMR)

Address offset: 0x0D00

Reset value: 0x0007 0008

The queue transmit operating mode register establishes the transmit queue operating modes and commands.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TQS[2:0]		
													r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TTC[2:0]			TXQEN[1:0]		TSF	FTQ
									rw	rw	rw	r	r	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **TQS[2:0]**: Transmit queue size

This field indicates the size of the allocated transmit queues in blocks of 256 bytes. Queue size range from 256 bytes (TQS=0b000) to 2048 bytes (TQS=0b111).

Bits 15:7 Reserved, must be kept at reset value.

Bits 6:4 **TTC[2:0]**: Transmit threshold control

These bits control the threshold level of the MTL Tx queue. The transmission starts when the packet size within the MTL Tx queue is larger than the threshold. In addition, full packets with length less than the threshold are also transmitted. These bits are used only when the TSF bit is reset.

000: 32
001: 64
010: 96
011: 128
100: 192
101: 256
110: 384
111: 512

Bits 3:2 **TXQEN[1:0]**: Transmit queue enable

This field is used to enable/disable the transmit queue.

00: Not enabled
10: Enabled
Others: Reserved, must not be used.

Bit 1 **TSF**: Transmit store and forward

When this bit is set, the transmission starts when a full packet resides in the MTL Tx queue. When this bit is set, the TTC values specified in Bits[6:4] of this register are ignored. This bit should be changed only when the transmission is stopped.

Bit 0 **FTQ**: Flush transmit queue

When this bit is set, the Tx queue controller logic is reset to its default values. Therefore, all the data in the Tx queue is lost or flushed. This bit is internally reset when the flushing operation is complete. Until this bit is reset, you should not write to the *Tx queue operating mode register (ETH_MTLTXQOMR)* register. The data which is already accepted by the MAC transmitter is not flushed. It is scheduled for transmission and results in underflow and runt packet transmission.

Note: The flush operation is complete only when the Tx queue is empty and the application has accepted the pending Tx Status of all transmitted packets. To complete this flush operation, the PHY Tx clock (eth_tx_clk) should be active.

Tx queue underflow register (ETH_MTLTXQUR)

Address offset: 0x0D04

Reset value: 0x0000 0000

The queue underflow counter register contains the counter for packets aborted because of transmit queue underflow and packets missed because of receive queue packet flush

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	UFCNT OVF	UFFRMCNT[10:0]										
				rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **UFCNTOVF**: Overflow Bit for Underflow packet counter

This bit is set every time the Tx queue Underflow packet counter field overflows, that is, it has crossed the maximum count. In such a scenario, the overflow packet counter is reset to all-zeros and this bit indicates that the rollover happened.

Bits 10:0 **UFFRMCNT[10:0]**: Underflow packet counter

This field indicates the number of packets aborted by the controller because of Tx queue Underflow. This counter is incremented each time the MAC aborts outgoing packet because of underflow. The counter is cleared when this register is read.

Tx queue debug register (ETH_MTLTXQDR)

Address offset: 0x0D08

Reset value: 0x0000 0000

The queue transmit debug register gives the debug status of various blocks related to the transmit queue.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STXSTSF[2:0]			Res.	PTXQ[2:0]		
									r	r	r		r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXSTS FSTS	TXQ STS	TWC STS	TRCSTS[1:0]		TXQPA USED
										r	r	r	r	r	r

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:20 **STXSTSF[2:0]**: Number of status words in Tx status FIFO of queue

This field indicates the current number of status in the Tx Status FIFO of this queue.
When the DTXSTS bit of ETH_MTLOMR register is set to 1, this field does not reflect the number of status words in Tx Status FIFO.

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **PTXQ[2:0]**: Number of packets in the transmit queue

This field indicates the current number of packets in the Tx queue.
When the DTXSTS bit of *Operating mode register (ETH_MTLOMR)* register is set to 1, this field does not reflect the number of packets in the transmit queue.

Bits 15:6 Reserved, must be kept at reset value.

Bit 5 **TXSTSFSTS**: MTL Tx status FIFO Full status

When high, this bit indicates that the MTL Tx Status FIFO is full. Therefore, the MTL cannot accept any more packets for transmission.

Bit 4 **TXQSTS**: MTL Tx queue not empty status

When this bit is high, it indicates that the MTL Tx queue is not empty and some data is left for transmission.

Bit 3 **TWCSTS**: MTL Tx queue write controller status

When high, this bit indicates that the MTL Tx queue write controller is active, and it is transferring the data to the Tx queue.

Bits 2:1 **TRCSTS[1:0]**: MTL Tx queue read controller status
This field indicates the state of the Tx queue read controller:
00: Idle state
01: Read state (transferring data to the MAC transmitter)
10: Waiting for pending Tx Status from the MAC transmitter
11: Flushing the Tx queue because of the Packet Abort request from the MAC

Bit 0 **TXQPAUSED**: Transmit queue in pause
When this bit is high and the Rx flow control is enabled, it indicates that the Tx queue is in the Pause condition (in the Full-duplex only mode) because of the following:
– Reception of the PFC packet for the priorities assigned to the Tx queue when PFC is enabled
– Reception of 802.3x Pause packet when PFC is disabled

Queue interrupt control status register (ETH_MTLQICSR)

Address offset: 0x0D2C

Reset value: 0x0000 0000

This register contains the interrupt enable and status bits for the queue interrupts.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXOIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXOVFIS
							rw								rc_w1

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXUIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXUNFIS
							rw								rc_w1

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **RXOIE**: Receive queue overflow interrupt enable
When this bit is set, the receive queue overflow interrupt is enabled. When this bit is reset, the Receive Queue Overflow interrupt is disabled.

Bits 23:17 Reserved, must be kept at reset value.

Bit 16 **RXOVFIS**: Receive queue overflow interrupt status
This bit indicates that the receive queue had an overflow while receiving the packet. If a partial packet is transferred to the application, the overflow status is set in RDES3[21]. This bit is cleared when the application writes 1 to this bit.

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **TXUIE**: Transmit queue underflow interrupt enable
When this bit is set, the transmit queue underflow interrupt is enabled. When this bit is reset, the Transmit Queue Underflow interrupt is disabled.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **TXUNFIS**: Transmit queue underflow interrupt status

This bit indicates that the transmit queue had an underflow while transmitting the packet. Transmission is suspended and an Underflow Error TDES3[2] is set. This bit is cleared when the application writes 1 to this bit.

Rx queue operating mode register (ETH_MTLRXQOMR)

Address offset: 0x0D30

Reset value: 0x0070 0000

The queue receive operating mode register establishes the receive queue operating modes and command.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RQS[2:0]			Res.	Res.	Res.	Res.
									r	r	r				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIS_ TCP_EF	RSF	FEP	FUP	Res.	RTC[1:0]	
									rw	rw	rw	rw		rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:20 **RQS[2:0]**: Receive Queue Size

This field is read-only and the configured Rx FIFO size in blocks of 256 bytes is reflected in the reset value. The size of the Queue is (RQS + 1) × 256 bytes.

Bits 19:7 Reserved, must be kept at reset value.

Bit 6 **DIS_TCP_EF**: Disable Dropping of TCP/IP Checksum Error Packets

When this bit is set, the MAC does not drop the packets which only have the errors detected by the receive checksum offload engine. Such packets have errors only in the encapsulated payload. There are no errors (including FCS error) in the Ethernet packet received by the MAC.

When this bit is reset, all error packets are dropped if the FEP bit is reset.

Bit 5 **RSF**: Receive Queue Store and Forward

When this bit is set, the Ethernet peripheral reads a packet from the Rx queue only after the complete packet has been written to it, ignoring the RTC field of this register. When this bit is reset, the Rx queue operates in the Threshold (cut-through) mode, subject to the threshold specified by the RTC field of this register.

Bit 4 **FEP**: Forward Error Packets

When this bit is reset, the Rx queue drops packets with error status (CRC error, receive error, watchdog timeout, or overflow). However, if the start byte (write) pointer of a packet is already transferred to the read controller side (in Threshold mode), the packet is not dropped.

When this bit is set, all packets except the runt error packets are forwarded to the application or DMA. If the RSF bit is set and the Rx queue overflows when a partial packet is written, the packet is dropped irrespective of the setting of this bit. However, if the RSF bit is reset and the Rx queue overflows when a partial packet is written, a partial packet may be forwarded to the application or DMA.

Bit 3 **FUP**: Forward Undersized Good Packets

When this bit is set, the Rx queue forwards the undersized good packets (packets with no error and length less than 64 bytes), including pad-bytes and CRC. When this bit is reset, the Rx queue drops all packets of less than 64 bytes, unless a packet is already transferred because of the lower value of Rx Threshold, for example, RTC = 01.

Bit 2 Reserved, must be kept at reset value.

Bits 1:0 **RTC[1:0]**: Receive Queue Threshold Control

These bits control the threshold level of the MTL Rx queue (in bytes):
00: 64
01: 32
10: 96
11: 128
The received packet is transferred to the application or DMA when the packet size within the MTL Rx queue is larger than the threshold. In addition, full packets with length less than the threshold are automatically transferred.
This field is valid only when the RSF bit is zero. This field is ignored when the RSF bit is set to 1.

Rx queue missed packet and overflow counter register (ETH_MTLRXQMPOCR)

Address offset: 0x0D34

Reset value: 0x0000 0000

The queue missed packet and overflow counter registers contain the counter for packets missed because of Receive queue packet flush and packets discarded because of Receive queue overflow.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	MISCNTOVF	MISPKTCNT[10:0]										
				rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	OVFCNTOVF	OVFPKTCNT[10:0]										
				rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **MISCNTOVF**: Missed packet counter Overflow Bit

When set, this bit indicates that the Rx Queue Missed packet counter crossed the maximum limit.

Bits 26:16 **MISPKTCNT[10:0]**: Missed packet counter

This field indicates the number of packets missed by the Ethernet peripheral because the application requested to flush the packets for this queue. This counter is reset when this register is read.
This counter is incremented by 1 when the DMA discards the packet because of buffer unavailability.

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **OVFCNTOVF**: Overflow Counter Overflow Bit
When set, this bit indicates that the Rx Queue Overflow packet counter field crossed the maximum limit.

Bits 10:0 **OVFPKTCNT[10:0]**: Overflow packet counter
This field indicates the number of packets discarded by the Ethernet peripheral because of Receive queue overflow. This counter is incremented each time the Ethernet peripheral discards an incoming packet because of overflow. This counter is reset when this register is read.

Rx queue debug register (ETH_MTLRXQDR)

Address offset: 0x0D38

Reset value: 0x0000 0000

The queue receive debug register gives the debug status of various blocks related to the receive queue.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	PRXQ[13:0]													
		r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXQSTS[1:0]		Res.	RRCSTS[1:0]		RWCSTS
										r	r		r	r	r

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:16 **PRXQ[13:0]**: Number of Packets in Receive Queue
This field indicates the current number of packets in the Rx queue. The theoretical maximum value for this field is 256 Kbytes/16 bytes = 16K packets, that is, Max_Queue_Size/Min_Packet_Size.

Bits 15:6 Reserved, must be kept at reset value.

Bits 5:4 **RXQSTS[1:0]**: MTL Rx Queue Fill-Level Status
This field gives the status of the fill-level of the Rx queue:
00: Rx queue empty
01: Rx queue fill-level below flow-control deactivate threshold
10: Rx queue fill-level above flow-control activate threshold
11: Rx queue full

Bit 3 Reserved, must be kept at reset value.

Bits 2:1 **RRCSTS[1:0]**: MTL Rx Queue Read Controller State
This field gives the state of the Rx queue Read controller:
00: Idle state
01: Reading packet data
10: Reading packet status (or timestamp)
11: Flushing the packet data and status

Bit 0 **RWCSTS**: MTL Rx Queue Write Controller Active Status
When high, this bit indicates that the MTL Rx queue Write controller is active, and it is transferring a received packet to the Rx queue.

Ethernet MTL register map and reset values

Table 828. ETH_MTL register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0C00	ETH_MTLOMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNTCLR	CNTPRST	Res.	Res.			Res.	Res.	Res.	DTXSTS	Res.
	Reset value																							0	0								0	
0x0C04 - 0x0C1C	Reserved																																
0x0C20	ETH_MTLISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Q0IS
	Reset value																																0
0x0C24 - 0x0CFC	Reserved																																
0x0C40	Reserved																																
0x0D00	ETH_ MTLTXQOMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TQS[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TTC[2:0]			TXQEN[1:0]		TSF	FTQ
	Reset value														1	1	1										0	0	0	1	0	0	0
0x0D04	ETH_ MTLTXQUR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UFCNTOVF	UFFRMCNT[10:0]										
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x0D08	ETH_ MTLTXQDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STXSTSF[2:0]			Res.	PTXQ[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXSTSFSTS	TXQSTS	TWCSTS	TRCSTS[1:0]		TXQPAUSED
	Reset value										0	0	0		0	0	0											0	0	0	0	0	0
0x0D0C - 0x0D28	Reserved																																
0x0D2C	ETH_MTLQICSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXOIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXOVFIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXUIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXUNFIS
	Reset value								0								0								0								0
0x0D30	ETH_ MTLRXQOMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RQS[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIS_TCP_EF	RSF	FEP	FUP	Res.	RTC[1:0]	
	Reset value										1	1	1														0	0	0	0		0	0
0x0D34	ETH_ MTLRXQMPOCR	Res.	Res.	Res.	Res.	MISCNTOVF	MISPKTCNT[10:0]											Res.	Res.	Res.	Res.	OVFCNTOVF	OVFPKTCNT[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0

Table 828. ETH_MTL register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0D38	ETH_ MTLRXQDR	Res.	Res.	PRXQ[13:0]														Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXQSTS[1:0]		Res.	RRCSTS[1:0]		RWCSTS
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0											0	0		0	0	0
0xD3C-0xD58	Reserved																																

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

69.11.4 Ethernet MAC and MMC registers

Operating mode configuration register (ETH_MACCR)

Address offset: 0x0000

Reset value: 0x0000 8000

The MAC Configuration register establishes the operating mode of the MAC.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARPEN	SARC[2:0]			IPC	IPG[2:0]			GPSLCE	S2KP	CST	ACS	WD	Res.	JD	JE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	FES	DM	LM	ECRSFD	DO	DCRS	DR	Res.	BL[1:0]		DC	PRELEN[1:0]		TE	RE
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bit 31 **ARPEN**: ARP Offload Enable

When this bit is set, the MAC can recognize an incoming ARP request packet and schedules the ARP packet for transmission. It forwards the ARP packet to the application and also indicate the events in the RxStatus.

When this bit is reset, the MAC receiver does not recognize any ARP packet and indicates them as Type frame in the RxStatus.

Bits 30:28 **SARC[2:0]**: Source Address Insertion or Replacement Control

This field controls the source address insertion or replacement for all transmitted packets. Bit 30 specifies which MAC Address register (0 or 1) is used for source address insertion or replacement based on the values of Bits[29:28]:

010:the MAC inserts the content of the MAC Address 0 registers (*MAC address 0 high register (ETH_MACA0HR)* and *MAC address x low register (ETH_MACAxLR)*) in the SA field of all transmitted packets.

011: the MAC replaces the content of the MAC Address 0 registers (*MAC address 0 high register (ETH_MACA0HR)* and *MAC address x low register (ETH_MACAxLR)*) in the SA field of all transmitted packets.

110: the MAC inserts the content of the MAC Address 1 registers (*MAC address x high register (ETH_MACAxHR)* and *MAC address x low register (ETH_MACAxLR)*) in the SA field of all transmitted packets

111: the MAC replaces the content of the MAC Address 1 registers (*MAC address x high register (ETH_MACAxHR)* and *MAC address x low register (ETH_MACAxLR)*) in the SA field of all transmitted packets.

Others: Reserved, must not be used.

Note: Changes to this field take effect only on the start of a packet. If you write to this register field when a packet is being transmitted, only the subsequent packet can use the updated value, that is, the current packet does not use the updated value.

Bit 27 **IPC**: Checksum Offload

When set, this bit enables the IPv4 header checksum checking and IPv4 or IPv6 TCP, UDP, or ICMP payload checksum checking. When this bit is reset, the COE function in the receiver is disabled.

The Layer 3 and Layer 4 Packet Filter feature automatically selects the IPC Full Checksum Offload Engine on the Receive side. When this feature is enabled, you must set the IPC bit.

Bits 26:24 **IPG[2:0]**: Inter-Packet Gap

These bits control the minimum IPG between packets during transmission.

000: 96 bit times

001: 88 bit times

010: 80 bit times

...

111: 40 bit times

This range of minimum IPG is valid in Full-duplex mode.

In the Half-duplex mode, the minimum IPG can be configured only for 64-bit times (IPG = 100). Lower values are not considered.

When a JAM pattern is being transmitted because of backpressure activation, the MAC does not consider the minimum IPG.

The above function (IPG less than 96 bit times) is valid only when EIPGEN bit in ETH_MACECR register is reset. When EIPGEN is set, then the minimum IPG (greater than 96 bit times) is controlled as per the description given in EIPG field in ETH_MACECR register.

Bit 23 **GPSLCE**: Giant Packet Size Limit Control Enable

When this bit is set, the MAC considers the value in GPSL field in ETH_MACECR register to declare a received packet as Giant packet. This field must be programmed to more than 1,518 bytes. Otherwise, the MAC considers 1,518 bytes as giant packet limit.

When this bit is reset, the MAC considers a received packet as Giant packet when its size is greater than 1,518 bytes (1522 bytes for tagged packet).

The watchdog timeout limit, Jumbo Packet Enable and 2K Packet Enable have higher precedence over this bit, that is the MAC considers a received packet as Giant packet when its size is greater than 9,018 bytes (9,022 bytes for tagged packet) with Jumbo Packet Enabled and greater than 2,000 bytes with 2K Packet Enabled. The watchdog timeout, if enabled, terminates the received packet when watchdog limit is reached. Therefore, the programmed giant packet limit should be less than the watchdog limit to get the giant packet status.

Bit 22 **S2KP**: IEEE 802.3as Support for 2K Packets

When this bit is set, the MAC considers all packets with up to 2,000 bytes length as normal packets. When the JE bit is not set, the MAC considers all received packets of size more than 2K bytes as Giant packets.

When this bit is reset and the JE bit is not set, the MAC considers all received packets of size more than 1,518 bytes (1,522 bytes for tagged) as giant packets. For more information about how the setting of this bit and the JE bit impact the Giant packet status, see *Table 829: Giant Packet Status based on S2KP and JE Bits*.

Note: When the JE bit is set, setting this bit has no effect on the giant packet status.

Bit 21 **CST**: CRC stripping for Type packets

When this bit is set, the last four bytes (FCS) of all packets of Ether type (type field greater than 1,536) are stripped and dropped before forwarding the packet to the application. This function is not valid when the IP Checksum Engine (Type 1) is enabled in the MAC receiver. This function is valid when Type 2 Checksum Offload Engine is enabled.

Note: For information about how the settings of the ACS bit and this bit impact the packet length, see Table 830: Packet Length based on the CST and ACS bits.

Bit 20 **ACS**: Automatic Pad or CRC Stripping

When this bit is set, the MAC strips the Pad or FCS field on the incoming packets only if the value of the length field is less than 1,536 bytes. All received packets with length field greater than or equal to 1,536 bytes are passed to the application without stripping the Pad or FCS field.

When this bit is reset, the MAC passes all incoming packets to the application, without any modification.

Note: For information about how the settings of CST bit and this bit impact the packet length, see Table 830: Packet Length based on the CST and ACS bits.

Bit 19 **WD**: Watchdog Disable

When this bit is set, the MAC disables the watchdog timer on the receiver. The MAC can receive packets of up to 16,383 bytes.

When this bit is reset, the MAC does not allow more than 2,048 bytes (10,240 if JE is set high) of the packet being received. The MAC cuts off any bytes received after 2,048 bytes.

Bit 18 Reserved, must be kept at reset value.

Bit 17 **JD**: Jabber Disable

When this bit is set, the MAC disables the jabber timer on the transmitter. The MAC can transfer packets of up to 16,383 bytes.

When this bit is reset, if the application sends more than 2,048 bytes of data (10,240 if JE is set high) during transmission, the MAC does not send rest of the bytes in that packet.

Bit 16 **JE**: Jumbo Packet Enable

When this bit is set, the MAC allows jumbo packets of 9,018 bytes (9,022 bytes for VLAN tagged packets) without reporting a giant packet error in the Rx packet status.

For more information about how the setting of this bit and the JE bit impact the Giant packet status, see *Table 829: Giant Packet Status based on S2KP and JE Bits*.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **FES**: MAC Speed

This bit selects the speed in the 10/100 Mbit/s mode:

0: 10 Mbit/s

1: 100 Mbit/s

Bit 13 **DM**: Duplex Mode

When this bit is set, the MAC operates in the Full-duplex mode in which it can transmit and receive simultaneously.

Bit 12 **LM**: Loopback Mode

When this bit is set, the MAC operates in the loopback mode at MII. The MII Rx clock input (eth_rx_clk) is required for the loopback to work properly. This is because the Tx clock is not internally looped back.

Bit 11 **ECRSFD**: Enable Carrier Sense Before Transmission in Full-duplex mode

When this bit is set, the MAC transmitter checks the CRS signal before packet transmission in the Full-duplex mode. The MAC starts the transmission only when the CRS signal is low.

When this bit is reset, the MAC transmitter ignores the status of the CRS signal.

Bit 10 **DO**: Disable Receive Own

When this bit is set, the MAC disables the reception of packets when the ETH_TX_EN is asserted in the Half-duplex mode. When this bit is reset, the MAC receives all packets given by the PHY.

This bit is not applicable in the Full-duplex mode. This bit is reserved and read-only (RO) with default value in the Full-duplex-only configurations.

Bit 9 **DCRS**: Disable Carrier Sense During Transmission

When this bit is set, the MAC transmitter ignores the MII CRS signal during packet transmission in the Half-duplex mode. As a result, no errors are generated because of Loss of Carrier or No Carrier during transmission.

When this bit is reset, the MAC transmitter generates errors because of Carrier Sense. The MAC can even abort the transmission.

Bit 8 **DR**: Disable Retry

When this bit is set, the MAC attempts only one transmission. When a collision occurs on the MII interface, the MAC ignores the current packet transmission and reports a Packet Abort with excessive collision error in the Tx packet status.

When this bit is reset, the MAC retries based on the settings of the BL field. This bit is applicable only in the Half-duplex mode.

Bit 7 Reserved, must be kept at reset value.

Bits 6:5 **BL[1:0]**: Back-Off Limit

The back-off limit determines the random integer number (r) of slot time delays (512 bit times for 10/100 Mbit/s) for which the MAC waits before rescheduling a transmission attempt during retries after a collision:

00: k= min (n, 10)

01: k = min (n, 8)

10: k = min (n, 4)

11: k = min (n, 1)

where n = retransmission attempt

The random integer r takes the value in the range $0 <= r < 2^k$.

This bit is applicable only in the Half-duplex mode.

Bit 4 **DC**: Deferral check

When this bit is set, the deferral check function is enabled in the MAC. The MAC issues a Packet Abort status, along with the excessive deferral error bit set in the Tx packet status, when the Tx state machine is deferred for more than 24,288 bit times in 10 or 100 Mbit/s mode.

Deferral begins when the transmitter is ready to transmit, but it is prevented because of an active carrier sense signal (CRS) on MII.

The defer time is not cumulative. For example, if the transmitter defers for 10,000 bit times because the CRS signal is active and the CRS signal becomes inactive, the transmitter transmits and collision happens. Because of collision, the transmitter needs to back off and then defer again after back off completion. In such a scenario, the deferral timer is reset to 0, and it is restarted.

When this bit is reset, the deferral check function is disabled and the MAC defers until the CRS signal goes inactive.

This bit is applicable only in the Half-duplex mode.

Bits 3:2 **PRELEN[1:0]**: Preamble length for transmit packets

These bits control the number of preamble bytes that are added to the beginning of every Tx packet. The preamble reduction occurs only when the MAC is operating in the Full-duplex mode.

00: 7 bytes of preamble

01: 5 bytes of preamble

10: 3 bytes of preamble

11: Reserved, must not be used

Bit 1 **TE**: Transmitter enable

When this bit is set, the Tx state machine of the MAC is enabled for transmission on the MII interface. When this bit is reset, the MAC Tx state machine is disabled after it completes the transmission of the current packet. The Tx state machine does not transmit any more packets.

Bit 0 **RE**: Receiver enable

When this bit is set, the Rx state machine of the MAC is enabled for receiving packets from the MII interface. When this bit is reset, the MAC Rx state machine is disabled after it completes the reception of the current packet. The Rx state machine does not receive any more packets from the MII interface.

Table 829 shows how the settings of S2KP and JE bits of the ETH_MACCR register impact the giant packet status.

Table 829. Giant Packet Status based on S2KP and JE Bits(1)

Length/Type Field	Received Packet Length	S2KP	JE	Giant Packet Status
Untagged packet	> 1,518	0	0	1
	> 2,000	1	0	1
	> 9,018	x	1	1
VLAN tagged packet	> 1,522	0	0	1
	> 2,000	1	0	1
	> 9,022	x	1	1

1. For all other combinations, the Giant Packet status is 0.

Table 830 shows how the settings of the CST and ACS bits of the ETH_MACCR register impact whether CRC length is included in the packet length.

Table 830. Packet Length based on the CST and ACS bits

Received Packet Length	CST	ACS	FCS Stripping Done
< 1,536	x	0	No
	x	1	Yes (for Ethernet packets)
≥ 1,536	0	x	No
	1	x	Yes (for Type packets)

Extended operating mode configuration register (ETH_MACECR)

Address offset: 0x0004

Reset value: 0x0000 0000

The MAC Extended Configuration register establishes the operating mode of the MAC.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	APDIM	EIPG[4:0]					EIPGEN	Res.	Res.	Res.	Res.	Res.	USP	SPEN	DCRCC
	rw	rw	rw	rw	rw	rw	rw						rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	GPSL[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **APDIM**: ARP Packet Drop if IP Address Mismatch

When this bit is set, Packet for which Target Protocol Address does not match IPv4 address is dropped in the MTL layer.
When this bit is reset, when target Protocol Address does not match, the packet is forwarded to MTL maintaining backward compatibility.

Bits 29:25 **EIPG[4:0]**: Extended Inter-Packet Gap

The value in this field is applicable when the EIPGEN bit is set. This field (as Most Significant bits) along with IPG field in *Operating mode configuration register (ETH_MACCR)*, gives the minimum IPG greater than 96 bit times in steps of 8 bit times. For example:

- EIPG = 0 and IPG = 0 give 104 bit times
- EIPG = 0 and IPG = 1 give 112 bit times
- EIPG = 0 and IPG = 2 give 120 bit times
- ..
- EIPG = 7 and IPG = 31 give 2144 bit times

Bit 24 **EIPGEN**: Extended Inter-Packet Gap Enable

When this bit is set, the MAC interprets EIPG field and IPG field in *Operating mode configuration register (ETH_MACCR)* together as minimum IPG greater than 96 bit times in steps of 8 bit times.
When this bit is reset, the MAC ignores EIPG field and interprets IPG field in *Operating mode configuration register (ETH_MACCR)* as minimum IPG less than or equal to 96 bit times in steps of 8 bit times.

Note: The extended Inter-Packet Gap feature must be enabled when operating in Full-duplex mode only. There may be undesirable effects on back-pressure function and frame transmission if it is enabled in Half-duplex mode.

Bits 23:19 Reserved, must be kept at reset value.

Bit 18 **USP**: Unicast Slow Protocol Packet Detect

When this bit is set, the MAC detects the Slow Protocol packets with unicast address of the station specified in the *MAC address 0 high register (ETH_MACA0HR)* and MAC Address 0 low register *MAC address x low register (ETH_MACAxLR)*. The MAC also detects the Slow Protocol packets with the Slow Protocols multicast address (01-80-C2-00-00-02).
When this bit is reset, the MAC detects only Slow Protocol packets with the Slow Protocol multicast address specified in the IEEE 802.3-2008, Section 5.

Bit 17 **SPEN**: Slow Protocol Detection Enable

When this bit is set, MAC processes the Slow Protocol packets (Ether Type 0x8809) and provides the Rx status. The MAC discards the Slow Protocol packets with invalid subtypes.
When this bit is reset, the MAC forwards all error-free Slow Protocol packets to the application. The MAC considers such packets as normal Type packets.

Bit 16 **DCRCC**: Disable CRC Checking for Received Packets

When this bit is set, the MAC receiver does not check the CRC field in the received packets.
When this bit is reset, the MAC receiver always checks the CRC field in the received packets.

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:0 **GPSL[13:0]**: Giant Packet Size Limit

If the received packet size is greater than the value programmed in this field in units of bytes, the MAC declares the received packet as Giant packet. The value programmed in this field must be greater than or equal to 1,518 bytes. Any other programmed value is considered as 1,518 bytes.

For VLAN tagged packets, the MAC adds 4 bytes to the programmed value. For double VLAN tagged packets, the MAC adds 8 bytes to the programmed value. The value in this field is applicable when the GPSLCE bit is set in ETH_MACCR register.

Packet filtering control register (ETH_MACPFR)

Address offset: 0x0008

Reset value: 0x0000 0000

The MAC Packet Filter register contains the filter controls for receiving packets. Some of the controls from this register go to the address check block of the MAC which performs the first level of address filtering. The second level of filtering is performed on the incoming packet based on other controls such as Pass Bad Packets and Pass Control Packets.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DNTU	IPFE	Res.	Res.	Res.	VTFE
rw										rw	rw				rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	HPF	SAF	SAIF	PCF[1:0]		DBF	PM	DAIF	HMC	HUC	PR
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **RA**: Receive All

When this bit is set, the MAC receiver module passes all received packets to the application, irrespective of whether they pass the address filter or not. The result of the SA or DA filtering is updated (pass or fail) in the corresponding bit in the Rx Status Word.

When this bit is reset, the receiver module passes only those packets to the application that pass the SA or DA address filter.

Bits 30:22 Reserved, must be kept at reset value.

Bit 21 **DNTU**: Drop Non-TCP/UDP over IP Packets

When this bit is set, the MAC drops the non-TCP or UDP over IP packets. The MAC forward only those packets that are processed by the Layer 4 filter. When this bit is reset, the MAC forwards all non-TCP or UDP over IP packets.

Bit 20 **IPFE**: Layer 3 and Layer 4 Filter Enable

When this bit is set, the MAC drops packets that do not match the enabled Layer 3 and Layer 4 filters. If Layer 3 or Layer 4 filters are not enabled for matching, this bit does not have any effect.

When this bit is reset, the MAC forwards all packets irrespective of the match status of the Layer 3 and Layer 4 fields.

Bits 19:17 Reserved, must be kept at reset value.

Bit 16 **VTFE**: VLAN Tag Filter Enable

When this bit is set, the MAC drops the VLAN tagged packets that do not match the VLAN Tag. When this bit is reset, the MAC forwards all packets irrespective of the match status of the VLAN Tag.

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **HPF**: Hash or Perfect Filter

When this bit is set, the address filter passes a packet if it matches either the perfect filtering or Hash filtering as set by the HMC or HUC bit.

When this bit is reset and the HUC or HMC bit is set, the packet is passed only if it matches the Hash filter.

Bit 9 **SAF**: Source Address Filter Enable

When this bit is set, the MAC compares the SA field of the received packets with the values programmed in the enabled SA registers. If the comparison fails, the MAC drops the packet.

When this bit is reset, the MAC forwards the received packet to the application with updated SAF bit of the Rx Status depending on the SA address comparison.

Note: According to the IEEE specification, Bit 47 of the SA is reserved. However, the MAC compares all 48 bits. The software driver should take this into consideration while programming the MAC address registers for SA.

Bit 8 **SAIF**: SA Inverse Filtering

When this bit is set, the Address Check block operates in the inverse filtering mode for SA address comparison. If the SA of a packet matches the values programmed in the SA registers, it is marked as failing the SA Address filter.

When this bit is reset, if the SA of a packet does not match the values programmed in the SA registers, it is marked as failing the SA Address filter.

Bits 7:6 **PCF[1:0]**: Pass Control Packets

These bits control the forwarding of all control packets (including unicast and multicast Pause packets).

00: The MAC filters all control packets from reaching the application.

01: The MAC forwards all control packets except Pause packets to the application even if they fail the Address filter.

10: The MAC forwards all control packets to the application even if they fail the Address filter.

11: The MAC forwards the control packets that pass the Address filter.

Bit 5 **DBF**: Disable Broadcast Packets

When this bit is set, the AFM module blocks all incoming broadcast packets. In addition, it overrides all other filter settings.

When this bit is reset, the AFM module passes all received broadcast packets.

Bit 4 **PM**: Pass All Multicast

When this bit is set, it indicates that all received packets with a multicast destination address (first bit in the destination address field is '1') are passed. When this bit is reset, filtering of multicast packet depends on HMC bit.

Bit 3 **DAIF**: DA Inverse Filtering

When this bit is set, the Address Check block operates in inverse filtering mode for the DA address comparison for both unicast and multicast packets. When this bit is reset, normal filtering of packets is performed.

Bit 2 **HMC**: Hash Multicast

When this bit is set, the MAC performs the destination address filtering of received multicast packets according to the Hash table.

When this bit is reset, the MAC performs the perfect destination address filtering for multicast packets, that is, it compares the DA field with the values programmed in DA registers.

Bit 1 **HUC**: Hash Unicast

When this bit is set, the MAC performs the destination address filtering of unicast packets according to the Hash table.

When this bit is reset, the MAC performs a perfect destination address filtering for unicast packets, that is, it compares the DA field with the values programmed in DA registers.

Bit 0 **PR**: Promiscuous Mode

When this bit is set, the Address Filtering module passes all incoming packets irrespective of the destination or source address. The SA or DA Filter Fails status bits of the Rx Status Word are always cleared when PR is set.

Watchdog and jabber timeout register (ETH_MACWJBTR)

Address offset: 0x000C

Reset value: 0x0000 0000

The watchdog and jabber timeout register controls the watchdog timeout for received packets and the jabber timeout limit for transmitted packets.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	PJE	Res.	Res.	Res.	Res.	JTO[3:0]			
							rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	PWE	Res.	Res.	Res.	Res.	WTO[3:0]			
							rw					rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **PJE**: Programmable Jabber Enable

When this bit is set and the JD bit of the *Operating mode configuration register (ETH_MACCR)* is reset, the JTO[3:0] bitfield is used as jabber timeout limit for transmitted packets.

When this bit is cleared, the jabber timeout for a received packet is controlled by setting the JD and JE bits of the *Operating mode configuration register (ETH_MACCR)*.

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **JTO[3:0]**: Jabber timeout

When the PJE bit is set and the JD bit of the *Operating mode configuration register (ETH_MACCR)* is cleared, this bitfield is used as jabber timeout limit for transmitted packets. If the length of a transmitted packet exceeds the value of this bitfield, such packet is terminated and declared as an error packet.

Encoding is as follows:

0x0: 2 Kbytes
0x1: 3 Kbytes
0x2: 4 Kbytes
0x3: 5 Kbytes
..
0xC: 14 Kbytes
0xD: 15 Kbytes
0xE: 16383 Bytes
0xF: Reserved, must not be used

Note: When the PJE bit is set, the value in this bitfield must be more than 1,522 (0x05F2). Otherwise, the IEEE 802.3-specified valid tagged packets are declared as error packets and terminated.

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **PWE**: Programmable Watchdog Enable

When this bit is set and the WD bit of the *Operating mode configuration register (ETH_MACCR)* register is reset, the WTO field is used as watchdog timeout for a received packet. When this bit is cleared, the watchdog timeout for a received packet is controlled by setting of WD and JE bits in *Operating mode configuration register (ETH_MACCR)* register.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **WTO[3:0]**: Watchdog timeout

When the PWE bit is set and the WD bit of the *Operating mode configuration register (ETH_MACCR)* register is reset, this field is used as watchdog timeout for a received packet. If the length of a received packet exceeds the value of this field, such packet is terminated and declared as an error packet.

Encoding is as follows:

0x0: 2 Kbytes
0x1: 3 Kbytes
0x2: 4 Kbytes
0x3: 5 Kbytes
..
0xC: 14 Kbytes
0xD: 15 Kbytes
0xE: 16383 Bytes
0xF: Reserved, must not be used

Note: When the PWE bit is set, the value in this bitfield should be more than 1,522 (0x05F2). Otherwise, the IEEE 802.3-specified valid tagged packets are declared as error packets and then dropped.

Hash Table 0 register (ETH_MACHT0R)

Address offset: 0x0010

Reset value: 0x0000 0000

The Hash Table Register 0 contains the first lower 32 bits of the Hash table (64 bits).

The Hash table is used for group address filtering.

For Hash filtering, the content of the destination address in the incoming packet is passed through the CRC logic and the upper six bits of the CRC register are used to index the content of the Hash table. The most significant bits determines the register to be used (Hash Table Register 0 or 1) and the least significant five bits determine the bit within the register. For example, a hash value of 0b100000 selects Bit 0 of the Hash Table Register 1.

The Hash value of the destination address is calculated in the following way:

1. Calculate the 32-bit CRC for the DA (See IEEE 802.3, Section 3.2.8 for the steps to calculate CRC32).
2. Perform bitwise reversal for the value obtained in Step 1.
3. Take the upper 7 or 8 bits from the value obtained in Step 2.

If the corresponding bit value of the register is 1, the packet is accepted. Otherwise, it is rejected. If the PM bit is set in ETH_MACPFR, all multicast packets are accepted regardless of the multicast Hash values.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HT31T0[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HT31T0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **HT31T0[31:0]**: MAC Hash Table First 32 Bits

This field contains the first 32 Bits [31:0] of the Hash table.

Hash Table 1 register (ETH_MACHT1R)

Address offset: 0x0014

Reset value: 0x0000 0000

The Hash Table 1 register contains the upper 32 bits of the Hash table (64 bits).

The Hash table is used for group address filtering.

For Hash filtering, the content of the destination address in the incoming packet is passed through the CRC logic and the upper six bits of the CRC register are used to index the content of the Hash table. The most significant bits determines the register to be used (Hash Table Register 0 or 1) and the least significant five bits determine the bit within the register. For example, a hash value of 6'b100000 selects Bit 0 of the Hash Table Register 1.

The Hash value of the destination address is calculated in the following way:

1. Calculate the 32-bit CRC for the DA (See IEEE 802.3, Section 3.2.8 for the steps to calculate CRC32).
2. Perform bitwise reversal for the value obtained in Step 1.
3. Take the upper 7 or 8 bits from the value obtained in Step 2.

If the corresponding bit value of the register is 1, the packet is accepted. Otherwise, it is rejected. If the PM bit is set in ETH_MACPFR, all multicast packets are accepted regardless of the multicast Hash values.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HT63T32[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HT63T32[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **HT63T32[31:0]**: MAC Hash Table Second 32 Bits

This field contains the second 32 Bits [63:32] of the Hash table.

VLAN tag register (ETH_MACVTR)

Address offset: 0x0050

Reset value: 0x0000 0000

The VLAN Tag register identifies the IEEE 802.1Q VLAN type packets.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EIVLRXS	Res.	EIVLS[1:0]		ERIVLT	EDVLP	VTHM	EVLRXS	Res.	EVLS[1:0]		DOVLTC	ERSVLM	ESVL	VTIM	ETV
rw		rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **EIVLRXS**: Enable Inner VLAN Tag in Rx Status

When this bit is set, the MAC provides the inner VLAN Tag in the Rx status. When this bit is reset, the MAC does not provide the inner VLAN Tag in Rx status.

Bit 30 Reserved, must be kept at reset value.

Bits 29:28 **EIVLS[1:0]**: Enable Inner VLAN Tag Stripping on Receive

This field indicates the stripping operation on inner VLAN Tag in received packet:
00: Do not strip
01: Strip if VLAN filter passes
10: Strip if VLAN filter fails
11: Always strip

Bit 27 **ERIVLT**: Enable Inner VLAN Tag

When this bit and the EDVLP field are set, the MAC receiver enables operation on the inner VLAN Tag (if present). When this bit is reset, the MAC receiver enables operation on the outer VLAN Tag (if present). The ERSVLM bit determines which VLAN type is enabled for filtering or matching.The ERSVLM bit and DOVLTC bit determines which VLAN type is enabled for filtering.

Bit 26 **EDVLP**: Enable Double VLAN Processing

When this bit is set, the MAC enables processing of up to two VLAN Tags on Tx and Rx (if present). When this bit is reset, the MAC enables processing of up to one VLAN Tag on Tx and Rx (if present).

Bit 25 **VTHM**: VLAN Tag Hash Table Match Enable

When this bit is set, the most significant four bits of CRC of VLAN Tag are used to index the content of the ETH_MACVLANHTR register. A value of 1 in the VLAN Hash Table register, corresponding to the index, indicates that the packet matched the VLAN Hash table.
When the ETV bit is set, the CRC of the 12-bit VLAN Identifier (VID) is used for comparison.
When the ETV bit is reset, the CRC of the 16-bit VLAN tag is used for comparison.
When this bit is reset, the VLAN Hash Match operation is not performed.

Bit 24 **EVLRXS**: Enable VLAN Tag in Rx status

When this bit is set, MAC provides the outer VLAN Tag in the Rx status. When this bit is reset, the MAC does not provide the outer VLAN Tag in Rx status.

Bit 23 Reserved, must be kept at reset value.

Bits 22:21 **EVLS[1:0]**: Enable VLAN Tag Stripping on Receive

This field indicates the stripping operation on the outer VLAN Tag in received packet:
00: Do not strip
01: Strip if VLAN filter passes
10: Strip if VLAN filter fails
11: Always strip

Bit 20 **DOVLTC**: Disable VLAN Type Check

When this bit is set, the MAC does not check whether the VLAN Tag specified by the ERIVLT bit is of type S-VLAN or C-VLAN.
When this bit is reset, the MAC filters or matches the VLAN Tag specified by the ERIVLT bit only when VLAN Tag type is similar to the one specified by the ERSVLM bit.

Bit 19 **ERSVLM**: Enable Receive S-VLAN Match

When this bit is set, the MAC receiver enables filtering or matching for S-VLAN (Type = 0x88A8) packets. When this bit is reset, the MAC receiver enables filtering or matching for C-VLAN (Type = 0x8100) packets.
The ERIVLT bit determines the VLAN tag position considered for filtering or matching.

Bit 18 **ESVL**: Enable S-VLAN

When this bit is set, the MAC transmitter and receiver consider the S-VLAN packets (Type = 0x88A8) as valid VLAN tagged packets.

Bit 17 **VTIM**: VLAN Tag Inverse Match Enable

When this bit is set, this bit enables the VLAN Tag inverse matching. The packets without matching VLAN Tag are marked as matched. When reset, this bit enables the VLAN Tag perfect matching. The packets with matched VLAN Tag are marked as matched.

Bit 16 **ETV**: Enable 12-Bit VLAN Tag Comparison

When this bit is set, a 12-bit VLAN identifier is used for comparing and filtering instead of the complete 16-bit VLAN tag. Bits[11:0] of VLAN tag are compared with the corresponding field in the received VLAN-tagged packet. Similarly, when enabled, only 12 bits of the VLAN tag in the received packet are used for Hash-based VLAN filtering.
When this bit is reset, all 16 bits of the 15th and 16th bytes of the received VLAN packet are used for comparison and VLAN Hash filtering.

Bits 15:0 **VL[15:0]**: VLAN Tag Identifier for Receive Packets

This field contains the 802.1Q VLAN tag to identify the VLAN packets. This VLAN tag identifier is compared to the 15th and 16th bytes of the packets being received for VLAN packets. The following list describes the bits of this field:
Bits[15:13]: User Priority
Bit 12: Canonical Format Indicator (CFI) or Drop Eligible Indicator (DEI)
Bits[11:0]: VLAN Identifier (VID) field of VLAN tag
When the ETV bit is set, only the VID is used for comparison.
If this field ([11:0] if ETV is set) is all zeros, the MAC does not check the 15th and 16th bytes for VLAN tag comparison and declares all packets with Type field value of 0x8100 or 0x88a8 as VLAN packets.

VLAN Hash table register (ETH_MACVHTR)

Address offset: 0x0058

Reset value: 0x0000 0000

When the VTHM bit of *VLAN tag register (ETH_MACVTR)* register is set, the 16-bit VLAN Hash Table register is used for group address filtering based on the VLAN tag. For Hash filtering, the content of the 16-bit VLAN tag or 12-bit VLAN ID (based on the ETV bit of *VLAN tag register (ETH_MACVTR)* register) in the incoming packet is passed through the CRC logic. The upper four bits of the calculated CRC are used to index the contents of the VLAN Hash table. For example, a Hash value of 1000 selects Bit 8 of the VLAN Hash table.

The Hash value of the destination address is calculated in the following way:

1. Calculate the 32-bit CRC for the VLAN tag or ID (For steps to calculate CRC32, see Section 3.2.8 of IEEE 802.3).
2. Perform bitwise reversal for the value obtained in step 1.
3. Take the upper four bits from the value obtained in step 2.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VLHT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **VLHT[15:0]**: VLAN Hash Table
This field contains the 16-bit VLAN Hash Table.

VLAN inclusion register (ETH_MACVIR)

Address offset: 0x0060

Reset value: 0x0000 0000

The VLAN Tag Inclusion or Replacement register contains the VLAN tag for insertion or replacement in the transmit packets. It also contains the VLAN tag insertion controls.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VLTI	CSVL	VLP	VLC[1:0]	
											rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VLT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **VLTI**: VLAN tag Input

When this bit is set, it indicates that the VLAN tag to be inserted or replaced in Tx packet should be taken from the Tx descriptor.

Bit 19 **CSVL**: C-VLAN or S-VLAN

When this bit is set, S-VLAN type (0x88A8) is inserted or replaced in the 13th and 14th bytes of transmitted packets. When this bit is reset, C-VLAN type (0x8100) is inserted or replaced in the 13th and 14th bytes of transmitted packets.

0: C-LAN

1: S-LAN

Bit 18 **VLP**: VLAN priority control

When this bit is set, the control bits[17:16] are used for VLAN deletion, insertion, or replacement. When this bit is reset, bits[17:16] are ignored.

Bits 17:16 **VLC[1:0]**: VLAN tag control in transmit packets

00: No VLAN tag deletion, insertion, or replacement

01: VLAN tag deletion. The MAC removes the VLAN type (bytes 13 and 14) and VLAN tag (bytes 15 and 16) of all transmitted packets with VLAN tags.

10: VLAN tag insertion. The MAC inserts VLT in bytes 15 and 16 of the packet after inserting the Type value (0x8100 or 0x88a8) in bytes 13 and 14. This operation is performed on all transmitted packets, irrespective of whether they already have a VLAN tag.

11: VLAN tag replacement. The MAC replaces VLT in bytes 15 and 16 of all VLAN-type transmitted packets (Bytes 13 and 14 are 0x8100 or 0x88a8).

Note: Changes to this field take effect only on the start of a packet. If you write this register field when a packet is being transmitted, only the subsequent packet can use the updated value, that is, the current packet does not use the updated value.

Bits 15:0 **VLT[15:0]**: VLAN tag for transmit packets

This field contains the value of the VLAN tag to be inserted or replaced. The value must only be changed when the transmit lines are inactive or during the initialization phase.

The following list describes the bits of this field:

Bits[15:13]: User Priority

Bit 12: Canonical Format Indicator (CFI) or Drop Eligible Indicator (DEI)

Bits[11:0]: VLAN Identifier (VID) field of VLAN tag

Inner VLAN inclusion register (ETH_MACIVIR)

Address offset: 0x0064

Reset value: 0x0000 0000

The Inner VLAN Tag Inclusion or Replacement register contains the inner VLAN tag to be inserted or replaced in the transmit packet. It also contains the inner VLAN tag insertion controls.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VLTI	CSVL	VLP	VLC[1:0]	
											rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VLT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **VLTI**: VLAN tag input

When this bit is set, it indicates that the VLAN tag to be inserted or replaced in Tx packet should be taken from the Tx descriptor

Bit 19 **CSVL**: C-VLAN or S-VLAN

When this bit is set, S-VLAN type (0x88A8) is inserted or replaced in the 13th and 14th bytes of transmitted packets. When this bit is reset, C-VLAN type (0x8100) is inserted or replaced in the 13th and 14th bytes of transmitted packets.

0: C-LAN

1: S-LAN

Bit 18 **VLP**: VLAN priority control

When this bit is set, the VLC field is used for VLAN deletion, insertion, or replacement. When this bit is reset, the VLC field is ignored.

Bits 17:16 **VLC[1:0]**: VLAN tag control in transmit packets

00: No VLAN tag deletion, insertion, or replacement

01: VLAN tag deletion

The MAC removes the VLAN type (bytes 17 and 18) and VLAN tag (bytes 19 and 20) of all transmitted packets with VLAN tags.

10: VLAN tag insertion

The MAC inserts VLT in bytes 19 and 20 of the packet after inserting the Type value (0x8100 or 0x88a8) in bytes 17 and 18. This operation is performed on all transmitted packets, irrespective of whether they already have a VLAN tag.

11: VLAN tag replacement

The MAC replaces VLT in bytes 19 and 20 of all VLAN-type transmitted packets (Bytes 17 and 18 are 0x8100 or 0x88a8).

Note: Changes to this field take effect only on the start of a packet. If you write to this register field when a packet is being transmitted, only the subsequent packet can use the updated value, that is, the current packet does not use the updated value.

Bits 15:0 **VLT[15:0]**: VLAN tag for transmit packets

This field contains the value of the VLAN tag to be inserted or replaced. The value must only be changed when the transmit lines are inactive or during the initialization phase.
The following list describes the bits of this field:
Bits[15:13]: User Priority
Bit 12: Canonical Format Indicator (CFI) or Drop Eligible Indicator (DEI)
Bits[11:0]: VLAN Identifier (VID) field of VLAN tag

Tx Queue flow control register (ETH_MACQTXFCR)

Address offset: 0x0070

Reset value: 0x0000 0000

The flow control register controls the generation and reception of the control (Pause Command) packets by the flow control module of the MAC. A Write to a register with the Busy bit set to 1 triggers the Flow Control block to generate a Pause packet. The fields of the control packet are selected as specified in the 802.3x specification, and the Pause Time value from this register is used in the Pause Time field of the control packet. The Busy bit remains set until the control packet is transferred onto the cable. The application must make sure that the Busy bit is cleared before writing to the register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DZPQ	PLT[2:0]			Res.	Res.	TFE	FCB_BPA
								rw	rw	rw	rw			rw	rw

Bits 31:16 **PT[15:0]**: Pause Time

This field holds the value to be used in the Pause Time field in the Tx control packet. I

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **DZPQ**: Disable Zero-Quanta Pause

When this bit is set, it disables the automatic generation of the zero-quanta Pause packets.
When this bit is reset, normal operation with automatic zero-quanta Pause packet generation is enabled.

Bits 6:4 **PLT[2:0]**: Pause Low Threshold

This field configures the threshold of the Pause timer at which the input flow is checked for automatic retransmission of the Pause packet.

The threshold values should be always less than the Pause Time configured in Bits[31:16]. For example, if PT = 100H (256 slot times), and PLT = 001, a second Pause packet is automatically transmitted at 228 (256-28) slot times after the first Pause packet is transmitted.

The following list provides the threshold values for different values:

000: Pause Time minus 4 Slot Times (PT -4 slot times)

001: Pause Time minus 28 Slot Times (PT -28 slot times)

010: Pause Time minus 36 Slot Times (PT -36 slot times)

011: Pause Time minus 144 Slot Times (PT -144 slot times)

100: Pause Time minus 256 Slot Times (PT -256 slot times)

101: Pause Time minus 512 Slot Times (PT -512 slot times)

110 to 111: Reserved, must not be used

The slot time is defined as the time taken to transmit 512 bits (64 bytes) on the MII interface.

This (approximate) computation is based on the packet size (64, 1518, 2000, 9018, 16384, or 32768) + 2 Pause Packet Size + IPG in Slot Times.

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **TFE**: Transmit Flow Control Enable

Full-duplex mode: when this bit is set, the MAC enables the flow control operation to Tx Pause packets. When this bit is reset, the flow control operation in the MAC is disabled, and the MAC does not transmit any Pause packets.

Half-duplex mode: when this bit is set, the MAC enables the backpressure operation. When this bit is reset, the backpressure feature is disabled.

Bit 0 **FCB_BPA**: Flow Control Busy or Backpressure Activate

This bit initiates a Pause packet in the Full-duplex mode and activates the backpressure function in the Half-duplex mode if the TFE bit is set.

Full-Duplex mode: this bit should be read as 0 before writing to this register. To initiate a Pause packet, the application must set this bit to 1. During Control packet transfer, this bit continues to be set to indicate that a packet transmission is in progress. When Pause packet transmission is complete, the MAC resets this bit to 0. You should not write to this register until this bit is cleared.

Half-duplex mode: When this bit is set (and TFE bit is set) in the Half-duplex mode, the MAC asserts the backpressure. During backpressure, when the MAC receives a new packet, the transmitter starts sending a JAM pattern resulting in a collision. When the MAC is configured for the Full-duplex mode, the BPA is automatically disabled.

Rx flow control register (ETH_MACRXFCR)

Address offset: 0x0090

Reset value: 0x0000 0000

The Receive Flow Control register controls the pausing of MAC transmit based on the received Pause packet.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UP	RFE
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **UP**: Unicast Pause Packet Detect

A pause packet is processed when it has the unique multicast address specified in the IEEE 802.3. When this bit is set, the MAC can also detect Pause packets with unicast address of the station. This unicast address should be as specified in *MAC address 0 high register (ETH_MACA0HR)* and MAC Address 0 low register *MAC address x low register (ETH_MACAxLR)*.

When this bit is reset, the MAC only detects Pause packets with unique multicast address.

Note: The MAC does not process a Pause packet if the multicast address is different from the unique multicast address. This is also applicable to the received PFC packet when the Priority Flow Control (PFC) is enabled. The unique multicast address (0x01 80 C2 00 00 01) is as specified in IEEE 802.1 Qbb-2011.

Bit 0 **RFE**: Receive Flow Control Enable

When this bit is set and the MAC is operating in Full-duplex mode, the MAC decodes the received Pause packet and disables its transmitter for a specified (Pause) time. When this bit is reset or the MAC is operating in Half-duplex mode, the decode function of the Pause packet is disabled.

When PFC is enabled, flow control is enabled for PFC packets. The MAC decodes the received PFC packet and disables the transmit queue, with matching priorities, for a duration of received Pause time.

Interrupt status register (ETH_MACISR)

Address offset: 0x00B0

Reset value: 0x0000 0000

The interrupt status register contains the status of interrupts.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MDIOIS	Res.	Res.
													rc_r		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RXSTSIS	TXSTSIS	TSIS	Res.	MMCTXIS	MMCRXIS	MMCIS	Res.	Res.	LPIIS	PMTIS	PHYIS	Res.	Res.	Res.
	rc_r	rc_r	rc_r		r	r	r			r	r	r			

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:19 Reserved, must be kept at reset value.

Bit 18 **MDIOIS**: MDIO interrupt status

This bit indicates an interrupt event after the completion of MDIO operation. To reset this bit, the application has to read this bit (or write it to 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* register is set) register is set.

Bits 17:15 Reserved, must be kept at reset value.

Bit 14 **RXSTSIS**: Receive status interrupt

This bit indicates the status of received packets. This bit is set when the RWT bit is set in the *Rx Tx status register (ETH_MACRXTXSR)*. This bit is cleared when the corresponding interrupt source bit is read (or corresponding interrupt source bit is written to 1 when RCWE bit of *CSR software control register (ETH_MACCSRSWCR)* is set) in the ETH_MACISR register.

Bit 13 **TXSTSIS**: Transmit status interrupt

This bit indicates the status of transmitted packets. This bit is set when any of the following bits is set in the *Rx Tx status register (ETH_MACRXTXSR)*:

- Excessive Collision (EXCOL)
- Late Collision (LCOL)
- Excessive Deferral (EXDEF)
- Loss of Carrier (LCARR)
- No Carrier (NCARR)
- Jabber timeout (TJT)

This bit is cleared when the corresponding interrupt source bit is read (or corresponding interrupt source bit is written to 1 when RCWE bit of *CSR software control register (ETH_MACCSRSWCR)* is set) in the ETH_MACISR register.

Bit 12 **TSIS**: Timestamp interrupt status

If the Timestamp feature is enabled, this bit is set when any of the following conditions is true:

– The system time value is equal to or exceeds the value specified in the Target Time High and Low registers.

– There is an overflow in the Seconds register.

– The Target Time Error occurred, that is, programmed target time already elapsed.

If the Auxiliary Snapshot feature is enabled, this bit is set when the auxiliary snapshot trigger is asserted.

When drop transmit status is enabled in MTL, this bit is set when the captured transmit timestamp is updated in the *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* and *Tx timestamp status seconds register (ETH_MACTXTSSSR)* registers.

When PTP offload feature is enabled, this bit is set when the captured transmit timestamp is updated in the *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* and *Tx timestamp status seconds register (ETH_MACTXTSSSR)* registers, for PTO generated Delay Request and Pdelay request packets.

This bit is cleared when the corresponding interrupt source bit is read (or corresponding interrupt source bit is written to 1 when RCWE bit of *CSR software control register (ETH_MACCSRSWCR)* is set) in the *Timestamp status register (ETH_MACTSSR)*.

Bit 11 Reserved, must be kept at reset value.

Bit 10 **MMCTXIS**: MMC transmit interrupt status

This bit is set high when an interrupt is generated in the *MMC Tx interrupt register (ETH_MMC_TX_INTERRUPT)*. This bit is cleared when all bits in this interrupt register are cleared.

Bit 9 **MMCRXIS**: MMC Receive interrupt status

This bit is set high when an interrupt is generated in the *MMC Rx interrupt register (ETH_MMC_RX_INTERRUPT)*. This bit is cleared when all bits in this interrupt register are cleared.

Bit 8 **MMCIS**: MMC interrupt status

This bit is set high when MMCTXIS or MMCRXIS is set high. This bit is cleared only when all these bits are low.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **LPIIS**: LPI interrupt status

This bit is set for any LPI state entry or exit in the MAC transmitter or receiver. This bit is cleared when the TLPIEN bit of *LPI control and status register (ETH_MACLCSR)* is read.

Bit 4 **PMTIS**: PMT interrupt status

This bit is set when a Magic packet or Wake-on-LAN packet is received in the power-down mode (RWKPRCVD and MGKPRCVD bits in ETH_MACPCSR register). This bit is cleared when Bits[6:5] are cleared because of a Read operation to the *PMT control status register (ETH_MACPCSR)*.

Bit 3 **PHYIS**: PHY Interrupt

This bit is set when rising edge is detected on the ETH_PHY_INTN input. This bit is cleared when this register is read.

Bits 2:0 Reserved, must be kept at reset value.

Interrupt enable register (ETH_MACIER)

Address offset: 0x00B4

Reset value: 0x0000 0000

The Interrupt Enable register contains the masks for generating the interrupts.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MDIOIE	Res.	Res.
													rw		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RXSTSIE	TXSTSIE	TSIE	Res.	Res.	Res.	Res.	Res.	Res.	LPIIE	PMTIE	PHYIE	Res.	Res.	Res.
	rw	rw	rw							rw	rw	rw			

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **MDIOIE**: MDIO Interrupt Enable
When this bit is set, it enables the assertion of the interrupt when MDIOIS field is set in the *Interrupt status register (ETH_MACISR)*.

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **RXSTSIE**: Receive Status Interrupt Enable
When this bit is set, it enables the assertion of the interrupt signal because of the setting of RXSTSIS bit in the *Interrupt status register (ETH_MACISR)*.

Bit 13 **TXSTSIE**: Transmit Status Interrupt Enable
When this bit is set, it enables the assertion of the interrupt signal because of the setting of TXSTSIS bit in the *Interrupt status register (ETH_MACISR)*.

Bit 12 **TSIE**: Timestamp Interrupt Enable
When this bit is set, it enables the assertion of the interrupt signal because of the setting of TSIS bit in *Interrupt status register (ETH_MACISR)*.

Bits 11:6 Reserved, must be kept at reset value.

Bit 5 **LPIIE**: LPI Interrupt Enable
When this bit is set, it enables the assertion of the interrupt signal because of the setting of LPIIS bit in *Interrupt status register (ETH_MACISR)*.

Bit 4 **PMTIE**: PMT Interrupt Enable
When this bit is set, it enables the assertion of the interrupt signal because of the setting of PMTIS bit in *Interrupt status register (ETH_MACISR)*.

Bit 3 **PHYIE**: PHY Interrupt Enable
When this bit is set, it enables the assertion of the interrupt signal because of the setting of PHYIS bit in *Interrupt status register (ETH_MACISR)*.

Bits 2:0 Reserved, must be kept at reset value.

Rx Tx status register (ETH_MACRXTXSR)

Address offset: 0x00B8

Reset value: 0x0000 0000

The receive transmit status register contains the receive and transmit error status.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	RWT	Res.	Res.	EXCOL	LCOL	EXDEF	LCARR	NCARR	TJT
							rc_r			rc_r	rc_r	rc_r	rc_r	rc_r	rc_r

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **RWT**: Receive watchdog timeout

This bit is set when a packet with length greater than 2,048 bytes is received (10, 240 bytes when Jumbo Packet mode is enabled) and the WD bit is reset in the *Operating mode configuration register (ETH_MACCR)*. This bit is set when a packet with length greater than 16,383 bytes is received and the WD bit is set in the *Operating mode configuration register (ETH_MACCR)*.

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **EXCOL**: Excessive Collisions

When the DTXSTS bit is set in the *Operating mode register (ETH_MTLOMR)*, this bit indicates that the transmission aborted after 16 successive collisions while attempting to transmit the current packet. If the DR bit is set in the *Operating mode configuration register (ETH_MACCR)*, this bit is set after the first collision and the packet transmission is aborted.

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 4 **LCOL**: Late Collision

When the DTXSTS bit is set in the *Operating mode register (ETH_MTLOMR)*, this bit indicates that the packet transmission aborted because a collision occurred after the collision window (64 bytes including Preamble in MII mode.

This bit is not valid if the Underflow error occurs.

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 3 **EXDEF**: Excessive Deferral

When the DTXSTS bit is set in the *Operating mode register (ETH_MTLOMR)* and the DC bit is set in the *Operating mode configuration register (ETH_MACCR)*, this bit indicates that the transmission ended because of excessive deferral of over 24,288 bit times (155,680 when Jumbo packet is enabled).

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 2 **LCARR**: Loss of Carrier

When the DTXSTS bit is set in the *Operating mode register (ETH_MTLOMR)*, this bit indicates that the loss of carrier occurred during packet transmission, that is, the ETH_CRS signal was inactive for one or more transmission clock periods during packet transmission. This bit is valid only for packets transmitted without collision.

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 1 **NCARR**: No Carrier

When the DTXSTS bit is set in the *Operating mode register (ETH_MTLOMR)*, this bit indicates that the carrier signal from the PHY is not present at the end of preamble transmission.

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 0 **TJT**: Transmit Jabber timeout

This bit indicates that the transmit jabber timer expired which happens when the packet size exceeds 2,048 bytes (10,240 bytes when the Jumbo packet is enabled) and JD bit is reset in the *Operating mode configuration register (ETH_MACCR)*. This bit is set when the packet size exceeds 16,383 bytes and the JD bit is set in the *Operating mode configuration register (ETH_MACCR)*.

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

PMT control status register (ETH_MACPCSR)

Address offset: 0x00C0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RWKFILTRST	Res.	Res.	RWKPTR[4:0]					Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw			r	r	r	r	r								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	RWKPFE	GLBLUCAST	Res.	Res.	RWKPRCVD	MGKPRCVD	Res.	Res.	RWKPKTEN	MGKPKTEN	PWRDWN
					rw	rw			r	rc_r			rw	rw	rw

Bit 31 **RWKFILTRST**: Remote Wake-up Packet Filter Register Pointer Reset

When this bit is set, the remote wake-up packet filter register pointer is reset to 0. It is automatically cleared after 1 clock cycle.

Bits 30:29 Reserved, must be kept at reset value.

Bits 28:24 **RWKPTR[4:0]**: Remote wake-up FIFO Pointer

This field gives the current value (0 to 7) of the Remote wake-up Packet Filter register pointer. When the value of this pointer is equal to 7, the contents of the Remote wake-up Packet Filter Register are transferred to the eth_rx_clk domain when a Write occurs to that register.

Bits 23:11 Reserved, must be kept at reset value.

Bit 10 **RWKPFE**: Remote wake-up Packet Forwarding Enable

When this bit is set along with RWKPKTEN, the MAC receiver drops all received frames until it receives the expected wake-up frame. All frames after that event including the received wake-up frame are forwarded to application. This bit is then self-cleared on receiving the wake-up packet.

The application can also clear this bit before the expected wake-up frame is received. In such cases, the MAC reverts to the default behavior where packets received are forwarded to the application. This bit must only be set when RWKPKTEN is set high and PWRDWN is set low. The setting of this bit has no effect when PWRDWN is set high.

Note: If Magic Packet Enable and wake-up Frame Enable are both set along with setting of this bit and Magic Packet is received prior to wake-up frame, this bit is self-cleared on receiving Magic Packet, the received Magic packet is dropped, and all frames after received Magic Packet are forwarded to application.

Bit 9 **GLBLUCAST**: Global Unicast

When this bit set, any unicast packet filtered by the MAC (DAF) address recognition is detected as a remote wake-up packet.

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **RWKPRCVD**: Remote wake-up Packet Received

When this bit is set, it indicates that the power management event is generated because of the reception of a remote wake-up packet. This bit is cleared when this register is read.

Bit 5 **MGKPRCVD**: Magic Packet Received

When this bit is set, it indicates that the power management event is generated because of the reception of a magic packet. This bit is cleared when this register is read (or written to 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bits 4:3 Reserved, must be kept at reset value.

Bit 2 **RWKPKTEN**: Remote wake-up Packet Enable

When this bit is set, a power management event is generated when the MAC receives a remote wake-up packet.

Bit 1 **MGKPKTEN**: Magic Packet Enable

When this bit is set, a power management event is generated when the MAC receives a magic packet.

Bit 0 **PWRDWN**: Power Down

When this bit is set, the MAC receiver drops all received packets until it receives the expected magic packet or remote wake-up packet. This bit is then self-cleared and the power-down mode is disabled. The software can clear this bit before the expected magic packet or remote wake-up packet is received. The packets received by the MAC after this bit is cleared are forwarded to the application. This bit must only be set when the Magic Packet Enable, Global Unicast, or Remote wake-up Packet Enable bit is set high.

Note: You can gate-off the CSR clock during the power-down mode. However, when the CSR clock is gated-off, you cannot perform any read or write operations on this register. Therefore, the Software cannot clear this bit.

Remote wake-up packet filter register (ETH_MACRWKPFR)

Address offset: 0x00C4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MACRWKPFR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MACRWKPFR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MACRWKPFR[31:0]**: Remote wake-up packet filter

Refer to *Table 798*, *Table 799* and *Table 800* for details on register content and programming sequence.

The ETH_MACRWKPFR register at address 0x00C4 loads the wake-up Packet Filter register.

To load values in a wake-up Packet Filter register, the entire register (ETH_MACRWKPFR) must be written. The ETH_MACRWKPFR register is loaded by sequentially loading the eight, sixteen or thirty two register values in address (0x00C4) for ETH_MACRWKPFR value 0 to 7, respectively. The ETH_MACRWKPFR register is read in a similar way. The Ethernet peripheral updates the ETH_MACRWKPFR register current pointer value in Bits[26:24] of ETH_MACPCSR register.

LPI control and status register (ETH_MACLCSR)

Address offset: 0x00D0

Reset value: 0x0000 0000

The LPI Control and Status Register controls the LPI functions and provides the LPI interrupt status. The status bits are cleared when this register is read.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LPITCSE	LPITE	LPITXA	Res.	PLS	LPIEN
										rw	rw	rw		rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	RLPIST	TLPIST	Res.	Res.	Res.	Res.	RLPIEX	RLPIEN	TLPIEX	TLPIEN
						r	r					r	r	r	r

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **LPITCSE**: LPI Tx Clock Stop Enable

When this bit is set, the MAC asserts sbd_tx_clk_gating_ctrl_o signal high after it enters Tx LPI mode to indicate that the Tx clock to MAC can be stopped. When this bit is reset, the MAC does not assert sbd_tx_clk_gating_ctrl_o signal high after it enters Tx LPI mode.
If RGMII Interface is selected, the Tx clock is required for transmitting the LPI pattern. The Tx Clock cannot be gated and so the LPITCSE bit cannot be programmed.

Bit 20 **LPITE**: LPI Timer Enable

This bit controls the automatic entry of the MAC transmitter into and exit out of the LPI state. When LPITE, LPITXA and LPIEN bits are set, the MAC transmitter enters LPI state only when the complete MAC TX data path is IDLE for a period indicated by the ETH_MACLETR register.

After entering LPI state, if the data path becomes non-IDLE (due to a new packet being accepted for transmission), the transmitter exits LPI state but does not clear LPIEN bit. This enables the re-entry into LPI state when it is IDLE again.

When LPITE is 0, the LPI Auto timer is disabled and MAC transmitter enters LPI state based on the settings of LPITXA and LPIEN bit descriptions.

Bit 19 **LPITXA**: LPI Tx Automate

This bit controls the behavior of the MAC when it is entering or coming out of the LPI mode on the transmit side.

If the LPITXA and LPIEN bits are set to 1, the MAC enters the LPI mode only after all outstanding packets (in the core) and pending packets (in the application interface) have been transmitted. The MAC comes out of the LPI mode when the application sends any packet for transmission or the application issues a Tx FIFO Flush command. In addition, the MAC automatically clears the LPIEN bit when it exits the LPI state. If Tx FIFO Flush is set in the FTQ bit of ETH_MTLTXQOMR, when the MAC is in the LPI mode, it exits the LPI mode.

When this bit is 0, the LPIEN bit directly controls behavior of the MAC when it is entering or coming out of the LPI mode.

Bit 18 Reserved, must be kept at reset value.

Bit 17 **PLS**: PHY Link Status

This bit indicates the link status of the PHY. The MAC transmitter asserts the LPI pattern only when the link status is up (OKAY) at least for the time indicated by the LPI LS TIMER.

When this bit is set, the link is considered to be okay (UP) and when this bit is reset, the link is considered to be down.

Bit 16 **LPIEN**: LPI Enable

When this bit is set, it instructs the MAC transmitter to enter the LPI state. When this bit is reset, it instructs the MAC to exit the LPI state and resume normal transmission.

This bit is cleared when the LPITXA bit is set and the MAC exits the LPI state because of the arrival of a new packet for transmission.

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **RLPIST**: Receive LPI State

When this bit is set, it indicates that the MAC is receiving the LPI pattern on the MII interface.

Bit 8 **TLPIST**: Transmit LPI State

When this bit is set, it indicates that the MAC is transmitting the LPI pattern on the MII interface.

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **RLPIEX**: Receive LPI Exit

When this bit is set, it indicates that the MAC receiver has stopped receiving the LPI pattern on the MII interface, exited the LPI state, and resumed the normal reception. This bit is cleared by a read into this register (or by writing it to 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Note: This bit may not be set if the MAC stops receiving the LPI pattern for a very short duration, such as, less than three clock cycles of CSR clock.

Bit 2 **RLPIEN**: Receive LPI Entry

When this bit is set, it indicates that the MAC receiver has received an LPI pattern and entered the LPI state. This bit is cleared by a read into this register (or by writing it to 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Note: This bit may not be set if the MAC stops receiving the LPI pattern for a very short duration, such as, less than three clock cycles of CSR clock.

Bit 1 **TLPIEX**: Transmit LPI Exit

When this bit is set, it indicates that the MAC transmitter exited the LPI state after the application cleared the LPIEN bit and the LPI TW Timer has expired. This bit is cleared by a read into this register (or by writing it to 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 0 **TLPIEN**: Transmit LPI Entry

When this bit is set, it indicates that the MAC transmitter has entered the LPI state because of the setting of the LPIEN bit. This bit is cleared by a read into this register (or by writing it to 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

LPI timers control register (ETH_MACLTCR)

Address offset: 0x00D4

Reset value: 0x03E8 0000

The LPI timers control register controls the timeout values in the LPI states. It specifies the time for which the MAC transmits the LPI pattern and also the time for which the MAC waits before resuming the normal transmission.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res	Res	Res	Res	Res	Res	LST[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TWT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:16 **LST[9:0]**: LPI LS Timer

This field specifies the minimum time (in milliseconds) for which the link status from the PHY should be up (OKAY) before the LPI pattern can be transmitted to the PHY. The MAC does not transmit the LPI pattern even when the LPIEN bit is set unless the LPI LS Timer reaches the programmed terminal count. The default value of the LPI LS Timer is 1000 (1 s) as defined in the IEEE standard.

Bits 15:0 **TWT[15:0]**: LPI TW Timer

This field specifies the minimum time (in microseconds) for which the MAC waits after it stops transmitting the LPI pattern to the PHY and before it resumes the normal transmission. The TLPIEX status bit is set after the expiry of this timer.

LPI entry timer register (ETH_MACLETR)

Address offset: 0x00D8

Reset value: 0x0000 0000

This register controls the Tx LPI entry timer. This counter is enabled only when LPITE bit of *LPI control and status register (ETH_MACLCSR)* register is set to 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LPIET[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LPIET[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r	r

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **LPIET[19:0]**: LPI Entry Timer

This field specifies the time in microseconds the MAC waits to enter LPI mode, after it has transmitted all the frames. This field is valid and used only when LPITE and LPITXA are set to 1.

Bits [2:0] are read-only so that the granularity of this timer is in steps of 8 micro-seconds.

One-microsecond-tick counter register (ETH_MAC1USTCR)

Address offset: 0x00DC

Reset value: 0x0000 0063

This register controls the generation of the Reference time (one-microsecond tick) for all the LPI timers. This timer has to be programmed by the software initially.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TIC_1US_CNTR[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 TIC_1US_CNTR[11:0]: 1 µs tick Counter

The application must program this counter so that the number of clock cycles of CSR clock is 1 µs (subtract 1 from the value before programming).

For example if the CSR clock is 100 MHz then this field needs to be programmed to 100 - 1 = 99 (which is 0x63).

This is required to generate the 1 µs events that are used to update some of the EEE related counters.

Version register (ETH_MACVR)

Address offset: 0x0110

Reset value: 0x0000 3354

The version register identifies the version of the Ethernet peripheral.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USERVER[7:0]								SNPSVER[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **USERVER[7:0]**: ST-defined version

Bits 7:0 **SNPSVER[7:0]**: IP version

Debug register (ETH_MACDR)

Address offset: 0x0114

Reset value: 0x0000 0000

The Debug register provides the debug status of various MAC blocks.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TFCSTS[1:0]		TPESTS
													r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFCFCSTS[1:0]		RPESTS
													r	r	r

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:17 **TFCSTS[1:0]**: MAC transmit packet controller status

This field indicates the state of the MAC transmit packet controller module:

00: Idle state

01: Waiting for one of the following:

- Status of the previous packet
- IPG or backoff period to be over

10: Generating and transmitting a Pause control packet (in Full-duplex mode)

11: Transferring input packet for transmission

Bit 16 **TPESTS**: MAC MII transmit protocol engine status
When this bit is set, it indicates that the MAC MII transmit protocol engine is actively transmitting data, and it is not in the Idle state.

Bits 15:3 Reserved, must be kept at reset value.

Bits 2:1 **RFCFCSTS[1:0]**: MAC receive packet controller FIFO status
When this bit is set, this field indicates the active state of the small FIFO Read and Write controllers of the MAC receive packet controller module.

Bit 0 **RPESTS**: MAC MII receive protocol engine status
When this bit is set, it indicates that the MAC MII receive protocol engine is actively receiving data, and it is not in the Idle state.

HW feature 0 register (ETH_MACHWF0R)

Address offset: 0x011C

Reset value: 0x0A0D 73F5

This register indicates the presence of first set of the optional features or functions of the Ethernet peripheral. The software driver can use this register to dynamically enable or disable the programs related to the optional blocks.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ACTPHYSEL[3:0]				SAVLANINS	TSSTSSEL[1:0]		MACADR64SEL	MACADR32SEL	ADDMACADRSEL[4:0]					Res.	RXCOESEL
r	r	r	r	r	r	r	r	r	r	r	r	r	r		r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TXCOESEL	EEESEL	TSSEL	Res.	Res.	ARPOFFSEL	MMCSEL	MGKSEL	RWKSEL	SMASEL	VLHASH	PCSSEL	HDSEL	GMIISEL	MIISEL
	r	r	r			r	r	r	r	r	r	r	r	r	r

Bits 31:28 **ACTPHYSEL[3:0]**: Active PHY selected
When you have multiple PHY interfaces in your configuration, this field indicates the sampled value of phy_intf_sel_i during reset de-assertion:
0x0: GMII or MII
0x1: RGMII
0x2: SGMII
0x3: TBI
0x4: RMII
0x5: RTBI
0x6: SMII
Others: Reserved, must not be used

Bit 27 **SAVLANINS**: Source Address or VLAN Insertion Enable
This bit is set to 1 when the Enable SA and VLAN Insertion on Tx option is selected

Bits 26:25 **TSSTSSEL[1:0]**: Timestamp System Time Source
This bit indicates the source of the Timestamp system time:
01: Internal
10: External
11: Both
00: Reserved, must not be used
This bit is set to 1 when the Enable IEEE 1588 Timestamp Support option is selected

Bit 24 **MACADR64SEL**: MAC Addresses 64-127 Selected
This bit is set to 1 when the Enable Additional 64 MAC Address Registers (64-127) option is selected

Bit 23 **MACADR32SEL**: MAC Addresses 32-63 Selected
This bit is set to 1 when the Enable Additional 32 MAC Address Registers (32-63) option is selected

Bits 22:18 **ADDMACADRSEL[4:0]**: MAC Addresses 1-31 Selected
This bit is set to 1 when the Enable Additional 1-31 MAC Address Registers option is selected

Bit 17 Reserved, must be kept at reset value.

Bit 16 **RXCOESEL**: Receive checksum offload Enabled
This bit is set to 1 when the enable receive TCP/IP checksum check option is selected

Bit 15 Reserved, must be kept at reset value.

Bit 14 **TXCOESEL**: Transmit Checksum Offload Enabled
This bit is set to 1 when the enable transmit TCP/IP checksum insertion option is selected

Bit 13 **EEESEL**: Energy Efficient Ethernet Enabled
This bit is set to 1 when the Enable Energy Efficient Ethernet (EEE) option is selected

Bit 12 **TSSEL**: IEEE 1588-2008 Timestamp Enabled
This bit is set to 1 when the Enable IEEE 1588 Timestamp Support option is selected

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **ARPOFFSEL**: ARP Offload Enabled
This bit is set to 1 when the Enable IPv4 ARP Offload option is selected

Bit 8 **MMCSEL**: RMON Module Enable
This bit is set to 1 when the Enable MAC management counters (MMC) option is selected

Bit 7 **MGKSEL**: PMT Magic Packet Enable
This bit is set to 1 when the Enable Magic Packet Detection option is selected

Bit 6 **RWKSEL**: PMT Remote Wake-up Packet Enable
This bit is set to 1 when the Enable Remote Wake-up Packet Detection option is selected

Bit 5 **SMASEL**: SMA (MDIO) Interface
This bit is set to 1 when the Enable Station Management (MDIO Interface) option is selected

Bit 4 **VLHASH**: VLAN Hash Filter Selected
This bit is set to 1 when the Enable VLAN Hash Table Based Filtering option is selected

Bit 3 **PCSSEL**: PCS Registers (TBI, SGMII, or RTBI PHY interface)
This bit is set to 1 when the TBI, SGMII, or RTBI PHY interface option is selected

Bit 2 **HDSEL**: Half-duplex Support
This bit is set to 1 when the Half-duplex mode is selected

Bit 1 **GMIISEL**: 1000 Mbit/s Support
This bit is set to 1 when 1000 Mbit/s is selected as operating mode.

Bit 0 **MIISEL**: 10 or 100 Mbit/s Support
This bit is set to 1 when 10/100 Mbit/s is selected as operating mode.

HW feature 1 register (ETH_MACHWF1R)

Address offset: 0x0120

Reset value: 0x1104 1924

This register indicates the presence of second set of the optional features or functions of the Ethernet peripheral. The software driver can use this register to dynamically enable or disable the programs related to the optional blocks.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	L3L4FNUM[3:0]				Res.	HASHTBLSZ[1:0]		POUOST	Res.	RAVSEL	AVSEL	DBGMEMA	TSOEN	SPHEN	DCBEN
	r	r	r	r		r	r	r		r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDR64[1:0]		ADVTHWORD	PTOEN	OSTEN	TXFIFOSIZE[4:0]					SPRAM	RXFIFOSIZE[4:0]				
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:27 **L3L4FNUM[3:0]**: Total number of L3 or L4 Filters
This field indicates the total number of L3 or L4 filters:
0000: No L3 or L4 Filter
0001: 1 L3 or L4 Filter
0010: 2 L3 or L4 Filters
..
1000: 8 L3 or L4

Bit 26 Reserved, must be kept at reset value.

Bits 25:24 **HASHTBLSZ[1:0]**: Hash Table Size
This field indicates the size of the Hash table:
00: No Hash table
01: 64
10: 128
11: 256

Bit 23 **POUOST**: One Step for PTP over UDP/IP Feature Enable
This bit is set to 1 when the Enable one step timestamp for PTP over UDP/IP feature is selected.

Bit 22 Reserved, must be kept at reset value.

Bit 21 **RAVSEL**: Rx Side Only AV Feature Enable
This bit is set to 1 when the Enable Audio video bridging option on Rx Side Only is selected.

Bit 20 **AVSEL**: AV Feature Enable
This bit is set to 1 when the Enable Audio video bridging option is selected.

Bit 19 **DBGMEMA**: DMA debug registers enable
This bit is set to 1 when the Debug Mode Enable option is selected

Bit 18 **TSOEN**: TCP segmentation offload enable
This bit is set to 1 when the Enable TCP Segmentation Offloading for TCP/IP Packets option is selected

Bit 17 **SPHEN**: Split header feature enable
This bit is set to 1 when the Enable Split Header Structure option is selected

Bit 16 **DCBEN**: DCB feature enable
This bit is set to 1 when the Enable Data Center Bridging option is selected

Bits 15:14 **ADDR64[1:0]**: Address width
This field indicates the configured address width.
00: 32 bits
Others: Reserved, must not be used

Bit 13 **ADVTHWORD**: IEEE 1588 High Word Register enable
This bit is set to 1 when the Add IEEE 1588 Higher Word Register option is selected

Bit 12 **PTOEN**: PTP offload enable
This bit is set to 1 when the Enable PTP Timestamp Offload Feature is selected.

Bit 11 **OSTEN**: One-step timestamping enable
This bit is set to 1 when the Enable One-Step Timestamp Feature is selected.

Bits 10:6 **TXFIFOSIZE[4:0]**: MTL transmit FIFO size
This field contains the configured value of MTL Tx FIFO in bytes expressed as Log to base 2 minus 7, that is, Log2(TXFIFO_SIZE) -7:
00000: 128 bytes
00001: 256 bytes
00010: 512 bytes
00011: 1,024 bytes
00100: 2,048 bytes
00101: 4,096 bytes
00110: 8,192 bytes
00111: 16,384 bytes
01000: 32 Kbytes
01001: 64 Kbytes
01010: 128 Kbytes
01011 to 11111: Reserved, must not be used

Bit 5 **SPRAM**: Single Port RAM Enable
This bit is set to 1 when the Use single port RAM feature is selected.

Bits 4:0 **RXFIFOSIZE[4:0]**: MTL receive FIFO Size
This field contains the configured value of MTL Rx FIFO in bytes expressed as Log to base 2 minus 7, that is, Log2(RXFIFO_SIZE) -7:
00000: 128 bytes
00001: 256 bytes
00010: 512 bytes
00011: 1,024 bytes
00100: 2,048 bytes
00101: 4,096 bytes
00110: 8,192 bytes
00111: 16,384 bytes
01000: 32 Kbytes
01001: 64 Kbytes
01010: 128 Kbytes
01011: 256 Kbytes
01100 to 11111: Reserved, must not be used

HW feature 2 register (ETH_MACHWF2R)

Address offset: 0x0124

Reset value: 0x4100 0000

This register indicates the presence of third set of the optional features or functions of the Ethernet peripheral. The software driver can use this register to dynamically enable or disable the programs related to the optional blocks.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	AUXSNAPNUM[2:0]			Res.	PPSOUTNUM[2:0]			TDCSZ[1:0]		TXCHCNT[3:0]				RDCSZ[1:0]	
	r	r	r		r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXCHCNT[3:0]				Res.	Res.	TXQCNT[3:0]				Res.	Res.	RXQCNT[3:0]			
r	r	r	r			r	r	r	r			r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:28 **AUXSNAPNUM[2:0]**: Number of auxiliary snapshot inputs
This field indicates the number of auxiliary snapshot inputs:
000: No auxiliary input
001: 1 auxiliary input
010: 2 auxiliary inputs
011: 3 auxiliary inputs
100: 4 auxiliary inputs
101 to 111: Reserved, must not be used

Bit 27 Reserved, must be kept at reset value.

Bits 26:24 **PPSOUTNUM[2:0]**: Number of PPS outputs
This field indicates the number of PPS outputs:
000: No PPS output
001: 1 PPS output
010: 2 PPS outputs
011: 3 PPS outputs
100: 4 PPS outputs
101 to 111: Reserved, must not be used

Bits 23:22 **TDCSZ[1:0]**: Tx DMA descriptor cache size in terms of 16-byte descriptors
00: Cache not configured
01: Four 16-byte descriptors
10: Eight 16-byte descriptors
11: Sixteen 16-byte descriptors

Bits 21:18 **TXCHCNT[3:0]**: Number of DMA transmit channels
This field indicates the number of DMA transmit channels:
0000: 1 DMA Tx channel
0001: 2 DMA Tx channels
..
0111: 8 DMA Tx

Bits 17:16 **RDCSZ[1:0]**: Rx DMA Descriptor Cache Size in terms of 16-byte descriptors
00: Cache not configured
01: Four 16-byte descriptors
10: Eight 16-byte descriptors
11: Sixteen 16-byte descriptors

Bits 15:12 **RXCHCNT[3:0]**: Number of DMA receive channels
This field indicates the number of DMA receive channels:
0000: 1 DMA Rx channel
0001: 2 DMA Rx channels
..
0111: 8 DMA Rx

Bits 11:10 Reserved, must be kept at reset value.

Bits 9:6 **TXQCNT[3:0]**: Number of MTL transmit queues
This field indicates the number of MTL transmit queues:
0000: 1 MTL Tx queue
0001: 2 MTL Tx queues
..
0111: 8 MTL Tx

Bits 5:4 Reserved, must be kept at reset value.

Bits 3:0 **RXQCNT[3:0]**: Number of MTL receive queues
This field indicates the number of MTL receive queues:
0000: 1 MTL Rx queue
0001: 2 MTL Rx queues
..
0111: 8 MTL Rx

HW feature 3 register (ETH_MACHWF3R)

Address offset: 0x0128

Reset value: 0x0000 0020

This register indicates the presence of fourth set the optional features or functions of the Ethernet peripheral. The software driver can use this register to dynamically enable or disable the programs related to the optional blocks.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	ASP[1:0]		TBSSEL	FPESEL	Res.	Res.	Res.	Res.	ESTWID[1:0]		ESTDEP[2:0]			ESTSEL
		r	r	r	r					r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	FRPES[1:0]		FRPBS[1:0]		FRPSEL	PDUPSEL	Res.	Res.	Res.	DVLAN	CBTISEL	Res.	NRVF[2:0]		
	r	r	r	r	r	r				r	r		r	r	r

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:28 **ASP[1:0]**: Automotive Safety Package
Following are the encoding for the different Safety features
00: None
01: ECC only
10: AS_NPPE
11: AS_PPE

Bit 27 **TBSSEL**: Time-based scheduling Enable
This bit is set to 1 when the time-based scheduling feature is selected.

Bit 26 **FPESEL**: Frame Preemption Enable
This bit is set to 1 when the Enable Frame preemption feature is selected.

Bits 25:22 Reserved, must be kept at reset value.

Bits 21:20 **ESTWID[1:0]**: Width of the Time Interval field in the Gate Control List
This field indicates the width of the Configured Time Interval Field
00: No width
01: 16
10: 20
11: 24

Bits 19:17 **ESTDEP[2:0]**: Depth of the Gate Control List
This field indicates the depth of Gate Control list
000: No depth
001: 64
010: 128
011: 256
100: 512
101: 1024
110: Reserved, must not be used

Bit 16 **ESTSEL**: Enhancements to Scheduled Traffic Enable
This bit is set to 1 when the enable enhancements to scheduling traffic feature is selected.

Bit 15 Reserved, must be kept at reset value.

Bits 14:13 **FRPES[1:0]**: Flexible receive parser table entries size
This field indicates the maximum number of parser entries supported by flexible receive parser.
00: 64 entries
01: 128 entries
10: 256 entries
11: Reserved, must not be used

Bits 12:11 **FRPBS[1:0]**: Flexible receive parser buffer size
This field indicates the supported maximum number of bytes of the packet data to be parsed by flexible receive parser.
00: 64 bytes
01: 128 bytes
10: 256 bytes
11: Reserved, must not be used

Bit 10 **FRPSEL**: Flexible receive parser Selected
This bit is set to 1 when the Enable Flexible Programmable receive parser option is selected.

Bit 9 **PDUPSEL**: Broadcast/Multicast Packet Duplication
This bit is set to 1 when the Broadcast/Multicast Packet Duplication feature is selected.

Bits 8:6 Reserved, must be kept at reset value.

Bit 5 **DVLAN**: Double VLAN processing enable
This bit is set to 1 when Double VLAN processing is enabled.

Bit 4 **CBTISEL**: Queue/channel based VLAN tag insertion on Tx enable
This bit is set to 1 when the Enable Queue/channel based VLAN tag insertion on Tx feature is selected.

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **NRVF[2:0]**: Number of Extended VLAN Tag Filters Enabled
This field indicates the Number of Extended VLAN Tag Filters selected:
000: No Extended Rx VLAN Filters
001: 4 Extended Rx VLAN Filters
010: 8 Extended Rx VLAN Filters
011: 16 Extended Rx VLAN Filters
100: 24 Extended Rx VLAN Filters
101: 32 Extended Rx VLAN Filters
110 to 111: Reserved, must not be used

MDIO address register (ETH_MACMDIOAR)

Address offset: 0x0200

Reset value: 0x0000 0000

The MDIO address register controls the management cycles to external PHY through a management interface.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	PSE	BTB	PA[4:0]					RDA[4:0]				
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	NTC[2:0]			CR[3:0]				Res.	Res.	Res.	SKAP	GOC[1:0]		C45E	MB
	rw	rw	rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **PSE**: Preamble suppression enable

When this bit is set, the SMA suppresses the 32-bit preamble and transmit MDIO frames with only 1 preamble bit.

When this bit is 0, the MDIO frame always has 32 bits of preamble as defined in the IEEE specifications.

Bit 26 **BTB**: Back-to-back transactions

When this bit is set and the NTC has value greater than 0, then the MAC informs the completion of a read or write command at the end of frame transfer (before the trailing clocks are transmitted). The software can thus initiate the next command which is executed immediately irrespective of the number trailing clocks generated for the previous frame.

When this bit is reset, then the read/write command completion (MII busy is cleared) only after the trailing clocks are generated. In this mode, it is ensured that the NTC is always generated after each frame.

This bit must not be set when NTC=0.

Bits 25:21 **PA[4:0]**: Physical layer address

This field indicates which Clause 22 PHY devices (out of 32 devices) the MAC is accessing.
This field indicates which Clause 45 capable PHYs (out of 32 PHYs) the MAC is accessing.

Bits 20:16 **RDA[4:0]**: Register/Device address

These bits select the PHY register in selected Clause 22 PHY device. These bits select the Device (MMD) in selected Clause 45 capable PHY.

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **NTC[2:0]**: Number of training cocks

This field controls the number of training clock cycles generated on ETH_MDC after the end of transmission of the MDIO frame. The valid values can be from 0 to 7. Programming the value to 011 indicates that there are three additional clock cycles on the MDC line after the end of the MDIO frame transfer.

Bits 11:8 **CR[3:0]**: CSR clock range

The CSR Clock Range selection determines the frequency of the MDC clock according to the CSR clock frequency (eth_hclk):
0000: MDC clock = eth_hclk / 42
0001: MDC clock = eth_hclk / 62
0010: MDC clock = eth_hclk / 16
0011: MDC clock = eth_hclk / 26
0100: MDC clock = eth_hclk / 102
0101: MDC clock = eth_hclk / 124
0110: MDC clock = eth_hclk / 204
0111: MDC clock = eth_hclk / 324
The suggested CSR clock frequency range applicable for each value (when Bit 11 = 0) ensures that the MDC clock is approximately in the 1.0 MHz to 2.5 MHz frequency range.
When Bit 11 is set, the MDC clock frequency can reach a higher value than the frequency limit of 2.5 MHz (specified in the IEEE 802.3). Therefore, a lower clock divider can be programmed. For example, when the CSR clock is of 100 MHz frequency and these bits are programmed to 1010, the resultant MDC clock is of 12.5 MHz, which is above the range specified in IEEE 802.3. Program the following values only if the interfacing chips support faster MDC clocks:
1000: eth_hclk / 4
1001: eth_hclk / 6
1010: eth_hclk / 8
1011: eth_hclk / 10
1100: eth_hclk / 12
1101: eth_hclk / 14
1110: eth_hclk / 16
1111: eth_hclk / 18

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **SKAP**: Skip address packet

When this bit is set, the SMA does not send the address packets before read, write, or post-read increment address packets. This bit is valid only when C45E is set.

Bits 3:2 **GOC[1:0]**: MII operation command

This bit indicates the operation command to the PHY.
00: Reserved, must not be used
01: Write
10: Post Read Increment Address for Clause 45 PHY
11: Read
When Clause 22 PHY is enabled, only Write and Read commands are valid.

Bit 1 **C45E**: Clause 45 PHY Enable

When this bit is set, Clause 45 capable PHY is connected to MDIO. When this bit is reset, Clause 22 capable PHY is connected to MDIO.

Bit 0 **MB**: MII Busy

The application sets this bit to instruct the SMA to initiate a Read or Write access to the MDIOS. The MAC clears this bit after the MDIO frame transfer is completed. Hence the software must not write or change any of the fields in *MDIO address register (ETH_MACMDIOAR)* and *MDIO data register (ETH_MACMDIODR)* as long as this bit is set.

For write transfers, the application must first write 16-bit data in the MD field (and also RA field when C45E is set) in *MDIO data register (ETH_MACMDIODR)* register before setting this bit. When C45E is set, it should also write into the RA field of *MDIO data register (ETH_MACMDIODR)* before initiating a read transfer. When a read transfer is completed (MII busy=0), the data read from the PHY register is valid in the MD field of the *MDIO data register (ETH_MACMDIODR)*.

Note: Even if the addressed PHY is not present, there is no change in the functionality of this bit.

MDIO data register (ETH_MACMDIODR)

Address offset: 0x0204

Reset value: 0x0000 0000

The MDIO data register stores the write data to be written to the PHY register located at the address specified in the *MDIO address register (ETH_MACMDIOAR)*. This register also stores the read data from the PHY register located at the address specified in the MDIO address register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **RA[15:0]**: Register address

This field is valid only when C45E is set. It contains the Register Address in the PHY to which the MDIO frame is intended for.

Bits 15:0 **MD[15:0]**: MII data

This field contains the 16-bit data value read from the PHY after a Management Read operation or the 16-bit data value to be written to the PHY before a Management Write operation.

ARP address register (ETH_MACARPAR)

Address offset: 0x0210

Reset value: 0x0000 0000

The ARP Address register contains the IPv4 Destination Address of the MAC.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARPPA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARPPA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ARPPA[31:0]**: ARP Protocol Address

This field contains the IPv4 Destination Address of the MAC. This address is used for perfect match with the Protocol Address of Target field in the received ARP packet.

CSR software control register (ETH_MACCSRSWCR)

Address offset: 0x0230

Reset value: 0x0000 0000

This register contains software-programmable controls for changing the CSR access response and status bit clearing.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RCWE
															rw

Bits 31:9 Reserved, must be kept at reset value.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **RCWE**: Register Clear on Write 1 Enable

When this bit is set, the access mode to some register fields changes to rc_w1 (clear on write) meaning that the application needs to set that respective bit to 1 to clear it.
When this bit is reset, the access mode to these register fields remains rc_r (clear on read).

MAC presentation time register (ETH_MACPRSTIMR)

Address offset: 0x0240

Reset value: 0x0000 0000

This register contains the 32-bit binary rollover equivalent time of the PTP System Time expressed in ns.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MPTN[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MPTN[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MPTN[31:0]**: MAC 1722 Presentation Time in ns

These bits indicate the value of the 32-bit binary rollover equivalent time of the PTP System Time in ns.

MAC presentation time update register (ETH_MACPRSTIMUR)

Address offset: 0x0244

Reset value: 0x0000 0000

This register holds the 32-bit value of MAC 1722 Presentation Time in ns, that should be added to the current presentation time counter value. The initialization happens when TSINIT is set, and the update when the TSUPDT bit is set (TSINIT or TSUPDT bits in *Timestamp control register (ETH_MACTSCR)*).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MPTU[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MPTU[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MPTU[31:0]**: MAC 1722 Presentation Time Update

This field holds the initialization value or the update value for the presentation time. When used for update, this field holds the 32-bit value, in ns, that should be added to the current presentation time counter value. The initialization happens when TSINIT is set, and the update when the TSUPDT bit is set (TSINIT or TSUPDT bits in *Timestamp control register (ETH_MACTSCR)*). When ADDSUB field of *System time nanoseconds update register (ETH_MACSTNUR)* is set, this value is directly used for subtraction.

MAC address 0 high register (ETH_MACA0HR)

Address offset: 0x0300

Reset value: 0x8000 FFFF

The MAC address0 high register holds the upper 16 bits of the first 6-byte MAC address of the station. The first DA byte that is received on the MII interface corresponds to the LS byte (Bits [7:0]) of the MAC Address Low register. For example, if 0x11 22 33 44 55 66 is received (0x11 in lane 0 of the first column) on the MII as the destination address, then the MacAddress0 Register [47:0] is compared with 0x66 55 44 33 22 11.

If the MAC address registers are configured to be double-synchronized to the MII clock domains, then the synchronization is triggered only when Bits[31:24] (in little-endian mode) or Bits[7:0] (in big-endian mode) of the MAC Address0 Low Register are written. For proper synchronization updates, the consecutive writes to this Address Low Register should be performed after at least four clock cycles in the destination clock domain.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDRHI[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **AE**: Address Enable

This bit is always set to 1.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **ADDRHI[15:0]**: MAC Address0[47:32]

This field contains the upper 16 bits [47:32] of the first 6-byte MAC address. The MAC uses this field for filtering the received packets and inserting the MAC address in the transmit flow control (Pause) packets.

MAC address x low register (ETH_MACAxLR)

Address offset: 0x0304 + 0x8 * x, (x = 0 to 3)

Reset value: 0xFFFF FFFF

The MAC address x low register holds the lower 32 bits of the 6-byte first MAC address of the station.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADDRLO[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDRLO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ADDRLO[31:0]**: MAC Address x [31:0] (x = 0 to 3)

This field contains the lower 32 bits of the first 6-byte MAC address. The MAC uses this field for filtering the received packets and inserting the MAC address in the transmit flow control (Pause) packets.

MAC address x high register (ETH_MACAxHR)

Address offset: 0x0308 + 0x8 * (x-1), (x = 1 to 3)

Reset value: 0x0000 FFFF

The MAC address x high register holds the upper 16 bits of the second 6-byte MAC address of the station.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AE	SA	MBC[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDRHI[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **AE**: Address Enable

When this bit is set, the address filter module uses the second MAC address for perfect filtering. When this bit is reset, the address filter module ignores the address for filtering.

Bit 30 **SA**: Source Address

When this bit is set, the MAC Addressx[47:0] is used to compare with the SA fields of the received packet. When this bit is reset, the MAC Address x[47:0] is used to compare with the DA fields of the received packet.

0: DA

1: SA

Bits 29:24 **MBC[5:0]**: Mask Byte Control

These bits are mask control bits for comparing each of the MAC Address bytes. When set high, the MAC does not compare the corresponding byte of received DA or SA with the contents of MAC Address1 registers. Each bit controls the masking of the bytes as follows:

Bit 29: ETH_MACAxHR[15:8]

Bit 28: ETH_MACAxHR[7:0]

Bit 27: ETH_MACAxLR[31:24]

Bit 26: ETH_MACAxLR[23:16]

Bit 25: ETH_MACAxLR[15:8]

Bit 24: ETH_MACAxLR[7:0]

You can filter a group of addresses (known as group address filtering) by masking one or more bytes of the address.

Bits 23:16 Reserved, must be kept at reset value.

Bits 15:0 **ADDRHI[15:0]**: MAC Address1 [47:32]

This field contains the upper 16 bits[47:32] of the second 6-byte MAC address.

MMC control register (ETH_MMC_CONTROL)

Address offset: 0x0700

Reset value: 0x0000 0000

This register configures the MMC operating mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	UCDBC	Res.	Res.	CNTPRSTLVL	CNTPRST	CNTFREEZ	RSTONRD	CNTSTOPRO	CNTRST
							rw			rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **UCDBC**: Update MMC Counters for Dropped Broadcast Packets

The CNTRST bit has a higher priority than the CNTPRST bit. Therefore, when the software tries to set both bits in the same write cycle, all counters are cleared and the CNTPRST bit is not set.

When set, the MAC updates all related MMC Counters for Broadcast packets that are dropped because of the setting of the DBF bit of *Packet filtering control register (ETH_MACPFR)*.

When reset, the MMC Counters are not updated for dropped Broadcast packets.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **CNTPRSTLVL**: Full-Half Preset

When this bit is low and the CNTPRST bit is set, all MMC counters get preset to almost-half value. All octet counters get preset to 0x7FFF F800 (Half 2Kbytes) and all packet-counters get preset to 0x7FFF FFF0 (Half 16).

When this bit is high and the CNTPRST bit is set, all MMC counters get preset to almost-full value. All octet counters get preset to 0xFFFF F800 (Full 2Kbytes) and all packet-counters get preset to 0xFFFF FFF0 (Full 16).

For 16-bit counters, the almost-half preset values are 0x7800 and 0x7FF0 for the respective octet and packet counters. Similarly, the almost-full preset values for the 16-bit counters are 0xF800 and 0xFFF0.

Bit 4 **CNTPRST**: Counters Preset

When this bit is set, all counters are initialized or preset to almost full or almost half according to the CNTPRSTLVL bit. This bit is cleared automatically after 1 clock cycle.

This bit, along with the CNTPRSTLVL bit, is useful for debugging and testing the assertion of interrupts because of MMC counter becoming half-full or full.

Bit 3 **CNTFREEZ**: MMC Counter Freeze

When this bit is set, it freezes all MMC counters to their current value.

Until this bit is reset to 0, no MMC counter is updated because of any transmitted or received packet. If any MMC counter is read with the Reset on Read bit set, then that counter is also cleared in this mode.

Bit 2 **RSTONRD**: Reset on Read

When this bit is set, the MMC counters are reset to zero after Read (self-clearing after reset). The counters are cleared when the least significant byte lane (Bits[7:0]) is read.

Bit 1 **CNTSTOPRO**: Counter Stop Rollover
When this bit is set, the counter does not roll over to zero after reaching the maximum value.

Bit 0 **CNTRST**: Counters Reset
When this bit is set, all counters are reset. This bit is cleared automatically after 1 clock cycle.

MMC Rx interrupt register (ETH_MMC_RX_INTERRUPT)

Address offset: 0x0704

Reset value: 0x0000 0000

This register maintains the interrupts generated from all receive statistics counters.

The MMC receive interrupt register maintains the interrupts that are generated when the following occur:

- Receive statistic counters reach half of their maximum values (0x8000 0000 for 32-bit counter and 0x8000 for 16-bit counter).
- Receive statistic counters cross their maximum values (0xFFFF FFFF for 32-bit counter and 0xFFFF for 16-bit counter).

When the CNTSTOPRO is set in *MMC control register (ETH_MMC_CONTROL)*, interrupts are set but the counter remains at all-ones. The MMC receive interrupt register is a 32-bit register. An interrupt bit is cleared when the respective MMC counter that caused the interrupt is read. The least significant byte lane (Bits[7:0]) of the respective counter must be read to clear the interrupt bit.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	RXLPITRCIS	RXLPIUSCIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXUCGPIS	Res.
				rc_r	rc_r									rc_r	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXALGNERPIS	RXCRCERPIS	Res.	Res.	Res.	Res.	Res.
									rc_r	rc_r					

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **RXLPITRCIS**: MMC receive LPI transition counter interrupt status
This bit is set when the *Rx LPI transition counter register (ETH_RX_LPI_TRAN_CNTR)* counter reaches half of the maximum value or the maximum value.

Bit 26 **RXLPIUSCIS**: MMC receive LPI microsecond counter interrupt status
This bit is set when the *Rx LPI microsecond counter register (ETH_RX_LPI_USEC_CNTR)* counter reaches half of the maximum value or the maximum value.

Bits 25:18 Reserved, must be kept at reset value.

Bit 17 **RXUCGPIS**: MMC receive Unicast good packet counter interrupt status
This bit is set when the *Rx unicast packets good register (ETH_RX_UNICAST_PACKETS_GOOD)* counter reaches half of the maximum value or the maximum value.

Bits 16:7 Reserved, must be kept at reset value.

Bit 6 **RXALGNERPIS**: MMC receive alignment error packet counter interrupt status
This bit is set when the *Rx alignment error packets register (ETH_RX_ALIGNMENT_ERROR_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bit 5 **RXCRCERPIS**: MMC receive CRC error packet counter interrupt status
This bit is set when the *Rx CRC error packets register (ETH_RX_CRC_ERROR_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bits 4:0 Reserved, must be kept at reset value.

MMC Tx interrupt register (ETH_MMC_TX_INTERRUPT)

Address offset: 0x0708

Reset value: 0x0000 0000

This register maintains the interrupts generated from all transmit statistics counters.

The MMC transmit interrupt register maintains the interrupts generated when transmit statistic counters reach half their maximum values (0x8000 0000 for 32-bit counter and 0x8000 for 16 bit counter), and when they cross their maximum values (0xFFFF FFFF for 32-bit counter and 0xFFFF for 16-bit counter).

When CNTSTOPRO is set in *MMC control register (ETH_MMC_CONTROL)*, the interrupts are set but the counter remains at all-ones.

The MMC transmit interrupt register is a 32-bit register. An interrupt bit is cleared when the respective MMC counter that caused the interrupt is read.

The least significant byte lane (Bits[7:0]) of the respective counter must be read to clear the interrupt bit.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TXLPITRCIS	TXLPIUSCIS	Res.	Res.	Res.	Res.	TXGPKTIS	Res.	Res.	Res.	Res.	Res.
				rc_r	rc_r					rc_r					

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXMCOLGPIS	TXSCOLGPIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rc_r	rc_r														

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **TXLPITRCIS**: MMC transmit LPI transition counter interrupt status
This bit is set when the *Tx LPI transition counter register (ETH_TX_LPI_TRAN_CNTR)* counter reaches half of the maximum value or the maximum value.

Bit 26 **TXLPIUSCIS**: MMC transmit LPI microsecond counter interrupt status
This bit is set when the *Tx LPI microsecond timer register (ETH_TX_LPI_USEC_CNTR)* counter reaches half of the maximum value or the maximum value.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **TXGPKTIS**: MMC transmit good packet counter interrupt status
This bit is set when the *Tx packet count good register (ETH_TX_PACKET_COUNT_GOOD)* counter reaches half of the maximum value or the maximum value.

Bits 20:16 Reserved, must be kept at reset value.

Bit 15 **TXMCOLGPIS**: MMC transmit multiple collision good packet counter interrupt status
This bit is set when the *Tx multiple collision good packets register (ETH_TX_MULTIPLE_COLLISION_GOOD_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bit 14 **TXSCOLGPIS**: MMC transmit single collision good packet counter interrupt status
This bit is set when the *Tx single collision good packets register (ETH_TX_SINGLE_COLLISION_GOOD_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bits 13:0 Reserved, must be kept at reset value.

MMC Rx interrupt mask register (ETH_MMC_RX_INTERRUPT_MASK)

Address offset: 0x070C

Reset value: 0x0000 0000

The MMC receive interrupt mask register maintains the masks for the interrupts generated when receive statistic counters reach half of their maximum value or the maximum values.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	RXLPITRCIM	RXLPIUSCIM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXUCGPIM	Res.
				rw	rw									rw	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXALGNERPIM	RXCRCERPIM	Res.	Res.	Res.	Res.	Res.
									rw	rw					

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **RXLPITRCIM**: MMC receive LPI transition counter interrupt Mask
Setting this bit masks the interrupt when the *Rx LPI transition counter register (ETH_RX_LPI_TRAN_CNTR)* counter reaches half of the maximum value or the maximum value.

Bit 26 **RXLPIUSCIM**: MMC receive LPI microsecond counter interrupt Mask
Setting this bit masks the interrupt when the *Rx LPI microsecond counter register (ETH_RX_LPI_USEC_CNTR)* counter reaches half of the maximum value or the maximum value.

Bits 25:18 Reserved, must be kept at reset value.

Bit 17 **RXUCGPIM**: MMC receive Unicast good packet counter interrupt mask
Setting this bit masks the interrupt when the *Rx unicast packets good register (ETH_RX_UNICAST_PACKETS_GOOD)* counter reaches half of the maximum value or the maximum value.

Bits 16:7 Reserved, must be kept at reset value.

Bit 6 **RXALGNERPIM**: MMC receive Alignment Error packet counter interrupt mask
Setting this bit masks the interrupt when the *Rx alignment error packets register (ETH_RX_ALIGNMENT_ERROR_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bit 5 **RXCRCERPIM**: MMC receive CRC Error packet counter interrupt mask
Setting this bit masks the interrupt when the *Rx CRC error packets register (ETH_RX_CRC_ERROR_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bits 4:0 Reserved, must be kept at reset value.

MMC Tx interrupt mask register (ETH_MMC_TX_INTERRUPT_MASK)

Address offset: 0x0710

Reset value: 0x0000 0000

The MMC transmit interrupt mask register maintains the masks for the interrupts generated when the transmit statistic counters reach half of their maximum value or the maximum values. This register is 32-bit wide.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TXLPITRCIM	TXLPIUSCIM	Res.	Res.	Res.	Res.	TXGPKTIM	Res.	Res.	Res.	Res.	Res.
				rw	rw					rw					

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXMCOLGPIM	TXSCOLGPIM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw														

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **TXLPITRCIM**: MMC transmit LPI transition counter interrupt mask
Setting this bit masks the interrupt when the *Tx LPI transition counter register (ETH_TX_LPI_TRAN_CNTR)* counter reaches half of the maximum value or the maximum value.

Bit 26 **TXLPIUSCIM**: MMC transmit LPI microsecond counter interrupt mask
Setting this bit masks the interrupt when the *Tx LPI microsecond timer register (ETH_TX_LPI_USEC_CNTR)* counter reaches half of the maximum value or the maximum value.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **TXGPKTIM**: MMC transmit good packet counter interrupt mask
Setting this bit masks the interrupt when the *Tx packet count good register (ETH_TX_PACKET_COUNT_GOOD)* counter reaches half of the maximum value or the maximum value.

Bits 20:16 Reserved, must be kept at reset value.

Bit 15 **TXMCOLGPIM**: MMC transmit multiple-collision good packet counter interrupt mask
Setting this bit masks the interrupt when the *Tx multiple collision good packets register (ETH_TX_MULTIPLE_COLLISION_GOOD_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bit 14 **TXSCOLGPIM**: MMC transmit single-collision good packet counter interrupt mask
Setting this bit masks the interrupt when the *Tx single collision good packets register (ETH_TX_SINGLE_COLLISION_GOOD_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bits 13:0 Reserved, must be kept at reset value.

Tx single collision good packets register (ETH_TX_SINGLE_COLLISION_GOOD_PACKETS)

Address offset: 0x074C

Reset value: 0x0000 0000

This register provides the number of successfully transmitted packets by Ethernet peripheral after a single collision in the Half-duplex mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXSNGLCOLG[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXSNGLCOLG[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXSNGLCOLG[31:0]**: Tx Single Collision Good Packets
This field indicates the number of successfully transmitted packets after a single collision in the Half-duplex mode.

Tx multiple collision good packets register (ETH_TX_MULTIPLE_COLLISION_GOOD_PACKETS)

Address offset: 0x0750

Reset value: 0x0000 0000

This register provides the number of successfully transmitted packets by Ethernet peripheral after multiple collisions in the Half-duplex mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXMULTCOLG[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXMULTCOLG[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXMULTCOLG[31:0]**: Tx Multiple Collision Good Packets
This field indicates the number of successfully transmitted packets after multiple collisions in the Half-duplex mode.

Tx packet count good register (ETH_TX_PACKET_COUNT_GOOD)

Address offset: 0x0768

Reset value: 0x0000 0000

This register provides the number of good packets transmitted by Ethernet peripheral.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXPKTG[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXPKTG[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXPKTG[31:0]**: Tx Packet Count Good
This field indicates the number of good packets transmitted.

Rx CRC error packets register (ETH_RX_CRC_ERROR_PACKETS)

Address offset: 0x0794

Reset value: 0x0000 0000

This register provides the number of packets received by Ethernet peripheral with CRC error.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXCRCERR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXCRCERR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXCRCERR[31:0]**: Rx CRC Error Packets
This field indicates the number of packets received with CRC error.

Rx alignment error packets register (ETH_RX_ALIGNMENT_ERROR_PACKETS)

Address offset: 0x0798

Reset value: 0x0000 0000

This register provides the number of packets received by Ethernet peripheral with alignment (dribble) error. It is valid only in 10/100 mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXALGNERR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXALGNERR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXALGNERR[31:0]**: Rx Alignment Error Packets
This field indicates the number of packets received with alignment (dribble) error. It is valid only in 10/100 mode.

Rx unicast packets good register (ETH_RX_UNICAST_PACKETS_GOOD)

Address offset: 0x07C4

Reset value: 0x0000 0000

This register provides the number of good unicast packets received by Ethernet peripheral.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXUCASTG[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXUCASTG[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXUCASTG[31:0]**: Rx Unicast Packets Good
This field indicates the number of good unicast packets received.

Tx LPI microsecond timer register (ETH_TX_LPI_USEC_CNTR)

Address offset: 0x07EC

Reset value: 0x0000 0000

This register provides the number of microseconds Tx LPI is asserted by Ethernet peripheral.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXLPIUSC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXLPIUSC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXLPIUSC[31:0]**: Tx LPI Microseconds Counter

This field indicates the number of microseconds Tx LPI is asserted. For every Tx LPI Entry and Exit, the Timer value can have an error of +/- 1 microsecond.

Tx LPI transition counter register (ETH_TX_LPI_TRAN_CNTR)

Address offset: 0x07F0

Reset value: 0x0000 0000

This register provides the number of times Ethernet peripheral has entered Tx LPI.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXLPITRC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXLPITRC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXLPITRC[31:0]**: Tx LPI Transition counter

This field indicates the number of times Tx LPI Entry has occurred. Even if Tx LPI Entry occurs in Automate mode (because of LPITXA bit set in the *LPI control and status register (ETH_MACLCSR)*), the counter is incremented.

Rx LPI microsecond counter register (ETH_RX_LPI_USEC_CNTR)

Address offset: 0x07F4

Reset value: 0x0000 0000

This register provides the number of microseconds Rx LPI is sampled by Ethernet peripheral.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXLPIUSC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXLPIUSC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXLPIUSC[31:0]**: Rx LPI Microseconds Counter

This field indicates the number of microseconds Rx LPI is asserted. For every Rx LPI Entry and Exit, the Timer value can have an error of +/- 1 microsecond.

Rx LPI transition counter register (ETH_RX_LPI_TRAN_CNTR)

Address offset: 0x07F8

Reset value: 0x0000 0000

This register provides the number of times Ethernet peripheral has entered Rx LPI.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXLPITRC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXLPITRC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXLPITRC[31:0]**: Rx LPI Transition counter

This field indicates the number of times Rx LPI Entry has occurred.

L3 and L4 control 0 register (ETH_MACL3L4C0R)

Address offset: 0x0900

Reset value: 0x0000 0000

The Layer 3 and Layer 4 Control register controls the operations of filter 0 of Layer 3 and Layer 4.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	L4DPIM0	L4DPM0	L4SPIM0	L4SPM0	Res.	L4PEN0
										rw	rw	rw	rw		rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3HDBM0[4:0]					L3HSBM0[4:0]					L3DAIM0	L3DAM0	L3SAIM0	L3SAM0	Res.	L3PEN0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **L4DPIM0**: Layer 4 Destination Port Inverse Match Enable

When this bit is set, the Layer 4 Destination Port number field is enabled for inverse matching. When this bit is reset, the Layer 4 Destination Port number field is enabled for perfect matching.

This bit is valid and applicable only when the L4DPM0 bit is set high.

Bit 20 **L4DPM0**: Layer 4 Destination Port Match Enable

When this bit is set, the Layer 4 Destination Port number field is enabled for matching. When this bit is reset, the MAC ignores the Layer 4 Destination Port number field for matching.

Bit 19 **L4SPIM0**: Layer 4 Source Port Inverse Match Enable

When this bit is set, the Layer 4 Source Port number field is enabled for inverse matching. When this bit is reset, the Layer 4 Source Port number field is enabled for perfect matching.

This bit is valid and applicable only when the L4SPM0 bit is set high.

Bit 18 **L4SPM0**: Layer 4 Source Port Match Enable

When this bit is set, the Layer 4 Source Port number field is enabled for matching. When this bit is reset, the MAC ignores the Layer 4 Source Port number field for matching.

Bit 17 Reserved, must be kept at reset value.

Bit 16 **L4PEN0**: Layer 4 Protocol Enable

When this bit is set, the Source and Destination Port number fields of UDP packets are used for matching. When this bit is reset, the Source and Destination Port number fields of TCP packets are used for matching.

The Layer 4 matching is done only when the L4SPM0 or L4DPM0 bit is set.

Bits 15:11 **L3HDBM0[4:0]**: Layer 3 IP DA higher bits match

Condition: IPv4 packets

This field contains the number of higher bits of IP Destination Address that are masked in the IPv4 packets:

0: No bits are masked.

1: LSb[0] is masked

2: Two LSbs [1:0] are masked

..

31: All bits except MSb are masked.

Condition: IPv6 packets

Bits[12:11] of this field correspond to Bits[6:5] of L3HSBM0 which indicate the number of lower bits of IP Source or Destination Address that are masked in the IPv6 packets. Number of bits masked is given by concatenated values of the L3HDBM0[1:0] and L3HSBM0 bits:

0: No bits are masked.

1: LSb[0] is masked

2: Two LSbs [1:0] are masked

..

31: All bits except MSb are masked.

This field is valid and applicable only when the L3DAM0 or L3SAM0 bit is set.

Bits 10:6 **L3HSBM0[4:0]**: Layer 3 IP SA higher bits match

Condition: IPv4 packets

This field contains the number of lower bits of IP source address that are masked for matching in the IPv4 packets. The following list describes the values of this field:

0: No bits are masked.

1: LSb[0] is masked

2: Two LSbs [1:0] are masked

..

31: All bits except MSb are masked.

Condition: IPv6 packets:

This field contains Bits[4:0] of L3HSBM0. These bits indicate the number of higher bits of IP source or destination address matched in the IPv6 packets. This field is valid and applicable only when the L3DAM0 or L3SAM0 bit is set high.

Bit 5 **L3DAIM0**: Layer 3 IP DA Inverse Match Enable

When this bit is set, the Layer 3 IP Destination Address field is enabled for inverse matching. When this bit is reset, the Layer 3 IP Destination Address field is enabled for perfect matching.

This bit is valid and applicable only when the L3DAM0 bit is set high.

Bit 4 **L3DAM0**: Layer 3 IP DA Match Enable

When this bit is set, the Layer 3 IP Destination Address field is enabled for matching. When this bit is reset, the MAC ignores the Layer 3 IP Destination Address field for matching.

Note: When the L3PEN0 bit is set, you should set either this bit or the L3SAM0 bit because either IPv6 DA or SA can be checked for filtering.

Bit 3 **L3SAIM0**: Layer 3 IP SA Inverse Match Enable

When this bit is set, the Layer 3 IP Source Address field is enabled for inverse matching. When this bit reset, the Layer 3 IP Source Address field is enabled for perfect matching.

This bit is valid and applicable only when the L3SAM0 bit is set.

Bit 2 **L3SAM0**: Layer 3 IP SA Match Enable

When this bit is set, the Layer 3 IP Source Address field is enabled for matching. When this bit is reset, the MAC ignores the Layer 3 IP Source Address field for matching.

Note: When the L3PEN0 bit is set, you should set either this bit or the L3DAM0 bit because either IPv6 SA or DA can be checked for filtering.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **L3PEN0**: Layer 3 Protocol Enable

When this bit is set, the Layer 3 IP Source or Destination Address matching is enabled for IPv6 packets. When this bit is reset, the Layer 3 IP Source or Destination Address matching is enabled for IPv4 packets.

The Layer 3 matching is done only when the L3SAM0 or L3DAM0 bit is set.

Layer4 address filter 0 register (ETH_MACL4A0R)

Address offset: 0x0904

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L4DP0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L4SP0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **L4DP0[15:0]**: Layer 4 Destination Port Number Field

When the L4PEN0 bit is reset and the L4DPM0 bit is set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with the TCP Destination Port Number field in the IPv4 or IPv6 packets.

When the L4PEN0 and L4DPM0 bits are set in *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with the UDP Destination Port Number field in the IPv4 or IPv6 packets.

Bits 15:0 **L4SP0[15:0]**: Layer 4 Source Port Number Field

When the L4PEN0 bit is reset and the L4DPM0 bit is set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with the TCP Source Port Number field in the IPv4 or IPv6 packets.

When the L4PEN0 and L4DPM0 bits are set in *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with the UDP Source Port Number field in the IPv4 or IPv6 packets.

Layer3 address 0 filter 0 register (ETH_MACL3A00R)

Address offset: 0x0910

Reset value: 0x0000 0000

For IPv4 packets, the Layer 3 Address 0 filter 0 register contains the 32-bit IP Source Address field. For IPv6 packets, it contains Bits[31:0] of the 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A00[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A00[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A00[31:0]**: Layer 3 Address 0 Field

When the L3PEN0 and L3SAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[31:0] of the IP Source Address field in the IPv6 packets.

When the L3PEN0 and L3DAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[31:0] of the IP Destination Address field in the IPv6 packets.

When the L3PEN0 bit is reset and the L3SAM0 bit is set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with the IP Source Address field in the IPv4 packets.

Layer3 address 1 filter 0 register (ETH_MACL3A10R)

Address offset: 0x0914

Reset value: 0x0000 0000

For IPv4 packets, the Layer 3 Address 1 filter 0 register contains the 32-bit IP Destination Address field. For IPv6 packets, it contains Bits[63:32] of the 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A10[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A10[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A10[31:0]**: Layer 3 Address 1 Field

When the L3PEN0 and L3SAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[63:32] of the IP Source Address field in the IPv6 packets.

When the L3PEN0 and L3DAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[63:32] of the IP Destination Address field in the IPv6 packets.

When the L3PEN0 bit is reset and the L3SAM0 bit is set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with the IP Destination Address field in the IPv4 packets.

Layer3 address 2 filter 0 register (ETH_MACL3A20R)

Address offset: 0x0918

Reset value: 0x0000 0000

The Layer 3 Address 2 filter 0 register is reserved for IPv4 packets. For IPv6 packets, it contains Bits[95:64] of 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A20[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A20[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A20[31:0]**: Layer 3 Address 2 Field

When the L3PEN0 and L3SAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[95:64] of the IP Source Address field in the IPv6 packets.

When the L3PEN0 and L3DAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[95:64] of the IP Destination Address field in the IPv6 packets.

When the L3PEN0 bit is reset in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field is not used.

Layer3 address 3 filter 0 register (ETH_MACL3A30R)

Address offset: 0x091C

Reset value: 0x0000 0000

The Layer 3 Address 3 filter 0 register is reserved for IPv4 packets. For IPv6 packets, it contains Bits[127:96] of 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A30[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A30[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A30[31:0]**: Layer 3 Address 3 Field

When the L3PEN0 and L3SAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[127:96] of the IP Source Address field in the IPv6 packets.

When the L3PEN0 and L3DAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[127:96] of the IP Destination Address field in the IPv6 packets.

When the L3PEN0 bit is reset in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field is not used.

L3 and L4 control 1 register (ETH_MACL3L4C1R)

Address offset: 0x0930

Reset value: 0x0000 0000

The Layer 3 and Layer 4 Control register controls the operations of filter 1 of Layer 3 and Layer 4.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	L4DPIM1	L4DPM1	L4SPIM1	L4SPM1	Res.	L4PEN1
										rw	rw	rw	rw		rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3HDBM1[4:0]					L3HSBM1[4:0]					L3DAIM1	L3DAM1	L3SAIM1	L3SAM1	Res.	L3PEN1
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **L4DPIM1**: Layer 4 Destination Port Inverse Match Enable

When this bit is set, the Layer 4 Destination Port number field is enabled for inverse matching. When this bit is reset, the Layer 4 Destination Port number field is enabled for perfect matching.

This bit is valid and applicable only when the L4DPM1 bit is set high.

Bit 20 **L4DPM1**: Layer 4 Destination Port Match Enable

When this bit is set, the Layer 4 Destination Port number field is enabled for matching. When this bit is reset, the MAC ignores the Layer 4 Destination Port number field for matching.

Bit 19 **L4SPIM1**: Layer 4 Source Port Inverse Match Enable

When this bit is set, the Layer 4 Source Port number field is enabled for inverse matching. When this bit is reset, the Layer 4 Source Port number field is enabled for perfect matching.

This bit is valid and applicable only when the L4SPM1 bit is set high.

Bit 18 **L4SPM1**: Layer 4 Source Port Match Enable

When this bit is set, the Layer 4 Source Port number field is enabled for matching. When this bit is reset, the MAC ignores the Layer 4 Source Port number field for matching.

Bit 17 Reserved, must be kept at reset value.

Bit 16 **L4PEN1**: Layer 4 Protocol Enable

When this bit is set, the Source and Destination Port number fields of UDP packets are used for matching. When this bit is reset, the Source and Destination Port number fields of TCP packets are used for matching.

The Layer 4 matching is done only when the L4SPM1 or L4DPM1 bit is set.

Bits 15:11 **L3HDBM1[4:0]**: Layer 3 IP DA higher bits match

Condition: IPv4 packets

This field contains the number of lower bits of IP Destination Address that are masked for matching in the IPv4 packets. The following list describes the values of this field:

0: No bits are masked.

1: LSb[0] is masked

2: Two LSbs [1:0] are masked

..

31: All bits except MSb are masked.

Condition: IPv6 packets

Bits[12:11] of this field correspond to Bits[6:5] of L3HSBM1, which indicate the number of lower bits of IP Source or Destination Address that are masked in the IPv6 packets. The following list describes the concatenated values of the L3HDBM1[1:0] and L3HSBM1 bits:

0: No bits are masked

1: LSb[0] is masked

2: Two LSbs [1:0] are masked

..

127: All bits except MSb are masked

This field is valid and applicable only when the L3DAM1 or L3SAM1 bit is set.

Bits 10:6 **L3HSBM1[4:0]**: Layer 3 IP SA Higher Bits Match

Condition: IPv4 packets

This field contains the number of lower bits of IP Source Address that are masked for matching in the IPv4 packets. The following list describes the values of this field:

0: No bits are masked.

1: LSb[0] is masked

2: Two LSbs [1:0] are masked

..

31: All bits except MSb are masked.

Condition: IPv6 packets

This field contains Bits[4:0] of L3HSBM1. These bits indicate the number of higher bits of IP Source or Destination Address matched in the IPv6 packets. This field is valid and applicable only when the L3DAM1 or L3SAM1 bit is set high.

Bit 5 **L3DAIM1**: Layer 3 IP DA Inverse Match Enable

When this bit is set, the Layer 3 IP Destination Address field is enabled for inverse matching. When this bit is reset, the Layer 3 IP Destination Address field is enabled for perfect matching.

This bit is valid and applicable only when the L3DAM1 bit is set high.

Bit 4 **L3DAM1**: Layer 3 IP DA Match Enable

When this bit is set, the Layer 3 IP Destination Address field is enabled for matching. When this bit is reset, the MAC ignores the Layer 3 IP Destination Address field for matching.

Note: When the L3PEN1 bit is set, you should set either this bit or the L3SAM1 bit because either IPv6 DA or SA can be checked for filtering.

Bit 3 **L3SAIM1**: Layer 3 IP SA Inverse Match Enable

When this bit is set, the Layer 3 IP Source Address field is enabled for inverse matching. When this bit reset, the Layer 3 IP Source Address field is enabled for perfect matching.

This bit is valid and applicable only when the L3SAM1 bit is set.

Bit 2 **L3SAM1**: Layer 3 IP SA Match Enable

When this bit is set, the Layer 3 IP Source Address field is enabled for matching. When this bit is reset, the MAC ignores the Layer 3 IP Source Address field for matching.

Note: When the L3PEN01 bit is set, you should set either this bit or the L3DAM1 bit because either IPv6 SA or DA can be checked for filtering.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **L3PEN1**: Layer 3 Protocol Enable

When this bit is set, the Layer 3 IP Source or Destination Address matching is enabled for IPv6 packets. When this bit is reset, the Layer 3 IP Source or Destination Address matching is enabled for IPv4 packets.

The Layer 3 matching is done only when the L3SAM1 or L3DAM1 bit is set.

Layer 4 address filter 1 register (ETH_MACL4A1R)

Address offset: 0x0934

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L4DP1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L4SP1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **L4DP1[15:0]**: Layer 4 Destination Port Number Field

When the L4PEN1 bit is reset and the L4DPM1 bit is set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with the TCP Destination Port Number field in the IPv4 or IPv6 packets.

When the L4PEN1 and L4DPM1 bits are set in *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with the UDP Destination Port Number field in the IPv4 or IPv6 packets.

Bits 15:0 **L4SP1[15:0]**: Layer 4 Source Port Number Field

When the L4PEN1 bit is reset and the L4DPM1 bit is set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with the TCP Source Port Number field in the IPv4 or IPv6 packets.

When the L4PEN1 and L4DPM1 bits are set in *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with the UDP Source Port Number field in the IPv4 or IPv6 packets.

Layer3 address 0 filter 1 Register (ETH_MACL3A01R)

Address offset: 0x0940

Reset value: 0x0000 0000

For IPv4 packets, the Layer 3 Address 0 filter 1 register contains the 32-bit IP Source Address field. For IPv6 packets, it contains Bits[31:0] of the 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A01[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A01[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A01[31:0]**: Layer 3 Address 0 Field

When the L3PEN1 and L3SAM1bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[31:0] of the IP Source Address field in the IPv6 packets.

When the L3PEN1 and L3DAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[31:0] of the IP Destination Address field in the IPv6 packets.

When the L3PEN1 bit is reset and the L3SAM1 bit is set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with the IP Source Address field in the IPv4 packets.

Layer3 address 1 filter 1 register (ETH_MACL3A11R)

Address offset: 0x0944

Reset value: 0x0000 0000

For IPv4 packets, the Layer 3 Address 1 filter 1 register contains the 32-bit IP Destination Address field. For IPv6 packets, it contains Bits[63:32] of the 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A11[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A11[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A11[31:0]**: Layer 3 Address 1 Field

When the L3PEN1 and L3SAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[63:32] of the IP Source Address field in the IPv6 packets.

When the L3PEN1 and L3DAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[63:32] of the IP Destination Address field in the IPv6 packets.

When the L3PEN1 bit is reset and the L3SAM1 bit is set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with the IP Destination Address field in the IPv4 packets.

Layer3 address 2 filter 1 Register (ETH_MACL3A21R)

Address offset: 0x0948

Reset value: 0x0000 0000

The Layer 3 Address 2 filter 1 register is reserved for IPv4 packets. For IPv6 packets, it contains Bits[95:64] of 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A21[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A21[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A21[31:0]**: Layer 3 Address 2 Field

When the L3PEN1 and L3SAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[95:64] of the IP Source Address field in the IPv6 packets.

When the L3PEN1 and L3DAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[95:64] of the IP Destination Address field in the IPv6 packets.

When the L3PEN1 bit is reset in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field is not used.

Layer3 address 3 filter 1 register (ETH_MACL3A31R)

Address offset: 0x94C

Reset value: 0x0000 0000

The Layer 3 Address 3 filter 1 register is reserved for IPv4 packets. For IPv6 packets, it contains Bits[127:96] of 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A31[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A31[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A31[31:0]**: Layer 3 Address 3 Field

When the L3PEN1 and L3SAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[127:96] of the IP Source Address field in the IPv6 packets.

When the L3PEN1 and L3DAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[127:96] of the IP Destination Address field in the IPv6 packets.

When the L3PEN1 bit is reset in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field is not used.

MAC indirect access control register (ETH_MAC_IACR)

Address offset: 0x0A70

Reset value: 0x0000 0000

This register provides the Indirect Access control and status for the *MAC type-based Rx queue mapping register (ETH_MAC_TMRQR)*.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MSEL[3:0]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AOFF[7:0]								Res.	Res.	AUTO	Res.	Res.	Res.	COM	OB
rw	rw	rw	rw	rw	rw	rw	rw			rw				rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:16 **MSEL[3:0]**: Mode Select

This field is used for indirect accesses to the *MAC type-based Rx queue mapping register (ETH_MAC_TMRQR)*. It must be set when initiating a read/write to the *MAC type-based Rx queue mapping register (ETH_MAC_TMRQR)* and should not be changed until the OB bit is reset.

0000:Typ_RXQ_ (Type-based RXQ mapping)
0001-1111: Reserved for future use

Bits 15:8 **AOFF[7:0]**: Address Offset

This field is used for indirect accesses to the *MAC type-based Rx queue mapping register (ETH_MAC_TMRQR)*. It must be set when initiating a read/write to the *MAC type-based Rx queue mapping register (ETH_MAC_TMRQR)* and should not be changed until the OB bit is reset.

00000000: IndReg0 (Indirect register 0)
00000001: IndReg1 (Indirect register 1)
...
00000111: IndReg7 (Indirect register 7)
00001000-11111111: Reserved, must not be used

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **AUTO**: Auto-increment

1: AOFF is incremented by 1. The software should ensure not to cause a wrap condition. Byte-wise read/write is not supported when auto-increment is enabled.
0: AOFF is not automatically incremented. The software should program the correct address offset for each access.

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **COM**: Command type

This bit indicates the register access type:
1: Indicates a read operation.
0: Indicates a write operation.

Bit 0 **OB**: Operation Busy.

This bit is set along with a read or write command to initiate an indirect access to the *MAC type-based Rx queue mapping register (ETH_MAC_TMRQR)*. This bit is reset when the read or write command to the *MAC type-based Rx queue mapping register (ETH_MAC_TMRQR)* is complete. The next indirect register access can be initiated only after this bit is reset. During a write operation, the bit is reset only after the data has been written to the *MAC type-based Rx queue mapping register (ETH_MAC_TMRQR)* register. During a read operation, the data should be read from the *MAC type-based Rx queue mapping register (ETH_MAC_TMRQR)* only after this bit is reset.

MAC type-based Rx queue mapping register (ETH_MAC_TMRQR)

Address offset: 0x0A74

Reset value: 0x0000 0000

This register contains the type, associated queue number related to Type-based RXQ mappings. It holds the data for eight indirect registers, defined by the AOFF[7:0] bitfield in the *MAC indirect access control register (ETH_MAC_IACR)*.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TMRQ[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TYP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:19 Reserved, must be kept at reset value.

Bits 18:16 **TMRQ[2:0]**: Type Match Rx Queue Number

Indicates the receive queue number to which the packet needs to be forwarded on detecting a type match.

Bits 15:0 **TYP[15:0]**: Type field Value

Indicates the type value of packet that needs to be compared with the received Ethernet packet. This field is valid when programmed to a value greater than or equal to 0x0600.

Timestamp control register (ETH_MACTSCR)

Address offset: 0x0B00

Reset value: 0x0000 2000

This register controls the operation of the System Time generator and processing of PTP packets for timestamping in the receiver.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	AV8021ASMEN	Res.	Res.	Res.	TXTSSTSM	Res.	Res.	Res.	Res.	Res.	TSENMACADDR	SNAPTYPSEL[1:0]	
			rw				rw						rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSMSTRENA	TSEVNTENA	TSIPV4ENA	TSIPV6ENA	TSIPENA	TSVER2ENA	TSCTRLSSR	TSENALL	Res.	PTGE	TSADDREG	Res.	TSUPDT	TSINIT	TSCFUPDT	TSENA
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw		rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **AV8021ASMEN**: AV 802.1AS Mode Enable

When this bit is set, the MAC processes only untagged PTP over Ethernet packets for providing PTP status and capturing timestamp snapshots, that is, IEEE 802.1AS operating mode.

When the PTP offload feature is enabled, for PTP offload, the transport-specific field in the PTP header is generated and checked based on the value of this bit.

Bits 27:25 Reserved, must be kept at reset value.

Bit 24 **TXTSSTSM**: Transmit Timestamp Status Mode

When this bit is set, the MAC overwrites the earlier transmit timestamp status even if it is not read by the software. The MAC indicates this by setting the TXTSSMIS bit of the *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* register.

When this bit is reset, the MAC ignores the timestamp status of current packet if the timestamp status of previous packet is not read by the software. The MAC indicates this by setting the TXTSSMIS bit of the *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)*.

Bits 23:19 Reserved, must be kept at reset value.

Bit 18 **TSENMACADDR**: Enable MAC Address for PTP Packet Filtering

When this bit is set, the DA MAC address (that matches any MAC Address register) is used to filter the PTP packets when PTP is directly sent over Ethernet.

When this bit is set, received PTP packets with DA containing a special multicast or unicast address that matches the one programmed in MAC address registers are considered for processing as indicated below, when PTP is directly sent over Ethernet.

For normal timestamping operation, MAC address registers 0 to 31 is considered for unicast destination address matching.

For PTP offload, only MAC address register 0 is considered for unicast destination address matching.

Bits 17:16 **SNAPTYPSEL[1:0]**: Select PTP packets for Taking Snapshots

These bits, along with Bits 15 and 14, define the set of PTP packet types for which snapshot needs to be taken. The encoding is given in *Table 784: Timestamp Snapshot Dependency on ETH_MACTSCR bits*.

Bit 15 **TSMSTRENA**: Enable Snapshot for Messages Relevant to Master

When this bit is set, the snapshot is taken only for the messages that are relevant to the master node. Otherwise, the snapshot is taken for the messages relevant to the slave node.

Bit 14 **TSEVNTENA**: Enable Timestamp Snapshot for Event Messages

When this bit is set, the timestamp snapshot is taken only for event messages (SYNC, Delay_Req, Pdelay_Req, or Pdelay_Resp). When this bit is reset, the snapshot is taken for all messages except Announce, Management, and Signaling. For more information about the timestamp snapshots, see *Table 784: Timestamp Snapshot Dependency on ETH_MACTSCR bits*.

Bit 13 **TSIPV4ENA**: Enable Processing of PTP Packets Sent over IPv4-UDP

When this bit is set, the MAC receiver processes the PTP packets encapsulated in IPv4-UDP packets. When this bit is reset, the MAC ignores the PTP transported over IPv4-UDP packets. This bit is set by default.

Bit 12 **TSIPV6ENA**: Enable Processing of PTP Packets Sent over IPv6-UDP

When this bit is set, the MAC receiver processes the PTP packets encapsulated in IPv6-UDP packets. When this bit is clear, the MAC ignores the PTP transported over IPv6-UDP packets.

Bit 11 **TSIPENA**: Enable Processing of PTP over Ethernet Packets

When this bit is set, the MAC receiver processes the PTP packets encapsulated directly in the Ethernet packets. When this bit is reset, the MAC ignores the PTP over Ethernet packets.

Bit 10 **TSVER2ENA**: Enable PTP Packet Processing for Version 2 Format

When this bit is set, the IEEE 1588 version 2 format is used to process the PTP packets. When this bit is reset, the IEEE 1588 version 1 format is used to process the PTP packets. The IEEE 1588 formats are described in 'PTP Processing and Control'.

Bit 9 **TSCTRLSSR**: Timestamp Digital or Binary Rollover Control

When this bit is set, the Timestamp Low register rolls over after 0x3B9A C9FF value (that is, 1 nanosecond accuracy) and increments the timestamp (High) seconds. When this bit is reset, the rollover value of subsecond register is 0x7FFF FFFF. The subsecond increment must be programmed correctly depending on the PTP reference clock frequency and the value of this bit.

Bit 8 **TSENALL**: Enable Timestamp for All Packets

When this bit is set, the timestamp snapshot is enabled for all packets received by the MAC.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **PTGE**: Presentation Time Generation Enable

When this bit is set the Presentation Time generation is enabled.

Bit 5 **TSADDREG**: Update Addend Register

When this bit is set, the content of the Timestamp Addend register is updated in the PTP block for fine correction. This bit is cleared when the update is complete. This bit should be zero before it is set.

Bit 4 Reserved, must be kept at reset value.

Bit 3 **TSUPDT**: Update Timestamp

When this bit is set, the system time is updated (added or subtracted) with the value specified in *System time seconds update register (ETH_MACSTSUR)* and *System time nanoseconds update register (ETH_MACSTNUR)*.
When Media Clock Generation and Recovery is enabled, ETH_MACPRSTIMUR should also be updated before setting this field.
This bit should be zero before updating it. This bit is reset when the update is complete in hardware.

Bit 2 **TSINIT**: Initialize Timestamp

When this bit is set, the system time is initialized (overwritten) with the value specified in the *System time seconds update register (ETH_MACSTSUR)* and *System time nanoseconds update register (ETH_MACSTNUR)*.
When Media Clock Generation and Recovery is enabled, *MAC presentation time update register (ETH_MACPRSTIMUR)* should also be updated before setting this field.
This bit should be zero before it is updated. This bit is reset when the initialization is complete.

Bit 1 **TSCFUPDT**: Fine or Coarse Timestamp Update

When this bit is set, the Fine method is used to update system timestamp. When this bit is reset, Coarse method is used to update the system timestamp.

Bit 0 **TSENA**: Enable Timestamp

When this bit is set, the timestamp is added for transmit and receive packets. When disabled, timestamp is not added for transmit and receive packets and the Timestamp Generator is also suspended. You need to initialize the Timestamp (system time) after enabling this mode.
On the receive side, the MAC processes the 1588 packets only if this bit is set.

Subsecond increment register (ETH_MACSSIR)

Address offset: 0x0B04

Reset value: 0x0000 0000

This register specifies the value to be added to the internal system time register every cycle of clk_ptp_ref_i clock.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SSINC[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **SSINC[7:0]**: Subsecond Increment Value

The value programmed in this field is accumulated every clock cycle (of clk_ptp_i) with the contents of the subsecond register. For example, when the PTP clock is 50 MHz (period is 20 ns), you should program 20 (0x14) when the System Time Nanoseconds register has an accuracy of 1 ns [TSCTRLSSR bit is set in *Timestamp control register (ETH_MACTSCR)*]. When TSCTRLSSR is cleared, the Nanoseconds register has a resolution of ~0.465 ns. In this case, you should program a value of 43 (0x2B) which is derived by 20 ns/0.465.

Bits 15:0 Reserved, must be kept at reset value.

System time seconds register (ETH_MACSTSR)

Address offset: 0x0B08

Reset value: 0x0000 0000

The System Time Seconds register, along with System Time Nanoseconds register, indicates the current value of the system time maintained by the MAC. Though it is updated on a continuous basis, there is some delay from the actual time because of clock domain transfer latencies (from clk_ptp_ref_i to CSR clock).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSS[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TSS[31:0]**: Timestamp Second

The value in this field indicates the current value in seconds of the System Time maintained by the MAC.

System time nanoseconds register (ETH_MACSTNR)

Address offset: 0x0B0C

Reset value: 0x0000 0000

The System Time Nanoseconds register, along with System Time Seconds register, indicates the current value of the system time maintained by the MAC.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	TSSS[30:16]														
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSSS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:0 **TSSS[30:0]**: Timestamp subseconds

The value in this field has the subsecond representation of time, with an accuracy of 0.46 ns. When TSCTRLSSR is set in *Timestamp control register (ETH_MACTSCR)*, each bit represents 1 ns. The maximum value is 0x3B9A C9FF after which it rolls-over to zero.

System time seconds update register (ETH_MACSTSUR)

Address offset: 0x0B10

Reset value: 0x0000 0000

The System Time Seconds Update register, along with the System Time Nanoseconds update register, initializes or updates the system time maintained by the MAC. You must write both registers before setting the TSINIT or TSUPDT bits in *Timestamp control register (ETH_MACTSCR)*.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSS[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSS[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TSS[31:0]**: Timestamp Seconds

The value in this field is the seconds part of the update.
When ADDSUB is reset, this field must be programmed with the seconds part of the update value.
When ADDSUB is set, this field must be programmed with the complement of the seconds part of the update value.
For example, to subtract 2.000000001 seconds from the system time, the TSS field in the ETH_MACSTSUR register must be 0xFFFF FFFE (that is, $2^{32} – 2$).

Caution: When the ADDSUB bit is set, TSSS[30:0] field cannot be set to 0 in *System time nanoseconds update register (ETH_MACSTNUR)*. The TSSS bitfield must be programmed to 0x7FFF FFFF (resulting in –0.46 ns) even if 0 ns must be subtracted.
For example, to subtract 2.000000000 seconds from the system time, the TSS field in the *System time seconds update register (ETH_MACSTSUR)* must be 0xFFFF FFFE (that is, $2^{32} – 1$) and the *System time nanoseconds update register (ETH_MACSTNUR)* must be 0xFFFF FFFF (ADDSUB = 1 and TSSS[30:0] field = 0x7FFF FFFF)

System time nanoseconds update register (ETH_MACSTNUR)

Address offset: 0x0B14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADD SUB	TSSS[30:16]														
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSSS[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **ADDSUB**: Add or Subtract Time

When this bit is set, the time value is subtracted with the contents of the update register.
When this bit is reset, the time value is added with the contents of the update register.

Bits 30:0 **TSSS[30:0]**: Timestamp subseconds

The value in this field is the subseconds part of the update.

– ADDSUB is 1: This field must be programmed with the complement of the subseconds part of the update value as described.

– ADDSUB is 0: This field must be programmed with the subseconds part of the update value, with an accuracy based on the TSCTRLSSR bit of the *Timestamp control register (ETH_MACTSCR)*.

– TSCTRLSSR field in the *Timestamp control register (ETH_MACTSCR)*is 1:
- The programmed value must be 10^9 – <subsecond value>.
- Each bit represents 1 ns and the programmed value should not exceed 0x3B9A C9FF.

– TSCTRLSSR field in the *Timestamp control register (ETH_MACTSCR)* is 0:
- The programmed value must be 2^{31} - <subsecond_value>.
- Each bit represents an accuracy of 0.46 ns.

For example, to subtract 2.000000001 seconds from the system time, then the TSSS field in the ETH_MACSTNUR register must be 0x7FFF FFFF (that is, 2^{31} – 1), when TSCTRLSSR bit in *Timestamp control register (ETH_MACTSCR)* is reset and 0x3B9A C9FF (that is, 10^9 –1), when TSCTRLSSR bit in *Timestamp control register (ETH_MACTSCR)* is set.

Caution: When the ADDSUB bit is set, TSSS[30:0] field cannot be set to 0. The TSSS bitfield must be programmed to 0x7FFF FFFF (resulting in –0.46 ns) even if 0 ns must be subtracted.
For example, to subtract 2.000000000 seconds from the system time, *System time nanoseconds update register (ETH_MACSTNUR)* must be 0xFFFF FFFF (ADDSUB = 1 and TSSS[30:0] = 0) and the TSS field in the *System time seconds update register (ETH_MACSTSUR)* must be 0xFFFF FFFE (that is, 2^{32} – 1).

Timestamp addend register (ETH_MACTSAR)

Address offset: 0x0B18

Reset value: 0x0000 0000

This register value is used only when the system time is configured for Fine Update mode (TSCFUPDT bit in the *Timestamp control register (ETH_MACTSCR)*). The content of this register is added to a 32-bit accumulator in every clock cycle of clk_ptp_ref_i and the system time is updated whenever the accumulator overflows.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSAR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSAR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TSAR[31:0]**: Timestamp Addend Register

This field indicates the 32-bit time value to be added to the Accumulator register to achieve time synchronization.

Timestamp status register (ETH_MACTSSR)

Address offset: 0x0B20

Reset value: 0x0000 0000

All bits except Bits[27:25] gets cleared when the application reads this register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	ATSNS[4:0]					ATSSTM	Res.	Res.	Res.	Res.	ATSSTN[3:0]			
		r	r	r	r	r	rc_r					rc_r	rc_r	rc_r	rc_r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXTSSIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSTRGTERR0	AUXTSTRIG	TSTARGT0	TSSOVF
rc_r												rc_r	rc_r	rc_r	rc_r

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:25 **ATSNS[4:0]**: Number of Auxiliary Timestamp Snapshots

This field indicates the number of Snapshots available in the FIFO. A value equal to the depth of FIFO (4) indicates that the Auxiliary Snapshot FIFO is full. These bits are cleared (to 00000) when the Auxiliary snapshot FIFO clear bit is set.

Bit 24 **ATSSTM**: Auxiliary Timestamp Snapshot Trigger Missed

This bit is set when the Auxiliary timestamp snapshot FIFO is full and external trigger was set. This indicates that the latest snapshot is not stored in the FIFO.

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **ATSSTN[3:0]**: Auxiliary Timestamp Snapshot Trigger Identifier

These bits identify the Auxiliary trigger inputs for which the timestamp available in the Auxiliary Snapshot Register is applicable. When more than one bit is set at the same time, it means that corresponding auxiliary triggers were sampled at the same clock. These bits are applicable only if the number of Auxiliary snapshots is more than one. One bit is assigned for each trigger as shown in the following list:

Bit 16: Auxiliary trigger 0

Bit 17: Auxiliary trigger 1

Bit 18: Auxiliary trigger 2

Bit 19: Auxiliary trigger 3

The software can read this register to find the triggers that are set when the timestamp is taken.

Bit 15 **TXTSSIS**: Tx Timestamp Status interrupt status

When drop transmit status is enabled in MTL, this bit is set when the captured transmit timestamp is updated in the *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* and *Tx timestamp status seconds register (ETH_MACTXTSSSR)*.

When PTP offload feature is enabled, this bit is set when the captured transmit timestamp is updated in the *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* and *Tx timestamp status seconds register (ETH_MACTXTSSSR)*, for PTO generated Delay Request and Pdelay request packets.

This bit is cleared when the *Tx timestamp status seconds register (ETH_MACTXTSSSR)* is read (or written to 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bits 14:4 Reserved, must be kept at reset value.

Bit 3 **TSTRGTERR0**: Timestamp Target Time Error

This bit is set when the latest target time programmed in the ETH_MACPPSTTSR and ETH_MACPPSTTSNR elapses (see *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*).
This bit is cleared when the application reads this bit (or writes it to 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 2 **AUXTSTRIG**: Auxiliary Timestamp Trigger Snapshot

This bit is set high when the auxiliary snapshot is written to the FIFO.
This bit is cleared when the application reads this bit (or writes it to 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 1 **TSTARGT0**: Timestamp Target Time Reached

When set, this bit indicates that the value of system time is greater than or equal to the value specified in the ETH_MACPPSTTSR and ETH_MACPPSTTSNR registers (see *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*).
This bit is cleared when the application reads this bit (or writes of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set)

Bit 0 **TSSOVF**: Timestamp Seconds Overflow

When this bit is set, it indicates that the seconds value of the timestamp (when supporting version 2 format) has overflowed beyond 0xFFFF FFFF.
This bit is cleared when the application reads this bit (or writes it to 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set)

Rx domain time increment register (ETH_MACRXDTI)

Address offset: 0x0B24

Reset value: 0x0000 0000

This register indicates the increment value of the PTP time maintained in the receive clock domain that is used for timestamping.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXNS[15:0]															
rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:16 **RXNS[15:0]**: Receive domain time increment value in nanoseconds

This bitfield indicates the nanosecond part of the increment value of the PTP time maintained in the receive clock domain that is used for timestamping.
For example, when operating in 2.5G speed, the clock period is 3.2 ns, so in digital rollover mode, the RXNS[15:0] bitfield must be programmed to 3. In binary rollover mode, 3 / 0.466 = 6.44, so the RXNS[15:0] bitfield must be programmed to 6. When RXNS[15:0] is zero, the fixed value based on the operating speed is used for PTP time increment in receive clock domain.

Bits 15:0 Reserved, must be kept at reset value.

Tx domain time increment register (ETH_MACTXDTI)

Address offset: 0x0B28

Reset value: 0x0000 0000

This register indicates the increment value of the PTP time maintained in the transmit clock domain that is used for timestamping.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXNS[15:0]															
rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:16 **TXNS[15:0]**: Transmit domain time increment value in nanoseconds

This bitfield indicates the nanosecond part of the increment value of the PTP time maintained in the transmit clock domain that is used for timestamping.

For example, when operating in 2.5G speed, the clock period is 3.2 ns, so in digital rollover mode, the TXNS[15:0] bitfield must be programmed to 3. In binary rollover mode, 3 / 0.466 = 6.44, so the TXNS[15:0] bitfield must be programmed to 6. When TXNS[15:0] is zero, the fixed value based on operating speed is used for PTP time increment in transmit clock domain.

Bits 15:0 Reserved, must be kept at reset value.

Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)

Address offset: 0x0B30

Reset value: 0x0000 0000

This register contains the nanosecond part of timestamp captured for transmit packets when Tx status is disabled.The *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* register, along with *Tx timestamp status seconds register (ETH_MACTXTSSSR)*, gives the 64-bit timestamp captured for the PTP packet successfully transmitted by the MAC. This value is considered to be read by the application when the last byte of *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* is read (bits[31:24]).

If the application does not read these registers and timestamp of another packet is captured, then either the current timestamp is lost (overwritten) or the new timestamp is lost (dropped), depending on the setting of the TXTSSTSM bit of the *Timestamp control register (ETH_MACTSCR)*. The status bit TXTSSIS bit [15] in *Timestamp status register (ETH_MACTSSR)* register is set when the MAC transmitter captures the timestamp.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXTSSMIS	TXTSSLO[30:16]														
r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXTSSLO[15:0]															
rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r

Bit 31 **TXTSSMIS**: Transmit Timestamp Status Missed

When this bit is set, it indicates one of the following:

– The timestamp of the current packet is ignored if TXTSSTSM bit of the *Timestamp control register (ETH_MACTSCR)* is reset

– The timestamp of the previous packet is overwritten with timestamp of the current packet if TXTSSTSM bit of the *Timestamp control register (ETH_MACTSCR)* is set.

Bits 30:0 **TXTSSLO[30:0]**: Transmit Timestamp Status Low

This field contains the 31 bits of the Nanoseconds field of the transmit packet's captured timestamp.

Tx timestamp status seconds register (ETH_MACTXTSSSR)

Address offset: 0x0B34

Reset value: 0x0000 0000

The register contains the higher 32 bits of the timestamp (in seconds) captured when a PTP packet is transmitted.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXTSSHI[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXTSSHI[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXTSSHI[31:0]**: Transmit Timestamp Status High

This field contains the lower 32 bits of the Seconds field of transmit packet's captured timestamp.

Auxiliary control register (ETH_MACACR)

Address offset: 0x0B40

Reset value: 0x0000 0000

The auxiliary timestamp control register controls the auxiliary timestamp snapshot.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ATSEN3	ATSEN2	ATSEN1	ATSEN0	Res.	Res.	Res.	ATSFC
								rw	rw	rw	rw				rw

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **ATSEN3**: Auxiliary Snapshot 3 Enable

– This bit controls the capturing of Auxiliary Snapshot Trigger 3. When this bit is set, the auxiliary snapshot of the event on eth_ptp_trg3 input is enabled. When this bit is reset, the events on this input are ignored.

Bit 6 **ATSEN2**: Auxiliary Snapshot 2 Enable

– This bit controls the capturing of Auxiliary Snapshot Trigger 2. When this bit is set, the auxiliary snapshot of the event on eth_ptp_trg2 input is enabled. When this bit is reset, the events on this input are ignored.

Bit 5 **ATSEN1**: Auxiliary Snapshot 1 Enable

– This bit controls the capturing of Auxiliary Snapshot Trigger 1. When this bit is set, the auxiliary snapshot of the event on eth_ptp_trg1 input is enabled. When this bit is reset, the events on this input are ignored.

Bit 4 **ATSEN0**: Auxiliary Snapshot 0 Enable

This bit controls the capturing of Auxiliary Snapshot Trigger 0. When this bit is set, the auxiliary snapshot of the event on eth_ptp_trg0 input is enabled. When this bit is reset, the events on this input are ignored.

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **ATSFC**: Auxiliary Snapshot FIFO Clear

When set, this bit resets the pointers of the Auxiliary Snapshot FIFO. This bit is cleared when the pointers are reset and the FIFO is empty. When this bit is high, the auxiliary snapshots are stored in the FIFO.

Auxiliary timestamp nanoseconds register (ETH_MACATSNR)

Address offset: 0x0B48

Reset value: 0x0000 0000

The *Auxiliary timestamp nanoseconds register (ETH_MACATSNR)*, along with *Auxiliary timestamp seconds register (ETH_MACATSSR)*, gives the 64-bit timestamp stored as auxiliary snapshot. These two registers form the read port of a 64-bit wide FIFO with a depth of 4 words.

You can store multiple snapshots in this FIFO. Bits[29:25] in *Timestamp status register (ETH_MACTSSR)* indicate the fill-level of the FIFO. The top of the FIFO is removed only when *Auxiliary timestamp seconds register (ETH_MACATSSR)* is read.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	AUXTSLO[30:16]														
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AUXTSLO[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:0 **AUXTSLO[30:0]**: Auxiliary Timestamp

Contains the lower 31 bits (nanoseconds field) of the auxiliary timestamp.

Auxiliary timestamp seconds register (ETH_MACATSSR)

Address offset: 0x0B4C

Reset value: 0x0000 0000

The Auxiliary Timestamp Seconds register contains the lower 32 bits of the Seconds field of the auxiliary timestamp register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AUXTSHI[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AUXTSHI[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **AUXTSHI[31:0]**: Auxiliary Timestamp

Contains the lower 32 bits of the Seconds field of the auxiliary timestamp.

Timestamp ingress asymmetric correction register (ETH_MACTSIACR)

Address offset: 0x0B50

Reset value: 0x0000 0000

The MAC Timestamp Ingress Asymmetry Correction register contains the Ingress Asymmetry Correction value to be used while updating correction field in PDelay_Resp PTP messages.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OSTIAC[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OSTIAC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **OSTIAC[31:0]**: One-Step Timestamp Ingress Asymmetry Correction

This field contains the ingress path asymmetry value to be added to correctionField of Pdelay_Resp PTP packet. The programmed value should be in units of nanoseconds and multiplied by 2^{16}. For example, 2.5 ns is represented as 0x00028000.

The value can also be negative, which is represented in 2's complement form with bit 31 representing the sign bit.

Timestamp egress asymmetric correction register (ETH_MACTSEACR)

Address offset: 0x0B54

Reset value: 0x0000 0000

The MAC Timestamp Egress Asymmetry Correction register contains the Egress Asymmetry Correction value to be used while updating the correction field in PDelay_Req PTP messages.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OSTEAC[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OSTEAC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **OSTEAC[31:0]**: One-Step Timestamp Egress Asymmetry Correction

This field contains the egress path asymmetry value to be subtracted from correctionField of Pdelay_Resp PTP packet. The programmed value must be the negated value in units of nanoseconds multiplied by 2^{16}.

For example, if the required correction is +2.5 ns, the programmed value must be 0xFFFD 8000, which is the 2's complement of 0x0002 8000(2.5×2^{16}). Similarly, if the required correction is -3.3 ns, the programmed value is 0x0003 4CCC (3.3×2^{16}).

Timestamp ingress correction nanosecond register (ETH_MACTSICNR)

Address offset: 0x0B58

Reset value: 0x0000 0000

This register contains the correction value in nanoseconds to be used with the captured timestamp value in the ingress path.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSIC[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSIC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TSIC[31:0]**: Timestamp Ingress Correction

This field contains the ingress path correction value as defined by the Ingress Correction expression.

Timestamp egress correction nanosecond register (ETH_MACTSECNR)

Address offset: 0x0B5C

Reset value: 0x0000 0000

This register contains the correction value in nanoseconds to be used with the captured timestamp value in the egress path.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSEC[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSEC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TSEC[31:0]**: Timestamp Egress Correction

This field contains the nanoseconds part of the egress path correction value as defined by the Egress Correction expression.

Timestamp ingress latency register (ETH_MACTSILR)

Address offset: 0x0B68

Reset value: 0x0000 0000

This register holds the ingress MAC latency.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	ITLNS[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ITLSNS[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r	r	r	r								

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **ITLNS[11:0]**: Ingress Timestamp Latency, in nanoseconds

This register holds the average latency (in nanoseconds) between the MAC input ports and the actual point (MII) where the ingress timestamp is taken. Ingress correction value is computed as described in *Section : Ingress correction*.

Bits 15:8 **ITLSNS[7:0]**: Ingress Timestamp Latency, in subnanoseconds

This register holds the average latency (in subnanoseconds) between the MAC input ports and the actual point (MII) where the ingress timestamp is taken. ingress correction value is computed as described in *Section : Ingress correction*.

Bits 7:0 Reserved, must be kept at reset value.

Timestamp egress latency register (ETH_MACTSELR)

Address offset: 0x0B6C

Reset value: 0x0000 0000

This register holds the Egress MAC latency.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	ETLNS[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETLSNS[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r	r	r	r								

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **ETLNS[11:0]**: Egress Timestamp Latency, in nanoseconds

This register holds the average latency in nanoseconds between the actual point (MII) where the egress timestamp is taken and the output ports of the MAC. Egress correction value is computed as described in *Section : Egress correction*.

Bits 15:8 **ETLSNS[7:0]**: Egress Timestamp Latency, in subnanoseconds

This register holds the average latency in subnanoseconds between the actual point (MII) where the egress timestamp is taken and the output ports of the MAC. Egress correction value is computed as described in *Section : Egress correction*.

Bits 7:0 Reserved, must be kept at reset value.

PPS control register (ETH_MACPPSCR)

Address offset: 0x0B70

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	TIMESEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
			rw												

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MCGREN0	TRGTMODSEL0[1:0]		PPSEN0	PPSCTRL[3:0]			
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **TIMESEL**: Time Select

When this bit is set, 64 bit PTP time is used to capture time at MCGR trigger[0] input
When this bit is reset, presentation time is used to capture time at trigger input, maintaining backward compatibility

Bits 27:8 Reserved, must be kept at reset value.

Bit 7 **MCGREN0**: MCGR Mode Enable for PPS0 Output

This field enables the 0th PPS instance to operate in PPS or MCGR mode. When set it operates in MCGR mode and on reset it operates in PPS mode.

0: PPS mode

1: MCGR mode

Bits 6:5 **TRGTMODSEL0[1:0]**: Target Time Register Mode for PPS Output

This field indicates the Target Time registers (*PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*) mode for PPS output signal:

00: Target Time registers are programmed only for generating the interrupt event.

01: Enables MCGR Interrupt whose status bit is indicated by TSTARGT0 bit in *Timestamp status register (ETH_MACTSSR)* register

10: Target Time registers are programmed for generating the interrupt event and starting or stopping the PPS output signal generation.

11: Target Time registers are programmed only for starting or stopping the PPS output signal generation. No interrupt is asserted.

Bit 4 **PPSEN0**: Flexible PPS Output Mode Enable

When this bit is set, PPSCTRL[3:0] function as PPSCMD[3:0]. When this bit is reset, PPSCTRL[3:0] function as PPSCTRL (Fixed PPS mode).

Bits 3:0 **PPSCTRL[3:0]**: PPS Output Frequency Control

This field controls the frequency of the PPS output (eth_ptp_pps_out) signal. The default value of PPSCTRL is 0000, and the PPS output is 1 pulse (of width clk_ptp_i) every second. For other values of PPSCTRL, the PPS output becomes a generated clock of following frequencies:

0001: The binary rollover is 2 Hz, and the digital rollover is 1 Hz.

0010: The binary rollover is 4 Hz, and the digital rollover is 2 Hz.

0011: The binary rollover is 8 Hz, and the digital rollover is 4 Hz.

0100: The binary rollover is 16 Hz, and the digital rollover is 8 Hz.

..

1111: The binary rollover is 32.768 KHz and the digital rollover is 16.384 KHz.

Note: In the binary rollover mode, the PPS output (eth_ptp_pps_out) has a duty cycle of 50 percent with these frequencies. In the digital rollover mode, the PPS output frequency is an average number. The actual clock is of different frequency that gets synchronized every second. For example:

- *When PPSCTRL = 0001, the PPS (1 Hz) has a low period of 537 ms and a high period of 463 ms.*
- *When PPSCTRL = 0010, the PPS (2 Hz) is a sequence of*
  One clock of 50 percent duty cycle and 537 ms period
  Second clock of 463 ms period (268 ms low and 195 ms high).
- *When PPSCTRL = 0011, the PPS (4 Hz) is a sequence of*
  Three clocks of 50 percent duty cycle and 268 ms period
  Fourth clock of 195 ms period (134 ms low and 61 ms high)

This behavior is because of the non-linear toggling of bits in the digital rollover mode in the ETH_MACSTNR register.

PPS control register [alternate] (ETH_MACPPSCR)

Address offset: 0x0B70

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	TIMESEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
			rw												

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MCGREN0	TRGTMODSEL0[1:0]		PPSEN0	PPSCMD[3:0]			
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **TIMESEL**: Time Select

When this bit is set, 64 bit PTP time is used to capture time at MCGR trigger[0] input
When this bit is reset, presentation time is used to capture time at trigger input, maintaining backward compatibility

Bits 27:8 Reserved, must be kept at reset value.

Bit 7 **MCGREN0**: MCGR Mode Enable for PPS Output

This field enables the 0th PPS instance to operate in PPS or MCGR mode. When set it operates in MCGR mode and on reset it operates in PPS mode.
0: PPS mode
1: MCGR mode

Bits 6:5 **TRGTMODSEL0[1:0]**: Target Time Register Mode for PPS Output

This field indicates the Target Time registers (*PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*) mode for PPS output signal:
00: Target Time registers are programmed only for generating the interrupt event.
01: Enables MCGR Interrupt whose status bit is indicated by TSTARGT0 bit in *Timestamp status register (ETH_MACTSSR)* register
10: Target Time registers are programmed for generating the interrupt event and starting or stopping the PPS output signal generation.
11: Target Time registers are programmed only for starting or stopping the PPS output signal generation. No interrupt is asserted.

Bit 4 **PPSEN0**: Flexible PPS Output Mode Enable

When this bit is set, Bits[3:0] function as PPSCMD[3:0]. When this bit is reset, Bits[3:0] function as PPSCTRL(Fixed PPS mode).

Bits 3:0 **PPSCMD[3:0]:** Flexible PPS Output (eth_ptp_pps_out) Control

Programming these bits with a non-zero value instructs the MAC to initiate an event. When the command is transferred or synchronized to the PTP clock domain, these bits get cleared automatically. The software should ensure that these bits are programmed only when they are ‘all zero’. The following list describes the values of PPSCMD0:

0000: No Command

0001: START Single Pulse.

This command generates single pulse rising at the start point defined in Target Time Registers (register 455 and 456) and of a duration defined in the PPS Width Register.

0010: START Pulse Train.

This command generates the train of pulses rising at the start point defined in the Target Time Registers and of a duration defined in the PPS Width Register and repeated at interval defined in the PPS Interval Register. By default, the PPS pulse train is free-running unless stopped by the 'Stop Pulse train at time' or 'Stop Pulse Train immediately' commands.

0011: Cancel START.

This command cancels the START Single Pulse and START Pulse Train commands if the system time has not crossed the programmed start time.

0100: STOP Pulse Train at time.

This command stops the train of pulses initiated by the START Pulse Train command (PPSCMD[3:0] = 0010) after the time programmed in the Target Time registers elapses.

0101: STOP Pulse Train immediately.

This command immediately stops the train of pulses initiated by the START Pulse Train command (PPSCMD[3:0] = 0010).

0110: Cancel STOP Pulse train.

This command cancels the STOP pulse train at time command if the programmed stop time has not elapsed. The PPS pulse train becomes free-running on the successful execution of this command.

0111 to 1111: Reserved, must not be used

PPS target time seconds register (ETH_MACPPSTTSR)

Address offset: 0x0B80

Reset value: 0x0000 0000

The PPS output Target Time Seconds register, along with *PPS target time nanoseconds register (ETH_MACPPSTTNR)*, is used to schedule an interrupt event (Bit TSSOVF of *Timestamp status register (ETH_MACTSSR)*) when the system time exceeds the value programmed in these registers.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSTRH0[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSTRH0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TSTRH0[31:0]**: PPS Target Time Seconds Register

This field stores the time in seconds. When the timestamp value matches or exceeds both Target Timestamp registers, the MAC starts or stops the PPS signal output and generates an interrupt (if enabled) based on Target Time mode selected for the corresponding PPS output in the *PPS control register (ETH_MACPPSCR)*.

If the PTGE field of *Timestamp control register (ETH_MACTSCR)* is set with Presentation time control set in Recovery mode, then these bits indicate the TPT being programmed by the application and in Generation mode it indicates the CPT generated at the sampled trigger.

PPS target time nanoseconds register (ETH_MACPPSTTNR)

Address offset: 0x0B84

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TRGTBUSY0	TTSL0[30:16]														
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TTSL0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **TRGTBUSY0**: PPS Target Time Register Busy

The MAC sets this bit when the PPSCMD0 field in the *PPS control register (ETH_MACPPSCR)* is programmed to 010 or 011. Programming the PPSCMD0 field to 010 or 011 instructs the MAC to synchronize the Target Time Registers to the PTP clock domain. The MAC clears this bit after synchronizing the Target Time Registers with the PTP clock domain The application must not update the Target Time Registers when this bit is read as 1. Otherwise, the synchronization of the previous programmed time gets corrupted.

Bits 30:0 **TTSL0[30:0]**: Target Time Low for PPS Register

This register stores the time in (signed) nanoseconds. When the value of the timestamp matches the value in both Target Timestamp registers, the MAC starts or stops the PPS signal output and generates an interrupt (if enabled) based on the TRGTMODSEL0 field (Bits [6:5]) in *PPS control register (ETH_MACPPSCR)*.

When the TSCTRLSSR bit is reset in the *Timestamp control register (ETH_MACTSCR)*, this value should be (time in ns / 0.465). The actual start or stop time of the PPS signal output might have an error margin up to one unit of subsecond increment value.

When the TSCTRLSSR bit is set in the *Timestamp control register (ETH_MACTSCR)*, this value should not exceed 0x3B9A C9FF. The actual start or stop time of the PPS signal output may have an error margin up to one unit of subsecond increment value.

PPS interval register (ETH_MACPPSIR)

Address offset: 0x0B88

Reset value: 0x0000 0000

The PPS Interval register contains the number of units of subsecond increment value between the rising edges of PPS output.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PPSINT0[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PPSINT0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PPSINT0[31:0]**: PPS Output Signal Interval

These bits store the interval between the rising edges of PPS signal output. The interval is stored in terms of number of units of subsecond increment value.

You need to program one value less than the required interval. For example, if the PTP reference clock is 50 MHz (period of 20 ns), and desired interval between the rising edges of PPS signal output is 100 ns (that is, 5 units of subsecond increment value), you should program value 4 (5-1) in this register.

PPS width register (ETH_MACPPSWR)

Address offset: 0x0B8C

Reset value: 0x0000 0000

The PPS Width register contains the number of units of subsecond increment value between the rising and corresponding falling edges of PPS output.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PPSWIDTH0[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PPSWIDTH0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PPSWIDTH0[31:0]**: PPS Output Signal Width

These bits store the width between the rising edge and corresponding falling edge of PPS signal output. The width is stored in terms of number of units of subsecond increment value.

You need to program one value less than the required interval. For example, if PTP reference clock is 50 MHz (period of 20 ns), and width between the rising and corresponding falling edges of PPS signal output is 80 ns (that is, four units of subsecond increment value), you should program value 3 (4-1) in this register.

Note: The value programmed in this register must be lesser than the value programmed in PPS interval register (ETH_MACPPSIR).

PTP offload control register (ETH_MACPOCR)

Address offset: 0x0BC0

Reset value: 0x0000 0000

This register controls the PTP Offload Engine operation.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DN[7:0]								PDRDIS	DRRDIS	APDREQTRIG	ASYNCTRIG	Res.	APDREQEN	ASYNCEN	PTOEN
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **DN[7:0]**: Domain Number

This field indicates the domain Number in which the PTP node is operating.

Bit 7 **PDRDIS**: Disable Peer Delay Response response generation

When this bit is set, the Peer Delay Response (Pdelay_Resp) response is not generated for received Peer Delay Request (Pdelay_Req) request packet, as required by the programmed mode.

Setting this bit to 1 affects the normal PTP Offload operation and the time synchronization. So, this bit must be set only if there is problem with Pdelay_Resp generation in hardware and/or Pdelay_Resp generation is handled by software.

Bit 6 **DRRDIS**: Disable PTO Delay Request/Response response generation

When this bit is set, the Delay Request and Delay response are not generated for received SYNC and Delay request packet respectively, as required by the programmed mode.

Bit 5 **APDREQTRIG**: Automatic PTP Pdelay_Req message Trigger

When this bit is set, one PTP Pdelay_Req message is transmitted. This bit is automatically cleared after the PTP Pdelay_Req message is transmitted. The application should set the APDREQEN bit for this operation.

Bit 4 **ASYNCTRIG**: Automatic PTP SYNC message Trigger

When this bit is set, one PTP SYNC message is transmitted. This bit is automatically cleared after the PTP SYNC message is transmitted. The application should set the ASYNCEN bit for this operation.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **APDREQEN**: Automatic PTP Pdelay_Req message Enable

When this bit is set, PTP Pdelay_Req message is generated periodically based on interval programmed or trigger from application, when the MAC is programmed to be in Peer-to-Peer Transparent mode.

Bit 1 **ASYNCEN**: Automatic PTP SYNC message Enable

When this bit is set, PTP SYNC message is generated periodically based on interval programmed or trigger from application, when the MAC is programmed to be in Clock Master mode.

Bit 0 **PTOEN**: PTP Offload Enable

When this bit is set, the PTP Offload feature is enabled.

PTP source port identity 0 register (ETH_MACSPI0R)

Address offset: 0x0BC4

Reset value: 0x0000 0000

This register contains Bits[31:0] of the 80-bit Source Port Identity of the PTP node.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SPI0[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SPI0[31:0]**: Source Port Identity 0
This field indicates bits [31:0] of sourcePortIdentity of PTP node.

PTP Source port identity 1 register (ETH_MACSPI1R)

Address offset: 0x0BC8

Reset value: 0x0000 0000

This register contains Bits[63:32] of the 80-bit Source Port Identity of the PTP node.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SPI1[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SPI1[31:0]**: Source Port Identity 1
This field indicates bits [63:32] of sourcePortIdentity of PTP node.

PTP Source port identity 2 register (ETH_MACSPI2R)

Address offset: 0x0BCC

Reset value: 0x0000 0000

This register contains Bits[79:64] of the 80-bit Source Port Identity of the PTP node.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **SPI2[15:0]**: Source Port Identity 2
This field indicates bits [79:64] of sourcePortIdentity of PTP node.

Log message interval register (ETH_MACLMIR)

Address offset: 0x0BD0

Reset value: 0x0000 0000

This register contains the periodic intervals for automatic PTP packet generation.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LMPDRI[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	DRSYNCR[2:0]			LSI[7:0]							
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **LMPDRI[7:0]**: Log Min Pdelay_Req Interval
This field indicates logMinPdelayReqInterval of PTP node. This is used to schedule the periodic Pdelay request packet transmission. Allowed values are -15 to 15.Negative value must be represented in 2's-complement form. For example, if the required value is -1, the value programmed must be 0xFF.

Bits 23:11 Reserved, must be kept at reset value.

Bits 10:8 **DRSYNCR[2:0]**:
Delay_Req to SYNC Ratio
In Slave mode, it is used for controlling frequency of Delay_Req messages transmitted.
0: DelayReq generated for every received SYNC
1: DelayReq generated every alternate reception of SYNC
2: for every 4 SYNC messages
3: for every 8 SYNC messages
4: for every 16 SYNC messages
5: for every 32 SYNC messages
Others: Reserved, must not be used
The master sends this information (logMinDelayReqInterval) in the DelayResp PTP messages to the slave. The reception processes this value from the received DelayResp messages and updates this field accordingly. In the Slave mode, the host must not write/update this register unless it has to override the received value. In Master mode, the sum of this field and logSyncInterval (LSI) field is provided in the logMinDelayReqInterval field of the generated multicast Delay_Resp PTP message.

Bits 7:0 **LSI[7:0]**:
Log Sync Interval
This field indicates the periodicity of the automatically generated SYNC message when the PTP node is Master. Allowed values are -15 to 15. Negative value must be represented in 2's-complement form. For example, if the required value is -1, the value programmed must be 0xFF.

Ethernet MAC register map and reset values

Table 831. Ethernet MAC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0000	ETH_MACCR	ARPEN	SARC[2:0]			IPC	IPG[2:0]			GPSLCE	S2KP	CST	ACS	WD	Res.	JD	JE	Res.	FES	DM	LM	ECRSFD	DO	DCRS	DR	Res.	BL[1:0]		DC	PRELEN[1:0]		TE	RE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
0x0004	ETH_MACECR	Res.	APDIM	EIPG[4:0]					EIPGEN	Res.	Res.	Res.	Res.	Res.	USP	SPEN	DCRCC	Res.	Res.	GPSL[13:0]														
	Reset value		0	0	0	0	0	0	0						0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0008	ETH_MACPFR	RA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DNTU	IPFE	Res.	Res.	Res.	VTFE	Res.	Res.	Res.	Res.	Res.	HPF	SAF	SAIF	PCF[1:0]		DBF	PM	DAIF	HMC	HUC	PR
	Reset value	0										0	0				0						0	0	0	0	0	0	0	0	0	0	0
0x000C	ETH_MACWJBTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PJE	Res.	Res.	Res.	Res.	JTO[3:0]					Res.	Res.	Res.	Res.	Res.	Res.	PWE	Res.	Res.	Res.	Res.	WTO[3:0]			
	Reset value								0					0	0	0	0								0					0	0	0	0
0x0010	ETH_MACHT0R	HT31T0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0014	ETH_MACHT1R	HT63T32[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0018 - 0x004C	Reserved																																
0x0050	ETH_MACVTR	EIVLRXS	Res.	EIVLS[1:0]		ERIVLT	EDVLP	VTHM	EVLRXS	Res.	EVLS[1:0]		DOVLTC	ERSVLM	ESVL	VTIM	ETV	VL[15:0]																
	Reset value	0		0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0054	Reserved																																
0x0058	ETH_MACVHTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VLHT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x005C	Reserved																																
0x0060	ETH_MACVIR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VLTI	CSVL	VLP	VLC[1:0]		VLT[15:0]															
	Reset value												0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0064	ETH_MACiVIR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VLTI	CSVL	VLP	VLC[1:0]		VLT[15:0]															
	Reset value												0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0068 - 0x006C	Reserved																																

Table 831. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0070	ETH_ MACQTXFCR	PT[15:0]																Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DZPQ	PLT[2:0]			Res.	Res.	TFE	FCB_BP
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									0	0	0	0			0	0
0x0074 - 0x008C	Reserved																																
0x0090	ETH_MACRXFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UP	RFE
	Reset value																															0	0
0x0094- 0x00AC	Reserved																																
0x00B0	ETH_MACISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MDIOIS	Res.	Res.	Res.	RXSTSIS	TXSTSIS	TSIS	Res.	MMCTXIS	MMCRXIS	MMCIS	Res.	Res.	LPIIS	PMTIS	PHYIS	Res.	Res.	Res.
	Reset value														0				0	0	0		0	0	0			0	0	0			
0x00B4	ETH_MACIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MDIOIE	Res.	Res.	Res.	RXSTSIE	TXSTSIE	TSIE	Res.	Res.	Res.	Res.	Res.	Res.	LPIIE	PMTIE	PHYIE	Res.	Res.	Res.
	Reset value														0				0	0	0							0	0	0			
0x00B8	ETH_ MACRXTXSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RWT	Res.	Res.	EXCOL	LCOL	EXDEF	LCARR	NCARR	TJT
	Reset value																								0			0	0	0	0	0	0
0x00BC	Reserved																																
0x00C0	ETH_MACPCSR	RWKFILTRS	Res.	Res.	RWKPTR[4:0]					Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RWKPFE	GLBLUCAST	Res.	Res.	RWKPRCVD	MGKPRCVD	Res.	Res.	RWKPKTEN	MGKPKTEN	PWRDWN
	Reset value	0			0	0	0	0	0														0	0			0	0			0	0	0
0x00C4	ETH_ MACRWKPFR	MACRWKPFR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C8 - 0x00CC	Reserved																																
0x00D0	ETH_MACLCSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LPITCSE	LPITE	LPITXA	Res.	PLS	LPIEN	Res.	Res.	Res.	Res.	Res.	Res.	RLPIST	TLPIST	Res.	Res.	Res.	Res.	RLPIEX	RLPIEN	TLPIEX	TLPIEN
	Reset value											0	0	0		0	0							0	0					0	0	0	0
0x00D4	ETH_MACLTCR	Res.	Res.	Res.	Res.	Res.	Res.	LST[9:0]										TWT[15:0]															
	Reset value							1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00D8	ETH_MACLETR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LPIET[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 831. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00DC	ETH_ MAC1USTCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIC_1US_CNTR[11:0]											
	Reset value																					0	0	0	0	0	1	1	0	0	0	1	1
0x00E0 - 0x010C	Reserved																																
0x0110	ETH_MACVR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	USERVER[7:0]								SNPSVER[7:0]							
	Reset value	0x0000 3354																															
0x0114	ETH_MACDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TFCSTS[1:0]		TPESTS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFCFCSTS[1:0]		RPESTS
	Reset value														0	0	0														0	0	0
0x0118	Reserved																																
0x011C	ETH_MACHWF0R	ACTPHYSEL[3:0]				SAVLANINS	TSSTSSEL[1:0]			MACADR64SEL	MACADR32SEL	ADDMACADRSEL[4:0]					Res.	RXCOESEL	Res.	TXCOESEL	EEESEL	TSSEL	Res.	Res.	ARPOFFSEL	MMCSEL	MGKSEL	RWKSEL	SMASEL	VLHASH	PCSSEL	HDSEL	GMIISEL	MIISEL
	Reset value	0x0A0D 73F5																															
0x0120	ETH_MACHWF1R	Res.	L3L4FNUM[3:0]			Res.	HASHTBLSZ[1:0]		POUOST	Res.	RAVSEL	AVSEL	DBGMEMA	TSOEN	SPHEN	DCBEN	ADDR64[1:0]		ADVTHWORD	PTOEN	OSTEN	TXFIFOSIZE[4:0]					SPRAM	RXFIFOSIZE[4:0]				
	Reset value	0x1104 1924																															
0x0124	ETH_MACHWF2R	Res.	AUXSNAPNUM[2:0]			Res.	PPSOUTNUM[2:0]			TDCSZ[1:0]		TXCHCNT[3:0]			RDCSZ[1:0]		RXCHCNT[3:0]			Res.	Res.	TXQCNT[3:0]				Res.	Res.	RXQCNT[3:0]				
	Reset value	0x4100 0000																															
0x0128	ETH_MACHWF3R	Res.	Res.	ASP[1:0]		TBSSEL	FPESEL	Res.	Res.	Res.	Res.	ESTWID[1:0]		ESTDEP[2:0]			ESTSEL	Res.	FRPES[1:0]		FRPBS[1:0]		FRPSEL	PDUPSEL	Res.	Res.	Res.	DVLAN	CBTISEL	Res.	NRVF[2:0]		
	Reset value	0x0000 0020																															
0x012C - 0x01FC	Reserved																																
0x0200	ETH_ MACMDIOAR	Res.	Res.	Res.	Res.	PSE	BTB	PA[4:0]					RDA[4:0]					Res.	NTC[2:0]			CR[3:0]				Res.	Res.	Res.	SKAP	GOC[1:0]		C45E	MB
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0				0	0	0	0	0

Table 831. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0204	ETH_ MACMDIODR	RA[15:0]																MD[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0208 - 0x020C	Reserved																																
0x0210	ETH_MACARPAR	ARPPA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0214 - 0x022C	Reserved																																
0x0230	ETH_ MACCSRSWCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RCWE
	Reset value																																0
0x0234- 0x23C	Reserved																																
0x0240	ETH_ MACPRSTIMR	MPTN[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0244	ETH_ MACPRSTIMUR	MPTU[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0248 - 0x02FC	Reserved																																
0x0300	ETH_MACA0HR	AE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDRHI[15:0]															
	Reset value	1																1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0304	ETH_MACA0LR	ADDRLO[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0308	ETH_MACA1HR	AE	SA	MBC[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDRHI[15:0]															
	Reset value	0	0	0	0	0	0	0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x30C	ETH_MACA1LR	ADDRLO[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0310	ETH_MACA2HR	AE	SA	MBC[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDRHI[15:0]															
	Reset value	0	0	0	0	0	0	0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0314	ETH_MACA2LR	ADDRLO[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 831. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0318	ETH_MACA3HR	AE	SA	MBC[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDRHI[15:0]															
	Reset value	0	0	0	0	0	0	0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x031C	ETH_MACA3LR	ADDRLO[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0320 - 0x06FC	Reserved																																
0x0700	ETH_MMC_ CONTROL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UCDBC	Res.	Res.	CNTPRSTLVL	CNTPRST	CNTFREEZ	RSTONRD	CNTSTOPRO	CNTRST
	Reset value																								0			0	0	0	0	0	0
0x0704	ETH_MMC_RX_ INTERRUPT	Res.	Res.	Res.	Res.	RXLPITRCIS	RXLPIUSCIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXUCGPIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXALGNERPIS	RXCRCERPIS	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0									0											0	0					
0x0708	ETH_MMC_TX_ INTERRUPT	Res.	Res.	Res.	Res.	TXLPITRCIS	TXLPIUSCIS	Res.	Res.	Res.	Res.	TXGPKTIS	Res.	Res.	Res.	Res.	Res.	TXMCOLGPIS	TXSCOLGPIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0					0						0	0														
0x070C	ETH_MMC_RX_ INTERRUPT_ MASK	Res.	Res.	Res.	Res.	RXLPITRCIM	RXLPIUSCIM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXUCGPIM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXALGNERPIM	RXCRCERPIM	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0									0											0	0					
0x0710	ETH_MMC_TX_ INTERRUPT_ MASK	Res.	Res.	Res.	Res.	TXLPITRCIM	TXLPIUSCIM	Res.	Res.	Res.	Res.	TXGPKTIM	Res.	Res.	Res.	Res.	Res.	TXMCOLGPIM	TXSCOLGPIM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0					0						0	0														
0x0714 - 0x0748	Reserved																																
0x074C	ETH_TX_SINGLE_ COLLISION_ GOOD_PACKETS	TXSNGLCOLG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 831. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0750	ETH_TX_MULTIPLE_COLLISION_GOOD_PACKETS	TXMULTCOLG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0754 - 0x0764	Reserved																																
0x0768	ETH_TX_PACKET_COUNT_GOOD	TXPKTG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x076C - 0x0790	Reserved																																
0x0794	ETH_RX_CRC_ERROR_PACKETS	RXCRCERR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0798	ETH_RX_ALIGNMENT_ERROR_PACKETS	RXALGNERR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x079C - 0x07C0	Reserved																																
0x07C4	ETH_RX_UNICAST_PACKETS_GOOD	RXUCASTG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x07C8 - 0x07E8	Reserved																																
0x07EC	ETH_TX_LPI_USEC_CNTR	TXLPIUSC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x07F0	ETH_TX_LPI_TRAN_CNTR	TXLPITRC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x07F4	ETH_RX_LPI_USEC_CNTR	RXLPIUSC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x07F8	ETH_RX_LPI_TRAN_CNTR	RXLPITRC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x07FC- 0x8FC	Reserved																																
0x0900	ETH_MACL3L4C0R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	L4DPIM0	L4DPM0	L4SPIM0	L4SPM0	Res.	L4PEN0	L3HDBM0[4:0]					L3HSBM0[4:0]					L3DAIM0	L3DAM0	L3SAIM0	L3SAM0	Res.	L3PEN0
	Reset value											0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
0x0904	ETH_MACL4A0R	L4DP0[15:0]																L4SP0[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 831. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0908 - 0x090C	Reserved																																
0x0910	ETH_MACL3A00R	L3A00[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0914	ETH_MACL3A10R	L3A10[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0918	ETH_MACL3A20R	L3A20[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x091C	ETH_MACL3A30R	L3A30[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0920 - 0x092C	Reserved																																
0x0930	ETH_ MACL3L4C1R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	L4DPIM1	L4DPM1	L4SPIM1	L4SPM1	Res.	L4PEN1	L3HDBM1[4:0]					L3HSBM1[4:0]					L3DAIM1	L3DAM1	L3SAIM1	L3SAM1	Res.	L3PEN1
	Reset value											0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
0x0934	ETH_MACL4A1R	L4DP1[15:0]																L4SP1[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0938 - 0x093C	Reserved																																
0x0940	ETH_MACL3A01R	L3A01[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0944	ETH_MACL3A11R	L3A11[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0948	ETH_MACL3A21R	L3A21[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x094C	ETH_MACL3A31R	L3A31[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0950 - 0x0A6C	Reserved																																
0x0A70	ETH_MAC_IACR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MSEL[3:0]				AOFF[7:0]								Res.	Res.	AUTO	Res.	Res.	Res.	COM.	OB
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0			0				0	0
0x0A74	ETH_MAC_ TMRQR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TMRW[2:0]			TYP[15:0]																	
	Reset value												0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A78 - 0x0AFC	Reserved																																

Table 831. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0B00	ETH_MACTSCR	Res.	Res.	Res.	AV8021ASMEN	Res.	Res.	Res.	TXTSSTSM	Res.	Res.	Res.	Res.	Res.	TSENMACADDR	SNAPTYPSEL[1:0]		TSMSTRENA	TSEVNTENA	TSIPV4ENA	TSIPV6ENA	TSIPENA	TSVER2ENA	TSCTRLSSR	TSENALL	Res.	PTGE	TSADDREG	Res.	TSUPDT	TSINIT	TSCFUPDT	TSENA
	Reset value				0				0						0	0	0	0	0	1	0	0	0	0	0		0	0		0	0	0	0
0x0B04	ETH_MACSSIR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SSINC[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value									0	0	0	0	0	0	0	0																
0x0B08	ETH_MACSTSR	TSS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B0C	ETH_MACSTNR	Res.	TSSS[30:0]																														
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B10	ETH_MACSTSUR	TSS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B14	ETH_MACSTNUR	ADDSUB	TSSS[30:0]																														
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B18	ETH_MACTSAR	TSAR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B1C	Reserved																																
0x0B20	ETH_MACTSSR	Res.	Res.	ATSNS[4:0]					ATSSTM	Res.	Res.	Res.	Res.	ATSSTN[3:0]				TXTSSIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSTRGTERR0	AUXTSTRIG	TSTARGT0	TSSOVF
	Reset value			0	0	0	0	0	0					0	0	0	0	0												0	0	0	0
0x0B24	ETH_MACRXDTI	RXNS[15:0]																Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																
0x0B28	ETH_MACTXDTI	TXNS[15:0]																Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																
0x0B2C	Reserved																																
0x0B30	ETH_ MACTXTSSNR	TXTSSMIS	TXTSSLO[30:0]																														
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 831. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0B34	ETH_ MACTXTSSR	TXTSSHI[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B38 - 0x0B3C	Reserved																																
0x0B40	ETH_MACACR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ATSEN3	ATSEN2	ATSEN1	ATSEN0	Res.	Res.	Res.	ATSFC
	Reset value																									0	0	0	0				0
0x0B44	Reserved																																
0x0B48	ETH_MACATSNR	Res.	AUXTSLO[30:0]																														
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B4C	ETH_MACATSSR	AUXTSHI[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B50	ETH_MACTSIACR	OSTIAC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B54	ETH_MACTSEACR	OSTEAC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B58	ETH_ MACTSICNR	TSIC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B5C	ETH_ MACTSECNR	TSEC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B60 - 0x0B64	Reserved																																
0x0B68	ETH_ MACTSILR	Res.	Res.	Res.	Res.	ITLNS[11:0]												ITLSNS[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								
0x0B6C	ETH_ MACTSELR	Res.	Res.	Res.	Res.	ETLNS[11:0]												ETLSNS[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								
0x0B70	ETH_MACPPSCR	Res.	Res.	Res.	TIMESEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MCGREN0	TRGTMODSEL0[1:0]		PPSEN0	PPSCTRL[3:0]			
	Reset value				0																					0	0	0	0	0	0	0	0

Table 831. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0B70	ETH_MACPPSCR (alternate)	Res.	Res.	Res.	TIMESEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MCGREN0	TRGTMODSEL0[1:0]		PPSEN0	PPSCMD[3:0]			
	Reset value				0																					0	0	0	0	0	0	0	0
0x0B74 - 0x0B7C	Reserved																																
0x0B80	ETH_ MACPPSTTSR	TSTRH0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B84	ETH_ MACPPSTTNR	TRGTBUSY0	TTSL0[30:0]																														
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B88	ETH_MACPPSIR	PPSINT0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B8C	ETH_MACPPSWR	PPSWIDTH0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B90 - 0x0BBC	Reserved																																
0x0BC0	ETH_MACPOCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DN[7:0]								PRDIS	DRRDIS	APDREQTRIG	ASYNCTRIG	Res.	APDREQEN	ASYNCEN	PTOEN
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
0x0BC4	ETH_MACSPI0R	SPI0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0BC8	ETH_MACSPI1R	SPI1[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0BCC	ETH_MACSPI2R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SPI2[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0BD0	ETH_MACLMIR	LMPDRI[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DRSYNCR[2:0]			LSI[7:0]							
	Reset value	0	0	0	0	0	0	0	0														0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

70 HDMI-CEC controller (CEC)

70.1 HDMI-CEC introduction

Consumer electronics control (CEC) is part of HDMI (high-definition multimedia interface) standard. It contains a protocol that provides high-level control functions between various audiovisual products. CEC operates at low speeds, with minimum processing and memory overhead.

The HDMI-CEC controller provides hardware support for this protocol.

70.2 HDMI-CEC controller main features

- Complies with HDMI-CEC v1.4 specification
- Independent 32 kHz CEC kernel (refer to *section RCC kernel clock distribution*)
- Works in Stop mode for ultra-low-power applications
- Configurable signal-free time before start of transmission
  - Automatic by hardware, according to CEC state and transmission history
  - Fixed by software (7 timing options)
- Configurable peripheral address (OAR)
- Supports Listen mode
  - Enables reception of CEC messages sent to destination address different from OAR without interfering with the CEC line
- Configurable Rx-tolerance margin
  - Standard tolerance
  - Extended tolerance
- Receive-error detection
  - Bit rising error (BRE), with optional stop of reception (BRESTP)
  - Short bit period error (SBPE)
  - Long bit period error (LBPE)
- Configurable error-bit generation
  - on BRE detection (BREGEN)
  - on LBPE detection (LBPEGEN)
  - always generated on SBPE detection
- Transmission error detection (TXERR)
- Arbitration lost detection (ARBLST)
  - with automatic transmission retry
- Transmission underrun detection (TXUDR)
- Reception overrun detection (RXOVR)

70.3 HDMI-CEC functional description

70.3.1 HDMI-CEC pin and internal signals

The CEC bus consists of a single bidirectional line that is used to transfer data in and out of the device. It is connected to a +3.3 V supply voltage via a 27 kΩ pull-up resistor. The output stage of the device must have an open-drain or open-collector to allow a wired-AND connection.

The HDMI-CEC controller manages the CEC bidirectional line as an alternate function of a standard GPIO, assuming that it is configured as alternate function open drain. The 27 kΩ pull-up must be added externally to the microcontroller.

To not interfere with the CEC bus when the application power is removed, it is mandatory to isolate the CEC pin from the bus in such conditions. This can be done by using a MOS transistor, as shown on *Figure 1026*.

Table 833 lists the internal signals that are exchanged between the HDMI-CEC and other functional blocks (such as RCC and EXTI).

Table 832. HDMI pin

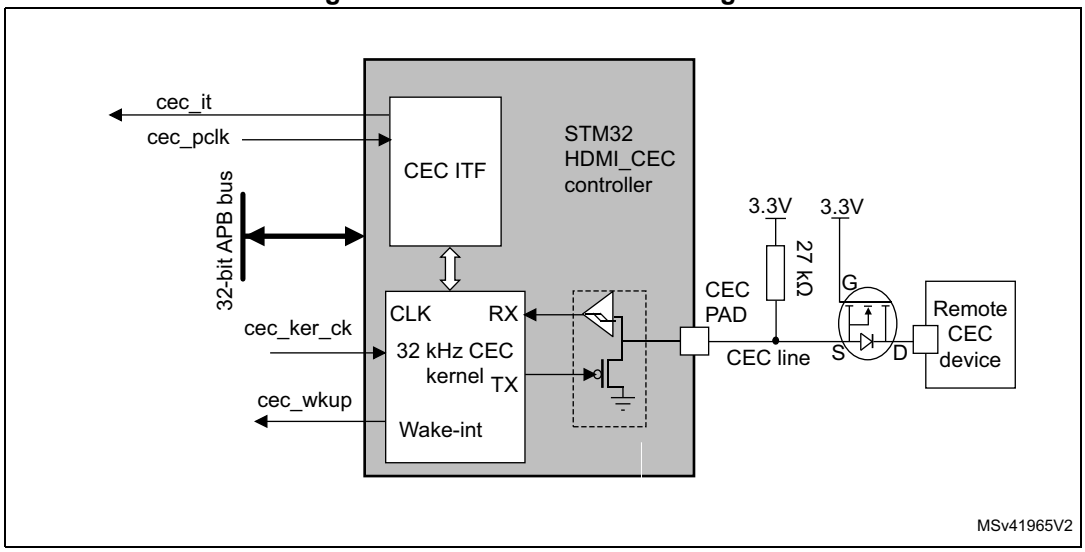
Name	Signal type	Remarks
CEC	Bidirectional	Two states: – 1 = high impedance – 0 = low impedance A 27 kΩ resistor must be added externally.

Table 833. HDMI-CEC internal input/output signals

Signal name	Signal type	Description
cec_wkup	Digital output	HDMI-CEC wake-up signal
cec_it	Digital output	HDMI-CEC interrupt signal
cec_pclk	Digital input	APB clock
cec_ker_ck	Digital input	HDMI-CEC kernel clock

70.3.2 HDMI-CEC block diagram

Figure 1026. HDMI-CEC block diagram



70.3.3 Message description

All transactions on the CEC line consist of an initiator and one or more followers. The initiator is responsible for sending the message structure and the data. The follower is the recipient of any data and is responsible for setting any acknowledgment bits.

A message is conveyed in a single frame that consists of a start bit followed by a header block and optionally an opcode and a variable number of operand blocks.

All these blocks are made of a 8-bit payload - most significant bit is transmitted first - followed by an end of message (EOM) bit and an acknowledge (ACK) bit.

The EOM bit is set in the last block of a message and kept reset in all others. In case a message contains additional blocks after an EOM is indicated, those additional blocks must be ignored. The EOM bit may be set in the header block to ‘ping’ other devices, to make sure they are active.

The acknowledge bit is always set to high impedance by the initiator so that it can be driven low either by the follower that has read its own address in the header, or by the follower that needs to reject a broadcast message.

The header consists of the source logical address field, and the destination logical address field. Note that the special address 0xF is used for broadcast messages.

Figure 1027. Message structure

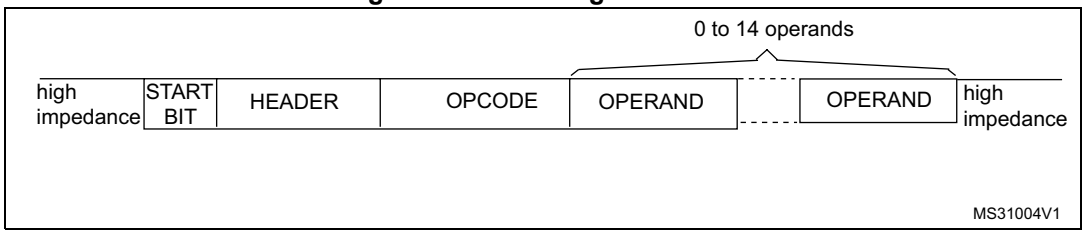
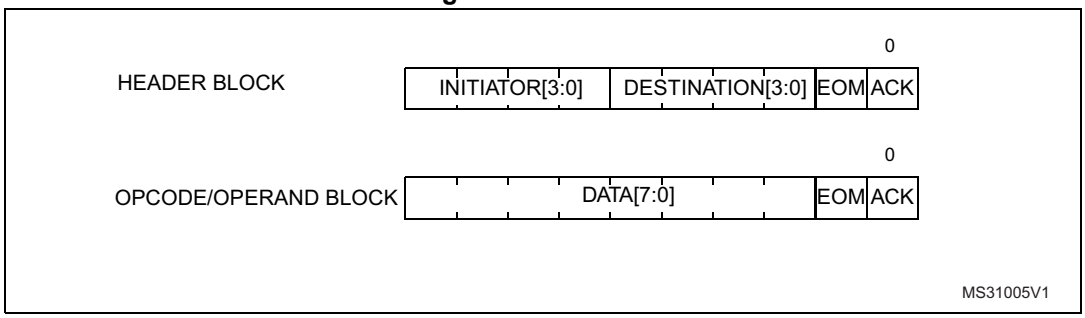


Figure 1028. Blocks

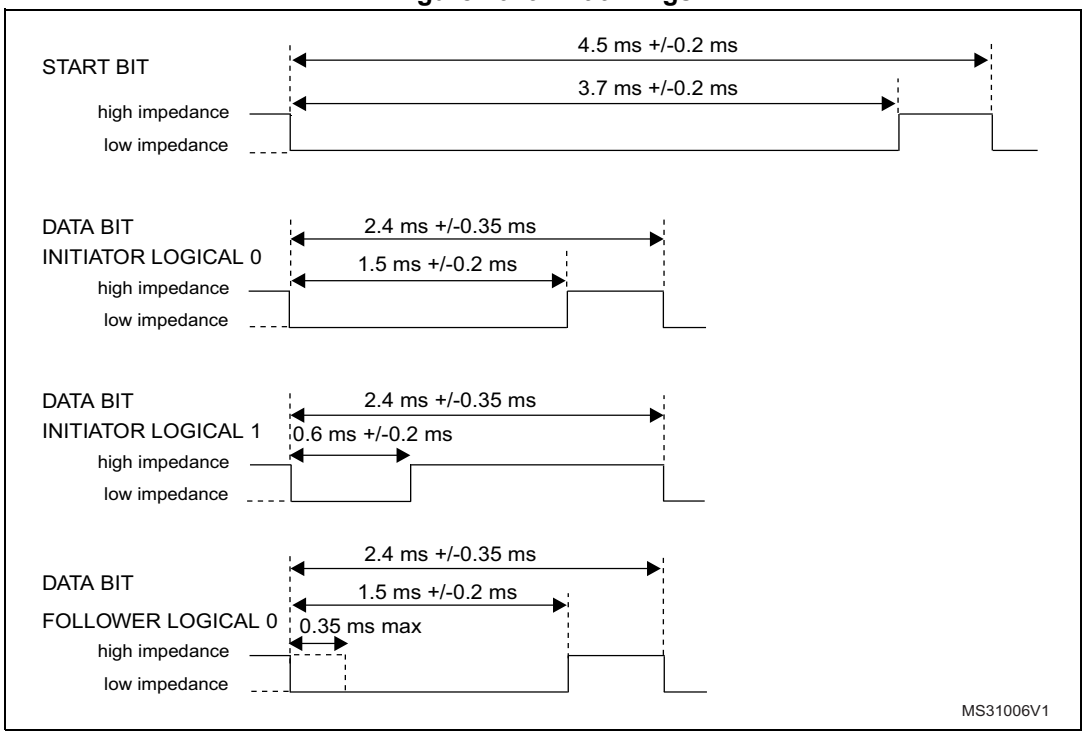


70.3.4 Bit timing

The format of the start bit is unique and identifies the start of a message. It must be validated by its low duration and its total duration.

All remaining data bits in the message, after the start bit, have consistent timing. The high-to-low transition at the end of the data bit is the start of the next data bit except for the final bit where the CEC line remains high.

Figure 1029. Bit timings

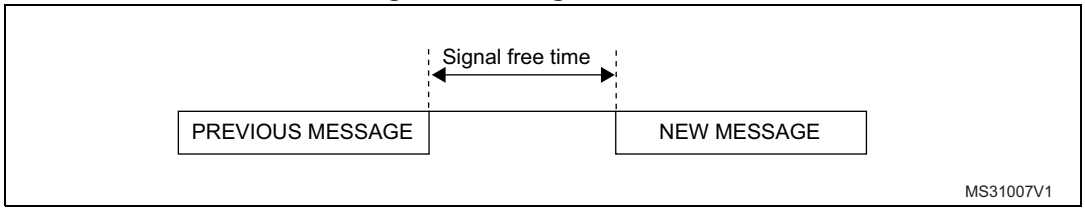


70.4 Arbitration

All devices transmitting - or retransmitting - a message onto the CEC line must ensure that it has been inactive for a number of bit periods. This signal-free time is defined as the time

starting from the final bit of the previous frame and depends on the initiating device and the current status as shown in the figure below.

Figure 1030. Signal free time



Since only one initiator is allowed at any one time, an arbitration mechanism is provided to avoid conflict when more than one initiator begins transmitting at the same time.

CEC line arbitration starts with the leading edge of the start bit and continues until the end of the initiator address bits within the header block. During this period, the initiator must monitor the CEC line, if whilst driving the line to high impedance it reads it back to 0. Assuming then it has lost arbitration, it stops transmitting and becomes a follower.

Figure 1031. Arbitration phase

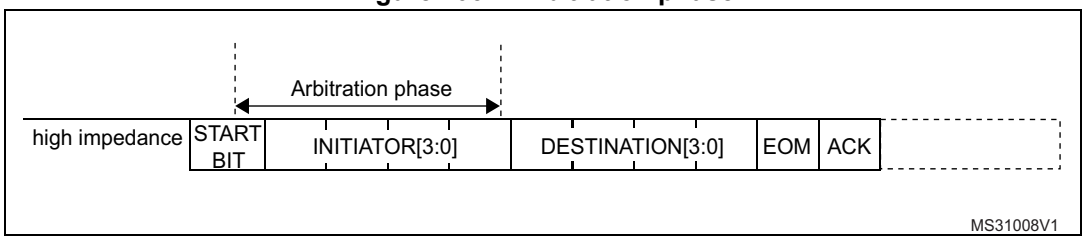
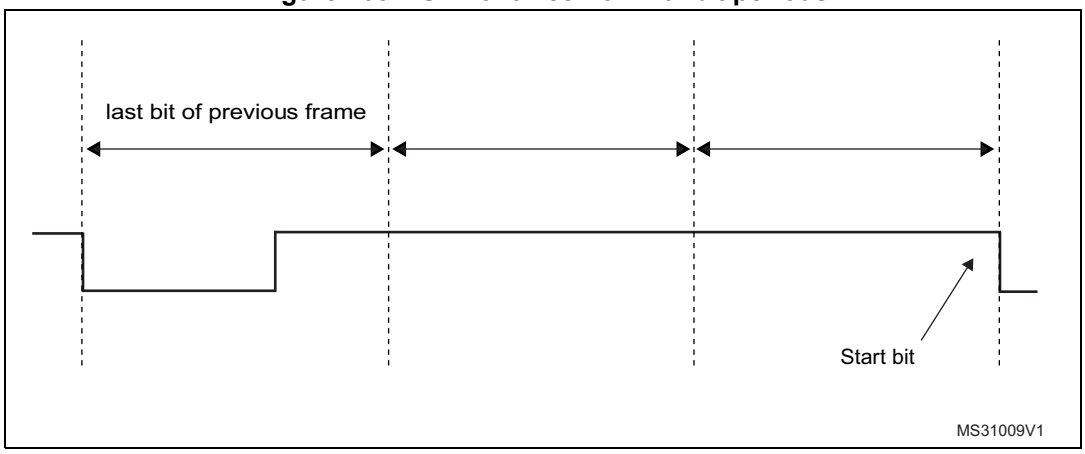


Figure 1032 shows an example for a SFT of three nominal bit periods.

Figure 1032. SFT of three nominal bit periods



A configurable time window is counted before starting the transmission.

In the SFT = 0 configuration, HDMI-CEC performs automatic SFT calculation ensuring compliance with the HDMI-CEC standard:

- 2.5 data bit periods if the CEC is the last bus initiator with unsuccessful transmission
- 4 data bit periods if the CEC is the new bus initiator
- 6 data bit periods if the CEC is the last bus initiator with successful transmission

This is done to guarantee the maximum priority to a failed transmission and the lowest one to the last initiator that completed successfully its transmission.

Otherwise there is the possibility to configure the SFT bits to count a fixed timing value. Possible values are 0.5, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5 data bit periods.

70.4.1 SFT option bit

In case of SFTOPT = 0 configuration, SFT starts being counted when the start-of-transmission command is set by software (TXSOM = 1).

In case of SFTOPT = 1, SFT starts automatically being counted by the HDMI-CEC device when a bus-idle or line error condition is detected. If the SFT timer is completed at the time TXSOM command is set then transmission starts immediately without latency. If the SFT timer is still running instead, the system waits until the timer elapses before transmission can start.

In case of SFTOPT = 1 a bus-event condition starting the SFT timer is detected in the following cases:

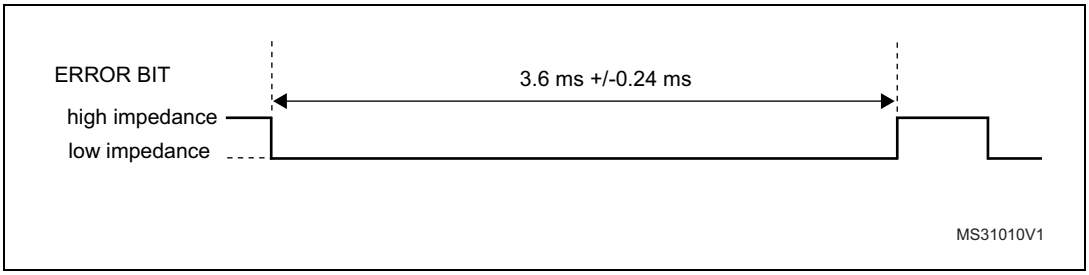
- In case of a regular end of transmission/reception, when TXEND/RXEND bits are set at the minimum nominal data bit duration of the last bit in the message (ACK bit).
- In case of a transmission error detection, SFT timer starts when the TXERR transmission error is detected (TXERR = 1).
- In case of a missing acknowledge from the CEC follower, the SFT timer starts when the TXACKE bit is set, that is at the nominal sampling time of the ACK bit.
- In case of a transmission underrun error, the SFT timer starts when the TXUDR bit is set at the end of the ACK bit.
- In case of a receive error detection implying reception abort, the SFT timer starts at the same time the error is detected. If an error bit is generated, then SFT starts being counted at the end of the error bit.
- In case of a wrong start bit or of any uncodified low impedance bus state from idle, the SFT timer is restarted as soon as the bus comes back to hi-impedance idleness.

70.5 Error handling

70.5.1 Bit error

If a data bit - excluding the start bit - is considered invalid, the follower is expected to notify such error by generating a low bit period on the CEC line of 1.4 to 1.6 times the nominal data bit period (3.6 ms nominally).

Figure 1033. Error bit timing



70.5.2 Message error

A message is considered lost and therefore may be retransmitted under the following conditions:

- a message is not acknowledged in a directly addressed message
- a message is negatively acknowledged in a broadcast message
- a low impedance is detected on the CEC line while it is not expected (line error)

Three kinds of error flag can be detected when the CEC interface is receiving a data bit:

70.5.3 Bit rising error (BRE)

BRE (bit rising error) is set when a bit rising edge is detected outside the windows where it is expected (see *Figure 1034*). BRE flag also generates a CEC interrupt if the BREIE = 1.

In the case of a BRE detection, the message reception can be stopped according to the BRESTP bit value and an error bit can be generated if BREGEN bit is set.

When BRE is detected in a broadcast message with BRESTP = 1 an error bit is generated even if BREGEN = 0 to enforce initiator's retry of the failed transmission. Error bit generation can be disabled by configuring BREGEN = 0, BRDNOGEN = 1.

70.5.4 Short bit period error (SBPE)

SBPE is set when a bit falling edge is detected earlier than expected (see *Figure 1034*). SBPE flag also generates a CEC interrupt if the SBPEIE = 1.

An error bit is always generated on the line in case of a SBPE error detection. An error bit is not generated upon SBPE detection only when Listen mode is set (LSTN = 1) and the following conditions are met:

- A directly addressed message is received containing SBPE
- A broadcast message is received containing SBPE AND BRDNOGEN = 1

70.5.5 Long bit period error (LBPE)

LBPE is set when a bit falling edge is not detected in a valid window (see *Figure 1034*). LBPE flag also generates a CEC interrupt if the LBPEIE = 1.

LBPE always stops the reception, an error bit is generated on the line when LBPEGEN bit is set.

When LBPE is detected in a broadcast message an error bit is generated even if LBPEGEN = 0 to enforce initiator's retry of the failed transmission. Error bit generation can be disabled by configuring LBPEGEN = 0, BRDNOGEN = 1.

Note: The BREGEN = 1, BRESTP = 0 configuration must be avoided.

Figure 1034. Error handling

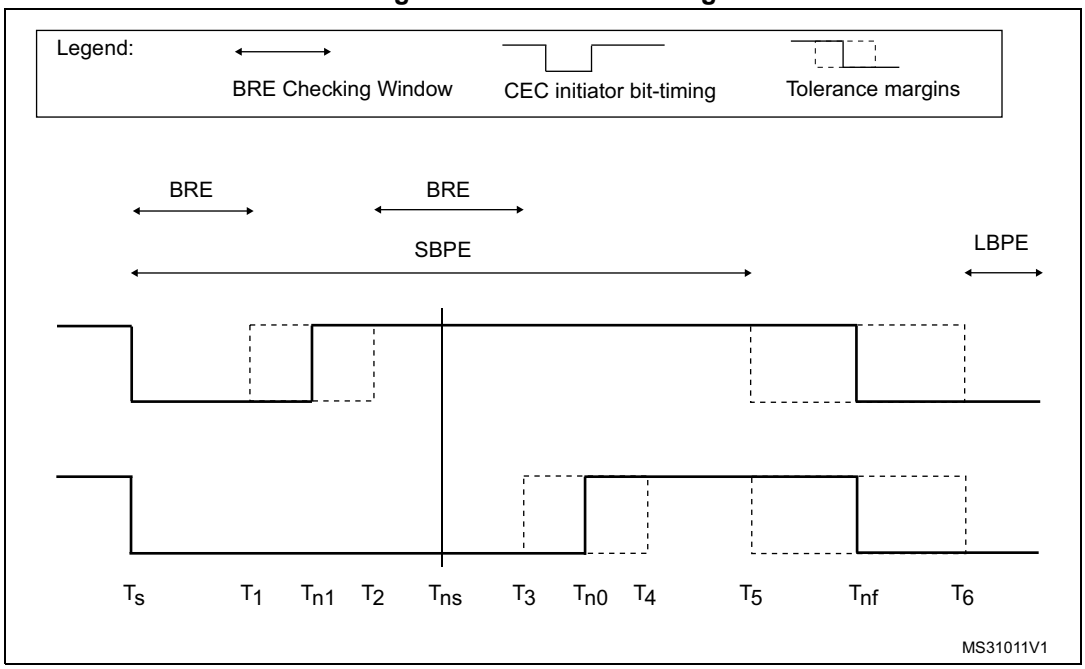


Table 834. Error handling timing parameters

Time	RXTOL	ms	Description
T_s	x	0	Bit start event.
T_1	1	0.3	The earliest time for a low - high transition when indicating a logical 1.
	0	0.4	
T_{n1}	x	0.6	The nominal time for a low - high transition when indicating a logical 1.
T_2	0	0.8	The latest time for a low - high transition when indicating a logical 1.
	1	0.9	
T_{ns}	x	1.05	Nominal sampling time.
T_3	1	1.2	The earliest time a device is permitted return to a high impedance state (logical 0).
	0	1.3	
T_{n0}	x	1.5	The nominal time a device is permitted return to a high impedance state (logical 0).
T_4	0	1.7	The latest time a device is permitted return to a high impedance state (logical 0).
	1	1.8	
T_5	1	1.85	The earliest time for the start of a following bit.
	0	2.05	
T_{nf}	x	2.4	The nominal data bit period.
T_6	0	2.75	The latest time for the start of a following bit.
	1	2.95	

70.5.6 Transmission error detection (TXERR)

The CEC initiator sets the TXERR flag if detecting low impedance on the CEC line when it is transmitting high impedance and is not expecting a follower asserted bit. TXERR flag also generates a CEC interrupt if the TXERRIE = 1.

TXERR assertion stops the message transmission. Application is in charge to retry the failed transmission up to five times.

TXERR checks are performed differently depending on the different states of the CEC line and on the RX tolerance configuration.

Figure 1035. TXERR detection

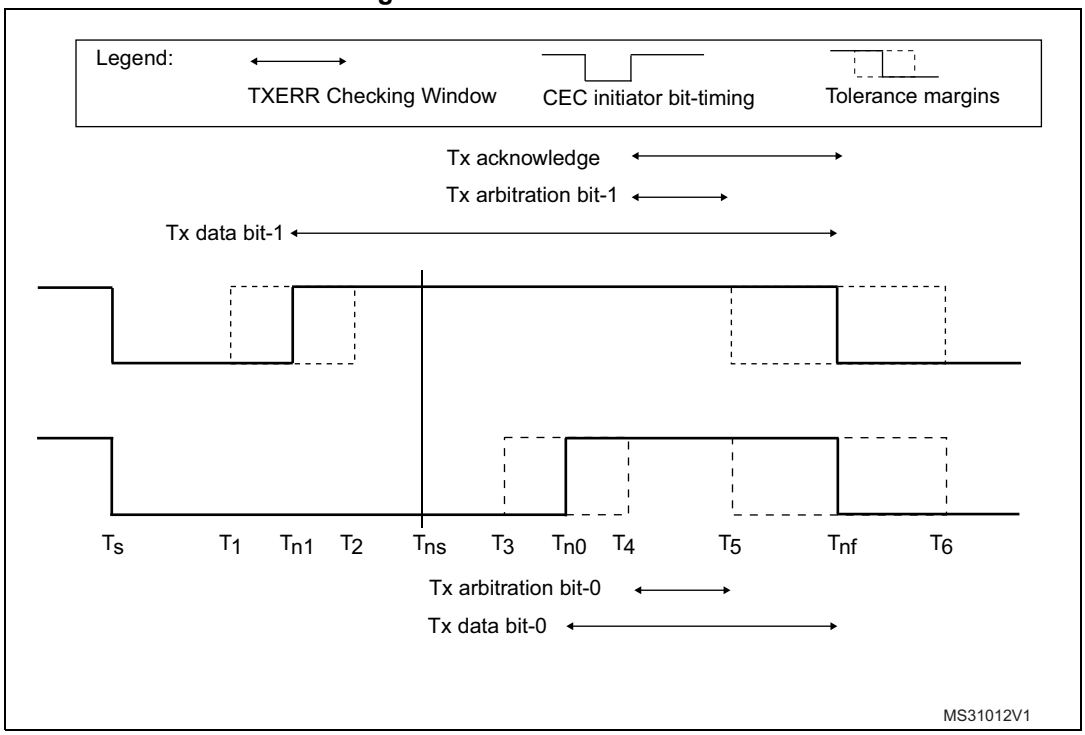


Table 835. TXERR timing parameters

Time	RXTOL	ms	Description
T_s	x	0	Bit start event.
T_1	1	0.3	The earliest time for a low - high transition when indicating a logical 1.
	0	0.4	
T_{n1}	x	0.6	The nominal time for a low - high transition when indicating a logical 1.
T_2	0	0.8	The latest time for a low - high transition when indicating a logical 1.
	1	0.9	
T_{ns}	x	1.05	Nominal sampling time.
T_3	1	1.2	The earliest time a device is permitted return to a high impedance state (logical 0).
	0	1.3	

Table 835. TXERR timing parameters (continued)

Time	RXTOL	ms	Description
T_{n0}	x	1.5	The nominal time a device is permitted return to a high impedance state (logical 0).
T_4	0	1.7	The latest time a device is permitted return to a high impedance state (logical 0).
	1	1.8	
T_5	1	1.85	The earliest time for the start of a following bit.
	0	2.05	
T_{nf}	x	2.4	The nominal data bit period.
T_6	0	2.75	The latest time for the start of a following bit.
	1	2.95	

70.6 HDMI-CEC interrupts

An interrupt can be produced:

- during reception if a receive block transfer is finished or if a receive error occurs.
- during transmission if a transmit block transfer is finished or if a transmit error occurs.

Table 836. HDMI-CEC interrupts

Interrupt event	Event flag	Enable control bit
Rx-byte received	RXBR	RXBRIE
End of reception	RXEND	RXENDIE
Rx-overrun	RXOVR	RXOVRIE
Rxbit rising error	BRE	BREIE
Rx-short bit period error	SBPE	SBPEIE
Rx-long bit period error	LBPE	LBPEIE
Rx-missing acknowledge error	RXACKE	RXACKEIE
Arbitration lost	ARBLST	ARBLSTIE
Tx-byte request	TXBR	TXBRIE
End of transmission	TXEND	TXENDIE
Tx-buffer underrun	TXUDR	TXUDRIE
Tx-error	TXERR	TXERRIE
Tx-missing acknowledge error	TXACKE	TXACKEIE

70.7 HDMI-CEC registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions. The registers have to be accessed by words (32 bits).

70.7.1 CEC control register (CEC_CR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXEOM	TXSOM	CECEN
													rs	rs	rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **TXEOM***:* Tx end of message

The TXEOM bit is set by software to command transmission of the last byte of a CEC message.
TXEOM is cleared by hardware at the same time and under the same conditions as for TXSOM.
0: TXDR data byte is transmitted with EOM = 0.
1: TXDR data byte is transmitted with EOM = 1.

Note: TXEOM must be set when CECEN = 1.

TXEOM must be set before writing transmission data to TXDR.

If TXEOM is set when TXSOM = 0, transmitted message consists of 1 byte (HEADER) only (PING message).

Bit 1 **TXSOM**: Tx start of message

TXSOM is set by software to command transmission of the first byte of a CEC message. If the CEC message consists of only one byte, TXEOM must be set before of TXSOM.
Start-bit is effectively started on the CEC line after SFT is counted. If TXSOM is set while a message reception is ongoing, transmission starts after the end of reception.
TXSOM is cleared by hardware after the last byte of the message is sent with a positive acknowledge (TXEND = 1), in case of transmission underrun (TXUDR = 1), negative acknowledge (TXACKE = 1), and transmission error (TXERR = 1). It is also cleared by CECEN = 0. It is not cleared and transmission is automatically retried in case of arbitration lost (ARBLST = 1).
TXSOM can be also used as a status bit informing application whether any transmission request is pending or under execution. The application can abort a transmission request at any time by clearing the CECEN bit.
0: No CEC transmission is on-going.
1: CEC transmission command

Note: TXSOM must be set when CECEN = 1.

TXSOM must be set when transmission data is available into TXDR.

HEADER first four bits containing own peripheral address are taken from TXDR[7:4], not from CEC_CFGR.OAR that is used only for reception.

Bit 0 **CECEN:** CEC enable

The CECEN bit is set and cleared by software. CECEN = 1 starts message reception and enables the TXSOM control. CECEN = 0 disables the CEC peripheral, clears all bits of CEC_CR register and aborts any on-going reception or transmission.

0: CEC peripheral is off.

1: CEC peripheral is on.

70.7.2 CEC configuration register (CEC_CFGR)

This register is used to configure the HDMI-CEC controller.

Address offset: 0x04

Reset value: 0x0000 0000

Caution: It is mandatory to write CEC_CFGR only when CECEN = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LSTN	OAR[14:0]														
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	SFTOP	BRDNOGEN	LBPEGEN	BREGEN	BRESTP	RXTOL	SFT[2:0]		
							rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **LSTN:** Listen mode

LSTN bit is set and cleared by software.

0: CEC peripheral receives only message addressed to its own address (OAR). Messages addressed to different destination are ignored. Broadcast messages are always received.

1: CEC peripheral receives messages addressed to its own address (OAR) with positive acknowledge. Messages addressed to different destination are received, but without interfering with the CEC bus: no acknowledge sent.

Bits 30:16 **OAR[14:0]:** Own addresses configuration

The OAR bits are set by software to select which destination logical addresses has to be considered in receive mode. Each bit, when set, enables the CEC logical address identified by the given bit position.

At the end of HEADER reception, the received destination address is compared with the enabled addresses. In case of matching address, the incoming message is acknowledged and received. In case of non-matching address, the incoming message is received only in listen mode (LSTN = 1), but without acknowledge sent. Broadcast messages are always received.

Example:

OAR = 0b000 0000 0010 0001 means that CEC acknowledges addresses 0x0 and 0x5. Consequently, each message directed to one of these addresses is received.

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **SFTOP**: SFT option bit

The SFTOPT bit is set and cleared by software.

0: SFT timer starts when TXSOM is set by software.

1: SFT timer starts automatically at the end of message transmission/reception.

Bit 7 **BRDNOGEN:** Avoid error-bit generation in broadcast

The BRDNOGEN bit is set and cleared by software.

0: BRE detection with BRESTP = 1 and BREGEN = 0 on a broadcast message generates an error-bit on the CEC line. LBPE detection with LBPEGEN = 0 on a broadcast message generates an error-bit on the CEC line.

1: Error-bit is not generated in the same condition as above. An error-bit is not generated even in case of an SBPE detection in a broadcast message if listen mode is set.

Bit 6 **LBPEGEN:** Generate error-bit on long bit period error

The LBPEGEN bit is set and cleared by software.

0: LBPE detection does not generate an error-bit on the CEC line.

1: LBPE detection generates an error-bit on the CEC line.

Note: If BRDNOGEN = 0, an error-bit is generated upon LBPE detection in broadcast even if LBPEGEN = 0.

Bit 5 **BREGEN:** Generate error-bit on bit rising error

The BREGEN bit is set and cleared by software.

0: BRE detection does not generate an error-bit on the CEC line.

1: BRE detection generates an error-bit on the CEC line (if BRESTP is set).

Note: If BRDNOGEN = 0, an error-bit is generated upon BRE detection with BRESTP = 1 in broadcast even if BREGEN = 0.

Bit 4 **BRESTP**: Rx-stop on bit rising error

The BRESTP bit is set and cleared by software.

0: BRE detection does not stop reception of the CEC message. Data bit is sampled at 1.05 ms.

1: BRE detection stops message reception.

Bit 3 **RXTOL:** Rx-tolerance

The RXTOL bit is set and cleared by software.

0: Standard tolerance margin:

- Start-bit, +/- 200 µs rise, +/- 200 µs fall
- Data-bit: +/- 200 µs rise. +/- 350 µs fall

1: Extended tolerance

- Start-bit: +/- 400 µs rise, +/- 400 µs fall
- Data-bit: +/-300 µs rise, +/- 500 µs fall

Bits 2:0 **SFT[2:0]**: Signal free time

SFT bits are set by software. In the SFT = 0x0 configuration, the number of nominal data bit periods waited before transmission is ruled by hardware according to the transmission history. In all the other configurations the SFT number is determined by software.

0x0

- 2.5 data-bit periods if CEC is the last bus initiator with unsuccessful transmission (ARBLST = 1, TXERR = 1, TXUDR = 1 or TXACKE = 1)
- 4 data-bit periods if CEC is the new bus initiator
- 6 data-bit periods if CEC is the last bus initiator with successful transmission (TXEOM = 1)

0x1: 0.5 nominal data bit periods

0x2: 1.5 nominal data bit periods

0x3: 2.5 nominal data bit periods

0x4: 3.5 nominal data bit periods

0x5: 4.5 nominal data bit periods

0x6: 5.5 nominal data bit periods

0x7: 6.5 nominal data bit periods

70.7.3 CEC Tx data register (CEC_TXDR)

Address offset: 0x8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXD[7:0]							
								w	w	w	w	w	w	w	w

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **TXD[7:0]**: Tx data

TXD is a write-only register containing the data byte to be transmitted.

70.7.4 CEC Rx data register (CEC_RXDR)

Address offset: 0xC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXD[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **RXD[7:0]**: Rx data

RXD is read-only and contains the last data byte that has been received from the CEC line.

70.7.5 CEC interrupt and status register (CEC_ISR)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TXACKE	TXERR	TXUDR	TXEND	TXBR	ARBLST	RXACKE	LBPE	SBPE	BRE	RXOVR	RXEND	RXBR
			rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:13 Reserved, must be kept at reset value.

Bit 12 **TXACKE:** Tx-missing acknowledge error

In transmission mode, TXACKE is set by hardware to inform application that no acknowledge was received. In case of broadcast transmission, TXACKE informs application that a negative acknowledge was received. TXACKE aborts message transmission and clears TXSOM and TXEOM controls.

TXACKE is cleared by software write at 1.

Bit 11 **TXERR:** Tx-error

In transmission mode, TXERR is set by hardware if the CEC initiator detects low impedance on the CEC line while it is released. TXERR aborts message transmission and clears TXSOM and TXEOM controls.

TXERR is cleared by software write at 1.

Bit 10 **TXUDR:** Tx-buffer underrun

In transmission mode, TXUDR is set by hardware if application was not in time to load TXDR before of next byte transmission. TXUDR aborts message transmission and clears TXSOM and TXEOM control bits.

TXUDR is cleared by software write at 1

Bit 9 **TXEND:** End of transmission

TXEND is set by hardware to inform application that the last byte of the CEC message has been successfully transmitted. TXEND clears the TXSOM and TXEOM control bits.

TXEND is cleared by software write at 1.

Bit 8 **TXBR:** Tx-byte request

TXBR is set by hardware to inform application that the next transmission data has to be written to TXDR. TXBR is set when the 4th bit of currently transmitted byte is sent. Application must write the next byte to TXDR within six nominal data-bit periods before transmission underrun error occurs (TXUDR).

TXBR is cleared by software write at 1.

Bit 7 **ARBLST:** Arbitration lost

ARBLST is set by hardware to inform application that CEC device is switching to reception due to arbitration lost event following the TXSOM command. ARBLST can be due either to a contending CEC device starting earlier or starting at the same time but with higher HEADER priority. After ARBLST assertion TXSOM bit keeps pending for next transmission attempt.

ARBLST is cleared by software write at 1.

Bit 6 **RXACKE:** Rx-missing acknowledge

In receive mode, RXACKE is set by hardware to inform application that no acknowledge was seen on the CEC line. RXACKE applies only for broadcast messages and in listen mode also for not directly addressed messages (destination address not enabled in OAR). RXACKE aborts message reception.

RXACKE is cleared by software write at 1.

Bit 5 **LBPE:** Rx-long bit period error

LBPE is set by hardware in case a data-bit waveform is detected with long bit period error. LBPE is set at the end of the maximum bit-extension tolerance allowed by RXTOL, in case falling edge is still longing. LBPE always stops reception of the CEC message. LBPE generates an error-bit on the CEC line if LBPEGEN = 1. In case of broadcast, error-bit is generated even in case of LBPEGEN = 0.

LBPE is cleared by software write at 1.

Bit 4 **SBPE:** Rx-short bit period error

SBPE is set by hardware in case a data-bit waveform is detected with short bit period error. SBPE is set at the time the anticipated falling edge occurs. SBPE generates an error-bit on the CEC line.

SBPE is cleared by software write at 1.

Bit 3 **BRE***:* Rx-bit rising error

BRE is set by hardware in case a data-bit waveform is detected with bit rising error. BRE is set either at the time the misplaced rising edge occurs, or at the end of the maximum BRE tolerance allowed by RXTOL, in case rising edge is still longing. BRE stops message reception if BRESTP = 1. BRE generates an error-bit on the CEC line if BREGEN = 1.

BRE is cleared by software write at 1.

Bit 2 **RXOVR***:* Rx-overrun

RXOVR is set by hardware if RXBR is not yet cleared at the time a new byte is received on the CEC line and stored into RXD. RXOVR assertion stops message reception so that no acknowledge is sent. In case of broadcast, a negative acknowledge is sent.

RXOVR is cleared by software write at 1.

Bit 1 **RXEND***:* End of reception

RXEND is set by hardware to inform application that the last byte of a CEC message is received from the CEC line and stored into the RXD buffer. RXEND is set at the same time of RXBR.

RXEND is cleared by software write at 1.

Bit 0 **RXBR***:* Rx-byte received

The RXBR bit is set by hardware to inform application that a new byte has been received from the CEC line and stored into the RXD buffer.

RXBR is cleared by software write at 1.

70.7.6 CEC interrupt enable register (CEC_IER)

Address offset: 0x14

Reset value: 0x0000 0000

Caution: It is mandatory to write CEC_IER only when CECEN = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TXACKIE	TXERRIE	TXUDRIE	TXENDIE	TXBRIE	ARBLSTIE	RXACKIE	LBPEIE	SBPEIE	BREIE	RXOVRIE	RXENDIE	RXBRIE
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bit 12 **TXACKIE***:* Tx-missing acknowledge error interrupt enable

The TXACKEIE bit is set and cleared by software.

0: TXACKE interrupt disabled

1: TXACKE interrupt enabled

Bit 11 **TXERRIE***:* Tx-error interrupt enable

The TXERRIE bit is set and cleared by software.

0: TXERR interrupt disabled

1: TXERR interrupt enabled

Bit 10 **TXUDRIE***:* Tx-underrun interrupt enable

The TXUDRIE bit is set and cleared by software.

0: TXUDR interrupt disabled

1: TXUDR interrupt enabled

Bit 9 **TXENDIE***:* Tx-end of message interrupt enable
The TXENDIE bit is set and cleared by software.
0: TXEND interrupt disabled
1: TXEND interrupt enabled

Bit 8 **TXBRIE***:* Tx-byte request interrupt enable
The TXBRIE bit is set and cleared by software.
0: TXBR interrupt disabled
1: TXBR interrupt enabled

Bit 7 **ARBLSTIE***:* Arbitration lost interrupt enable
The ARBLSTIE bit is set and cleared by software.
0: ARBLST interrupt disabled
1: ARBLST interrupt enabled

Bit 6 **RXACKIE***:* Rx-missing acknowledge error interrupt enable
The RXACKIE bit is set and cleared by software.
0: RXACKE interrupt disabled
1: RXACKE interrupt enabled

Bit 5 **LBPEIE***:* Long bit period error interrupt enable
The LBPEIE bit is set and cleared by software.
0: LBPE interrupt disabled
1: LBPE interrupt enabled

Bit 4 **SBPEIE***:* Short bit period error interrupt enable
The SBPEIE bit is set and cleared by software.
0: SBPE interrupt disabled
1: SBPE interrupt enabled

Bit 3 **BREIE***:* Bit rising error interrupt enable
The BREIE bit is set and cleared by software.
0: BRE interrupt disabled
1: BRE interrupt enabled

Bit 2 **RXOVRIE***:* Rx-buffer overrun interrupt enable
The RXOVRIE bit is set and cleared by software.
0: RXOVR interrupt disabled
1: RXOVR interrupt enabled

Bit 1 **RXENDIE***:* End of reception interrupt enable
The RXENDIE bit is set and cleared by software.
0: RXEND interrupt disabled
1: RXEND interrupt enabled

Bit 0 **RXBRIE***:* Rx-byte received interrupt enable
The RXBRIE bit is set and cleared by software.
0: RXBR interrupt disabled
1: RXBR interrupt enabled

70.7.7 HDMI-CEC register map

Table 837. HDMI-CEC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	CEC_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXEOM	TXSOM	CECEN
	Reset value																														0	0	0
0x04	CEC_CFGR	LSTN	OAR[14:0]															Res.	Res.	Res.	Res.	Res.	Res.	Res.	SFTOPT	BRDNOGEN	LBPEGEN	BREGEN	BRESTP	RXTOL	SFT[2:0]		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								0	0	0	0	0	0	0	0	0
0x08	CEC_TXDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXD[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x0C	CEC_RXDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXD[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x10	CEC_ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXACKE	TXERR	TXUDR	TXEND	TXBR	ARBLST	RXACKE	LBPE	SBPE	BRE	RXOVR	RXEND	RXBR
	Reset value																				0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	CEC_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXACKIE	TXERRIE	TXUDRIE	TXENDIE	TXBRIE	ARBLSTIE	RXACKIE	LBPEIE	SBPEIE	BREIE	RXOVRIE	RXENDIE	RXBRIE
	Reset value																				0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

71 Debug support (DBG)

71.1 Introduction

A comprehensive set of debug features is provided to support software development and system integration:

- Breakpoint debugging of the CPU core
- Code execution tracing
- Software instrumentation
- Cross-triggering

The debug features can be controlled via a JTAG/Serial-wire debug access port, using industry-standard debugging tools. A trace port allows data to be captured for logging and analysis.

The debug features are based on Arm® CoreSight™ components.

- SWJ-DP: JTAG/Serial-wire debug port
- AHB-AP: AHB access port
- ROM table
- System control space (SCS)
- Breakpoint unit (BPU)
- Data watchpoint and trace unit (DWT)
- Instrumentation trace macrocell (ITM)
- Embedded Trace Macrocell™ (ETM)
- Cross-trigger interface (CTI)
- Trace port interface unit (TPU)

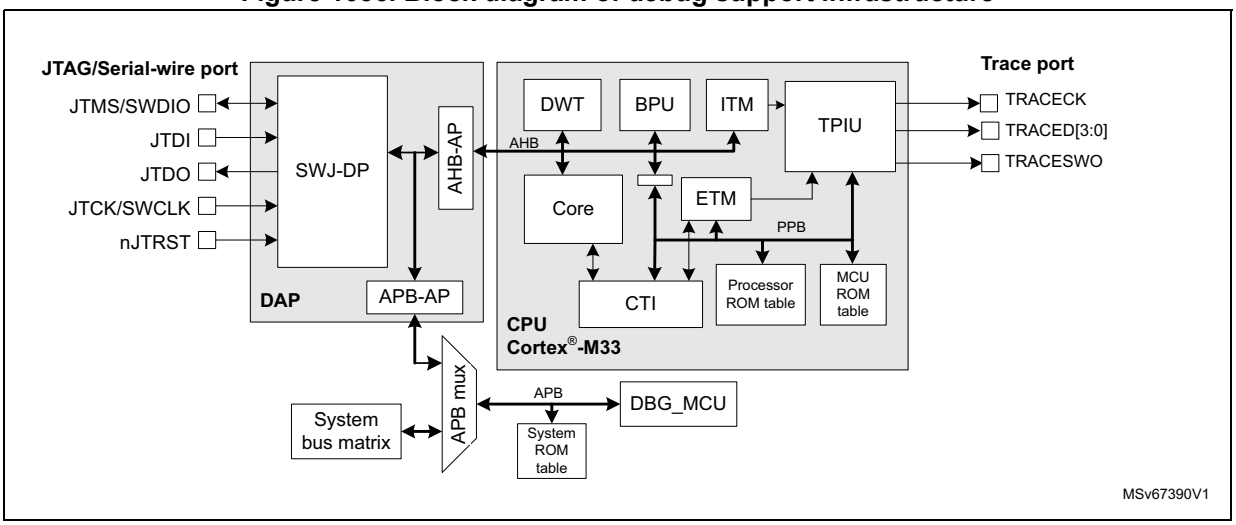
The debug features are accessible by the debugger via the AHB-AP.

Additional information can be found in the Arm® documents referenced in *Section 71.13*.

71.2 DBG functional description

71.2.1 DBG block diagram

Figure 1036. Block diagram of debug support infrastructure



71.2.2 DBG pins and internal signals

Table 838. JTAG/Serial-wire debug port pins

Pin name	JTAG debug port		SW debug port		Pin assignment
	Type	Description	Type	Description	
JTMS/SWDIO	I	JTAG test mode select	IO	Serial-wire data in/out	PA13
JTCK/SWCLK	I	JTAG test clock	I	Serial-wire clock	PA14
JTDI	I	JTAG test data input	-	-	PA15
JTDO	O	JTAG test data output	-	-	PB3
nJTRST	I	JTAG test reset	-	-	PB4

Table 839. Trace port pins

Pin name	Type	Description	Pin assignment
TRACED0	O	Trace synchronous data out 0	Refer to the datasheet
TRACED1		Trace synchronous data out 1	
TRACED2		Trace synchronous data out 2	
TRACED3		Trace synchronous data out 3	
TRACECK		Trace clock	

Table 840. Single-wire trace port pins

Pin name	Type	Description	Pin assignment
TRACESWO	O	Single-wire trace asynchronous data out	PB3(1)

1. TRACESWO is multiplexed with JTDO. This means that a single-wire trace is only available when using the serial-wire debug interface, and not when using JTAG.

71.2.3 DBG reset and clocks

The debug port (SWJ-DP) is reset by a power-on reset and when waking up from Standby mode.

The debugger supplies the clock for the debug port via the debug interface pin JTCK/SWCLK. This clock is used to register the serial input data in both serial-wire and JTAG modes, as well as to operate the state machines and internal logic of the debug port. This clock must therefore continue to toggle for several cycles after the end of an access, to ensure that the debug port returns to the idle state.

The SWJ-DP contains an asynchronous interface to the DCLK domain that covers the rest of the SWJ-DP and the access port.

The DCLK is a gated version of the system clock.

The DCLK domain is enabled by the debugger using the CDBGPWRUPREQ bit in the *DP control and status register (DP_CTRLSTATR)*. The clock must be enabled before the debugger can access any of the debug features on the device. The availability of the clock is reflected in the CDBGPWRUPACK bit in DP_CTRL/STATR. The DCLK is disabled at power-up, and must be disabled when the debugger is disconnected, to avoid wasting energy.

The debug and trace components included in the processor are clocked with the processor clock.

71.2.4 DBG power domains

The debug components are located in the core power domain. This means that the debugger connection is not possible in Shutdown or Standby low-power mode. To avoid losing the connection when the device enters Standby mode, the power can be maintained to the core by setting a bit in the *DBGMCU configuration register (DBGMCU_CR)*. This also keeps the processor clocks active and holds off the reset, so that the debug session is maintained.

71.2.5 Debug and low-power modes

The devices include power saving features that allow the core power domain to be switched off or stopped when not required. If the power is switched off or if the core is not clocked, all debug components are inaccessible to the debugger. To avoid this, power-saving mode emulation is implemented. If the emulation is enabled for a domain, the domain still enters power-saving mode, but its clock and power are maintained. In other words, the domain behaves as if it is in power-saving mode, but the debugger does not lose the connection.

The emulation mode is programmed in the microcontroller debug (DBGMCU) unit. For more information, refer to *Section 71.12*.

71.2.6 Security

The trace and debug components allow a high degree of access to the processor and system during product development. To protect user code and ensure that the debug features cannot be used to alter or compromise the normal operation of the finished product, these features can be disabled or limited in scope. For example, secure software debug and trace can be disabled without preventing the debug of nonsecure code.

Debugger access to secure memory (when permitted) must be performed using secure transactions on the debug AHB, that is, with the PROT[6] bit set in the *AP1 control/status word register (AP1_CSWR)*.

Debugger access is disabled while the processor is booting from system flash memory.

The following authentication signals are used by the system to determine which debug features are enabled or disabled:

- **dbgen**: global enable for all debug features

  0: All debug features are disabled.

  1: Debug features in the nonsecure state are enabled. Debug features in a secure state are dependent on the state of the **spiden** signal.
- **spiden**: enables debug in the secure state when **dbgen** = 1.

  0: Debug features are disabled in the secure state.

  1: Debug features are enabled in the secure state.
- **niden**: enables trace and performance monitoring (non-invasive debug).

  0: Trace generation is disabled.

  1: Trace generation in the nonsecure state is enabled. Trace generation in a secure state is dependent on the state of the **spniden** signal.
- **spniden**: enables trace and performance monitoring in the secure state when **niden** = 1.

  0: Trace generation is disabled in the secure state.

  1: Trace generation is enabled in the secure state.

For detailed information on the behavior of each component according to the state of the authentication signals, refer to the relevant chapter, or to the relevant Arm® technical documentation.

The state of the signals are set according to the debug state as shown in *Table 841*, when TrustZone is enabled (TZEN = 0xB4), and *Table 842* when TrustZone is disabled (TZEN = 0xC3).

Table 841. Authentication signal states with TrustZone enabled (TZEN = 0xB4)

Debug state	Authentication signal state	Description
OPEN	dbgen = 1 spiden = 1 niden = 1 spniden = 1	Debug and trace is enabled whatever the state of the processor. Debugger access to secure memory is permitted.
CLOSED SECURE	dbgen = 1 spiden = 0 niden = 1 spniden = 0	Debug and trace is enabled when the processor is in nonsecure state. Debugger access to nonsecure memory is permitted. Debugger access to secure memory is disabled.
CLOSED	dbgen = 0 spiden = 0 niden = 0 spniden = 0	Debug and trace is disabled.

Table 842. Authentication signal states with TrustZone disabled (TZEN = 0xC3)

Debug state	Authentication signal state	Description
OPEN	dbgen = 1 spiden = 1 niden = 1 spniden = 1	Debug and trace is enabled whatever the state of the processor. All memory and resources are considered nonsecure and accessible to the debugger.
CLOSED	dbgen = 0 spiden = 0 niden = 0 spniden = 0	Debug and trace is disabled.

The state of the authentication signals can be read from the DAUTHSTATUS register in the system control space (SCS) of the Cortex®-M33.

The debug state depends upon the product life cycle state and the debug authentication state (see *Section 71.2.7*).

Table 843. Life cycle state and debug states

Product life cycle state	Debug state
OPEN	OPEN
TZ_CLOSED	CLOSED-SECURE
CLOSED (debug not authenticated)	CLOSED

Table 843. Life cycle state and debug states

Product life cycle state	Debug state
CLOSED (debug constrained)	OPEN/CLOSED-SECURE(1)
LOCKED	CLOSED

1. Depends on the authorization level.

71.2.7 Debug authentication

Figure 1037. Product life cycle states and debug authentication

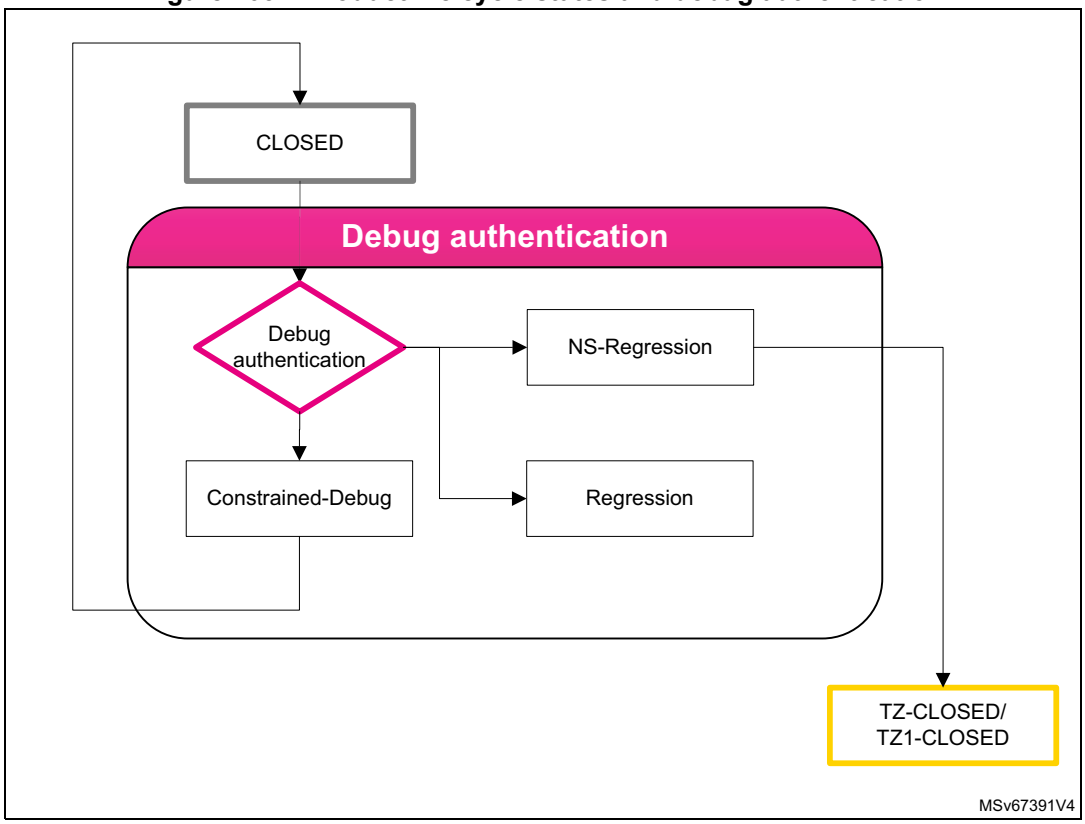


Figure 1037 shows the product life cycle and debug authentication states.

If the device is in CLOSED (product life cycle) state, the debug state is CLOSED. The debug authentication procedure allows a trusted debugger to reopen access without compromising sensitive information called the Root Of Trust (ROT).

Reopening the debug is possible only if sensitive asset security is ensured (and TrustZone is enabled (TZEN = 0xB4). This is called Constrained-Debug, as constraints ensure the security of the ROT information.

Alternatively, a partial or full regression mechanism can be used when security of sensitive information cannot be guaranteed. This is called regression, as regression ensures removal of the sensitive information before reopening the debug.

- Partial regression corresponds to releasing nonsecure code and assets. The intermediate state, which allows partial regression management is called NS-regression.
- Full regression corresponds to releasing all code and assets. The intermediate state allowing full regression management is called regression.

Debug authentication control principle

The debug authentication is one of the most critical security features of the system considering that with a debugger the user can access a large part of the system.

To control the reopening of the debug, the device imposes a debug authentication protocol.

The protocol implements a challenge response mechanism based on asymmetric cryptography to authenticate the host. It relies on a key pair, with a public key stored in the device, and a private key from the host library, used to sign a random value (the challenge) generated by the device.

The protocol implements a bidirectional communication between the host and the device through a mailbox interface located in the DBGMCU.

The host can write to the mailbox via the JTAG/SWD interface. It expects to get responses and messages from the device via the same mailbox.

The debug authentication protocol is launched on a power-on reset of the device, when an “open request” message is posted by the host.

The protocol is based on:

- Initial message: posted by the host combined with a reset to launch the debug authentication process on the device.
- Challenge message: the device generates a random value, to be signed by the host, when sending back the response.
- Response: the host sends a message to the device proving its authenticity. This is done using a tool to generate a token.

The implementation is ensured by code embedded in the system flash. This code is called automatically after reset if an initial message has been posted by the host in the mailbox.

After a first sequence of mutual authentication to align on protocol version, type of device, and similar parameters, the device generates a random value that to be signed by the host with a private key when building the response.

The STMicroelectronics implementation is based on the Arm® PSA-ADAC solution for debug authentication.

The debug authentication can be implemented using a proprietary or open-source protocol.

As this feature is critical for security, the STM32H5 devices come with debug authentication provisioned in system flash. STMicroelectronics provides the host tools integrated with some debug environments (IDEs).

Debug authentication provisioning

Debug authentication is natively supported by the STM32H5 platform. The data used by ST debug authentication (ST-DA) must be provisioned at a defined location in the secure key storage area (OBKeys defined in flash memory).

The debug authentication configuration must be done only when the PRODUCT_STATE is “Provisioning”, cannot be performed when PRODUCT_STATE is “Open”.

The following data must be provisioned (refer to *Section 7.7.2: RSS user functions*):

- Data must be provisioned at the very beginning of the OBK_HDPL1 mapping (0x0FFD 0100) (see *Section 7.5.2: OBK access per HDPL level*)
- RSS_Lib encryption option must be set for STM32H5Fxxx devices
- RSS_Lib encryption option must be reset for STM32H5Exxx devices

The data to provision are defined in *Table 844*. They depend upon the TZEN option byte setting (enabled or disabled).

Table 844. Definition of data to provision

Data size	TZEN enabled (certificates)	TZEN disabled (password: only full regression is allowed)
32 bytes	SHA256 of the overall blob (i.e. the two next fields)	
	SHA256 of the ROT certificate public key	SHA256 of the password
16 bytes	128-bis permission mask (see *Table 845*)	128 bits are reserved, to be set to 0

Caution: Configure debug authentication as explained above before changing to states different from Open or Provisioning.

Table 845. Permission mask (Endianness: Little Endian)

Bit(s)	Description
Bit 0	When set it allows Intrusive debug from HDPL1 – NS
Bit 1	When set it allows Intrusive debug from HDPL2 – NS
Bit 2	When set it allows Intrusive debug from HDPL3 – NS
Bit 3	Reserved
Bit 4	When set it allows Intrusive debug from HDPL1 – S
Bit 5	When set it allows Intrusive debug from HDPL2 – S
Bit 6	When set it allows Intrusive debug from HDPL3 – S
Bits 7:11	Reserved
Bit 12	Regression to TZ-Closed, when 1 regression to TZ-Closed is allowed
Bit 13	Reserved
Bit 14	Regression (Full regression), when 1 full regression is allowed
Bit 15:127	Reserved

71.3 Serial-wire and JTAG debug port (SWJ-DP)

The SWJ-DP is a CoreSight™ component that implements an external access port for connecting debugging equipment.

Two types of interface can be configured:

- A 5-pin standard JTAG interface (JTAG-DP)
- A 2-pin (clock + data) serial-wire debug port (SW-DP)

These two modes are mutually exclusive, since they share the same IO pins.

By default, the JTAG-DP is selected after a system or a power-on reset. The five IO pins are configured by hardware in debug alternative function mode. The SWJ-DP incorporates pull-up resistors on JTDI, JTMS/SWDIO, and nJTRST, as well as a pull-down resistor on JTCK/SWCLK.

A debugger can select the SW-DP by transmitting the following serial data sequence on JTMS/SWDIO:

... (50 or more ones) ..., 0, 1, 1, 1, 1, 0, 0, 1, 1, 1, 1, 0, 0, 1, 1, 1, ... (50 or more ones) ...

JTCK/SWCLK must be cycled for each data bit.

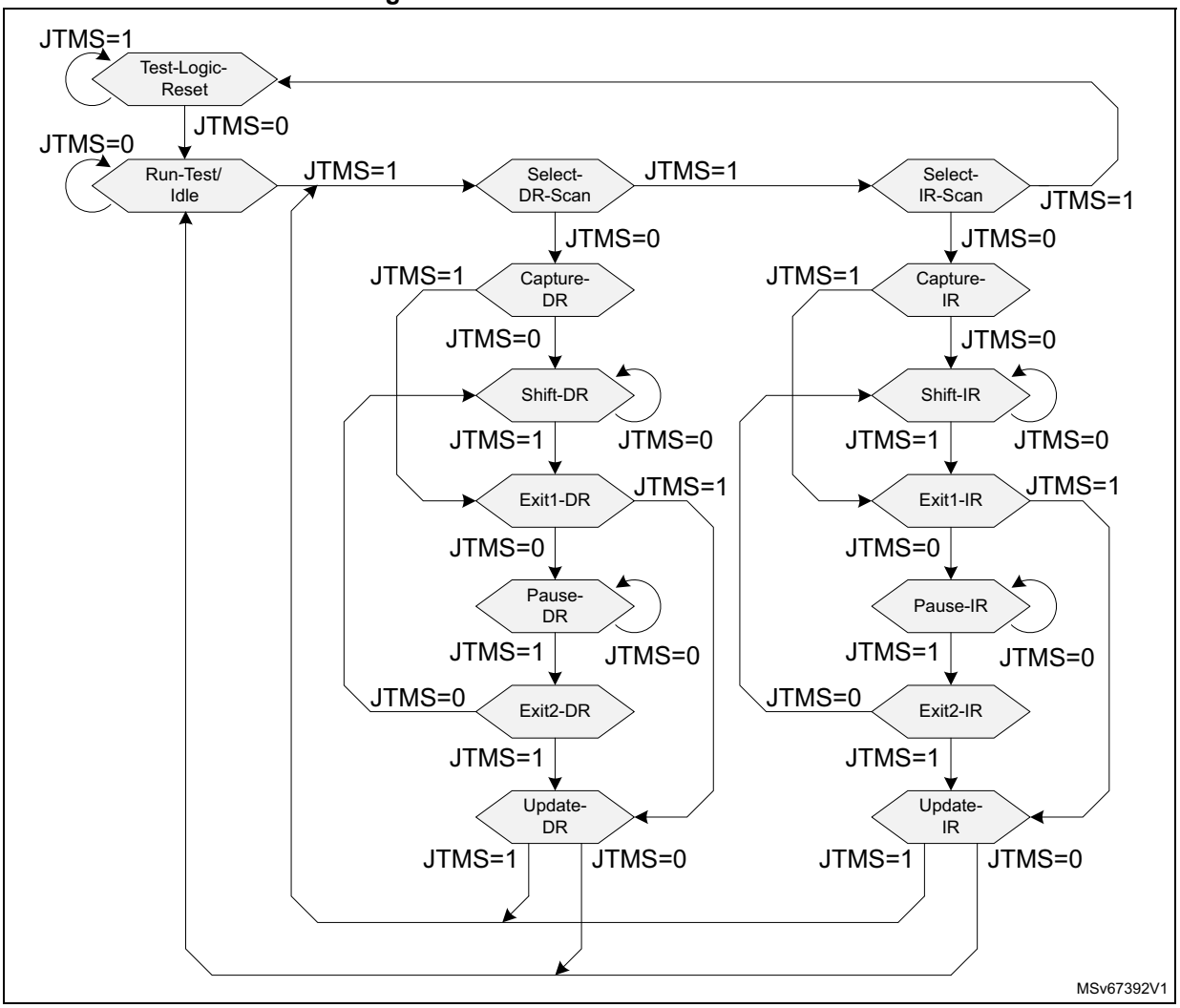
In SW-DP mode, the unused JTAG pins JTDI, JTDO, and nJTRST can be used for other functions.

Note: All SWJ port IOs can be reconfigured to other functions by software, but debugging is no longer possible.

71.3.1 JTAG debug port

The JTAG-DP implements a TAP state machine (TAPSM), shown in the figure below, based on IEEE Std 1149.1-1990. The state machine controls two scan chains, one associated with an instruction register (IR) and the other one with a number of data registers (DR).

Figure 1038. JTAG TAP state machine



The operation of the JTAG-DP is as follows:

1. When the TAPSM goes through the Capture-IR state, 0b0001 is transferred to the instruction register (IR) scan chain. The IR scan chain is connected between JTDI and JTDO.
2. While the TAPSM is in the Shift-IR state, the IR scan chain shifts one bit for each rising edge of JTCK. This means that on the first tick:
   – The LSB of the IR scan chain is output on JTDO.
   – Bit[n] of the IR scan chain is transferred to bit[n-1].
   – The value on JTDI is transferred to the MSB of the IR scan chain.
3. When the TAPSM goes through the Update-IR state, the value scanned into the IR scan chain is transferred to the instruction register.
4. When the TAPSM goes through the Capture-DR state, a value is transferred from one of the data registers to one of the DR scan chains, connected between JTDI and JTDO.
5. The value held in the instruction register determines which data register, and associated DR scan chain, are selected.
6. This data is then shifted while the TAPSM is in the Shift-DR state, in the same manner as the IR shifts in the Shift-IR state.
7. When the TAPSM goes through the Update-DR state, the value scanned into the DR scan chain is transferred to the selected data register.
8. When the TAPSM is in the Run-Test/Idle state, no special action occurs. The IDCODE instruction is loaded in IR.

When active, the nJTRST signal resets the state machine asynchronously to the test-logic-reset state.

The data registers corresponding to the 4-bit IR instructions are listed in the table below.

Table 846. JTAG-DP data registers

IR instruction	DR register	Scan chain length	Description
0000 to 0111	(BYPASS)	1	Not implemented: BYPASS selected
1000	ABORT	35	ABORT register – bits 34:3 = APABORT[31:0]: Write 0x0000 0001 to abort an ongoing access port transaction – bits 2:1 = A[3:2] = 00 – bit 0 = RnW = 0: write only
1001	(BYPASS)	1	Reserved: BYPASS selected

Table 846. JTAG-DP data registers (continued)

IR instruction	DR register	Scan chain length	Description
1010	DPACC	35	Debug port access register Initiates the debug port and gives access to a debug port register. – When transferring data IN: bits 34:3 = DATA[31:0] = 32-bit data to transfer for a write request bits 2:1 = A[3:2] = 2-bit address of a debug port register bit 0 = RnW = read request (1) or write request (0) – When transferring data OUT: bits 34:3 = DATA[31:0] = 32-bit data read following a read request bits 2:0 = ACK[2:0] = 3-bit Acknowledge: – 010 = OK/FAULT – 001 = WAIT – others = reserved
1011	APACC	35	Access port access register Initiates an access port and gives access to an access port register. – When transferring data IN: bits 34:3 = DATA[31:0] = 32-bit data to shift in for a write request bits 2:1 = A[3:2] = 2-bit sub-address of an access port register bit 0 = RnW= Read request (1) or write request (0) – When transferring data OUT: bits 34:3 = DATA[31:0] = 32-bit data read following a read request bits 2:0 = ACK[2:0] = 3-bit Acknowledge: – 010 = OK/FAULT – 001 = WAIT – others= reserved
1100	(BYPASS)	1	Reserved: BYPASS selected
1101	(BYPASS)	1	Reserved: BYPASS selected
1110	IDCODE	32	Identification code 0x6BA0 0477: Cortex®-M33 JTAG debug port ID code
1111	BYPASS	1	Bypass A single JTCK cycle delay is inserted between JTDI and JTDO.

The DR registers are described in more detail in the Arm® Debug Interface Architecture Specification (see *Section 71.13*).

71.3.2 Serial-wire debug port

The serial-wire debug protocol uses the following pins:

- SWCLK: clock from host to target
- SWDIO: bi-directional serial data (100 kΩ pull-up required)

Serial data is transferred LSB first, synchronously with the clock.

A transfer comprises three phases:

1. Packet request (8 bits) transmitted by the host, see *Table 847*
2. Acknowledge response (3 bits) transmitted by the target, see *Table 848*
3. Data transfer (33 bits) transmitted by the host (in case of a write) or target (in case of a read), see *Table 849*

The data transfer only occurs if the acknowledge response is OK.

Between each phase, if the direction of the data is reversed, a single clock-cycle turn-around time is inserted.

Table 847. Packet request

Bit field	Name	Description
0	Start	Must be 1
1	APnDP	– 0: DP register access - see *Section 71.3.3* – 1: AP register access - see *Section 71.4*
2	RnW	– 0: write request – 1: read request
4:3	A(3:2)	Address field of the DP or AP register (refer to *Table 851* or *Table 853*)
5	Parity	Single bit parity of preceding bits
6	Stop	0
7	Park	Not driven by host, must be read as 1 by target

Table 848. ACK response

Bit field	Name	Description
2:0	ACK	– 000: FAULT – 010: WAIT – 100: OK

Table 849. Data transfer

Bit field	Name	Description
31:0	WDATA or RDATA	Write or read data
32	Parity	Single-bit parity of 32 data bits

In the case of a FAULT or WAIT ACK response from the target, the data transfer phase is canceled, unless overrun detection is enabled: in this case, the data is ignored by the target (in the case of a write), or not driven (in the case of a read).

A line reset must be generated by the host when it is first connected, or following a protocol error. The line reset consists in 50 or more SWCLK cycles with SWDIO high, followed by two SWCLK cycles with SWDIO low.

For more details on the serial-wire debug protocol, refer to the Arm® Debug Interface Architecture Specification *[1]*.

Note: The SWJ-DP implements SWD protocol version 2.

71.3.3 Debug port registers

Both the SW-DP and the JTAG-DP access the debug port (DP) registers listed in *Table 851*.

The debugger can access the DP registers as follows:

1. Program the A(3:2) field in the DPACC register, if using JTAG, with the register address within the bank. Program the RnW bit to select a read or write. In the case of a write, program the data field with the write data. If using SWD, the A(3:2) and RnW fields are part of the packet request word sent to the SW-DP with the APnDP bit reset (see *Table 847*). The write data are sent in the data phase.
2. To access one of the banked DP registers at address 0x4, the register number must first be written to the DP_SELECTR register at address 0x8. Any subsequent read or write to address 0x4 accesses the register corresponding to the contents of the DP_SELECTR register.

Table 850. Debug port registers

Address	A(3:2) value	R/W	Description
0x0	00	R	*DP debug port identification register (DP_DPIDR)* contains the IDCODE for the debug port.
		W	*DP abort register (DP_ABORTR)*(1) aborts the current AP transaction. This register is also used to clear the error flags in the DP_CTRLSTATR register.
0x4	01	R/W	If DP_SELECTR.DPBANKSEL[3:0] = 0x0, *DP control and status register (DP_CTRLSTATR)* controls the DP and provides status information.
			If DP_SELECTR.DPBANKSEL[3:0] = 0x1, *DP data link control register (DP_DLCR)*(2) controls the operating mode of the SWD data link.
			If DP_SELECTR.DPBANKSEL[3:0] = 0x2, *DP target identification register (DP_TARGETIDR)* provides target identification information.
			If DP_SELECTR.DPBANKSEL[3:0] = 0x3, *DP data link protocol identification register (DP_DLPIDR)*(2) provides the SWD protocol version.
0x8	10	R	*DP event status register (DP_RESENDR)*(2) returns the value that was returned by the last AP read or DP_RDBUFF read. Used in the event of a corrupted read transfer.
		W	*DP access port select register (DP_SELECTR)* selects the access port, access port register bank, and DP register at address 0x4.
0xC	11	R	*DP read buffer register (DP_RDBUFFR)* – Via JTAG-DP, this register allows the debugger to get the final result after a sequence of operations (without requesting new JTAG-DP operation) – Via SW-DP, this register contains the result of the preceding AP read access, allowing a new AP access to be avoided.

1. Access to the AP ABORT register from the JTAG-DP is done using the ABORT instruction.
2. Only accessible via SW-DP. Register is “reserved” via JTAG-DP.

DP debug port identification register (DP_DPIDR)

Address offset: 0x0

Reset value: 0x6BA0 2477

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REVISION[3:0]				PARTNO[7:0]								Res.	Res.	Res.	MIN
r	r	r	r	r	r	r	r	r	r	r	r				r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VERSION[3:0]				DESIGNER[10:0]											Res.
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	

Bits 31:28 **REVISION[3:0]**: revision code
0x6: Rev 6

Bits 27:20 **PARTNO[7:0]**: part number for the debug port
0xBA

Bits 19:17 Reserved, must be kept at reset value.

Bit 16 **MIN**: minimal debug port (MINDP) implementation
0x0: MINDP not implemented

Bits 15:12 **VERSION[3:0]**: debug port architecture version
0x2: DPv2

Bits 11:1 **DESIGNER[10:0]**: JEDEC designer identity code
0x23B: Arm® JEDEC code

Bit 0 Reserved, must be kept at reset value.

DP abort register (DP_ABORTR)

Address offset: 0x0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ORUNERRCLR	WDERRCLR	STKERRCLR	Res.	DAPABORT
											w	w	w		w

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **ORUNERRCLR**: overrun error clear
0: no effect
1: STICKYORUN bit cleared in DP_CTRL/STATR register

Bit 3 **WDERRCLR**: write data error clear
0: no effect
1: WDATAERR bit cleared in DP_CTRL/STATR register

Bit 2 **STKERRCLR**: sticky error clear
0: no effect
1: STICKYERR bit cleared in DP_CTRL/STATR register

Bit 1 Reserved, must be kept at reset value.

Bit 0 **DAPABORT**: current AP transaction aborted if excessive number of WAIT responses returned
This bit indicates that the transaction is stalled.
0: no effect
1: transaction aborted

DP control and status register (DP_CTRLSTATR)

Address offset: 0x4

Reset value: 0x0000 0000

This register is accessible when DP_SELECTR.DPBANKSEL[3:0] = 0x0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	CDBGPWRUPACK	CDBGPWRUPREQ	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
		r	r												

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDATAERR	READOK	STICKYERR	Res.	Res.	Res.	STICKYORUN	ORUNDETECT
								r	r	r				r	r

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **CDBGPWRUPACK**: debug power-up acknowledge
See description in *Section 71.2.5: Debug and low-power modes*.
0: DCLK gated
1: DCLK enabled

Bit 28 **CDBGPWRUPREQ**: debug power-up request
This bit controls the DCLK enable request signal.
0: requests DCLK gating
1: requests DCLK enable

Bits 27:8 Reserved, must be kept at reset value.

Bit 7 **WDATAERR**: write data error (read-only) in SW-DP

This bit indicates that there is a parity or framing error on the data phase of a write, or a write accepted by the DP is then discarded without being submitted to the AP.

This bit is reset by writing 1 to the ABORT.WDERRCLR bit.

0: no error

1: an error occurred

Note: This bit is reserved in JTAG-DP.

Bit 6 **READOK**: AP read response (read-only) in SW-DP

This bit indicates the response to the last AP read access.

0: read not OK

1: read OK

Note: This bit is reserved in JTAG-DP.

Bit 5 **STICKYERR**: transaction error (read-only in SW-DP, read/write in JTAG-DP)

This bit indicates that an error occurred in an AP transaction.It is reset by writing 1 to the DP_ABORTR.STKERRCLR bit (in SW-DP and JTAG-DP)

0: no error

1: an error occurred

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **STICKYORUN**: overrun (read-only in SW-DP, read/write in JTAG-DP).

This bit indicates that an overrun occurred (new transaction received before previous transaction completed). This bit is only set if the ORUNDETECT bit is set. it is reset by writing 1 to the DP_ABORTR.ORUNERRCLR bit (in SW-DP and JTAG-DP).

0: no overrun

1: an overrun occurred

Bit 0 **ORUNDETECT**: overrun detection mode enable.

0: disabled

1: enabled. In the event of an overrun, the STICKYORUN bit is set and subsequent transactions are blocked until the STICKYORUN bit is cleared.

DP data link control register (DP_DLCR)

Address offset: 0x4

Reset value: 0x0000 0000

This register is accessible when DP_SELECTR.DPBANKSEL[3:0] = 0x1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	TURNROUND[1:0]		WIREMODE[1:0]		Res.	Res.	Res.	Res.	Res.	Res.
						r	r	r	r						

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:8 **TURNROUND[1:0]**: tristate period for SWDIO
0x0: 1 data bit period

Bits 7:6 **WIREMODE[1:0]**: SW-DP mode
0x0: synchronous mode

Bits 5:0 Reserved, must be kept at reset value.

DP target identification register (DP_TARGETIDR)

Address offset: 0x4

Reset value: 0xXXXX 0041

This register is accessible when DP_SELECTR.DPBANKSEL[3:0] = 0x2.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TREVISION[3:0]				TPARTNO[15:4]											
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TPARTNO[3:0]				TDESIGNER[10:0]											Res.
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	

Bits 31:28 **TREVISION[3:0]**: target revision

Bits 27:12 **TPARTNO[15:0]**: target part number
0x47A0: STM32H5Ex/Fx

Bits 11:1 **TDESIGNER[10:0]**: target designer JEDEC code
0x020: STMicroelectronics

Bit 0 Reserved, must be kept at reset value.

DP data link protocol identification register (DP_DLPIDR)

Address offset: 0x4

Reset value: 0x0000 0001

This register is accessible when DP_SELECTR.DPBANKSEL[3:0] = 0x3.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TINSTANCE[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r												
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PROTSVN[3:0]			
												r	r	r	r

Bits 31:28 **TINSTANCE[3:0]**: target instance number
this field defines the instance number for the device in a multi-drop system.
0x0: instance number 0

Bits 27:4 Reserved, must be kept at reset value.

Bits 3:0 **PROTSVN[3:0]**: Serial-wire debug protocol version
0x1: version 2

DP event status register (DP_RESENDR)

Address offset: 0x8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RESEND[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESEND[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RESEND[31:0]**: value returned by the last AP read or DP_RDBUFF read
This register is used in the event of a corrupted read transfer.

DP access port select register (DP_SELECTR)

Address offset: 0x8

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
APSEL[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
w	w	w	w	w	w	w	w								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APBANKSEL[3:0]				DPBANKSEL[3:0]			
								w	w	w	w	w	w	w	w

Bits 31:24 **APSEL[7:0]**: access port select
This field selects the access port for the next transaction.
0x00: AP0 - System debug access port (APB-AP)
0x01: AP1 - Cortex®-M33 debug access port (AHB-AP)
Others: reserved

Bits 23:8 Reserved, must be kept at reset value.

Bits 7:4 **APBANKSEL[3:0]**: AP register bank select
This field selects the 4-word register bank on the active AP for the next transaction.

Bits 3:0 **DPBANKSEL[3:0]**: DP register bank select
This field selects the register at address 0x4 of the debug port.
0x0: DP_CTRLSTAT register
0x1: DP_DLCR register
0x2: DP_TARGETID register
0x3: DP_DLPIDR register
Others: reserved

DP read buffer register (DP_RDBUFFR)

Address offset: 0xC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDBUFF[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDBUFF[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RDBUFF[31:0]**: value returned by the last AP read access

The value returned by an AP read access can be obtained using a second read access to the same address (initiates a new transaction on the corresponding bus), or can be read from this register, in which case no new AP transaction occurs.

71.3.4 Debug port register map and reset values

These registers are not on the CPU memory bus, they are accessed only through the SW-DP and JTAG-DP debug interface.

The debug port address offset is 4-bit wide, where the two most significant bits are defined in the JTAG-DP register DPACC or SW-DP packet request A[3:2] field. The two least significant bits are 00.

Table 851. Debug port register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0	**DP_DPIDR**	REVISION [3:0]				PARTNO[7:0]								Res.	Res.	Res.	MIN	VERSION [3:0]				DESIGNER[10:0]											Res.
	Reset value	0	1	1	0	1	0	1	1	1	0	1	0				0	0	0	1	0	0	1	0	0	0	1	1	1	0	1	1	1
0x0	**DP_ABORTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ORUNERRCLR	WDERRCLR	STKERRCLR	Res.	DAPABORT
	Reset value																												0	0	0		0
0x4(1)	**DP_CTRLSTATR**	Res.	Res.	CDBGPWRUPACK	CDBGPWRUPREQ	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDATAERR	READOK	STICKYERR	Res.	Res.	Res.	STICKYORUN	ORUNDETECT
	Reset value			0	0																					0	0	0				0	0
0x4(2)	**DP_DLCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TURNROUND[1:0]		WIREMODE[1:0]		Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																							0	0	0	0						

Table 851. Debug port register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x4[3]	**DP_TARGETIDR**	TREVISION[3:0]				TPARTNO[15:0]																TDESIGNER[10:0]											Res.
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0	0	0	0	0	0	0	0	1	0	0	0	0	0	
0x4[4]	**DP_DLPIDR**	TINSTANCE[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PROTSVN[3:0]			
	Reset value	0	0	0	0																									0	0	0	1
0x8	**DP_RESENDR**	RESEND[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x8	**DP_SELECTR**	APSEL[7:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APBANKSEL[3:0]				DPBANKSEL[3:0]			
	Reset value	x	x	x	x	x	x	x	x																	x	x	x	x	x	x	x	x
0xC	**DP_RDBUFFR**	RDBUFF[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1. DP_SELECTR.DPBANKSEL[3:0] = 0x0.
2. DP_SELECTR.DPBANKSEL[3:0] = 0x1.
3. DP_SELECTR.DPBANKSEL[3:0] = 0x2.
4. DP_SELECTR.DPBANKSEL[3:0] = 0x3.

71.4 Access ports

There are two access ports (AP) attached to the DP.

- System debug access port (AP0): Enables access to the DBGMCU and the system ROM table via an APB bus.
- Cortex®-M33 debug access port (AP1): Enables access to the debug and trace features integrated in the Cortex®-M33 processor core via its internal AHB bus.

71.4.1 Access port registers

The access ports are of type MEM-AP: the debug and trace component registers are mapped in the address space of the AHB. The AP is seen by the debugger as a set of 32-bit registers organized in banks of four registers each. Some of these registers are used to configure or monitor the AP itself, while others are used to perform a transfer on the bus. The AP registers are listed in *Table 853*.

The address of the AP registers is composed of the following fields:

- bits [7:4]: content of the APBANKSEL[3:0] field in the *DP access port select register (DP_SELECTR)*)
- bits [3:2]: content of the A(3:2) field of the APACC data register in the JTAG-DP (see *Table 846*), or of the SW-DP packet request (see *Table 847*), depending on the debug interface used
- bits [1:0]: always set to 0

The content of the DP_SELECTR.APSEL[3:0] field defines which MEM-AP is being accessed.

Table 852. MEM-AP registers

Address	APBANKSEL	A(3:2)	Name	Description
0x00	0x0	0	CSWR	Control/status word register
0x04	0x0	1	TAR	Transfer address register Target address for the bus transaction.
0x08	-	-	-	Reserved
0x0C	0x0	3	DRWR	Data read/write register Access to this register triggers a corresponding transaction on the debug bus to the address in TAR[31:0]
0x10	0x1	0	BD0R	Banked data 0 register Access to this register triggers a corresponding transaction on the debug bus to the address in TAR[31:4] + 0x0.
0x14	0x1	1	BD1R	Banked data 1 register Access to this register triggers a corresponding transaction on the debug bus to the address in TAR[31:4] + 0x4.
0x18	0x1	2	BD2R	Banked data 2 register Access to this register triggers a corresponding transaction on the debug bus to the address in TAR[31:4] + 0x8.
0x1C	0x1	3	BD3R	Banked data 3 register Access to this register triggers a corresponding transaction on the debug bus to the address in TAR[31:4] + 0xC.
0x20	-	-	-	Reserved
0x24 to 0xEC	-	-	-	Reserved
0xF0	-	-	-	Reserved
0xF4	0xF	1	CFGR	Configuration register (read only)
0xF8	0xF	2	BASER	Debug base address register (read only) Base address of the ROM table
0xFC	0xF	3	IDR	Identification register (read only)

The debugger can access the AP registers as follows:

1. Program the APSEL[3:0] field in the *DP access port select register (DP_SELECTR)* to choose the AP, and the APBANKSEL[3:0] field in DP_SELECTR to select the register bank to be accessed.
2. Program the A(3:2) field in the APACC data register, if using JTAG, with the register address within the bank. Program the RnW bit to select a read or write. In the case of a write, program the DATA field with the write data. If using SWD, the A(3:2) and RnW fields are part of the packet request word sent to the SW-DP with the APnDP bit set (see *Table 847*). The write data is sent in the data phase.

The debugger can access the memory mapped debug component registers through the AP registers (using the above AP register access procedure) as follows:

1. Program the transaction target address in the *APx transfer address register (APx_TAR) (x = 0, 1)*.
2. Program the *AP1 control/status word register (AP1_CSWR)*, if necessary, with the transfer parameters (AddrInc for example).
3. Write to or read from the *APx data read/write register (APx_DRWR) (x = 0, 1)* to initiate a bus transaction at the address held in AP_TAR. Alternatively, a read or write to the *APx banked data n register (APx_BDnR) (x = 0, 1)* triggers an access to the TAR[31:4] + n address, allowing up to four consecutive addresses to be accessed without changing the address in the AP_TAR register.

For more detailed information on the MEM-AP, refer to the Arm® Debug Interface Architecture Specification *[1]*.

AP0 control/status word register (AP0_CSWR)

Address offset: 0x0

Reset value: 0x8000 0042

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DBGSWEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	MODE[3:0]				TRINPROG	DEVICEEN	ADDRINC[1:0]		Res.	SIZE[2:0]		
				rw	rw	rw	rw	r	r	rw	rw		r	r	r

Bit 31 **DBGSWEN**: software access enable
Enables or disables software access to the APB bus
0: disable software access
1: enable software access

Bits 30:12 Reserved, must be kept at reset value.

Bits 11:8 **MODE[3:0]**: mode of operation
0b0000: normal download or upload
other: reserved

Bit 7 **TRINPROG**: transfer in progress (read only)
This field indicates whether a transfer is currently in progress on the APB master port
0: no APB transfer in progress
1: APB transfer in progress

Bit 6 **DEVICEEN**: device enable status (read only)
1: APB transfers always enabled

Bits 5:4 **ADDRINC[1:0]**: auto-increment mode
Defines whether TAR address is automatically incremented after a transaction.
0x0: no auto-increment
0x1: address incremented by the size in bytes of the transaction (SIZE field)
other: reserved

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **SIZE[2:0]**: size of next memory access transaction
0x2: word (32-bit)

AP1 control/status word register (AP1_CSWR)

Address offset: 0x0

Reset value: 0x43X0 00X2

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	SPROT	Res.	Res.	PROT[3:0]				SPISTATUS	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw			rw	rw	rw	rw	r							

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRINPROG	DBGSTATUS	ADDRINC[1:0]		Res.	SIZE[2:0]		
								r	r	rw	rw		rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **SPROT**: Secure transfer request
This field sets the protection attribute HPROT[6] of the bus transfer.
0: Secure transfer, HPROT[6] = low
1: Nonsecure transfer, HPROT[6] = high
If SPIDEN = 0 and SPROT = 0, no bus transfer occurs

Bits 29:28 Reserved, must be kept at reset value.

Bits 27:24 **PROT[3:0]**: bus transfer protection
This field sets the protection attributes HPROT[3:0] of the bus transfer.
0bXXX0: Instruction access
0bXXX1: Data access
0bXX0X: User mode
0bXX1X: Privilege mode
0bX0XX: Non-bufferable
0bX1XX: Bufferable
0b0XXX: Non-shareable, no look-up, non-modifiable
0b1XXX: Shareable, look-up, modifiable

Bit 23 **SPISTATUS**: secure debug authentication status
This field indicates the state of the SPIDEN signal
0: No secure AHB transfers allowed
1: Secure AHB transfers allowed

Bits 22:8 Reserved, must be kept at reset value.

Bit 7 **TRINPROG**: transfer in progress (read only)
This field indicates whether a transfer is currently in progress on the APB master port
0: No AHB transfer in progress
1: AHB transfer in progress

Bit 6 **DBGSTATUS**: debug enable (DBGEN) status
0: AHB transfers blocked
1: AHB transfers enabled

Bits 5:4 **ADDRINC[1:0]**: auto-increment mode
Defines whether TAR address is automatically incremented after a transaction.
0x0: no auto-increment
0x1: address incremented by the size of the transaction (SIZE field), in bytes. Single transfer.
0x2: address incremented by the size of the transaction (SIZE field), in bytes. Packs four 8-bit or two 16-bit transfers into a 32-bit DAP transfer. Multiple transactions are carried out on the AHB interface.
Others: reserved

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **SIZE[2:0]**: size of next memory access transaction
0x0: byte (8-bit)
0x1: halfword (16-bit)
0x2: word (32-bit)
Others: reserved

APx transfer address register (APx_TAR) (x = 0, 1)

Address offset: 0x04

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TA[31:0]**: address of current transfer. In AP0, TA[1:0] are fixed at 0.

APx data read/write register (APx_DRWR) (x = 0, 1)

Address offset: 0x0C

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TD[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TD[31:0]**: data of current transfer

APx banked data n register (APx_BDnR) (x = 0, 1)

Address offset: 0x10 + 0x4 * n, (n = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DATA[31:0]:** banked data of current transfer to address TA [31:4] + 4 * n.
Auto address incrementing is not performed on APx_BD0-3R. Banked transfers are only supported for word transfers.

APx base address register (APx_BASER) (x = 0, 1)

Address offset: 0xF8

Reset value: AP 0: 0xE00E 0003

Reset value: AP 1: 0xE00F E003

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BASEADDR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BASEADDR[15:12]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FORMAT	ENTRYPRESENT
r	r	r	r											r	r

Bits 31:12 **BASEADDR[31:12]**: base address (bits 31 to 12) of the first ROM table
The 12 LSBs are zero since the ROM table must be aligned on a 4-Kbyte boundary.
0xE00E0: AP0
0xE00FE: AP1

Bits 11:2 Reserved, must be kept at reset value.

Bit 1 **FORMAT**: base-address register format
1: Arm® debug interface v5

Bit 0 **ENTRYPRESENT**: debug components presence
Indicates that debug components are present on the access port bus.
1: debug components present

APx identification register (APx_IDR) (x = 0, 1)

Address offset: 0xFC

Reset value: AP 0: 0x5477 0002

Reset value: AP 1: 0x8477 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REVISION[3:0]				JEDECBANK[3:0]				JEDECCODE[6:0]							CLASS[3]
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CLASS[2:0]			Res.	Res.	Res.	Res.	Res.	IDENTITY[7:0]							
r	r	r						r	r	r	r	r	r	r	r

Bits 31:28 **REVISION[3:0]**: revision number
0x5: r1p0
0x8: r0p9

Bits 27:24 **JEDECBANK[3:0]**: JEDEC bank
0x4: Arm®

Bits 23:17 **JEDECCODE[6:0]**: JEDEC code
0x3B: Arm®

Bits 16:13 **CLASS[3:0]**:
0x1: MEM-AP

Bits 12:8 Reserved, must be kept at reset value.

Bits 7:0 **IDENTITY[7:0]**:
0x1: AHB-AP
0x2: APB-AP

71.4.2 Access port register map

These registers are not on the CPU memory bus, they are only accessed through SW-DP and JTAG-DP debug interfaces.

The access port address is 8-bit wide, defined by DP_SELECTR.APBANKSEL[3:0] field and by JTAG-DP register DPACC or SW-DP packet request A[3:2] field.

Table 853. Access port register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**AP0_CSWR**	DBGSWEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE[3:0]				TRINPROG	DEVICEEN	ADDRINC[1:0]		Res.	SIZE[2:0]		
	Reset value	1																				0	0	0	0	0	1	0	0		0	1	0
0x00	**AP1_CSWR**	Res.	SPROT	Res.	Res.	PROT[3:0]				SPISTATUS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE[3:0]				TRINPROG	DBGSTATUS	ADDRINC[1:0]		Res.	SIZE[2:0]		
	Reset value		1			0	0	1	1	X												0	0	0	0	0	X	0	0		0	1	0
0x04	**APx_TAR**	TA[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x08	Reserved	Reserved																															
0x0C	**APx_DRWR**	TD[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x10	**APx_BD0R**	DATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	**APx_BD1R**	DATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	**APx_BD2R**	DATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	**APx_BD3R**	DATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20 to 0xF4	Reserved	Reserved																															
0xF8	**AP0_BASER**	BASEADDR[31:12]																				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FORMAT	ENTRYPRESENT
	Reset value	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0										1	1
0xF8	**AP1_BASER**	BASEADDR[31:12]																				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FORMAT	ENTRYPRESENT
	Reset value	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0										1	1

Table 853. Access port register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFC	**AP0_IDR**	REVISION[3:0]				JEDECBANK[3:0]				JEDECCODE[6:0]							CLASS[3:0]				Res.	Res.	Res.	Res.	Res.	IDENTITY[7:0]							
	Reset value	0	1	0	1	0	1	0	0	0	1	1	1	0	1	1	1	0	0	0						0	0	0	0	0	0	1	0
0xFC	**AP0_IDR**	REVISION[3:0]				JEDECBANK[3:0]				JEDECCODE[6:0]							CLASS[3:0]				Res.	Res.	Res	Res.	Res.	IDENTITY[7:0]							
	Reset value	1	0	0	0	0	1	0	0	0	1	1	1	0	1	1	1	0	0	0						0	0	0	0	0	0	0	1

71.5 ROM tables

The ROM table is a CoreSight™ component that contains the base addresses of the CoreSight™ debug components accessible via the access port to which it is attached. These tables allow a debugger to discover the topology of the CoreSight™ system automatically.

There is one top-level ROM table behind each access port, APn. The base address of this ROM table can be obtained by reading the APn_BASER register of the access port. The top-level ROM table may point in turn to other ROM tables.

The system ROM table is pointed to by the AP0 base register, AP0_BASER. It contains the base address pointer for the DBGMCU.

The system ROM table occupies a 4-Kbyte, 32-bit wide chunk of address space, from 0xE00E 4000 to 0xE00E 4FFC, when accessed by the debugger. It can be accessed by the CPU at the address range 0x4402 4000 to 0x4402 4FFC.

Table 854. System ROM table

Address offset in ROM table	Component name	Component base address	Component address offset	Size (Kbytes)	Entry
0x000	DBGMCU	0xE00E 4000 (debugger) 0x4402 4000 (CPU)	0x0000 4000	4	0x0000 4003
0x004	Top of table	-	-	-	0x0000 0000
0x008 to 0xFC8	Reserved	-	-	-	0x0000 0000
0xFCC to 0xFFC	ROM table registers	-	-	-	See *Table 857*

There are two ROM tables in the CPU subsystem. The MCU ROM table is pointed to by the AP1 base register, AP1_BASER. It contains the base-address pointer for the processor ROM table and for the TPIU registers.

The MCU ROM table (see the table below) occupies a 4-Kbyte, 32-bit wide chunk of address space, from 0xE00F E000 to 0xE00F EFFC.

Table 855. MCU ROM table

Address offset in ROM table	Component name	Component base address	Component address offset	Size (Kbytes)	Entry
0x000	Processor ROM table	0xE00F F000	0x0000 1000	4	0x0000 1003
0x004	TPIU	0xE004 0000	0xFFF4 2000	4	0xFFF4 2003
0x008	Reserved	-	-	-	0x1FF0 2002
0x00C	Reserved	-	-	-	0x1FF0 2002
0x010	Top of table	-	-	-	0x0000 0000
0x014 to 0xFC8	Reserved	-	-	-	0x0000 0000
0xFCC to 0xFFC	ROM table registers	-	-	-	See *Table 858*

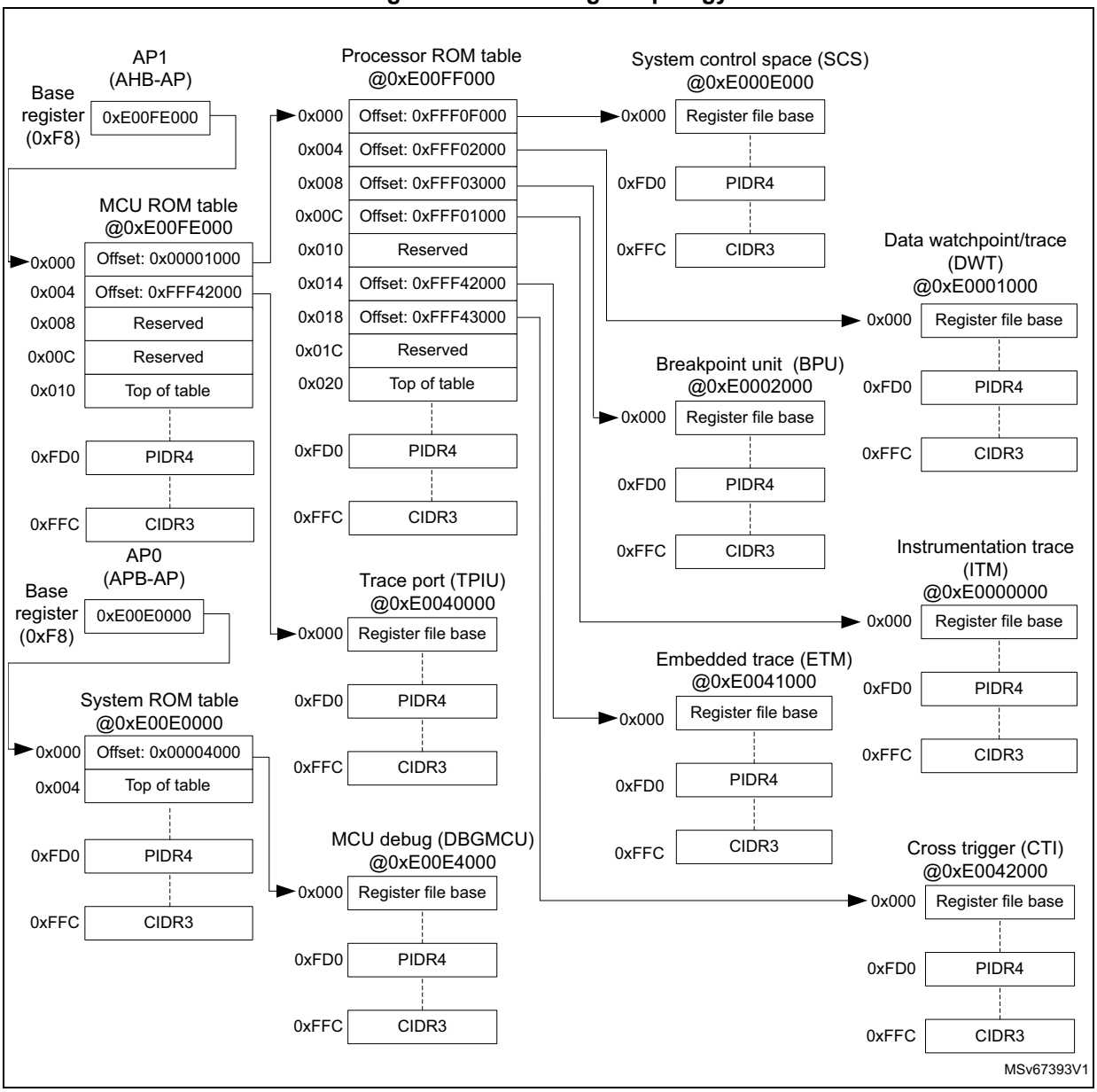
The processor ROM table contains the base-address pointer for the system control space (SCS) registers that allow the debugger to identify the CPU core, as well as for the BPU, DWT, ITM, ETM, and CTI.

The processor ROM table (see *Table 856*) occupies a 4-Kbyte, 32-bit wide chunk of address space, from 0xE00F F000 to 0xE00F FFFC.

Table 856. Processor ROM table

Address in ROM table	Component name	Component base address	Component address offset	Size (Kbytes)	Entry
0xE00F F000	SCS	0xE000 E000	0xFFF0 F000	4	0xFFF0 F003
0xE00F F004	DWT	0xE000 1000	0xFFF0 2000	4	0xFFF0 2003
0xE00F F008	BPU	0xE000 2000	0xFFF0 3000	4	0xFFF0 3003
0xE00F F00C	ITM	0xE000 0000	0xFFF0 1000	4	0xFFF0 1003
0xE00F F010	Reserved	-	-	-	0xFFF4 1002
0xE00F F014	ETM	0xE004 1000	0xFFF4 2000	4	0xFFF4 2003
0xE00F F018	CTI	0xE004 2000	0xFFF4 3000	4	0xFFF4 3003
0xE00F F01C	Reserved	-	-	-	0xFFF4 4002
0xE00F F020	Top of table	-	-	-	0x0000 0000
0xE00F F024 to 0xE00F FFC8	Reserved	-	-	-	0x0000 0000
0xE00F FFCC to 0xE00F FFFC	ROM table registers	-	-	-	See *Table 859*

Figure 1039. CoreSight topology



71.5.1 System ROM table registers

System ROM memory type register (SYSROM_MEMTYPER)

Address offset: 0xFCC

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
															r

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **SYSMEM**: system memory
0x1: system memory present on this bus

System ROM CoreSight™ peripheral identity register 4 (SYSROM_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SIZE[3:0]**: register file size
0x0: The register file occupies a single 4-Kbyte region.

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x0: STMicroelectronics JEDEC continuation code

System ROM CoreSight peripheral identity register 0 (SYSROM_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 00XX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: part number bits [7:0]
0x7A: STM32H5Ex/Fx

System ROM CoreSight peripheral identity register 1 (SYSROM_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code bits [3:0]
0x0: STMicroelectronics JEDEC code

Bits 3:0 **PARTNUM[11:8]**: part number bits [11:8]
0x4: STM32H5Ex/Fx

System ROM CoreSight peripheral identity register 2 (SYSROM_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000A

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: component revision number
0x0: rev r0p0

Bit 3 **JEDEC**: JEDEC assigned value
1: designer identification specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code bits [6:4]
0x2: STMicroelectronics JEDEC code

System ROM CoreSight peripheral identity register 3 (SYSROM_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: customer modified
0x0: No customer modifications

System ROM CoreSight component identity register 0 (SYSROM_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: component identification bits [7:0]
0x0D: Common identification value

System ROM CoreSight peripheral identity register 1 (SYSROM_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0010

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component identification bits [15:12] - component class
0x1: ROM table component

Bits 3:0 **PREAMBLE[11:8]**: Component identification bits [11:8]
0x0: Common identification value

System ROM CoreSight component identity register 2 (SYSROM_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: component identification bits [23:16]
0x05: common identification value

System ROM CoreSight component identity register 3 (SYSROM_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component identification bits [31:24]
0xB1: Common identification value

71.5.2 System ROM table register map

Table 857. System ROM table register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFCC	**SYSROM_ MEMTYPER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
	Reset value																																1
0xFD0	**SYSROM_PIDR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE [3:0]				JEP106CON [3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFD4 to FDC	Reserved	Reserved																															
0xFE0	**SYSROM_PIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value																									X	X	X	X	X	X	X	X
0xFE4	**SYSROM_PIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID [3:0]				PARTNUM [11:8]			
	Reset value																									0	0	0	0	X	X	X	X
0xFE8	**SYSROM_PIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION [3:0]				JEDEC	JEP106ID [6:4]		
	Reset value																									0	0	0	0	1	0	1	0
0xFEC	**SYSROM_PIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFF0	**SYSROM_CIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value																									0	0	0	0	1	1	0	1
0xFF4	**SYSROM_CIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE [11:8]			
	Reset value																									0	0	0	1	0	0	0	0
0xFF8	**SYSROM_CIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value																									0	0	0	0	0	1	0	1
0xFFC	**SYSROM_CIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value																									1	0	1	1	0	0	0	1

Refer to *Table 854* for register boundary addresses.

71.5.3 MCU ROM table registers

MCU ROM memory type register (MCUROM_MEMTYPER)

Address offset: 0xFCC

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
															r

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **SYSMEM**: system memory
0x1: system memory present on this bus

MCU ROM CoreSight peripheral identity register 4 (MCUROM_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SIZE[3:0]**: register file size
0x0: The register file occupies a single 4-Kbyte region.

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x0: STMicroelectronics JEDEC continuation code

MCU ROM CoreSight peripheral identity register 0 (MCUROM_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 00XX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: part number bits [7:0]
0x84: STM32H5

MCU ROM CoreSight peripheral identity register 1 (MCUROM_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code bits [3:0]
0x0: STMicroelectronics JEDEC code

Bits 3:0 **PARTNUM[11:8]**: part number bits [11:8]
0x4: STM32H5

MCU ROM CoreSight peripheral identity register 2 (MCUROM_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000A

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: component revision number
0x0: rev r0p0

Bit 3 **JEDEC**: JEDEC assigned value
1: designer identification specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code bits [6:4]
0x2: STMicroelectronics JEDEC code

MCU ROM CoreSight peripheral identity register 3 (MCUROM_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: customer modified
0x0: No customer modifications

MCU ROM CoreSight component identity register 0 (MCUROM_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: component identification bits [7:0]
0x0D: Common identification value

MCU ROM CoreSight peripheral identity register 1 (MCUROM_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0010

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component identification bits [15:12] - component class
0x1: ROM table component

Bits 3:0 **PREAMBLE[11:8]**: Component identification bits [11:8]
0x0: Common identification value

MCU ROM CoreSight component identity register 2 (MCUROM_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: component identification bits [23:16]
0x05: common identification value

MCU ROM CoreSight component identity register 3 (MCUROM_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component identification bits [31:24]
0xB1: Common identification value

71.5.4 MCU ROM table register map

Table 858. MCU ROM table register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFCC	**MCUROM_ MEMTYPER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
	Reset value																																1
0xFD0	**MCUROM_PIDR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE [3:0]				JEP106CON [3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFD4 to FDC	Reserved	Reserved																															
0xFE0	**MCUROM_PIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value																									X	X	X	X	X	X	X	X
0xFE4	**MCUROM_PIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID [3:0]				PARTNUM [11:8]			
	Reset value																									0	0	0	0	X	X	X	X
0xFE8	**MCUROM_PIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION [3:0]				JEDEC	JEP106ID [6:4]		
	Reset value																									0	0	0	0	1	0	1	0
0xFEC	**MCUROM_PIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFF0	**MCUROM_CIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value																									0	0	0	0	1	1	0	1
0xFF4	**MCUROM_CIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE [11:8]			
	Reset value																									0	0	0	1	0	0	0	0
0xFF8	MCUROM_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value																									0	0	0	0	0	1	0	1
0xFFC	MCUROM_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value																									1	0	1	1	0	0	0	1

Refer to *Table 855* for register boundary addresses.

71.5.5 Processor ROM table registers

CPU ROM memory type register (CPUROM_MEMTYPER)

Address offset: 0xFCC

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
															r

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **SYSMEM**: system memory
1: system memory present on this bus

CPU ROM CoreSight peripheral identity register 4 (CPUROM_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SIZE[3:0]**: register file size
0x0: The register file occupies a single 4-Kbyte region.

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: ARM® JEDEC continuation code

CPU ROM CoreSight peripheral identity register 0 (CPUROM_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 00C9

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number bits [7:0]
0xC9: Cortex®-M33

CPU ROM CoreSight peripheral identity register 1 (CPUROM_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00B4

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code bits [3:0]
0xB: ARM® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: part number bits [11:8]
0x4: Cortex®-M33

CPU ROM CoreSight peripheral identity register 2 (CPUROM_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: component revision number
0x0: rev r0p0

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code bits [6:4]
0x3: Arm® JEDEC code

CPU ROM CoreSight peripheral identity register 3 (CPUROM_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: customer modified
0x0: no customer modifications

CPU ROM CoreSight component identity register 0 (CPUROM_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component identification bits [7:0]
0x0D: Common identification value

CPU ROM CoreSight peripheral identity register 1 (CPUROM_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0010

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component identification bits [15:12] - component class
0x1: ROM table component

Bits 3:0 **PREAMBLE[11:8]**: Component identification bits [11:8]
0x0: Common identification value

CPU ROM CoreSight component identity register 2 (CPUROM_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: component identification bits [23:16]
0x05: common identification value

CPU ROM CoreSight component identity register 3 (CPUROM_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: component identification bits [31:24]
0xB1: common identification value

71.5.6 Processor ROM table register map

Table 859. CPU ROM table register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFCC	**CPUROM_ MEMTYPER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
	Reset value																																1
0xFD4 to FDC	Reserved	Reserved																															
0xFD0	**CPUROM_PIDR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE [3:0]				JEP106CON [3:0]			
	Reset value																									0	0	0	0	0	1	0	0
0xFE0	**CPUROM_PIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value																									1	1	0	0	1	0	0	1
0xFE4	**CPUROM_PIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID [3:0]				PARTNUM [11:8]			
	Reset value																									1	0	1	1	0	1	0	0
0xFE8	**CPUROM_PIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION [3:0]				JEDEC	JEP106ID [6:4]		
	Reset value																									0	0	0	0	1	0	1	1
0xFEC	**CPUROM_PIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFF0	**CPUROM_CIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value																									0	0	0	0	1	1	0	1
0xFF4	**CPUROM_CIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE [11:8]			
	Reset value																									0	0	0	1	0	0	0	0
0xFF8	**CPUROM_CIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value																									0	0	0	0	0	1	0	1
0xFFC	**CPUROM_CIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value																									1	0	1	1	0	0	0	1

Refer to *Table 856* for register boundary addresses.

71.6 Data watchpoint and trace unit (DWT)

The DWT provides four comparators that can be used as one of the following:

- Watchpoint
- ETM trigger
- PC sampling trigger
- Data address sampling trigger
- Data comparator (COMP 1 only)
- Clock cycle counter comparator (COMP 0 only)

It also contains counters for:

- Clock cycles
- Folded instructions
- Load store unit (LSU) operations
- Sleep cycles
- Number of cycles per instruction
- Interrupt overhead

A DWT comparator compares the value held in its *DWT comparator x register (DWT_COMPxR)* with one of the following:

- A data address
- An instruction address
- A data value
- The cycle-count value, for COMP 0 only

For address matching, the comparator can use a mask, so it matches a range of addresses.

On a successful match, the comparator generates one of the following:

- One or more DWT data trace packets, containing one or more of:
  - The address of the instruction that caused a data access
  - An address offset, bits[15:0] of the data access address
  - The matched data value
- A watchpoint debug event, on either the PC value or the accessed data address
- A CMPMATCH[N] event that signals the match outside the DWT unit

A watchpoint debug event either generates a DebugMonitor exception, or causes the processor to halt execution and enter the debug state.

For more details on how to use the DWT, refer to the Arm®v8-M Architecture Reference Manual *[4]*.

71.6.1 DWT registers

The DWT registers are located at the address range 0xE000 1000 to 0xE000 1FFC.

DWT control register (DWT_CTRLR)

Address offset: 0x000

Reset value: 0x4000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMCOMP[3:0]				NOTRCPKT	NOEXTTRIG	NOCYCCNT	NOPRFCNT	CYCDISS	CYCEVTENA	FOLDEVTENA	LSUEVTENA	SLEEPEVTENA	EXCEVTENA	CPIEVTENA	EXCTRCENA
r	r	r	r	r	r	r	r	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	PCSAMPLENA	SYNCTAP[1:0]		CYCTAP	POSTINIT[3:0]				POSTRESET[3:0]				CYCCNTENA
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 **NUMCOMP[3:0]**: number of comparators implemented (read only)
0x4: four comparators

Bit 27 **NOTRCPKT**: trace sampling and exception tracing support (read only)
0: supported

Bit 26 **NOEXTTRIG**: external match signal, CMPMATCH support (read only)
0: supported

Bit 25 **NOCYCCNT**: cycle counter support (read only)
0: supported

Bit 24 **NOPRFCNT**: profiling counter support (read only)
0: supported

Bit 23 **CYCDISS**: cycle counter disabled secure.
Controls whether the cycle counter is disabled in secure mode.
0: no effect
1: disable incrementing of the cycle counter when the processor is in secure state

Bit 22 **CYCEVTENA**: enable for POSTCNT underflow event counter packet generation
0: disabled
1: enabled

Bit 21 **FOLDEVTENA**: enable for folded instruction counter overflow event generation
0: disabled
1: enabled

Bit 20 **LSUEVTENA**: enable for LSU counter overflow event generation
0: disabled
1: enabled

Bit 19 **SLEEPEVTENA**: enable for sleep counter overflow event generation
0: disabled
1: enabled

Bit 18 **EXCEVTENA**: enable for exception overhead counter overflow event generation
0: disabled
1: enabled

Bit 17 **CPIEVTENA**: enable for CPI counter overflow event generation
0: disabled
1: enabled

Bit 16 **EXCTRCENA**: enable for exception trace generation
0: disabled
1: enabled

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **PCSAMPLENA**: enable for POSTCNT counter to be used as a timer for periodic PC sample packet generation
0: disabled
1: enabled

Bits 11:10 **SYNCTAP[1:0]**: position of the synchronization packet counter tap on the CYCCNT counter
This field determines the synchronization packet rate.
00: disabled, no synchronization packets
01: Tap at CYCCNT[24]
10: Tap at CYCCNT[26]
11: Tap at CYCCNT[28]

Bit 9 **CYCTAP**: Selects the position of the POSTCNT tap on the CYCCNT counter.
0: Tap at CYCCNT[6]
1: Tap at CYCCNT[10]

Bits 8:5 **POSTINIT[3:0]**: initial value of the POSTCNT counter
Writes to this field are ignored if POSTCNT counter is enabled. CYCEVTENA or PCSAMPLENA bits must be reset prior to writing POSTINIT.

Bits 4:1 **POSTRESET[3:0]**: reload value of the POSTCNT counter

Bit 0 **CYCCNTENA**: enable CYCCNT counter
0: disabled
1: enabled

DWT cycle count register (DWT_CYCCNTR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CYCCNT[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CYCCNT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CYCCNT[31:0]**: processor clock-cycle counter

DWT CPI count register (DWT_CPICNTR)

Address offset: 0x008

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CPICNT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **CPICNT[7:0]**: CPI counter

Counts additional cycles required to execute multi-cycle instructions, except those recorded by DWT_LSUCNTR, and counts any instruction fetch stalls.

DWT exception count register (DWT_EXCCNTR)

Address offset: 0x00C

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXCCNT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **EXCCNT[7:0]**: exception overhead cycle counter

Counts the number of cycles spent in exception processing.

DWT sleep count register (DWT_SLPCNTR)

Address offset: 0x010

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SLEEPCNT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **SLEEPCNT[7:0]**: sleep cycle counter
Counts the number of cycles spent in sleep mode (WFI, WFE, sleep-on-exit).

DWT LSU count register (DWT_LSUCNTR)

Address offset: 0x014

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LSUCNT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **LSUCNT[7:0]**: load store counter
Counts additional cycles required to execute load and store instructions.

DWT fold count register (DWT_FOLDCNTR)

Address offset: 0x018

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FOLDCNT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **FOLDCNT[7:0]**: folded instruction counter
Increments on each instruction that takes 0 cycles.

DWT program counter sample register (DWT_PCSR)

Address offset: 0x01C

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EIASAMPLE[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EIASAMPLE[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **EIASAMPLE[31:0]**: executed instruction address sample value.
Samples the current value of the program counter.

DWT comparator x register (DWT_COMPxR)

Address offset: 0x020 + 0x010 * x, (x = 0 to 3)

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
COMP[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
COMP[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **COMP[31:0]**: reference value for comparison

DWT function register 0 (DWT_FUNCTR0)

Address offset: 0x028

Reset value: 0x5800 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ID[4:0]					Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r			r								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DATAVSIZE[1:0]		Res.	Res.	Res.	Res.	ACTION[1:0]		MATCH[3:0]			
				rw	rw					rw	rw	rw	rw	rw	rw

Bits 31:27 **ID[4:0]**: capability identification
Identifies the capability for match for comparator 0.
0b01011: Cycle Counter, Instruction Address, Data Address and Data Address With Value

Bits 26:25 Reserved, must be kept at reset value.

Bit 24 **MATCHED**: comparator match
Indicates if a comparator match has occurred since the register was last read.
0: no match
1: a match occurred

Bits 23:12 Reserved, must be kept at reset value.

Bits 11:10 **DATAVSIZE[1:0]**: data value size
Defines the size of the object being watched for by Data Value and Data Address comparators.
0x0: 1 byte
0x1: 2 bytes
0x2: 4 bytes
0x3: reserved

Bits 9:6 Reserved, must be kept at reset value.

Bits 5:4 **ACTION[1:0]**: action on match
0x0: trigger only
0x1: generate debug event
0x2: For a Cycle Counter, Instruction Address, Data Address, Data Value or Linked Data Value comparator, generate a Data Trace Match packet. For a Data Address With Value comparator, generate a Data Trace Data Value packet.
0x3: For a Data Address Limit comparator, generate a Data Trace Data Address packet. For a Cycle Counter, Instruction Address Limit, or Data Address comparator, generate a Data Trace PC Value packet. For a Data Address With Value comparator, generate both a Data Trace PC Value packet and a Data Trace Data Value packet.

Bits 3:0 **MATCH[3:0]**: match type
Controls the type of match generated by comparator 0.
For possible values of this field, refer to *[4]*.

DWT function register 1 (DWT_FUNCTR1)

Address offset: 0x038

Reset value: 0xD000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ID[4:0]					Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r			r								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DATAVSIZE[1:0]		Res.	Res.	Res.	Res.	ACTION[1:0]		MATCH[3:0]			
				rw	rw					rw	rw	rw	rw	rw	rw

Bits 31:27 **ID[4:0]**: capability identification
Identifies the capability for match for comparator 1.
0b11010: Instruction Address, Instruction Address Limit, Data Address, Data Address Limit, and Data Address With Value

Bits 26:25 Reserved, must be kept at reset value.

Bit 24 **MATCHED**: Comparator match
Indicates if a comparator match has occurred since the register was last read.
0: no match
1: a match occurred

Bits 23:12 Reserved, must be kept at reset value.

Bits 11:10 **DATAVSIZE[1:0]**: data value size
Defines the size of the object being watched for by Data Value and Data Address comparators.
0x0: 1 byte
0x1: 2 bytes
0x2: 4 bytes
0x3: reserved

Bits 9:6 Reserved, must be kept at reset value.

Bits 5:4 **ACTION[1:0]**: action on match
0x0: trigger only
0x1: generate debug event
0x2: For a Cycle Counter, Instruction Address, Data Address, Data Value or Linked Data Value comparator, generate a Data Trace Match packet. For a Data Address With Value comparator, generate a Data Trace Data Value packet.
0x3: For a Data Address Limit comparator, generate a Data Trace Data Address packet. For a Cycle Counter, Instruction Address Limit, or Data Address comparator, generate a Data Trace PC Value packet. For a Data Address With Value comparator, generate both a Data Trace PC Value packet and a Data Trace Data Value packet.

Bits 3:0 **MATCH[3:0]**: match type
Controls the type of match generated by comparator 1.
For possible values of this field, refer to *[4]*.

DWT function register 2 (DWT_FUNCTR2)

Address offset: 0x048

Reset value: 0x5000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ID[4:0]					Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r			r								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DATAVSIZE[1:0]		Res.	Res.	Res.	Res.	ACTION[1:0]		MATCH[3:0]			
				rw	rw					rw	rw	rw	rw	rw	rw

Bits 31:27 **ID[4:0]**: capability identification
Identifies the capability for MATCH for comparator 2
0b01010: Instruction Address, Data Address, and Data Address With Value

Bits 26:25 Reserved, must be kept at reset value.

Bit 24 **MATCHED**: comparator match

Indicates if a comparator match has occurred since the register was last read.

0: no match

1: a match occurred

Bits 23:12 Reserved, must be kept at reset value.

Bits 11:10 **DATAVSIZE[1:0]**: Data value size:

Defines the size of the object being watched for by Data Value and Data Address comparators.

0x0: 1 byte

0x1: 2 bytes

0x2: 4 bytes

0x3: reserved

Bits 9:6 Reserved, must be kept at reset value.

Bits 5:4 **ACTION[1:0]**: action on match

0x0: trigger only

0x1: Generate debug event

0x2: For a Cycle Counter, Instruction Address, Data Address, Data Value or Linked Data Value comparator, generate a Data Trace Match packet. For a Data Address With Value comparator, generate a Data Trace Data Value packet.

0x3: For a Data Address Limit comparator, generate a Data Trace Data Address packet. For a Cycle Counter, Instruction Address Limit, or Data Address comparator, generate a Data Trace PC Value packet. For a Data Address With Value comparator, generate both a Data Trace PC Value packet and a Data Trace Data Value packet.

Bits 3:0 **MATCH[3:0]**: match type

Controls the type of match generated by comparator 2.

For possible values of this field, refer to *[4]*

DWT function register 3 (DWT_FUNCTR3)

Address offset: 0x058

Reset value: 0xF000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ID[4:0]					Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r			r								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DATAVSIZE[1:0]		Res.	Res.	Res.	Res.	ACTION[1:0]		MATCH[3:0]			
				rw	rw					rw	rw	rw	rw	rw	rw

Bits 31:27 **ID[4:0]**: capability identification

Identifies the capability for MATCH for comparator 2.

0b11110: Instruction Address, Instruction Address Limit, Data Address, Data Address Limit, Data value, Linked Data Value, and Data Address With Value

Bits 26:25 Reserved, must be kept at reset value.

Bit 24 **MATCHED**: comparator match
Indicates if a comparator match has occurred since the register was last read.
0: no match
1: a match occurred

Bits 23:12 Reserved, must be kept at reset value.

Bits 11:10 **DATAVSIZE[1:0]**: data value size
Defines the size of the object being watched for by Data Value and Data Address comparators.
0x0: 1 byte
0x1: 2 bytes
0x2: 4 bytes
0x3: reserved

Bits 9:6 Reserved, must be kept at reset value.

Bits 5:4 **ACTION[1:0]**: action on match
0x0: trigger only
0x1: Generate debug event
0x2: For a Cycle Counter, Instruction Address, Data Address, Data Value or Linked Data Value comparator, generate a Data Trace Match packet. For a Data Address With Value comparator, generate a Data Trace Data Value packet.
0x3: For a Data Address Limit comparator, generate a Data Trace Data Address packet. For a Cycle Counter, Instruction Address Limit, or Data Address comparator, generate a Data Trace PC Value packet. For a Data Address With Value comparator, generate both a Data Trace PC Value packet and a Data Trace Data Value packet.

Bits 3:0 **MATCH[3:0]**: match type
Controls the type of match generated by comparator 2.
For possible values of this field, refer to *[4]*

DWT device type architecture register (DWT_DEVARCHR)

Address offset: 0xFC8

Reset value: 0x4770 1A02

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARCHITECT[10:0]											PRESENT	REVISION[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARCHVER[3:0]				ARCHPART[11:0]											
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:21 **ARCHITECT[10:0]**: architect JEP106 code
0x23B: JEP106 continuation code 0x4, JEP106 ID code 0x3B. Arm® limited.

Bit 20 **PRESENT**: DWT_DEVARCH register present
0x1: present

Bits 19:16 **REVISION[3:0]**: architecture revision
0x0: DWT architecture v2.0

Bits 15:12 **ARCHVER[3:0]**: architecture version
0x1: DWT architecture v2.0

Bits 11:0 **ARCHPART[11:0]**: architecture part
0xA02: DWT architecture

DWT device type register (DWT_DEVTYPER)

Address offset: 0xFCC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUB[3:0]				MAJOR[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SUB[3:0]**: sub-type
0x0: other

Bits 3:0 **MAJOR[3:0]**: major type
0x0: miscellaneous

DWT CoreSight peripheral identity register 4 (DWT_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SIZE[3:0]**: register file size
0x0: The register file occupies a single 4-Kbyte region.

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

DWT CoreSight peripheral identity register 0 (DWT_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0021

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: part number bits [7:0]
0x21: Cortex®-M33 DWT part number

DWT CoreSight peripheral identity register 1 (DWT_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00BD

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: part number bits [11:8]
0xD: Cortex®-M33 DWT part number

DWT CoreSight peripheral identity register 2 (DWT_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: component revision number
0x0: r0p0

Bit 3 **JEDEC**: JEDEC assigned value
0x1: designer identification specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code bits [6:4]
0x3: Arm® JEDEC code

DWT CoreSight peripheral identity register 3 (DWT_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: metal fix version
0x0: no metal fix

Bits 3:0 **CMOD[3:0]**: customer modified
0x0: No customer modifications

DWT CoreSight component identity register 0 (DWT_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: component identification bits [7:0]
0x0D: Common identification value

DWT CoreSight peripheral identity register 1 (DWT_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0090

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: component identification bits [15:12] - component class
0x9: debug component

Bits 3:0 **PREAMBLE[11:8]**: component identification bits [11:8]
0x0: common identification value

DWT CoreSight component identity register 2 (DWT_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: component identification bits [23:16]
0x05: common identification value

DWT CoreSight component identity register 3 (DWT_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: component identification bits [31:24]
0xB1: common identification value

71.6.2 DWT register map

The DWT registers are located at the address range 0xE000 1000 to 0xE000 1FFC.

Table 860. DWT register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**DWT_CTRLR**	NUMCOMP[3:0]				NOTRCPKT	NOEXTTRIG	NOCYCCNT	NOPRFCNT	CYCDISS	CYCEVTENA	FOLDEVTENA	LSUEVTENA	SLEEPEVTENA	EXCEVTENA	CPIEVTENA	EXCTRCENA	Res.	Res.	Res.	PCSAMPLENA	SYNCTAP[1:0]		CYCTAP	POSTINIT[3:0]				POSTPRESET[3:0]				CYCCNTENA
	Reset value	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0	0
0x004	**DWT_CYCCNTR**	CYCCNT[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x008	**DWT_CPICNTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CPICNT[7:0]							
	Reset value																									X	X	X	X	X	X	X	X
0x00C	**DWT_EXCCNTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXCCNT[7:0]							
	Reset value																									X	X	X	X	X	X	X	X
0x010	**DWT_SLPCNTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SLEEPCNT[7:0]							
	Reset value																									X	X	X	X	X	X	X	X
0x014	**DWT_LSUCNTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LSUCNT[7:0]							
	Reset value																									X	X	X	X	X	X	X	X
0x018	**DWT_FOLDCNTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FOLDCNT[7:0]							
	Reset value																									X	X	X	X	X	X	X	X

Table 860. DWT register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x01C	**DWT_PCSR**	EIASAMPLE[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x020	**DWT_COMP0R**	COMP[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x024	Reserved	Reserved																															
0x028	**DWT_FUNCTR0**	ID[4:0]					Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATAVSIZE[1:0]		Res.	Res.	Res.	Res.	ACTION[1:0]		MATCH[3:0]			
	Reset value	0	1	0	1	1			0													0	0					0	0	0	0	0	0
0x02C	Reserved	Reserved																															
0x030	**DWT_COMP1R**	COMP[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x034	Reserved	Reserved																															
0x038	**DWT_FUNCTR1**	ID[4:0]					Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATAVSIZE[1:0]		Res.	Res.	Res.	Res.	ACTION[1:0]		MATCH[3:0]			
	Reset value	1	1	0	1	0			0													0	0					0	0	0	0	0	0
0x03C	Reserved	Reserved																															
0x040	**DWT_COMP2R**	COMP[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x044	Reserved	Reserved																															
0x048	**DWT_FUNCTR2**	ID[4:0]					Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATAVSIZE[1:0]		Res.	Res.	Res.	Res.	ACTION[1:0]		MATCH[3:0]			
	Reset value	0	1	0	1	0			0													0	0					0	0	0	0	0	0
0x04C	Reserved	Reserved																															
0x050	**DWT_COMP3R**	COMP[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x054	Reserved	Reserved																															
0x058	**DWT_FUNCTR3**	ID[4:0]					Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATAVSIZE[1:0]		Res.	Res.	Res.	Res.	ACTION[1:0]		MATCH[3:0]			
	Reset value	1	1	1	1	0			0													0	0					0	0	0	0	0	0
0x05C to 0xFC4	Reserved	Reserved																															
0xFC8	**DWT_DEVARCHR**	ARCHITECT[10:0]											PRESENT	REVISION[3:0]				ARCHVER[3:0]				ARCHPART[11:0]												
	Reset value	0	1	0	0	0	1	1	1	0	1	1	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	1	0

Table 860. DWT register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFCC	**DWT_DEVTYPER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUB[3:0]				MAJOR[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFD0	**DWT_PIDR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE[3:0]				JEP106CON[3:0]			
	Reset value																									0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	**DWT_PIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value																									0	0	1	0	0	0	0	1
0xFE4	**DWT_PIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value																									1	0	1	1	1	1	0	1
0xFE8	**DWT_PIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value																									0	0	0	0	1	0	1	1
0xFEC	**DWT_PIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFF0	**DWT_CIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value																									0	0	0	0	1	1	0	1
0xFF4	**DWT_CIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value																									1	0	0	1	0	0	0	0
0xFF8	**DWT_CIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value																									0	0	0	0	0	1	0	1
0xFFC	**DWT_CIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value																									1	0	1	1	0	0	0	1

Refer to *Table 856: Processor ROM table* for register boundary addresses.

71.7 Instrumentation trace macrocell (ITM)

The ITM generates trace information in packets. Three sources can generate packets. If multiple sources generate packets at the same time, the ITM arbitrates the order in which packets are output. The three sources in decreasing order of priority are the following:

- Software trace

  The software can write directly to any of 32 x 32-bit ITM stimulus registers, to generate packets. The permission level for each port can be programmed. When software writes to an enabled stimulus port, the ITM combines the identity of the port, the size of the write access and the data written, into a packet that it writes to a FIFO. The ITM outputs packets from the FIFO onto the trace bus. Reading a stimulus port register returns the status of the stimulus register (empty or pending) in bit 0.
- Hardware trace

  The DWT generates trace packets in response to a data trace event, a PC sample or a performance profiling counter wraparound. The ITM outputs these packets on the trace bus.
- Local timestamping

  The ITM contains a 21-bit counter clocked by the (predivided) processor clock. The counter value is output in a timestamp packet on the trace bus. The counter is reset to zero every time a timestamp packet is generated. The timestamps thus indicate the time elapsed since the previous timestamp packet.

For more information on the ITM and how to use it, refer to *[4]*.

71.7.1 ITM registers

The ITM registers are located at the address range 0xE000 0000 to 0xE000 0FFC.

ITM stimulus register x (ITM_STIMRx)

Address offset: 0x000 + 0x004 * x, (x = 0 to 31)

Reset value: 0xXXXX XXXX

Condition: when writing

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
STIMULUS[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STIMULUS[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	rw	rw

Bits 31:0 **STIMULUS[31:0]**: trace output data
write data is output on the trace bus as a software event packet.

ITM stimulus register x [alternate] (ITM_STIMRx)

Address offset: 0x000 + 0x004 * x, (x = 0 to 31)

Reset value: 0xXXXX XXXX

Condition: when reading

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DISABLE	FIFO_READY
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **DISABLE**: Disable flag
0: stimulus port and ITM enabled
1: stimulus port and ITM disabled

Bit 0 **FIFO_READY**: FIFO ready indicator
0: stimulus port buffer is full (or port is disabled)
1: stimulus port can accept new write data

ITM trace enable register (ITM_TER)

Address offset: 0xE00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
STIMENA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STIMENA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **STIMENA[31:0]**: stimulus port enable
Each bit x(0 to 31) enables the stimulus port associated with the ITM_STIMRx register.
0: port disabled
1: port enabled

ITM trace privilege register (ITM_TPR)

Address offset: 0xE40

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIVMASK[3:0]			
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **PRIVMASK[3:0]**: disable unprivileged access to ITM stimulus ports
Each bit controls eight stimulus ports.
XXX0: unprivileged access permitted on ports 0 to 7
XXX1: only privileged access permitted on ports 0 to 7
XX0X: unprivileged access permitted on ports 8 to 15
XX1X: only privileged access permitted on ports 8 to 15
X0XX: unprivileged access permitted on ports 16 to 23
X1XX: only privileged access permitted on ports 16 to 23
0XXX: unprivileged access permitted on ports 24 to 31
1XXX: only privileged access permitted on ports 24 to 31

ITM trace control register (ITM_TCR)

Address offset: 0xE80

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSY	TRACEBUSID[6:0]						
								r	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	TSPRESCALE[1:0]		Res.	Res.	STALLENA	SWOENA	TXENA	SYNCENA	TSENA	ITMENA
						rw	rw			rw	r	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **BUSY**: indicates whether the ITM is currently processing events
0: not busy
1: busy

Bits 22:16 **TRACEBUSID[6:0]**: identifier for multi-source trace stream formatting
If multi-source trace is in use, the debugger must write a non-zero value to this field.
Note: Different identifiers must be used for each trace source in the system.

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **TSPRESCALE[1:0]**: local timestamp prescaler, used with the trace packet reference clock
0x0: no prescaling
0x1: Divide by 4.
0x2: Divide by 16.
0x3: Divide by 64.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **STALLENA**: stall enable
0: Drop hardware source packets and generate an overflow if the ITM output is stalled.
1: Stall the processor to guarantee delivery of data trace packets.

Bit 4 **SWOENA**: SWO enable
Enables asynchronous clocking of the timestamp counter (read only).
0: Timestamp counter uses processor clock.

Bit 3 **TXENA**: transmit enable
Enables forwarding of hardware event packets from the DWT unit to the trace port.
0: disabled
1: enabled

Bit 2 **SYNCENA**: synchronization packet transmission enable
The debugger setting this bit must also configure the DWT_CTRLR.SYNCTAP field for the correct synchronization speed.
0: disabled
1: enabled

Bit 1 **TSENA**: local timestamp generation enable
0: disabled
1: enabled

Bit 0 **ITMENA**: ITM enable
0: disabled
1: enabled

ITM device type architecture register (ITM_DEVARCHR)

Address offset: 0xFBC

Reset value: 0x4770 1A01

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARCHITECT[10:0]											PRESENT	REVISION[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARCHVER[3:0]				ARCHPART[11:0]											
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:21 **ARCHITECT[10:0]**: architect JEP106 code
0x23B: JEP106 continuation code 0x4, JEP106 ID code 0x3B. Arm® limited.

Bit 20 **PRESENT**: DEVARCH register presence
0x1: present

Bits 19:16 **REVISION[3:0]**: architecture revision
0x0: ITM architecture v2.0

Bits 15:12 **ARCHVER[3:0]**: architecture version
0x1: ITM architecture v2.0

Bits 11:0 **ARCHPART[11:0]**: architecture part
0xA01: ITM architecture

ITM device type register (ITM_DEVTYPER)

Address offset: 0xFCC

Reset value: 0x0000 0043

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUB[3:0]				MAJOR[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SUB[3:0]**: sub-type
0x4: associated with a bus, stimulus derived from bus activity

Bits 3:0 **MAJOR[3:0]**: major type
0x3: trace source

ITM CoreSight peripheral identity register 4 (ITM_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SIZE[3:0]**: register file size
0x0: The register file occupies a single 4-Kbyte region.

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

ITM CoreSight peripheral identity register 0 (ITM_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0021

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: part number bits [7:0]
0x21: ITM part number

ITM CoreSight peripheral identity register 1 (ITM_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00BD

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: part number bits [11:8]
0xD: ITM part number

ITM CoreSight peripheral identity register 2 (ITM_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: component revision number
0x0: r0p0

Bit 3 **JEDEC**: JEDEC assigned value
0x1: designer identification specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code bits [6:4]
0x3: Arm® JEDEC code

ITM CoreSight peripheral identity register 3 (ITM_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: metal fix version
0x0: no metal fix

Bits 3:0 **CMOD[3:0]**: customer modified
0x0: no customer modifications

ITM CoreSight component identity register 0 (ITM_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component identification bits [7:0]
0x0D: Common identification value

ITM CoreSight peripheral identity register 1 (ITM_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 00E0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component identification bits [15:12] - component class
0xE: Trace generator component

Bits 3:0 **PREAMBLE[11:8]**: Component identification bits [11:8]
0x0: Common identification value

ITM CoreSight component identity register 2 (ITM_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component identification bits [23:16]
0x05: Common identification value

ITM CoreSight component identity register 3 (ITM_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component identification bits [31:24]
0xB1: Common identification value

71.7.2 ITM register map

The ITM registers are located at the address range 0xE000 0000 to 0xE000 0FFC.

Table 861. ITM register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000 to 0x07C	**ITM_STIMR0 to ITM_STIMR31**	STIMULUS[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x07C to 0xDFC	Reserved	Reserved																															
0xE00	**ITM_TER**	STIMENA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xE04 to 0xE3C	Reserved	Reserved																															
0xE40	**ITM_TPR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIVMASK [3:0]			
	Reset value																													0	0	0	0
0xE44 to 0xE7C	Reserved	Reserved																															
0xE80	**ITM_TCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSY	TRACEBUSID[6:0]							Res.	Res.	Res.	Res.	Res.	Res.	TSPRESCALE [1:0]		Res.	Res.	STALLENA	SWOENA	TXENA	SYNCENA	TSENA	ITMENA
	Reset value									0	0	0	0	0	0	0	0							0	0			0	0	0	0	0	0
0xE84 to 0xFB8	Reserved	Reserved																															

Table 861. ITM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFBC	**ITM_DEVARCHR**	ARCHITECT[10:0]											PRESEN	REVISION [3:0]				ARCHVER [3:0]				ARCHPART[3:0]											
	Reset value	0	1	0	0	0	1	1	1	0	1	1	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	1
0xFC0 to 0xFC8	Reserved	Reserved																															
0xFCC	**ITM_DEVTYPER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUB[3:0]				MAJOR[3:0]			
	Reset value																									0	1	0	0	0	0	1	1
0xFD0	**ITM_PIDR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE [3:0]				JEP106CON [3:0]			
	Reset value																									0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	**ITM_PIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value																									0	0	1	0	0	0	0	1
0xFE4	**ITM_PIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID [3:0]				PARTNUM [11:8]			
	Reset value																									1	0	1	1	1	1	0	1
0xFE8	**ITM_PIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION [3:0]				JEDEC	JEP106ID [6:4]		
	Reset value																									0	0	0	0	1	0	1	1
0xFEC	**ITM_PIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFF0	**ITM_CIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value																									0	0	0	0	1	1	0	1
0xFF4	**ITM_CIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE [11:8]			
	Reset value																									1	1	1	0	0	0	0	0
0xFF8	**ITM_CIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value																									0	0	0	0	0	1	0	1
0xFFC	**ITM_CIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value																									1	0	1	1	0	0	0	1

Refer to *Table 856: Processor ROM table* for register boundary addresses.

71.8 Breakpoint unit (BPU)

The BPU allows the user to set hardware breakpoints. It contains eight comparators that monitor the instruction fetch address. If a match occurs, the instruction comparators can be configured to generate a breakpoint instruction.

For more information on the breakpoint unit and how to use it, refer to *[4]*.

71.8.1 BPU registers

The BPU registers are located at the address range 0xE0002000 to 0xE0002FFC.

BPU control register (BPU_CTRLR)

Address offset: 0x000

Reset value: 0x1000 0080

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REV[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r												

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	NUM_CODE[6:4]			Res.	Res.	Res.	Res.	NUM_CODE[3:0]				Res.	Res.	KEY	ENABLE
	r	r	r					r	r	r	r			rw	rw

Bits 31:28 **REV[3:0]**: revision number
0x1: BPU version 2

Bits 27:15 Reserved, must be kept at reset value.

Bits 14:12, 7:4 **NUM_CODE[6:0]**: number of instruction address comparators supported
0x08: 8 instruction comparators supported

Bits 11:8, 3:2 Reserved, must be kept at reset value.

Bit 1 **KEY**: Write protect key
A write to FPB_CTRLR register is ignored if this bit is not set to 1.

Bit 0 **ENABLE**: FPB enable
0: disabled
1: enabled

BPU comparator x register (BPU_COMPxR)

Address offset: 0x008 + 0x004 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BPADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BPADDR[15:1]															BE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:1 **BPADDR[31:1]**: breakpoint address

Bit 0 **BE**: breakpoint enable
0: disabled
1: enabled

BPU device type architecture register (BPU_DEVARCHR)

Address offset: 0xFBC

Reset value: 0x4770 1A03

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARCHITECT[10:0]											PRESENT	REVISION[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARCHVER[3:0]				ARCHPART[11:0]											
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:21 **ARCHITECT[10:0]**: architect JEP106 code
0x23B: JEP106 continuation code 0x4, JEP106 ID code 0x3B. Arm® limited.

Bit 20 **PRESENT**: DEVARCH register present
0x1: present

Bits 19:16 **REVISION[3:0]**: architecture revision
0x0: BPU architecture v2.0

Bits 15:12 **ARCHVER[3:0]**: architecture version
0x1: BPU architecture v2.0

Bits 11:0 **ARCHPART[11:0]**: architecture part
0xA03: BPU architecture

BPU device type register (BPU_DEVTYPER)

Address offset: 0xFCC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUB[3:0]				MAJOR[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SUB[3:0]**: sub-type
0x0: other

Bits 3:0 **MAJOR[3:0]**: major type
0x0: miscellaneous

BPU CoreSight peripheral identity register 4 (BPU_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SIZE[3:0]**: register file size
0x0: The register file occupies a single 4-Kbyte region.

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

BPU CoreSight peripheral identity register 0 (BPU_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0021

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: part number bits [7:0]
0x21: BPU part number

BPU CoreSight peripheral identity register 1 (BPU_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00BD

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: part number bits [11:8]
0xD: BPU part number

BPU CoreSight peripheral identity register 2 (BPU_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: component revision number
0x0: r0p0

Bit 3 **JEDEC**: JEDEC assigned value
0x1: designer identification specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code bits [6:4]
0x3: Arm ® JEDEC code

BPU CoreSight peripheral identity register 3 (BPU_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: metal fix version
0x0: no metal fix

Bits 3:0 **CMOD[3:0]**: customer modified
0x0: no customer modifications

BPU CoreSight component identity register 0 (BPU_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: component identification bits [7:0]
0x0D: common identification value

BPU CoreSight peripheral identity register 1 (BPU_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0090

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: component identification bits [15:12] - component class
0x9: debug component

Bits 3:0 **PREAMBLE[11:8]**: component identification bits [11:8]
0x0: common identification value

BPU CoreSight component identity register 2 (BPU_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: component identification bits [23:16]
0x05: common identification value

BPU CoreSight component identity register 3 (BPU_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: component identification bits [31:24]
0xB1: common identification value

71.8.2 BPU register map

The BPU registers are located at the address range 0xE000 2000 to 0xE000 2FFC.

Table 862. BPU register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**BPU_CTRLR**	REV[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NUM_CODE [6:4]			Res.	Res.	Res.	Res.	NUM_CODE [3:0]				Res.	Res.	KEY	ENABLE
	Reset value	0	0	0	1														0	0	0					1	0	0	0			0	0
0x004	Reserved	Reserved																															
0x008 to 0x024	**BPU_COMP0R to BPU_COMP7R**	BPADDR[31:1]																															BE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x028 to 0xFB8	Reserved	Reserved																															
0xFBC	**BPU_DEVARCHR**	ARCHITECT[10:0]											PRESEN	REVISION [3:0]				ARCHVER [3:0]				ARCHPART[11:0]											
	Reset value	0	1	0	0	0	1	1	1	0	1	1	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	1	1
0xFC0 to 0xFC8	Reserved	Reserved																															
0xFCC	**BPU_DEVTYPER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUB[3:0]				MAJOR[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFD0	**BPU_PIDR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE [3:0]				JEP106CON [3:0]			
	Reset value																									0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	**BPU_PIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value																									0	0	1	0	0	0	0	1
0xFE4	**BPU_PIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID [3:0]				PARTNUM [11:8]			
	Reset value																									1	0	1	1	1	1	0	1
0xFE8	**BPU_PIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION [3:0]				JEDEC	JEP106ID [6:4]		
	Reset value																									0	0	0	0	1	0	1	1
0xFEC	**BPU_PIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFF0	**BPU_CIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value																									0	0	0	0	1	1	0	1
0xFF4	**BPU_CIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE [11:8]			
	Reset value																									1	0	0	1	0	0	0	0

Table 862. BPU register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFF8	**BPU_CIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value																									0	0	0	0	0	1	0	1
0xFFC	**BPU_CIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value																									1	0	1	1	0	0	0	1

Refer to *Table 856: Processor ROM table* for register boundary addresses.

71.9 Embedded Trace Macrocell (ETM)

The ETM is a CoreSight™ component closely coupled to the CPU. The ETM generates trace packets that allow the execution of the Cortex®-M33 core to be traced. In the STM32H5E4/5F4 and STM32H5E5/5F5, the ETM is configured for instruction trace only. Data accesses are not included in the trace information.

The ETM receives information from the CPU over the processor trace interface, including:

- number of instructions executed in the same cycle
- changes in program flow
- current processor instruction state
- addresses of memory locations accessed by load and store instructions
- type, direction, and size of a transfer
- condition code information
- exception information
- wait for interrupt state information

For more information, refer to the Arm® CoreSight™ ETM-M33 Technical Reference Manual *[6]*.

71.9.1 ETM registers

The ETM registers are located at the address range 0xE004 1000 to 0xE004 1FFC.

ETM programming control register (ETM_PRGCTLR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EN
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **EN**: trace unit enable
0: disabled
1: enabled

ETM status register (ETM_STATR)

Address offset: 0x00C

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PMSTABLE	IDLE
														r	r

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **PMSTABLE**: stability status
Indicates that the ETM-M33 registers are stable and can be read.
0: not stable
1: stable

Bit 0 **IDLE**: trace unit status
Indicates that the trace unit is inactive.
0: not idle
1: idle

ETM configuration register (ETM_CONFIGR)

Address offset: 0x010

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	RS	Res.	COND[5:0]						CCI	BB	Res.	Res.	Res.
			rw		rw	rw	rw	rw	rw	rw	rw	rw			

Bits 31:13 Reserved, must be kept at reset value.

Bit 12 **RS**: return stack enable
0: disabled
1: enabled

Bit 11 Reserved, must be kept at reset value.

Bits 10:5 **COND[5:0]**: conditional instruction tracing
0x0: conditional instruction tracing disabled
0x1: conditional load instructions traced
0x2: conditional store instructions traced
0x3: conditional load and store instructions traced
0x7: All conditional instructions traced

Bit 4 **CCI**: cycle counting in instruction trace
0: disabled
1: enabled

Bit 3 **BB**: branch broadcast mode
0: disabled
1: enabled

Bits 2:0 Reserved, must be kept at reset value.

ETM event control 0 register (ETM_EVENTCTL0R)

Address offset: 0x020

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TYPE1	Res.	Res.	Res.	SEL1[3:0]				TYPE0	Res.	Res.	Res.	SEL0[3:0]			
rw				rw	rw	rw	rw	rw				rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **TYPE1**: resource type for event1
0: single selected resource
1: boolean combined resource pair

Bits 14:12 Reserved, must be kept at reset value.

Bits 11:8 **SEL1[3:0]**: resource number based on TYPE1
Selects the resource number, based on the value of TYPE1.
When TYPE1 = 0, a single resource from 0-15 defined by SEL1[3:0] is selected.
When TYPE1 = 1, a boolean combined resource pair defined by SEL1[2:0] is selected.

Bit 7 **TYPE0**: resource type for event0
0: single selected resource
1: boolean combined resource pair

Bits 6:4 Reserved, must be kept at reset value.

Bits 3:0 **SEL0[3:0]**: resource number based on TYPE0
Selects the resource number, based on the value of TYPE0.
When TYPE0 = 0, a single resource from 0-15 defined by SEL0[3:0] is selected.
When TYPE0 = 1, a boolean combined resource pair defined by SEL0[2:0] is selected.

ETM event control 1 register (ETM_EVENTCTL1R)

Address offset: 0x024

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	LPOVERRIDE	ATB	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INSTEN[1:0]	
			rw	rw										rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bit 12 **LPOVERRIDE**: low-power state behavior override
0: normal low-power state behavior
1: The resources and event trace generation are not affected by entry to a low-power state.

Bit 11 **ATB**: ATB trigger enable
0: disabled
1: enabled

Bits 10:2 Reserved, must be kept at reset value.

Bits 1:0 **INSTEN[1:0]**: instruction event generation
Enables generation of an event element in the instruction stream.
0bX0: Event0 does not cause an event element.
0bX1: Event0 causes an event element when it occurs.
0b0X: Event1 does not cause an event element.
0b1X: Event1 causes an event element when it occurs.

ETM stall control register (ETM_STALLCTLR)

Address offset: 0x02C

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	INSTPRIORITY	Res.	ISTALL	Res.	Res.	Res.	Res.	LEVEL[3:0]			
					rw		rw					rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **INSTPRIORITY**: instruction trace priority
Prioritizes instruction trace if instruction trace buffer space is less than LEVEL[3:0].
0: The ETM must not prioritize instruction trace.
1: The ETM can prioritize instruction trace.

Bit 9 Reserved, must be kept at reset value.

Bit 8 **ISTALL**: processor stalling
Stalls processor based on instruction trace buffer space.
0: The ETM must not stall the processor.
1: The ETM can stall the processor.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **LEVEL[3:0]**: Threshold at which stalling becomes active
This field provides four levels. This level can be varied to optimize the level of invasion caused by stalling, balanced against the risk of a FIFO overflow.
0x0: zero invasion, but greater risk of FIFO overflow
...
0xF: maximum invasion but less risk of FIFO overflow

ETM synchronization period register (ETM_SYNCPR)

Address offset: 0x034

Reset value: 0x0000 000A

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PERIOD[4:0]				
											r	r	r	r	r

Bits 31:5 Reserved, must be kept at reset value.

Bits 4:0 **PERIOD[4:0]**: synchronization period
Defines the number of bytes of trace between trace synchronization requests as a total of the number of bytes generated by the instruction stream.
0xA: 1024 bytes

ETM cycle count control register (ETM_CCCTLR)

Address offset: 0x038

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	THRESHOLD[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **THRESHOLD[11:0]**: instruction trace cycle count threshold

Sets the threshold value for instruction trace cycle counting. The threshold represents the minimum interval between cycle-count trace packets.

ETM trace identification register (ETM_TRACEIDR)

Address offset: 0x040

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRACEID[6:0]						
									rw	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bits 6:0 **TRACEID[6:0]**: Trace identification to output onto the trace bus

This field must be programmed with a unique value to differentiate it from other trace sources in the system.

Values 0x00 and 0x70-0x7F are reserved.

ETM ViewInst main control register (ETM_VICTLR)

Address offset: 0x080

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXLEVEL_S[3:0]			
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TRCERR	TRCRESET	SSSTATUS	Res.	EVENT[7:0]							
				rw	rw	rw		rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:16 **EXLEVEL_S[3:0]**: exception level in secure state

Controls whether instruction tracing is enabled for the corresponding exception level, in secure state.
0bXXX0: instruction trace not generated in secure state, for exception level 0
0bXXX1: instruction trace generated in secure state, for exception level 0
0b0XXX: instruction trace not generated in secure state, for exception level 3
0b1XXX: instruction trace generated in secure state, for exception level 3

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **TRCERR**: trace system error exception

0: The system error exception is traced only if the instruction or exception immediately before the system error exception is traced.
1: The system error exception is always traced.

Bit 10 **TRCRESET**: trace reset exception

0: The reset exception is traced only if the instruction or exception immediately before the reset exception is traced.
1: The reset exception is always traced.

Bit 9 **SSSTATUS**: start/stop logic status

0: stopped
1: started

Bit 8 Reserved, must be kept at reset value.

Bits 7:0 **EVENT[7:0]**: event selector

ETM counter reload value register 0 (ETM_CNTRLDVR0)

Address offset: 0x140

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VALUE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **VALUE[15:0]**: counter reload value
This value is loaded in to the counter each time the reload event occurs.

ETM identification register 8 (ETM_IDR8)

Address offset: 0x180

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MAXSPEC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MAXSPEC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **MAXSPEC[31:0]**: maximum speculation depth
Indicates the maximum speculation depth of the instruction trace stream. This is the maximum number of P0 elements that have not been committed in the trace stream at any one time.
0x0: The maximum trace speculation depth is zero.

ETM identification register 9 (ETM_IDR9)

Address offset: 0x184

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMP0KEY[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMP0KEY[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **NUMP0KEY[31:0]**: number of P0 right-hand keys used
0x0: no P0 right-hand keys used in instruction trace

ETM identification register 10 (ETM_IDR10)

Address offset: 0x188

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMP1KEY[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMP1KEY[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **NUMP1KEY[31:0]**: number of P1 right-hand keys used (including normal and special keys)
0x0: no P1 right-hand keys used in instruction trace

ETM identification register 11 (ETM_IDR11)

Address offset: 0x18C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMP1SPC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMP1SPC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **NUMP1SPC[31:0]**: number of special P1 right-hand keys used
0x0: no special P1 right-hand keys used in any configuration

ETM identification register 12 (ETM_IDR12)

Address offset: 0x190

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMCONDKEY[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMCONDKEY[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **NUMCONDKEY[31:0]**: number of conditional instruction right-hand keys used (including normal and special keys)
0x1: one conditional instruction right-hand key implemented

ETM identification register 13 (ETM_IDR13)

Address offset: 0x194

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMCONDSPC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMCONDSPC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **NUMCONDSPC[31:0]**: number of special conditional instruction right-hand keys used
0x0: no special conditional instruction right-hand keys implemented

ETM implementation specific register 0 (ETM_IMSPECR0)

Address offset: 0x1C0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUPPORT[3:0]			
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **SUPPORT[3:0]**: implementation specific extension support
0x0: no implementation specific extensions are supported

ETM identification register 0 (ETM_IDR0)

Address offset: 0x1E0

Reset value: 0x2800 06E1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	COMMOPT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRCEXDATA	QSUPP[1]
		r												r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
QSUPP[0]	Res.	CONDTYPE[1:0]		NUMEVENT[1:0]		RETSTACK	Res.	TRCCCI	TRCCOND	TRCBB	TRCDATA[1:0]		INSTP0[1:0]		Res.
r		r	r	r	r	r		r	r	r	r	r	r	r	

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **COMMOPT**: commit field meaning
Indicates the meaning of the commit field in some packets.
1: commit mode 1

Bits 28:18 Reserved, must be kept at reset value.

Bit 17 **TRCEXDATA**: trace data transfers for exceptions
Indicates support for the tracing of data transfers for exceptions and exception returns.
0: not implemented

Bits 16:15 **QSUPP[1:0]**: Q element support
0: not supported

Bit 14 Reserved, must be kept at reset value.

Bits 13:12 **CONDTYPE[1:0]**: conditional results tracing
Indicates how conditional results are traced.
0: The trace unit indicates only if a conditional instruction passes or fails its condition code check

Bits 11:10 **NUMEVENT[1:0]**: Number of events supported
0x1: two events

Bit 9 **RETSTACK**: return stack support
1: two entry return stacks

Bit 8 Reserved, must be kept at reset value.

Bit 7 **TRCCCI**: cycle counting support
1: cycle counting implemented

Bit 6 **TRCCOND**: conditional instruction support
1: conditional instruction tracing implemented

Bit 5 **TRCBB**: branch broadcast support
1: branch broadcast tracing implemented

Bits 4:3 **TRCDATA[1:0]**: data tracing support
0x0: data tracing not supported

Bits 2:1 **INSTP0[1:0]**: support for tracing of load and store instructions as P0 elements
0x0: not supported

Bit 0 Reserved, must be kept at reset value.

ETM identification register 1 (ETM_IDR1)

Address offset: 0x1E4

Reset value: 0x4100 F421

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DESIGNER[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r	r	r	r								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TRCARCHMAJ[3:0]				TRCARCHMIN[3:0]				REVISION[3:0]			
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 **DESIGNER[7:0]**: trace unit designer
0x41: Arm®

Bits 23:12 Reserved, must be kept at reset value.

Bits 11:8 **TRCARCHMAJ[3:0]**: major trace unit architecture version number
0x4: ETMv4

Bits 7:4 **TRCARCHMIN[3:0]**: minor trace unit architecture version number
0x2: minor revision 2

Bits 3:0 **REVISION[3:0]**: implementation revision number
0x1: implementation revision 1

ETM identification register 2 (ETM_IDR2)

Address offset: 0x1E8

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	CCSIZE[3:0]				DVSIZE[4:0]					DASIZE[4:1]			
			r	r	r	r	r	r	r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DASIZE[0]	VMIDSIZE[4:0]					CIDSIZE[4:0]					IASIZE[4:0]				
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:25 **CCSIZE[3:0]**: cycle counter size
0x0: 12 bits

Bits 24:20 **DVSIZE[4:0]**: data value size
0x0: data value size not supported

Bits 19:15 **DASIZE[4:0]**: data address size.
0x0: data address size not supported

Bits 14:10 **VMIDSIZE[4:0]**: virtual machine ID size
0x0: virtual machine ID tracing not implemented

Bits 9:5 **CIDSIZE[4:0]**: context ID size
0x0: context ID tracing not implemented

Bits 4:0 **IASIZE[4:0]**: instruction address size
0x4: maximum 32-bit address size

ETM identification register 3 (ETM_IDR3)

Address offset: 0x1EC

Reset value: 0x0F09 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NOOVERFLOW	NUMPROC[2:0]			SYSSTALL	STALLCTL	SYNCPR	TRCERR	Res.	Res.	Res.	Res.	EXLEVEL_S[3:0]			
r	r	r	r	r	r	r	r					r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	CCITMIN[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **NOOVERFLOW**: ETM_STALLCTLR.NOOVERFLOW implementation
0: not implemented

Bits 30:28 **NUMPROC[2:0]**: number of processors available for tracing
0x0: one processor

Bit 27 **SYSSTALL**: system support for stall control of the processor
1: system supports stall control

Bit 26 **STALLCTL**: stall control support
1: ETM_STALLCTLR implemented

Bit 25 **SYNCPR**: trace synchronization period support
1: ETM_SYNCPR is read-only for instruction trace only configuration. The trace synchronization period is fixed.

Bit 24 **TRCERR**: ETM_VICTLR.TRCERR implementation
0x1: implemented

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **EXLEVEL_S[3:0]**: privilege levels implementation
0x9: privilege levels thread and handler implemented

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **CCITMIN[11:0]**: minimum value that can be programmed to TRCCCCTLR.THRESHOLD
Defines the minimum cycle counting threshold.
0x4: minimum of four-instruction trace cycles

ETM identification register 4 (ETM_IDR4)

Address offset: 0x1F0

Reset value: 0x0011 4000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMVMIDC[3:0]				NUMCIDC[3:0]				NUMSSCC[3:0]				NUMRSPAIR[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMPC[3:0]				Res.	Res.	Res.	SUPPDAC	NUMDVC[3:0]				NUMACPAIRS[3:0]			
r	r	r	r				r	r	r	r	r	r	r	r	r

Bits 31:28 **NUMVMIDC[3:0]**: number of virtual machine ID (VMID) comparators
0x0: VMID comparators not implemented

Bits 27:24 **NUMCIDC[3:0]**: number of context ID comparators
0x0: context ID comparators not supported

Bits 23:20 **NUMSSCC[3:0]**: number of single-shot comparator controls
0x1: one single-shot comparator control implemented

Bits 19:16 **NUMRSPAIR[3:0]**: number of resource selection pairs
0x1: two resource selection pairs implemented

Bits 15:12 **NUMPC[3:0]**: number of processor comparator inputs for the DWT
0x4: four processor comparator inputs implemented

Bits 11:9 Reserved, must be kept at reset value.

Bit 8 **SUPPDAC**: data address comparisons
0: data address comparisons not supported

Bits 7:4 **NUMDVC[3:0]**: number of data value comparators
0x0: no data value comparators implemented

Bits 3:0 **NUMACPAIRS[3:0]**: number of address comparator pairs
0x0: no address comparator pairs implemented

ETM identification register 5 (ETM_IDR5)

Address offset: 0x1F4

Reset value: 0x90C7 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REDFUNCNTR	NUMCNTR[2:0]			NUMSEQSTATE[2:0]			Res.	LPOVERRIDE	ATBTRIG	TRACEIDSIZE[5:0]					
r	r	r	r	r	r	r		r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	NUMEXTINSEL[2:0]			NUMEXTIN[8:0]								
				r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **REDFUNCNTR**: reduced function counter
1: counter 0 implemented as a reduced function counter

Bits 30:28 **NUMCNTR[2:0]**: number of counters
0x1: one counter implemented.

Bits 27:25 **NUMSEQSTATE[2:0]**: number of sequencer states
0x0: no sequencer states implemented.

Bit 24 Reserved, must be kept at reset value.

Bit 23 **LPOVERRIDE**: low-power state override support
1: low-power state override support implemented

Bit 22 **ATBTRIG**: ATB trigger support
1: ATB trigger support implemented

Bits 21:16 **TRACEIDSIZE[5:0]**: number of bits of trace identification
0x7: 7-bit trace identification implemented

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:9 **NUMEXTINSEL[2:0]**: number of external input selectors
0x0: no external input selectors implemented.

Bits 8:0 **NUMEXTIN[8:0]**: number of external inputs
0x004: four external inputs implemented.

ETM resource register 2 (ETM_RSCTLR2)

Address offset: 0x208

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PAIRINV	INV	Res.	GROUP[2:0]		
										rw	rw		rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SELECT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **PAIRINV**: result of a combined pair of resources inversion
0: not inverted
1: inverted

Bit 20 **INV**: selected resources inversion
0: not inverted
1: inverted

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **GROUP[2:0]**: group of resources selection
0x0: external input selectors (select 0-3)
0x1: inputs from processor DWT comparators element (select 0-3)
0x2: counter at zero (select 0)
0x3: single-shot comparator (select 0)
Others: reserved

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **SELECT[7:0]**: more resources selection
Selects one or more resources from the group selected in GROUP[2:0].

ETM resource register 3 (ETM_RSCTLR3)

Address offset: 0x20C

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INV	Res.	GROUP[2:0]		
											rw		rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SELECT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **INV**: selected resources inversion
0: not inverted
1: inverted

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **GROUP[2:0]**: group of resources selection
0x0: external input selectors (select 0-3)
0x1: inputs from processor DWT comparators element (select 0-3)
0x2: counter at zero (select 0)
0x3: single-shot comparator (select 0)
Others: reserved

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **SELECT[7:0]**: more resources selection
Selects one or more resources from the group selected in GROUP[2:0].

ETM single-shot comparator control register 0 (ETM_SSCCR0)

Address offset: 0x280

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
							rw								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **RST**: single-shot comparator reset
Enables the single-shot comparator resource to be reset when it occurs, to enable another comparator match to be detected.
1: reset enabled

Bits 23:0 Reserved, must be kept at reset value.

ETM single-shot comparator status register 0 (ETM_SSCSR0)

Address offset: 0x2A0

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
STATUS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PC	DV	DA	INST
												r	r	r	r

Bit 31 **STATUS**: single-shot comparator status
Indicates whether any of the selected comparators have matched.
0: no match occurred
1: at least one match occurred

Bits 30:4 Reserved, must be kept at reset value.

Bit 3 **PC**: processor comparator input sensitivity
1: single-shot comparator sensitive to processor comparator inputs

Bit 2 **DV**: data value comparator support
0: single-shot data value comparisons not supported

Bit 1 **DA**: data address comparator support
0: single-shot data address comparisons not supported

Bit 0 **INST**: instruction address comparator support
0: single-shot instruction address comparisons not supported

ETM single-shot processor comparator input control register 0 (ETM_SSPCICR0)

Address offset: 0x2C0

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PC[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **PC[3:0]**: processor comparator inputs selection for single-shot control
0xXXX0: processor comparator input 0 not selected
0xXXX1: processor comparator input 0 selected
0xXX0X: Processor comparator input 1 not selected
0xXX1X: processor comparator input 1 selected
0xX0XX: processor comparator input 2 not selected
0xX1XX: processor comparator input 2 selected
0x0XXX: processor comparator input 3 not selected
0x1XXX: processor comparator input 3 selected

ETM power-down control register (ETM_PDCR)

Address offset: 0x310

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PU	Res.	Res.	Res.
												rw			

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **PU**: power-up request
0: power-up not requested
1: power-up requested

Bits 2:0 Reserved, must be kept at reset value.

ETM power-down status register (ETM_PDSR)

Address offset: 0x314

Reset value: 0x0000 0003

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STICKYPD	POWER
														r	r

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **STICKYPD**: sticky power-down state
0: Trace register power has not been removed since the ETM_PDSR was last read.
1: Trace register power has been removed since the ETM_PDSR was last read.

Bit 0 **POWER**: ETM power-up status
1: ETM powered up

ETM claim tag set register (ETM_CLAIMSETR)

Address offset: 0xFA0

Reset value: 0x0000 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMSET[3:0]**: claim tag bits setting

Write:
0000: no effect
xxx1: Sets bit 0.
xx1x: Sets bit 1.
x1xx: Sets bit 2.
1xxx: Sets bit 3.
Read:
0xF: Indicates there are four bits in claim tag.

ETM claim tag clear register (ETM_CLAIMCLR)

Address offset: 0xFA4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMCLR[3:0]**: claim tag bits reset

Write:
0000: no effect
xxx1: Clears bit 0.
xx1x: Clears bit 1.
x1xx: Clears bit 2.
1xxx: Clears bit 3.
Read: Returns current value of claim tag.

ETM authentication status register (ETM_AUTHSTATR)

Address offset: 0xFB8

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:6 **SNID[1:0]**: Security level for secure non-invasive debug
0x2: Secure non-invasive debug disabled
0x3: Secure non-invasive debug enabled

Bits 5:4 **SID[1:0]**: security level for secure invasive debug
0x0: not implemented

Bits 3:2 **NSNID[1:0]**: security level for nonsecure non-invasive debug
0x2: Nonsecure non-invasive debug disabled
0x3: Nonsecure non-invasive debug enabled

Bits 1:0 **NSID[1:0]**: security level for nonsecure invasive debug
0x0: Not implemented

ETM device type architecture register (ETM_DEVARCHR)

Address offset: 0xFBC

Reset value: 0x4772 4A13

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARCHITECT[10:0]											PRESENT	REVISION[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARCHVER[3:0]				ARCHPART[11:0]											
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:21 **ARCHITECT[10:0]**: architect JEP106 code
0x23B: JEP106 continuation code 0x4, JEP106 ID code 0x3B. Arm® limited.

Bit 20 **PRESENT**: DEVARCH register presence
0x1: present

Bits 19:16 **REVISION[3:0]**: architecture revision
0x2: ETM architecture v4.2

Bits 15:12 **ARCHVER[3:0]**: architecture version
0x4: ETM architecture v4.2

Bits 11:0 **ARCHPART[11:0]**: architecture part
0xA13: ETM architecture

ETM CoreSight device type register (ETM_DEVTYPER)

Address offset: 0xFCC

Reset value: 0x0000 0013

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYPE[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SUBTYPE[3:0]**: device sub-type identifier
0x1: processor trace

Bits 3:0 **MAJORTYPE[3:0]**: device main type identifier
0x3: trace source

ETM CoreSight peripheral identity register 4 (ETM_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SIZE[3:0]**: register file size
0x0: The register file occupies a single 4-Kbyte region.

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

ETM CoreSight peripheral identity register 0 (ETM_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0021

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: part number bits [7:0]
0x21: ETM part number

ETM CoreSight peripheral identity register 1 (ETM_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00BD

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: part number bits [11:8]
0xD: ETM part number

ETM CoreSight peripheral identity register 2 (ETM_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 001B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: component revision number
0x1: r0p1

Bit 3 **JEDEC**: JEDEC assigned value
0x1: designer identification specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code bits [6:4]
0x3: Arm® JEDEC code

ETM CoreSight peripheral identity register 3 (ETM_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: metal fix version
0x0: no metal fix

Bits 3:0 **CMOD[3:0]**: customer modified
0x0: no customer modifications

ETM CoreSight component identity register 0 (ETM_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: component identification bits [7:0]
0x0D: common identification value

ETM CoreSight peripheral identity register 1 (ETM_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0090

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: component identification bits [15:12] - component class
0x9: trace generator component

Bits 3:0 **PREAMBLE[11:8]**: component identification bits [11:8]
0x0: common identification value

ETM CoreSight component identity register 2 (ETM_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: component identification bits [23:16]
0x05: common identification value

ETM CoreSight component identity register 3 (ETM_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: component identification bits [31:24]
0xB1: common identification value

71.9.2 ETM register map

The ETM registers are accessed by the debugger at the address range 0xE0041000 to 0xE0041FFC.

Table 863. ETM register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x004	**ETM_PRGCTLR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EN
	Reset value																																0
0x008	Reserved	Reserved																															
0x00C	**ETM_STATR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PMSTABLE	IDLE
	Reset value																															X	X
0x010	**ETM_CONFIGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RS	Res.	COND[5:0]						CCI	BB	Res.	Res.	Res.
	Reset value																				X		X	X	X	X	X	X	X	X			
0x014 to 0x01C	Reserved	Reserved																															
0x020	**ETM_ EVENTCTL0R**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TYPE1	Res.	Res.	Res.	SEL1[3:0]				TYPE0	Res.	Res.	Res.	SEL0[3:0]			
	Reset value																	X				X	X	X	X	X				X	X	X	X
0x024	**ETM_ EVENTCTL1R**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LPOVERRIDE	ATB	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INSTEN[1:0]	
	Reset value																				X	X										X	X
0x028	Reserved	Reserved																															

Table 863. ETM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x02C	**ETM_STALLCTLR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INSTPRIORITY	Res.	ISTALL	Res.	Res.	Res.	Res.	LEVEL[3:0]			
	Reset value																						X		X					X	X	X	X
0x030	Reserved	Reserved																															
0x034	**ETM_SYNCPR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PERIOD[4:0]			
	Reset value																												0	1	0	1	0
0x038	**ETM_CCCTLR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	THRESHOLD[11:0]											
	Reset value																					X	X	X	X	X	X	X	X	X	X	X	X
0x03C	Reserved	Reserved																															
0x040	**ETM_TRACEIDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRACEID[6:0]						
	Reset value																										X	X	X	X	X	X	X
0x044 to 0x07C	Reserved	Reserved																															
0x080	**ETM_VICTLR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXLEVEL_S [3:0]				Res.	Res.	Res.	Res.	TRCERR	TRCRESET	SSSTATUS	Res.	EVENT[7:0]							
	Reset value													X	X	X	X					X	X	X		X	X	X	X	X	X	X	X
0x084 to 0x13C	Reserved	Reserved																															
0x140	**ETM_CNTRLDVR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VALUE[15:0]															
	Reset value																	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x144 to 0x17C	Reserved	Reserved																															
0x180	**ETM_IDR8**	MAXSPEC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x184	**ETM_IDR9**	NUMP0KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x188	**ETM_IDR10**	NUMP1KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18C	**ETM_IDR11**	NUMP1SPC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x190	**ETM_IDR12**	NUMCONDKEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x194	**ETM_IDR13**	NUMCONDSPC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x198 to 0x1BC	Reserved	Reserved																															
0x1C0	**ETM_IMSPECR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUPPORT [3:0]			
	Reset value																													0	0	0	0
0x1C4 to 0x1DC	Reserved	Reserved																															

Table 863. ETM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x1E0	**ETM_IDR0**	Res.	Res.	COMMOPT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRCEXDATA	QSUPP[1:0]		Res.	CONDTYPE [1:0]		NUMEVENT [1:0]		RETSTACK	Res.	TRCCCI	TRCCOND	TRCBB	TRCDATA[1:0]		INSTP0[1:0]		Res.
	Reset value			1												0	0	0		0	0	0	1	1		1	1	1	0	0	0	0	
0x1E4	**ETM_IDR1**	DESIGNER[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRCARCHMAJ [3:0]				TRCARCHMIN [3:0]			REVISION [3:0]				
	Reset value	0	1	0	0	0	0	0	1													0	1	0	0	0	0	1	0	0	0	0	1
0x1E8	**ETM_IDR2**	Res.	Res.	Res.	CCSIZE[3:0]				DVSIZE[4:0]					DASIZE[4:0]					VMIDSIZE[4:0]			CIDSIZE[4:0]				IASIZE[4:0]							
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
0x1EC	**ETM_IDR3**	NOOVERFLOW	NUMPROC[2:0]			SYSSTALL	STALLCTL	SYNCPR	TRCERR	Res.	Res.	Res.	Res.	EXLEVEL_S [3:0]				Res.	Res.	Res.	Res.	CCITMIN[11:0]											
	Reset value	0	0	0	0	1	1	1	1					1	0	0	1					0	0	0	0	0	0	0	0	0	1	0	0
0x1F0	**ETM_IDR4**	NUMVMIDC [3:0]				NUMCIDC [3:0]				NUMSSCC [3:0]				NUMRSPAIR [3:0]				NUMPC [3:0]				Res.	Res.	Res.	SUPPDAC	NUMDVC [3:0]				NUMACPAIRS [3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0				0	0	0	0	0	0	0	0	0
0x1F4	**ETM_IDR5**	REDFUNCNTR	NUMCNTR[2:0]			NUMSEQSTATE [2:0]			Res.	LPOVERRIDE	ATBTRIG	TRACEIDSIZE [5:0]						Res.	Res.	Res.	Res.	NUMEXTINSEL [2:0]			NUMEXTIN[8:0]								
	Reset value	1	0	0	1	0	0	0		1	1	0	0	0	1	1	1					0	0	0	0	0	0	0	0	0	1	0	0
0x1F8 to 0x204	Reserved	Reserved																															
0x208	**ETM_RSCTLR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PAIRINV	INV	Res.	GROUP [2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SELECT[7:0]							
	Reset value											X	X		X	X	X									X	X	X	X	X	X	X	X
0x20C	**ETM_RSCTLR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INV	Res.	GROUP [2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SELECT[7:0]							
	Reset value												X		X	X	X									X	X	X	X	X	X	X	X
0x210 to 0x27C	Reserved	Reserved																															
0x280	**ETM_SSCCR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value								X																								
0x284 to 0x29C	Reserved	Reserved																															
0x2A0	**ETM_SSCSR0**	STATUS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PC	DV	DA	INST
	Reset value	X																											X	X	X	X
0x2A4 to 0x2BC	Reserved	Reserved																															

Table 863. ETM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x2C0	**ETM_SSPCICR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PC[3:0]			
	Reset value																													X	X	X	X
0x2C4 to 0x30C	Reserved	Reserved																															
0x310	**ETM_PDCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PU	Res.	Res.	Res.
	Reset value																													0			
0x314	**ETM_PDSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STICKYPD	POWER
	Reset value																															1	1
0x318 to 0xF9C	Reserved	Reserved																															
0xFA0	**ETM_CLAIMSETR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET [3:0]			
	Reset value																													1	1	1	1
0xFA4	**ETM_CLAIMCLR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR [3:0]			
	Reset value																													0	0	0	0
0xFA8 to 0xFB4	Reserved	Reserved																															
0xFB8	**ETM_AUTHSTATR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	SNID [1:0]		SID [1:0]		NSNID [1:0]		NSID [1:0]	
	Reset value																									X	X	X	X	X	X	X	X
0xFBC	**ETM_DEVARCHR**	ARCHITECT[10:0]											PRESEN	REVISION [3:0]				ARCHVER [3:0]				ARCHPART[11:0]											
	Reset value	0	1	0	0	0	1	1	1	0	1	1	1	0	0	1	0	0	1	0	0	1	0	1	0	0	0	0	1	0	0	1	1
0xFC0to 0xFC8	Reserved	Reserved																															
0xFCC	**ETM_DEVTYPER**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	SUBTYPE [3:0]				MAJORTYP [3:0]			
	Reset value																									0	0	0	1	0	0	1	1
0xFD0	**ETM_PIDR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE [3:0]				JEP106CON [3:0]			
	Reset value																									0	0	0	0	0	1	0	0
0xFD4to 0xFDC	Reserved	Reserved																															
0xFE0	**ETM_PIDR0**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	PARTNUM[7:0]							
	Reset value																									0	0	1	0	0	0	0	1
0xFE4	**ETM_PIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID [3:0]				PARTNUM [11:8]			
	Reset value																									1	0	1	1	1	1	0	1
0xFE8	**ETM_PIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION [3:0]				JEDEC	JEP106ID [6:4]		
	Reset value																									0	0	0	1	1	0	1	1
0xFEC	**ETM_PIDR3**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	REVAND[3:0]				CMOD[3:0]			
	Reset value																									0	0	0	0	0	0	0	0

Table 863. ETM register map and reset values (continued)

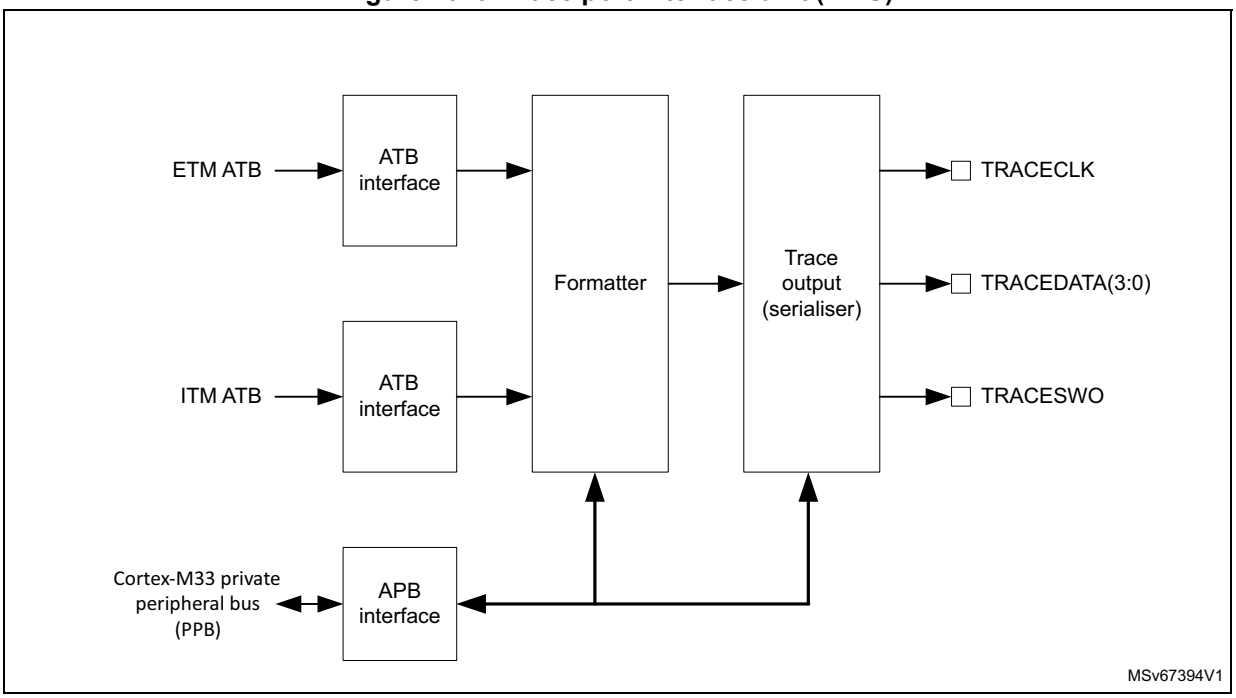
Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFF0	**ETM_CIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value																									0	0	0	0	1	1	0	1
0xFF4	**ETM_CIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE [11:8]			
	Reset value																									1	0	0	1	0	0	0	0
0xFF8	**ETM_CIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value																									0	0	0	0	0	1	0	1
0xFFC	**ETM_CIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value																									1	0	1	1	0	0	0	1

Refer to *Table 856: Processor ROM table* for register boundary addresses.

71.10 Trace port interface unit (TPIU)

The TPIU formats the trace stream and outputs it on the external trace port signals. As shown in the figure below, the TPIU has two ATB slave ports for incoming trace data from the ETM and ITM respectively. The trace port is a synchronous parallel port, comprising a clock output, TRACECLK, and four data outputs, TRACEDATA(3:0). The trace port width is programmable in the range 1 to 4. Using a smaller port width reduces the number of test points/connector pins needed, and frees up IOs for other purposes, at the expense of bandwidth restriction of the trace port, and hence of the quantity of trace information that can be output in real time.

Figure 1040. Trace port interface unit (TPIU)



Trace data can also be output on the serial-wire output, TRACESWO.

For more information on the trace port interface in the Cortex®-M33, refer to the Arm® Cortex®-M33 Technical Reference Manual *[5]*.

71.10.1 TPIU registers

TPIU supported port size register (TPIU_SSPSR)

Address offset: 0x000

Reset value: 0x0000 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PORTSIZE[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PORTSIZE[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **PORTSIZE[31:0]**: trace port sizes, from 1 to 32 pins
Bit n-1 when set, indicates that port size n is supported.
0x0000 000F: port sizes 1 to 4 supported

TPIU current port size register (TPIU_CSPSR)

Address offset: 0x004

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PORTSIZE[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PORTSIZE[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **PORTSIZE[31:0]**: current trace port size
Bit n-1 when set, indicates that the current port size is n pins. The value of n must be within the range of supported port sizes (1-4). Only one bit can be set, or unpredictable behavior may result.
This register must only be modified when the formatter is stopped.

TPIU asynchronous clock prescaler register (TPIU_ACPR)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	PRESCALER[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:0 **PRESCALER[12:0]**: baud rate for the asynchronous output, TRACESWO
The baud rate is given by the TRACELKIN frequency divided by (PRESCALER +1).

TPIU selected pin protocol register (TPIU_SPPR)

Address offset: 0x0F0

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXMODE[1:0]	
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bits 1:0 **TXMODE[1:0]**: protocol used for trace output
0x0: parallel trace port mode
0x1: asynchronous SWO using Manchester encoding
0x2: asynchronous SWO using NRZ encoding
0x3: reserved

TPIU formatter and flush status register (TPIU_FFSR)

Address offset: 0x300

Reset value: 0x0000 0008

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FTNONSTOP	TCPRESENT	FTSTOPPED	FLINPROG
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **FTNONSTOP**: formatter stop

Indicates whether formatter can be stopped or not.

1: The formatter cannot be stopped.

Bit 2 **TCPRESENT**: TRACECTL output pin availability

Indicates whether the optional TRACECTL output pin is available for use.

0: TRACECTL pin is not present in this device.

Bit 1 **FTSTOPPED**: formatter stop

The formatter has received a stop request signal and all trace data and post-amble is sent. Any additional trace data on the ATB interface is ignored.

0: The formatter has not stopped.

Bit 0 **FLINPROG**: flush in progress

Indicates whether a flush on the ATB slave port is in progress. This bit reflects the status of the AFVALIDS output. A flush can be initiated by the flush control bits in the TPIU_FFCR register.

0: no flush in progress

1: flush in progress

TPIU formatter and flush control register (TPIU_FFCR)

Address offset: 0x304

Reset value: 0x0000 0102

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGIN	Res.	FONMAN	Res.	Res.	Res.	Res.	ENFCONT	Res.
							r		rw					rw	

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **TRIGIN**: trigger on trigger in

1: Indicates a trigger in the trace stream when the TRIGIN input is asserted.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **FONMAN**: flush on manual

0: flush completed

1: Generates a flush.

Bits 5:2 Reserved, must be kept at reset value.

Bit 1 **ENFCONT:** continuous formatting enable

Setting this bit to zero in SWO mode bypasses the formatter and only ITM/DWT trace is output, ETM trace is discarded.

0: continuous formatting disabled

1: continuous formatting enabled

Bit 0 Reserved, must be kept at reset value.

TPIU periodic synchronization counter register (TPIU_PSCR)

Address offset: 0x308

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	PSCOUNT[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:0 **PSCOUNT[12:0]**: formatter frames counter

Enables effective use of different sized TPAs without wasting large amounts of the storage capacity of the capture device. This counter contains the number of formatter frames since the last synchronization packet of 128 bits. It is a 12-bit counter with a maximum count value of 4096. This equates to synchronization every 65536 bytes, that is, 4096 packets x 16 bytes per packet. The default is set up for a synchronization packet every 1024 bytes, that is, every 64 formatter frames. If the formatter is configured for continuous mode, full and half-word synchronization frames are inserted during normal operation. Under these circumstances, the count value is the maximum number of complete frames between full synchronization packets.

TPIU claim tag set register (TPIU_CLAIMSETR)

Address offset: 0xFA0

Reset value: 0x0000 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMSET[3:0]**: claim tag bits setting
Write:
0000: no effect
xxx1: Sets bit 0.
xx1x: Sets bit 1.
x1xx: Sets bit 2.
1xxx: Sets bit 3.
Read:
0xF: Indicates there are four bits in claim tag.

TPIU claim tag clear register (TPIU_CLAIMCLR)

Address offset: 0xFA4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMCLR[3:0]**: claim tag bits reset
Write:
0000: no effect
xxx1: Clears bit 0.
xx1x: Clears bit 1.
x1xx: Clears bit 2.
1xxx: Clears bit 3.
Read: Returns current value of claim tag.

TPIU device configuration register (TPIU_DEVIDR)

Address offset: 0xFC8

Reset value: 0x0000 0CA1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	SWOUARTNRZ	SWOMAN	TCLKDATA	FIFOSIZE[2:0]			CLKRELAT	MAXNUM[4:0]				
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **SWOUARTNRZ**: Serial-wire output, NRZ support
0x1: supported

Bit 10 **SWOMAN**: Serial-wire output, Manchester encoded format, support
0x1: supported

Bit 9 **TCLKDATA**: trace clock plus data support
0x0: supported

Bits 8:6 **FIFOSIZE[2:0]**: FIFO size in powers of 2
0x2: FIFO size = 4 bytes

Bit 5 **CLKRELAT**: ATB clock and TRACECLKIN relationship (synchronous or asynchronous)
0x1: asynchronous

Bits 4:0 **MAXNUM[4:0]**: number/type of ATB input port multiplexing
0x1: two input ports

TPIU device type identifier register (TPIU_DEVTYPER)

Address offset: 0xFCC

Reset value: 0x0000 0011

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYPE[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SUBTYPE[3:0]**: sub-classification
0x1: trace port component

Bits 3:0 **MAJORTYPE[3:0]**: major classification
0x1: trace sink component

TPIU CoreSight peripheral identity register 4 (TPIU_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SIZE[3:0]**: register file size
0x0: The register file occupies a single 4-Kbyte region.

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

TPIU CoreSight peripheral identity register 0 (TPIU_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0021

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: part number bits [7:0]
0x21: TPIU part number

TPIU CoreSight peripheral identity register 1 (TPIU_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00BD

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: part number bits [11:8]
0xD: TPIU part number

TPIU CoreSight peripheral identity register 2 (TPIU_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: component revision number
0x0: r0p0

Bit 3 **JEDEC**: JEDEC assigned value
0x1: designer identification specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code bits [6:4]
0x3: Arm® JEDEC code

TPIU CoreSight peripheral identity register 3 (TPIU_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: metal fix version
0x0: no metal fix

Bits 3:0 **CMOD[3:0]**: customer modified
0x0: no customer modifications

TPIU CoreSight component identity register 0 (TPIU_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: component identification bits [7:0]
0x0D: common identification value

TPIU CoreSight peripheral identity register 1 (TPIU_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0090

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: component ID bits [15:12] - component class
0x9: CoreSight™ component

Bits 3:0 **PREAMBLE[11:8]**: component identification bits [11:8]
0x0: common identification value

TPIU CoreSight component identity register 2 (TPIU_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: component identification bits [23:16]
0x05: common identification value

TPIU CoreSight component identity register 3 (TPIU_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: component identification bits [31:24]
0xB1: common identification value

71.10.2 TPIU register map

Table 864. TPIU register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**TPIU_SSPSR**	PORTSIZE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
0x004	**TPIU_CSPSR**	PORTSIZE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x008	Reserved	Reserved																															
0x010	**TPIU_ACPR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[12:0]												
	Reset value																				0	0	0	0	0	0	0	0	0	0	0	0	0
0x014 to 0x0EC	Reserved	Reserved																															
0x0F0	**TPIU_SPPR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXMODE [1:0]	
	Reset value																															0	1
0x0F4 to 0x2FC	Reserved	Reserved																															
0x300	**TPIU_FFSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FTNONSTOP	TCPRESENT	FTSTOPPED	FLINPROG
	Reset value																													1	0	0	0
0x304	**TPIU_FFCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGIN	Res.	FONMAN	Res.	Res.	Res.	Res.	ENFCONT	Res.
	Reset value																								1		0					1	

Table 864. TPIU register map and reset values (continued)

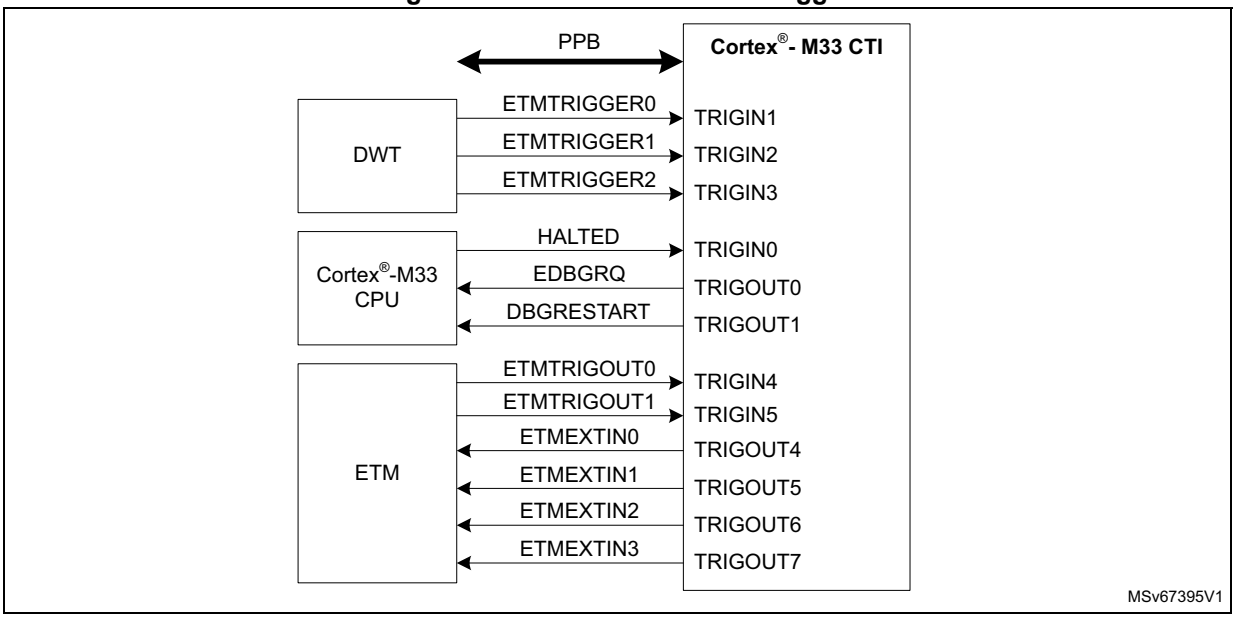
Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x308	**TPIU_PSCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSCOUNT[12:0]												
	Reset value																				0	0	0	0	0	0	0	0	0	0	0	0	0
030C to 0xF9C	Reserved	Reserved																															
0xFA0	**TPIU_CLAIMSETR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET [3:0]			
	Reset value																													1	1	1	1
0xFA4	**TPIU_CLAIMCLR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR [3:0]			
	Reset value																													0	0	0	0
0FA8 to 0xFC4	Reserved	Reserved																															
0xFC8	**TPIU_DEVIDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWOUARTNRZ:	SWOMAN	TCLKDATA	FIFOSIZE[2:0]			CLKRELAT	MaXNUM[4:0]				
	Reset value																					1	1	0	0	1	0	1	0	0	0	0	1
0xFCC	**TPIU_DEVTYPER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE [3:0]				MAJORTYPE [3:0]			
	Reset value																									0	0	0	1	0	0	0	1
0xFD0	**TPIU_PIDR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE [3:0]				JEP106CON [3:0]			
	Reset value																									0	0	0	0	0	1	0	0
0xFE0	**TPIU_PIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value																									0	0	1	0	0	0	0	1
0xFE4	**TPIU_PIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID [3:0]				PARTNUM [11:8]			
	Reset value																									1	0	1	1	1	1	0	1
0xFE8	**TPIU_PIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION [3:0]				JEDEC	JEP106ID [6:4]		
	Reset value																									0	0	0	0	1	0	1	1
0xFEC	**TPIU_PIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFF0	**TPIU_CIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value																									0	0	0	0	1	1	0	1
0xFF4	**TPIU_CIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE [11:8]			
	Reset value																									1	0	0	1	0	0	0	0
0xFF8	**TPIU_CIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value																									0	0	0	0	0	1	0	1
0xFFC	**TPIU_CIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value																									1	0	1	1	0	0	0	1

Refer to *Table 855: MCU ROM table* for register boundary addresses.

71.11 Cross-trigger interface (CTI)

The CTI (see *Figure 1041*) allows cross-triggering between the processor and the ETM.

Figure 1041. Embedded cross-trigger



The CTI enables events from various sources to trigger debug and/or trace activity. For example, a watch-point reached in the processor can start or stop the code trace, or a trace comparator can halt the processor.

The trigger input and output signals for the CTI are listed in the tables below.

Table 865. CTI inputs

Number	Source signal	Source component	Comments
0	HALTED	CPU	Processor halted - CPU is in debug mode
1	ETMTRIGGER0	DWT	DWT comparator output 0
2	ETMTRIGGER1	DWT	DWT comparator output 1
3	ETMTRIGGER2	DWT	DWT comparator output 2
4	ETMTRIGOUT0	ETM	ETM event output 0
5	ETMTRIGOUT1	ETM	ETM event output 1
6	-	-	Not used
7	-	-	Not used

Table 866. CTI outputs

Number	Source signal	Destination component	Comments
0	EDBGRQ	CPU	CPU halt request - Puts CPU in debug mode
1	DBGRESTART	CPU	CPU restart request - CPU exits debug mode

Table 866. CTI outputs (continued)

Number	Source signal	Destination component	Comments
2	ETMEXTIN0	ETM	ETM event input 0
3	ETMEXTIN1	ETM	ETM event input 1
4	ETMEXTIN2	ETM	ETM event input 2
5	ETMEXTIN3	ETM	ETM event input 3
6	-	-	Not used
7	-	-	Not used

For more information on the cross-trigger interface CoreSight™ component, refer to the Arm® CoreSight™ SoC-400 Technical Reference Manual *[2]*.

71.11.1 CTI registers

The register file base address for the CTI is 0xE004 2000.

CTI control register (CTI_CONTROLR)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GLBEN
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **GLBEN**: global CTI enable
0: disabled
1: enabled

CTI trigger acknowledge register (CTI_INTACKR)

Address offset: 0x010

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INTACK[7:0]							
								w	w	w	w	w	w	w	w

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **INTACK[7:0]**: trigger acknowledge
There is one bit of the register for each CTITRIGOUT output. When a 1 is written to a bit in this register, the corresponding CTITRIGOUT output is acknowledged, causing it to be cleared.

CTI application trigger set register (CTI_APPSETR)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APPSET[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **APPSET[3:0]**: channel event setting
Read:
XXX0: channel 0 event inactive
XXX0: channel 0 event active
XX0X: channel 1 event inactive
XX1X: channel 1 event active
X0XX: channel 2 event inactive
X1XX: channel 2 event active
0XXX: channel 3 event inactive
1XXX: channel 3 event active
Write:
XXX0: no effect
XXX0: Sets event on channel 0.
XX0X: no effect
XX1X: Sets event on channel 1.
X0XX: no effect
X1XX: Sets event on channel 2.
0XXX: no effect
1XXX: Sets event on channel 3.

CTI application trigger clear register (CTI_APPCLEAR)

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APPCLEAR[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **APPCLEAR[3:0]**: channel event clear
0000: no effect
XXX1: Clears event on channel 0.
XX1X: Clears event on channel 1.
X1XX: Clears event on channel 2.
1XXX: Clears event on channel 3.

CTI application pulse register (CTI_APPPULSER)

Address offset: 0x01C

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APPPULSE[3:0]			
												w	w	w	w

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **APPPULSE[3:0]**: pulse channel event
This register clears itself immediately.
0000: no effect
XXX1: Generates pulse on channel 0.
XX1X: Generates pulse on channel 1.
X1XX: Generates pulse on channel 2.
1XXX: Generates pulse on channel 3.

CTI trigger input x enable register (CTI_INENxR)

Address offset: 0x020 + 0x004 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGINEN[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **TRIGINEN[3:0]**: trigger input event enable

Enables or disables a cross-trigger event on each of the four channels when CTITRIGINx is activated (x = 0 to 7).

0000: Trigger does not generate events on channels.

XXX1: Trigger x generates events on channel 0.

XX1X: Trigger x generates events on channel 1.

X1XX: Trigger x generates events on channel 2.

1XXX: Trigger x generates events on channel 3.

CTI trigger output x enable register (CTI_OUTENxR)

Address offset: 0x0A0 + 0x004 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGOUTEN[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **TRIGOUTEN[3:0]**: trigger output event enable

For each channel, defines whether an event on that channel generates a trigger on CTITRIGOUTx (x = 0 to 7).

0000: Channel events do not generate triggers on trigger outputs.

XXX1: Channel 0 events generate triggers on trigger output x.

XX1X: Channel 1 events generate triggers on trigger output x.

X1XX: Channel 2 events generate triggers on trigger output x.

1XXX: Channel 3 events generate triggers on trigger output x.

CTI trigger input status register (CTI_TRGISTSR)

Address offset: 0x130

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGINSTATUS[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **TRIGINSTATUS[7:0]**: trigger input status

There is one bit of the register for each CTITRIGINx input. When a bit is set to 1, it indicates that the corresponding trigger input is active. When it is set to 0, the corresponding trigger input is inactive.

CTI trigger output status register (CTI_TRGOSTSR)

Address offset: 0x134

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGOUTSTATUS[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **TRIGOUTSTATUS[7:0]**: trigger output status

There is one bit of the register for each CTITRIGOUT output. When a bit is set to 1, it indicates that the corresponding trigger output is active. When it is set to 0, the corresponding trigger output is inactive.

CTI channel input status register (CTI_CHINSTSR)

Address offset: 0x138

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CHINSTATUS[3:0]			
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CHINSTATUS[3:0]**: channel input status

There is one bit of the register for each channel input. When a bit is set to 1 it indicates that the corresponding channel input is active. When it is set to 0, the corresponding channel input is inactive.

CTI channel output status register (CTI_CHOUTSTSR)

Address offset: 0x13C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CHOUTSTATUS[3:0]			
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CHOUTSTATUS[3:0]**: channel output status

There is one bit of the register for each channel output. When a bit is set to 1 it indicates that the corresponding channel output is active. When it is set to 0, the corresponding channel output is inactive.

CTI channel gate register (CTI_GATER)

Address offset: 0x140

Reset value: 0x0000 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GATEEN[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **GATEEN[3:0]**: channel output enable

For each channel, defines whether an event on that channel can propagate over the CTM to other CTIs.

0000: Channels events do not propagate.

XXX1: Channel 0 events propagate.

XX1X: Channel 1 events propagate.

X1XX: Channel 2 events propagate.

1XXX: Channel 3 events propagate.

CTI device configuration register (CTI_DEVIDR)

Address offset: 0xFC8

Reset value: 0x0004 0800

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NUMCH[3:0]			
												r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMTRIG[7:0]								Res.	Res.	Res.	EXTMUXNUM[4:0]				
r	r	r	r	r	r	r	r				r	r	r	r	r

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:16 **NUMCH[3:0]**: number of ECT channels available
0x4: four channels

Bits 15:8 **NUMTRIG[7:0]**: number of ECT triggers available
0x8: height trigger inputs and height trigger outputs

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **EXTMUXNUM[4:0]**: number of trigger input/output multiplexers
0x0: none

CTI device type identifier register (CTI_DEVTYPER)

Address offset: 0xFCC

Reset value: 0x0000 0014

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYPE[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SUBTYPE[3:0]**: sub-classification
0x1: cross-triggering component.

Bits 3:0 **MAJORTYPE[3:0]**: major classification
0x4: Indicates that this component allows a debugger to control other components in a CoreSight™ SoC-400 system.

CTI CoreSight peripheral identity register 4 (CTI_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SIZE[3:0]**: register file size
0x0: The register file occupies a single 4-Kbyte region.

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

CTI CoreSight peripheral identity register 0 (CTI_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0021

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: part number bits [7:0]
0x21: CTI part number

CTI CoreSight peripheral identity register 1 (CTI_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00BD

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: part number bits [11:8]
0xD: CTI part number

CTI CoreSight peripheral identity register 2 (CTI_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: component revision number
0x0: r0p0

Bit 3 **JEDEC**: JEDEC assigned value
0x1: designer identification specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code bits [6:4]
0x3: Arm® JEDEC code

CTI CoreSight peripheral identity register 3 (CTI_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: metal fix version
0x0: no metal fix

Bits 3:0 **CMOD[3:0]**: customer modified
0x0: no customer modifications

CTI CoreSight component identity register 0 (CTI_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: component identification bits [7:0]
0x0D: common identification value

CTI CoreSight peripheral identity register 1 (CTI_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0090

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: component identification bits [15:12] - component class
0x9: CoreSight™ component

Bits 3:0 **PREAMBLE[11:8]**: component identification bits [11:8]
0x0: common identification value

CTI CoreSight component identity register 2 (CTI_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: component identification bits [23:16]
0x05: common identification value

CTI CoreSight component identity register 3 (CTI_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: component identification bits [31:24]
0xB1: common identification value

71.11.2 CTI register map

Table 867. CTI register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**CTI_CONTROLR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GLBEN
	Reset value																																0
0x004 to 0x00C	Reserved	Reserved																															
0x010	**CTI_INTACKR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INTACK[7:0]							
	Reset value																									X	X	X	X	X	X	X	X
0x014	**CTI_APPSETR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APPSET[3:0]			
	Reset value																													0	0	0	0
0x018	**CTI_APPCLEAR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APPCLEAR [3:0]			
	Reset value																													0	0	0	0

Table 867. CTI register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x01C	**CTI_APPPULSER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APPPULSE [3:0]			
	Reset value																													X	X	X	X
0x020 to 0x03C	**CTI_INEN0R to CTI_INEN7R**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGINEN [3:0]			
	Reset value																													0	0	0	0
0x040 to 0x09C	Reserved	Reserved																															
0x0A0 to 0x0BC	**CTI_OUTEN0R to CTI_OUTEN7R**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGOUTEN [3:0]			
	Reset value																													0	0	0	0
0x0C0 to 0x12C	Reserved	Reserved																															
0x130	**CTI_TRGISTSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGINSTATUS[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x134	**CTI_TRGOSTSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGOUTSTATUS[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x138	**CTI_CHINSTSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CHINSTATUS [3:0]			
	Reset value																													0	0	0	0
0x13C	**CTI_CHOUTSTSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CHOUTSTATUS[3:0]			
	Reset value																													0	0	0	0
0x140	**CTI_GATER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GATEEN[3:0]			
	Reset value																													1	1	1	1
0x144 to 0xFC4	Reserved	Reserved																															
0xFC8	**CTI_DEVIDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NUMCH[3:0]				NUMTRIG[7:0]								Res.	Res.	Res.	EXTMUXNUM [4:0]				
	Reset value													0	1	0	0	0	0	0	0	1	0	0	0				0	0	0	0	0
0xFCC	**CTI_DEVTYPER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUB[3:0]				MAJOR[3:0]			
	Reset value																									0	0	0	1	0	1	0	0
0xFD0	**CTI_PIDR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE [3:0]				JEP106CON [3:0]			
	Reset value																									0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	**CTI_PIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value																									0	0	0	1	0	0	0	1
0xFE4	**CTI_PIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID [3:0]				PARTNUM [11:8]			
	Reset value																									1	0	1	1	1	1	0	1

Table 867. CTI register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFE8	**CTI_PIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION [3:0]				JEDEC	JEP106ID [6:4]		
	Reset value																									0	0	0	0	1	0	1	1
0xFEC	**CTI_PIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFF0	**CTI_CIDR0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value																									0	0	0	0	1	1	0	1
0xFF4	**CTI_CIDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE [11:8]			
	Reset value																									1	0	0	1	0	0	0	0
0xFF8	**CTI_CIDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value																									0	0	0	0	0	1	0	1
0xFFC	**CTI_CIDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value																									1	0	1	1	0	0	0	1

Refer to *Table 856: Processor ROM table* for register boundary addresses.

71.12 Microcontroller debug unit (DBGMCU)

The DBGMCU is a component containing a number of registers that control the power and clock behavior in debug mode. It allows the debugger (or the software) to:

- Maintain the clock and power to the processor cores, when in low-power modes (Sleep, Stop, or Standby)
- Maintain the clock and power to the system debug and trace components, when in low-power modes
- Stop the clock to certain peripherals (SMBUS timeout, watchdogs, timers, RTC), when either processor core is stopped in debug mode

71.12.1 Device ID

The DBGMCU includes an identity code register, DBGMCU_IDCODE. This register contains the ID code for the device. Debug tools can locate this register via the CoreSight™ discovery procedure described in *Section 71.5*.

71.12.2 Low-power mode emulation

When the device enters either Stop mode (clocks are stopped) or Standby mode (core power is switched off), the debugger can no longer access the debug access port and loses the connection with the device. To avoid this, the debugger (or software) can set the DBG_STANDBY and/or DBG_STOP bits in the *DBGMCU configuration register (DBGMCU_CR)*. These bits, when set, maintain the clock and power to the processor while the device is in the corresponding low-power mode. The processor remains in Sleep mode, and exits the low-power mode in the normal way. However, peripheral devices continue to operate, so the device behavior may not be identical to that of the actual low-power mode.

71.12.3 Peripheral clock freeze

The DBGMCU peripheral clock freeze registers allow to suspend operation of certain peripherals in debug mode. The peripherals supporting this feature are listed in *Table 868*.

Table 868. Peripheral clock freeze control bits

Bus	Control register	Peripheral	Description
APB1L	DBGMCU_APB1LFZR	I3C1	I3C1 SCL stall timeout counter
		I2C2	I2C2 SMBUS timeout
		I2C1	I2C1 SMBUS timeout
		IWDG	Independent watchdog
		WWDG	Window watchdog
		TIM14	General purpose timer 14
		TIM13	General purpose timer 13
		TIM12	General purpose timer 12
		TIM7	General purpose timer 7
		TIM6	General purpose timer 6
		TIM5	General purpose timer 5
		TIM4	General purpose timer 4
		TIM3	General purpose timer 3
		TIM2	General purpose timer 2
APB1H	DGBMCU_APB1HFZR	LPTIM2	Low power timer 2
APB2	DBGMCU_APB2FZR	TIM17	General purpose timer 17
		TIM16	General purpose timer 16
		TIM15	General purpose timer 15
		TIM8	General purpose timer 8
		TIM1	General purpose timer 1
APB3	DBGMCU_APB3FZR	RTC	Real time clock
		LPTIM6	Low power timer 6
		LPTIM5	Low power timer 5
		LPTIM4	Low power timer 4
		LPTIM3	Low power timer 3
		LPTIM1	Low power timer 1
		I2C4	I2C4 SMBUS timeout
		I2C3	I2C3 SMBUS timeout
		I3C2	I3C2 SCL stall timeout counter
AHB1	DBGMCU_AHB1FZR	GPDMA2 0 to 11	General purpose DMA2 channels 0 to 11
		GPDMA1 0 to 11	General purpose DMA1 channels 0 to 11

Each peripheral unit or DMA channel has a corresponding control bit, DBG_xxx_STOP, where xxx is the acronym of the peripheral (or DMA channel). The control bits are organized in DBGMCU_zzzFZR registers, where zzz corresponds to the name of the bus (AHB or APB). For example, DBGMCU_APB1LFZR contains the control bits for peripherals on the APB1L bus.

The control bit, when set, causes the corresponding peripheral operation to be suspended when the CPU is stopped in debug (HALTED = 1), according to the table below:

Table 869. Peripheral behaviour in debug mode

HALTED	DBG_xxx_STOP	Peripheral behaviour
0	X	The operation continues.
1	0	The operation continues.
1	1	The operation is suspended.

The accessibility of the bits DBG_xxx_STOP by the debugger depends on the state of the authentication signal spiden.

When spiden = 1 (secure privilege debug enabled), all bits can be modified and read by both debugger and software (secure or nonsecure).

When spiden = 0 (secure privilege debug disabled), only bits corresponding to nonsecure peripherals (or DMA channels) can be modified by the debugger or software. All bits can be read.

The status (secure or nonsecure) of a TrustZone-aware peripheral or a DMA channel, is signaled to the DBGMCU by the peripheral.

71.12.4 DBGMCU registers

The DBGMCU registers are reset only by a power-on reset. They are accessible to the debugger via the AHB access port at base address 0xE00E 4000, and to software at base address 0x4402 4000.

DBGMCU identity code register (DBGMCU_IDCODE)

Address offset: 0x00

Reset value: 0xXXXX 6XXX

This register is always accessible.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REV_ID[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DEV_ID[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **REV_ID[15:0]**: Revision
A: 0x1000
Z: 0x1001

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **DEV_ID[11:0]**: Device identification
0x47A: STM32H5Exx/Fxx

DBGMCU configuration register (DBGMCU_CR)

Address offset: 0x04

Reset value: 0x0000 0000

This register is accessible to the debugger and to the CPU after successful authentication. Prior to this, debugger accesses are ignored.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCRT
															rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRACE_MODE [1:0]		TRACE_EN	TRACE_IOEN	Res.	DBG_STANDBY	DBG_STOP	Res.
								rw	rw	rw	rw		rw	rw	

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **DCRT**: Debug credentials reset type
This bit selects which type of reset is used to revoke the debug authentication credentials
0: System reset
1: Power reset

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:6 **TRACE_MODE[1:0]**: trace pin assignment
0x0: trace pins assigned for asynchronous mode (TRACESWO)
0x1: trace pins assigned for synchronous mode with a port width of 1 (TRACECK, TRACED0)
0x2: trace pins assigned for synchronous mode with a port width of 2 ((TRACECK, TRACED0-1)
0x3: trace pins assigned for synchronous mode with a port width of 4 ((TRACECK, TRACED0-3)

Bit 5 **TRACE_EN**: trace port and clock enable.
This bit enables the trace port clock, TRACECK.
0: disabled
1: enabled

Bit 4 **TRACE_IOEN**: trace pin enable
0: disabled - trace pins not assigned
1: enabled - trace pins assigned according to the value of TRACE_MODE field

Bit 3 Reserved, must be kept at reset value.

Bit 2 **DBG_STANDBY**: Allows debug in Standby mode
0: normal operation
All clocks are disabled and the core powered down automatically in Standby mode.
1: automatic clock stop/power down disabled
All active clocks and oscillators continue to run during Standby mode, and the core supply is maintained, allowing full debug capability. On exit from Standby mode, a system reset is performed.

Bit 1 **DBG_STOP**: Allows debug in Stop mode
0: normal operation
All clocks are disabled automatically in Stop mode.
1: automatic clock stop disabled
All active clocks and oscillators continue to run during Stop mode, allowing full debug capability. On exit from Stop mode, the clock settings are set to the Stop mode exit state.

Bit 0 Reserved, must be kept at reset value.

DBGMCU APB1L peripheral freeze register (DBGMCU_APB1LFZR)

Address offset: 0x08

Reset value: 0x0000 0000

This register is accessible to the debugger and to the CPU after successful authentication. Prior to this, accesses are ignored.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBG_I3C1_STOP	DBG_I2C2_STOP	DBG_I2C1_STOP	Res.	Res.	Res.	Res.	Res.
								rw	rw	rw					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DBG_IWDG_STOP	DBG_WWDG_STOP	Res.	Res.	DBG_TIM14_STOP	DBG_TIM13_STOP	DBG_TIM12_STOP	DBG_TIM7_STOP	DBG_TIM6_STOP	DBG_TIM5_STOP	DBG_TIM4_STOP	DBG_TIM3_STOP	DBG_TIM2_STOP
			rw	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **DBG_I3C1_STOP**: I3C1 SCL stall counter stop in debug
0: normal operation. I3C1 SCL stall timeout counter continues to operate while CPU is in debug mode.
1: stop in debug. I3C1 SCL stall timeout counter is frozen while CPU is in debug mode.

Bit 22 **DBG_I2C2_STOP**: I2C2 SMBUS timeout stop in debug
0: normal operation. I2C2 SMBUS timeout continues to operate while CPU is in debug mode.
1: stop in debug. I2C2 SMBUS timeout is frozen while CPU is in debug mode.

Bit 21 **DBG_I2C1_STOP**: I2C1 SMBUS timeout stop in debug
0: normal operation. I2C1 SMBUS timeout continues to operate while CPU is in debug mode.
1: stop in debug. I2C1 SMBUS timeout is frozen while CPU is in debug mode.

Bits 20:13 Reserved, must be kept at reset value.

Bit 12 **DBG_IWDG_STOP**: IWDG stop in debug
0: normal operation. IWDG continues to operate while CPU is in debug mode.
1: stop in debug. IWDG is frozen while CPU is in debug mode.

Bit 11 **DBG_WWDG_STOP**: WWDG stop in debug
0: normal operation. WWDG continues to operate while CPU is in debug mode.
1: stop in debug. WWDG is frozen while CPU is in debug mode.

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **DBG_TIM14_STOP**: TIM14 stop in debug
0: normal operation. TIM14 continues to operate while CPU is in debug mode.
1: stop in debug. TIM14 is frozen while CPU is in debug mode.

Bit 7 **DBG_TIM13_STOP**: TIM13 stop in debug
0: normal operation. TIM13 continues to operate while CPU is in debug mode.
1: stop in debug. TIM13 is frozen while CPU is in debug mode.

Bit 6 **DBG_TIM12_STOP**: TIM12 stop in debug
0: normal operation. TIM12 continues to operate while CPU is in debug mode.
1: stop in debug. TIM12 is frozen while CPU is in debug mode.

Bit 5 **DBG_TIM7_STOP**: TIM7 stop in debug
0: normal operation. TIM7 continues to operate while CPU is in debug mode.
1: stop in debug. TIM7 is frozen while CPU is in debug mode.

Bit 4 **DBG_TIM6_STOP**: TIM6 stop in debug
0: normal operation. TIM6 continues to operate while CPU is in debug mode.
1: stop in debug. TIM6 is frozen while CPU is in debug mode.

Bit 3 **DBG_TIM5_STOP**: TIM5 stop in debug
0: normal operation. TIM5 continues to operate while CPU is in debug mode.
1: Stop in debug. TIM5 is frozen while CPU is in debug mode.

Bit 2 **DBG_TIM4_STOP**: TIM4 stop in debug
0: normal operation. TIM4 continues to operate while CPU is in debug mode.
1: stop in debug. TIM4 is frozen while CPU is in debug mode.

Bit 1 **DBG_TIM3_STOP**: TIM3 stop in debug
0: normal operation. TIM3 continues to operate while CPU is in debug mode.
1: stop in debug. TIM3 is frozen while CPU is in debug mode.

Bit 0 **DBG_TIM2_STOP**: TIM2 stop in debug
0: normal operation. TIM2 continues to operate while CPU is in debug mode.
1: stop in debug. TIM2 is frozen while CPU is in debug mode.

DBGMCU APB1H peripheral freeze register (DBGMCU_APB1HFZR)

Address offset: 0x0C

Reset value: 0x0000 0000

This register is accessible to the debugger and to the CPU after successful authentication. Prior to this, accesses are ignored.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBG_LPTIM2_STOP	Res.	Res.	Res.	Res.	Res.
										rw					

Bits 31:6 Reserved, must be kept at reset value.

Bit 5 **DBG_LPTIM2_STOP**: LPTIM2 stop in debug
0: normal operation. LPTIM2 continues to operate while CPU is in debug mode.
1: stop in debug. LPTIM2 is frozen while CPU is in debug mode.

Bits 4:0 Reserved, must be kept at reset value.

DBGMCU APB2 peripheral freeze register (DBGMCU_APB2FZR)

Address offset: 0x10

Reset value: 0x0000 0000

This register is accessible to the debugger and to the CPU after successful authentication. Prior to this, access are ignored.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBG_TIM17_STOP	DBG_TIM16_STOP	DBG_TIM15_STOP
													rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	DBG_TIM8_STOP	Res.	DBG_TIM1_STOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
		rw		rw											

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **DBG_TIM17_STOP**: TIM17 stop in debug
0: normal operation. TIM17 continues to operate while CPU is in debug mode.
1: stop in debug. TIM17 is frozen while CPU is in debug mode.

Bit 17 **DBG_TIM16_STOP**: TIM16 stop in debug
0: normal operation. TIM16 continues to operate while CPU is in debug mode.
1: stop in debug. TIM16 is frozen while CPU is in debug mode.

Bit 16 **DBG_TIM15_STOP**: TIM15 stop in debug
0: normal operation. TIM15 continues to operate while CPU is in debug mode.
1: stop in debug. TIM15 is frozen while CPU is in debug mode.

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **DBG_TIM8_STOP**: TIM8 stop in debug
0: normal operation. TIM8 continues to operate while CPU is in debug mode.
1: stop in debug. TIM8 is frozen while CPU is in debug mode.

Bit 12 Reserved, must be kept at reset value.

Bit 11 **DBG_TIM1_STOP**: TIM1 stop in debug
0: normal operation. TIM1 continues to operate while CPU is in debug mode.
1: stop in debug. TIM1 is frozen while CPU is in debug mode.

Bits 10:0 Reserved, must be kept at reset value.

DBGMCU APB3 peripheral freeze register (DBGMCU_APB3FZR)

Address offset: 0x14

Reset value: 0x0000 0000

This register is accessible to the debugger and to the CPU after successful authentication. Prior to this, accesses are ignored.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	DBG_RTC_STOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBG_LPTIM6_STOP	DBG_LPTIM5_STOP	DBG_LPTIM4_STOP	DBG_LPTIM3_STOP	DBG_LPTIM1_STOP	Res.
	rw									rw	rw	rw	rw	rw	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DBG_I3C2_STOP	DBG_I2C4_STOP	DBG_I2C3_STOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
			rw	rw	rw										

Bit 31 Reserved, must be kept at reset value.

Bit 30 **DBG_RTC_STOP**: RTC stop in debug
0: normal operation. RTC continues to operate while CPU is in debug mode.
1: stop in debug. RTC is frozen while CPU is in debug mode.

Bits 29:22 Reserved, must be kept at reset value.

Bit 21 **DBG_LPTIM6_STOP**: LPTIM6 stop in debug
0: normal operation. LPTIM6 continues to operate while CPU is in debug mode.
1: stop in debug. LPTIM6 is frozen while CPU is in debug mode.

Bit 20 **DBG_LPTIM5_STOP**: LPTIM5 stop in debug
0: normal operation. LPTIM5 continues to operate while CPU is in debug mode.
1: stop in debug. LPTIM5 is frozen while CPU is in debug mode.

Bit 19 **DBG_LPTIM4_STOP**: LPTIM4 stop in debug
0: normal operation. LPTIM4 continues to operate while CPU is in debug mode.
1: stop in debug. LPTIM4 is frozen while CPU is in debug mode.

Bit 18 **DBG_LPTIM3_STOP**: LPTIM3 stop in debug
0: normal operation. LPTIM3 continues to operate while CPU is in debug mode.
1: stop in debug. LPTIM3 is frozen while CPU is in debug mode.

Bit 17 **DBG_LPTIM1_STOP**: LPTIM1 stop in debug
0: normal operation. LPTIM1 continues to operate while CPU is in debug mode.
1: stop in debug. LPTIM1 is frozen while CPU is in debug mode.

Bits 16:13 Reserved, must be kept at reset value.

Bit 12 **DBG_I3C2_STOP**: I3C2 SCL stall counter stop in debug
0: normal operation. I3C2 SCL stall timeout counter continues to operate while CPU is in debug mode.
1: stop in debug. I3C2 SCL stall timeout counter is frozen while CPU is in debug mode.

Bit 11 **DBG_I2C4_STOP**: I2C4 SMBUS timeout stop in debug
0: normal operation. I2C4 SMBUS timeout counter continues to operate while CPU is in debug mode.
1: stop in debug. I2C4 SMBUS timeout counter is frozen while CPU is in debug mode.

Bit 10 **DBG_I2C3_STOP**: I2C3 SMBUS timeout stop in debug
0: normal operation. I2C3 SMBUS timeout counter continues to operate while CPU is in debug mode.
1: stop in debug. I2C3 SMBUS timeout counter is frozen while CPU is in debug mode.

Bits 9:0 Reserved, must be kept at reset value.

DBGMCU AHB1 peripheral freeze register (DBGMCU_AHB1FZR)

Address offset: 0x20

Reset value: 0x0000 0000

This register is accessible to the debugger and to the CPU after successful authentication. Prior to this, accesses are ignored.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	DBG_GPDMA2_11_STOP	DBG_GPDMA2_10_STOP	DBG_GPDMA2_9_STOP	DBG_GPDMA2_8_STOP	DBG_GPDMA2_7_STOP	DBG_GPDMA2_6_STOP	DBG_GPDMA2_5_STOP	DBG_GPDMA2_4_STOP	DBG_GPDMA2_3_STOP	DBG_GPDMA2_2_STOP	DBG_GPDMA2_1_STOP	DBG_GPDMA2_0_STOP
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DBG_GPDMA1_11_STOP	DBG_GPDMA1_10_STOP	DBG_GPDMA1_9_STOP	DBG_GPDMA1_8_STOP	DBG_GPDMA1_7_STOP	DBG_GPDMA1_6_STOP	DBG_GPDMA1_5_STOP	DBG_GPDMA1_4_STOP	DBG_GPDMA1_3_STOP	DBG_GPDMA1_2_STOP	DBG_GPDMA1_1_STOP	DBG_GPDMA1_0_STOP
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **DBG_GPDMA2_11_STOP**: GPDMA2 channel 11 stop in debug
0: normal operation. GPDMA2 channel 11 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA2 channel 11 is frozen while CPU is in debug mode.

Bit 26 **DBG_GPDMA2_10_STOP**: GPDMA2 channel 10 stop in debug
0: normal operation. GPDMA2 channel 10 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA2 channel 10 is frozen while CPU is in debug mode.

Bit 25 **DBG_GPDMA2_9_STOP**: GPDMA2 channel 9 stop in debug
0: normal operation. GPDMA2 channel 9 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA2 channel 9 is frozen while CPU is in debug mode.

Bit 24 **DBG_GPDMA2_8_STOP**: GPDMA2 channel 8 stop in debug
0: normal operation. GPDMA2 channel 8 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA2 channel 8 is frozen while CPU is in debug mode.

Bit 23 **DBG_GPDMA2_7_STOP**: GPDMA2 channel 7 stop in debug
0: normal operation. GPDMA2 channel 7 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA2 channel 7 is frozen while CPU is in debug mode.

Bit 22 **DBG_GPDMA2_6_STOP**: GPDMA2 channel 6 stop in debug
0: normal operation. GPDMA2 channel 6 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA2 channel 6 is frozen while CPU is in debug mode.

Bit 21 **DBG_GPDMA2_5_STOP**: GPDMA2 channel 5 stop in debug
0: normal operation. GPDMA2 channel 5 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA2 channel 5 is frozen while CPU is in debug mode.

Bit 20 **DBG_GPDMA2_4_STOP**: GPDMA2 channel 4 stop in debug
0: normal operation. GPDMA2 channel 4 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA2 channel 4 is frozen while CPU is in debug mode.

Bit 19 **DBG_GPDMA2_3_STOP**: GPDMA2 channel 3 stop in debug
0: normal operation. GPDMA2 channel 3 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA2 channel 3 is frozen while CPU is in debug mode.

Bit 18 **DBG_GPDMA2_2_STOP**: GPDMA2 channel 2 stop in debug
0: normal operation. GPDMA2 channel 2 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA2 channel 2 is frozen while CPU is in debug mode.

Bit 17 **DBG_GPDMA2_1_STOP**: GPDMA2 channel 1 stop in debug
0: normal operation. GPDMA2 channel 1 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA2 channel 1 is frozen while CPU is in debug mode.

Bit 16 **DBG_GPDMA2_0_STOP**: GPDMA2 channel 0 stop in debug
0: normal operation. GPDMA2 channel 0 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA2 channel 0 is frozen while CPU is in debug mode.

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **DBG_GPDMA1_11_STOP**: GPDMA1 channel 11 stop in debug
0: normal operation. GPDMA1 channel 11 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA1 channel 11 is frozen while CPU is in debug mode.

Bit 10 **DBG_GPDMA1_10_STOP**: GPDMA1 channel 10 stop in debug
0: normal operation. GPDMA1 channel 10 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA1 channel 10 is frozen while CPU is in debug mode.

Bit 9 **DBG_GPDMA1_9_STOP**: GPDMA1 channel 9 stop in debug
0: normal operation. GPDMA1 channel 9 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA1 channel 9 is frozen while CPU is in debug mode.

Bit 8 **DBG_GPDMA1_8_STOP**: GPDMA1 channel 8 stop in debug
0: normal operation. GPDMA1 channel 8 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA1 channel 8 is frozen while CPU is in debug mode.

Bit 7 **DBG_GPDMA1_7_STOP**: GPDMA1 channel 7 stop in debug
0: normal operation. GPDMA1 channel 7 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA1 channel 7 is frozen while CPU is in debug mode.

Bit 6 **DBG_GPDMA1_6_STOP**: GPDMA1 channel 6 stop in debug
0: normal operation. GPDMA1 channel 6 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA1 channel 6 is frozen while CPU is in debug mode.

Bit 5 **DBG_GPDMA1_5_STOP**: GPDMA1 channel 5 stop in debug
0: normal operation. GPDMA1 channel 5 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA1 channel 5 is frozen while CPU is in debug mode.

Bit 4 **DBG_GPDMA1_4_STOP**: GPDMA1 channel 4 stop in debug
0: normal operation. GPDMA1 channel 4 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA1 channel 4 is frozen while CPU is in debug mode.

Bit 3 **DBG_GPDMA1_3_STOP**: GPDMA1 channel 3 stop in debug
0: normal operation. GPDMA1 channel 3 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA1 channel 3 is frozen while CPU is in debug mode.

Bit 2 **DBG_GPDMA1_2_STOP**: GPDMA1 channel 2 stop in debug
0: normal operation. GPDMA1 channel 2 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA1 channel 2 is frozen while CPU is in debug mode.

Bit 1 **DBG_GPDMA1_1_STOP**: GPDMA1 channel 1 stop in debug
0: normal operation. GPDMA1 channel 1 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA1 channel 1 is frozen while CPU is in debug mode.

Bit 0 **DBG_GPDMA1_0_STOP**: GPDMA1 channel 0 stop in debug
0: normal operation. GPDMA1 channel 0 continues to operate while CPU is in debug mode.
1: stop in debug. GPDMA1 channel 0 is frozen while CPU is in debug mode.

DBGMCU EDBGRQ debug request control (DBGMCU_EDBGRQ)

Address offset: 0x80

Reset value: 0x0000 0000

This register can be written and read by an external debugger while the system reset is asserted, or if debug is enabled after a successful authentication.

It is read-only when accessed by the CPU, writes have no effect. Read accesses only return meaningful data if debug is enabled after a successful authentication.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBG_ CPU
															r

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **DBG_CPU**: drives the CPU external debug request (EDBGRQ) signal. This bit can be used to halt the CPU in debug after the reset is released (vector catch), instead of writing to VC_CORERESET in DEMCR register.
0: External debug request de-asserted.
1: External debug request asserted. The CPU stops in debug when halting debug is authorized.

DBGMCU status register (DBGMCU_SR)

Address offset: 0xFC

Reset value: 0x0001 XX03

This register is always accessible.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AP_ENABLED[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AP_PRESENT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **AP_ENABLED[15:0]**: Bit n identifies whether access port AP n is open (can be accessed via the debug port) or locked (debug access to the AP is blocked)
Bit n = 0: APn locked
Bit n = 1: APn enabled

Bits 15:0 **AP_PRESENT[15:0]**: Bit n identifies whether access port AP n is present in device
Bit n = 0: APn absent
Bit n = 1: APn present

DBGMCU debug authentication mailbox host register (DBGMCU_DBG_AUTH_HOST)

Address offset: 0x100

Reset value: 0xXXXX XXXX

This register is read only when accessed by the CPU, writes have no effect.

This register can be written and read by an external debugger when system reset is asserted, or when access is granted during the authentication process.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MESSAGE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MESSAGE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MESSAGE[31:0]**: Debug host to device mailbox message.
The debug host requests authentication by writing a value to this register prior to releasing the system reset. During debug authentication the debug host communicates with the device (CPU) via this register.

DBGMCU debug authentication mailbox device register (DBGMCU_DBG_AUTH_DEVICE)

Address offset: 0x104

Reset value: 0xXXXX XXXX

This register is read only when accessed via the debug port, writes have no effect.

This register can be written and read by the CPU.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MESSAGE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MESSAGE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MESSAGE[31:0]**: Device to debug host mailbox message.
During debug authentication the device (CPU) communicates with the debug host via this register.

DBGMCU debug authentication mailbox acknowledge register (DBGMCU_DBG_AUTH_ACK)

Address offset: 0x108

Reset value: 0x0000 0000

This register is always accessible.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEV_ACK	HOST_ACK
														r	r

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **DEV_ACK**: Device to host acknowledge.

This bit is set by hardware when the device (CPU) writes a message in the DBGMCU_DBG_AUTH_DEVICE register. It is reset automatically when the host (debugger) reads the message.

0: DBGMCU_DBG_AUTH_DEVICE register is empty

1. DBGMCU_DBG_AUTH_DEVICE register contains an unread message

Bit 0 **HOST_ACK**: Host to device acknowledge.

This bit is set by hardware when the host (debugger) writes a message in the DBGMCU_DBG_AUTH_HOST register. It is reset automatically when the device (CPU) reads the message.

0: DBGMCU_DBG_AUTH_HOST register is empty

1. DBGMCU_DBG_AUTH_HOST register contains an unread message

DBGMCU CoreSight peripheral identity register 4 (DBGMCU_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0000

This register is always accessible.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SIZE[3:0]**: register file size

0x0: The register file occupies a single 4-Kbyte region.

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code

0x0: STMicroelectronics JEDEC code

DBGMCU CoreSight peripheral identity register 0 (DBGMCU_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0000

This register is always accessible.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: part number bits [7:0]
0x00: DBGMCU part number

DBGMCU CoreSight peripheral identity register 1 (DBGMCU_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 0000

This register is always accessible

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code bits [3:0]
0x0: STMicroelectronics JEDEC code

Bits 3:0 **PARTNUM[11:8]**: part number bits [11:8]
0x0: DBGMCU part number

DBGMCU CoreSight peripheral identity register 2 (DBGMCU_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000A

This register is always accessible.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: component revision number
0x0: r0p0

Bit 3 **JEDEC**: JEDEC assigned value
0x1: designer identification specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code bits [6:4]
0x2: STMicroelectronics JEDEC code

DBGMCU CoreSight peripheral identity register 3 (DBGMCU_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

This register is always accessible.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: metal fix version
0x0: no metal fix

Bits 3:0 **CMOD[3:0]**: customer modified
0x0: no customer modifications

DBGMCU CoreSight component identity register 0 (DBGMCU_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

This register is always accessible.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: component identification bits [7:0]
0x0D: common identification value

DBGMCU CoreSight component identity register 1 (DBGMCU_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 00F0

This register is always accessible.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: component identification bits [15:12] - component class
0xF: Non-CoreSight component

Bits 3:0 **PREAMBLE[11:8]**: component identification bits [11:8]
0x0: common identification value

DBGMCU CoreSight component identity register 2 (DBGMCU_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

This register is always accessible.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: component identification bits [23:16]
0x05: common identification value

DBGMCU CoreSight component identity register 3 (DBGMCU_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

This register is always accessible.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: component identification bits [31:24]
0xB1: common identification value

71.12.5 DBGMCU register map

Table 870. DBGMCU register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**DBGMCU_IDCODE**	REV_ID[15:0]																Res.	Res.	Res.	Res.	DEV_ID[11:0]											
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
0x004	**DBGMCU_CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCRT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRACE_MODE [1:0]		TRACE_EN	TRACE_IOEN	Res.	DBG_STANDBY	DBG_STOP	Res.
	Reset value																0									0	0	0	0		0	0	
0x008	**DBGMCU_ APB1LFZR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBG_I3C1_STOP	DBG_I2C2_STOP	DBG_I2C1_STOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBG_IWDG_STOP	DBG_WWDG_STOP	Res.	Res.	DBG_TIM14_STOP	DBG_TIM13_STOP	DBG_TIM12_STOP	DBG_TIM7_STOP	DBG_TIM6_STOP	DBG_TIM5_STOP	DBG_TIM4_STOP	DBG_TIM3_STOP	DBG_TIM2_STOP
	Reset value									0	0	0									0	0			0	0	0	0	0	0	0	0	0
0x0C0	**DBGMCU_ APB1HFZR**	Res.	Res.	Res.	Res	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBG_LPTIM2_STOP	Res.	Res.	Res.	Res.	Res.
	Reset value																											0					

Table 870. DBGMCU register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x010	**DBGMCU_ APB2FZR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBG_TIM17_STOP	DBG_TIM16_STOP	DBG_TIM15_STOP	Res.	Res.	DBG_TIM8_STOP	Res.	DBG_TIM1_STOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value														0	0	0			0		0											
0x04	**DBGMCU_ APB3FZR**	Res.	DBG_RTC_STOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBG_LPTIM6_STOP	DBG_LPTIM5_STOP	DBG_LPTIM4_STOP	DBG_LPTIM3_STOP	DBG_LPTIM1_STOP	Res.	Res.	Res.	Res.	DBG_I3C2_STOP	DBG_I2C4_STOP	DBG_I2C3_STOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value		0									0	0	0	0	0					0	0	0										
0x018 to 0x01C	Reserved	Reserved																															
0x020	**DBGMCU_ AHB1FZR**	Res.	Res.	Res.	Res.	DBG_GPDMA2_11_STOP	DBG_GPDMA2_10_STOP	DBG_GPDMA2_9_STOP	DBG_GPDMA2_8_STOP	DBG_GPDMA2_7_STOP	DBG_GPDMA2_6_STOP	DBG_GPDMA2_5_STOP	DBG_GPDMA2_4_STOP	DBG_GPDMA2_3_STOP	DBG_GPDMA2_2_STOP	DBG_GPDMA2_1_STOP	DBG_GPDMA2_0_STOP	Res.	Res.	Res.	Res.	DBG_GPDMA1_11_STOP	DBG_GPDMA1_10_STOP	DBG_GPDMA1_9_STOP	DBG_GPDMA1_8_STOP	DBG_GPDMA1_7_STOP	DBG_GPDMA1_6_STOP	DBG_GPDMA1_5_STOP	DBG_GPDMA1_4_STOP	DBG_GPDMA1_3_STOP	DBG_GPDMA1_2_STOP	DBG_GPDMA1_1_STOP	DBG_GPDMA1_0_STOP
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x024 to 0x07C	Reserved	Reserved																															
0x080	**DBGMCU_EDBGR Q**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBG_CPU
	Reset value																																0
0x084 to 0x0F8	Reserved	Reserved																															
0x0FC	**DBGMCU_SR**	AP_ENABLED[15:0]																AP_PRESENT[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
0x100	**DBGMCU_DBG_ AUTH_HOST**	MESSAGE[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x104	**DBGMCU_DBG_ AUTH_DEVICE**	MESSAGE[31:0]																															
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x108	**DBGMCU_DBG_ AUTH_ACK**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEV_ACK	HOST_ACK
	Reset value																															0	0
0x10C to 0xFBC	Reserved	Reserved																															
0xFD0	**DBGMCU_PIDR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SIZE [3:0]				JEP106CON [3:0]			
	Reset value																									0	0	0	0	0	0	0	0

Table 870. DBGMCU register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	**DBGMCU_PIDR0**	Res.																								PARTNUM[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0xFE4	**DBGMCU_PIDR1**	Res.																								JEP106ID [3:0]				PARTNUM [11:8]			
	Reset value																									0	0	0	0	0	0	0	0
0xFE8	**DBGMCU_PIDR2**	Res.																								REVISION [3:0]				JEDEC	JEP106ID [6:4]		
	Reset value																									0	0	0	0	1	0	1	0
0xFEC	**DBGMCU_PIDR3**	Res.																								REVAND[3:0]				CMOD[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0xFF0	**DBGMCU_CIDR0**	Res.																								PREAMBLE[7:0]							
	Reset value																									0	0	0	0	1	1	0	1
0xFF4	**DBGMCU_CIDR1**	Res.																								CLASS[3:0]				PREAMBLE [11:8]			
	Reset value																									1	1	1	1	0	0	0	0
0xFF8	**DBGMCU_CIDR2**	Res.																								PREAMBLE[19:12]							
	Reset value																									0	0	0	0	0	1	0	1
0xFFC	**DBGMCU_CIDR3**	Res.																								PREAMBLE[27:20]							
	Reset value																									1	0	1	1	0	0	0	1

Refer to *Section 2.3* for register boundary addresses.

71.13 References

1. IHI 0031C (ID080813) - Arm® Debug Interface Architecture Specification ADIv5.0 to ADIv5.2, Issue C, 8th Aug 2013
2. DDI 0480F (ID100313) - Arm® CoreSight™ SoC-400 r3p2 Technical Reference Manual, Issue G, 16th March 2015
3. DDI 0314H - Arm® CoreSight™ Components Technical Reference Manual, Issue H, 10 July, 2009
4. DDI 0553A (ID092917) - Arm® v8-M Architecture Reference Manual, Issue A.f, 29 September 2017
5. 100230_0002_00_en - Arm® Cortex®-M33 Processor r0p2 Technical Reference Manual, Issue 0002-00, 10 May 2017
6. 100232_0001_00_en - Arm® CoreSight™ ETM-M33 r0p1 Technical Reference Manual, Issue 0001-00, 3 February 2017

72 Device electronic signature

The device electronic signature is stored in the system memory area of the flash memory module and can be read using the debug interface or by the CPU.

It contains factory-programmed identification and calibration data that allow the user firmware or other external devices to automatically match to the characteristics of the devices.

72.1 Unique device ID register (96 bits)

The unique device identifier is ideally suited:

- For use as serial numbers (for example USB string serial numbers or other end applications)
- For use as part of the security keys to increase the security of code in flash memory while using and combining this unique ID with software cryptographic primitives and protocols before programming the internal flash memory
- To activate secure boot processes

The 96-bit unique device identifier provides a reference number, which is unique for any device and in any context. These bits cannot be altered by the user.

Base address: 0x08FF F800

Address offset: 0x00

Read only = 0xXXXX XXXX where X is factory-programmed

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UID[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
UID[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **UID[31:0]:** X and Y coordinates on the wafer

Address offset: 0x04

Read only = 0xXXXX XXXX where X is factory-programmed

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UID[63:48]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
UID[47:32]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:8 **UID[63:40]:** LOT_NUM[23:0]
Lot number (ASCII encoded)

Bits 7:0 **UID[39:32]:** WAF_NUM[7:0]
Wafer number (8-bit unsigned number)

Address offset: 0x08

Read only = 0xXXXX XXXX where X is factory-programmed

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UID[95:80]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
UID[79:64]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **UID[95:64]:** LOT_NUM[55:24]
Lot number (ASCII encoded)

72.2 Flash size data register

Base address: 0x08FF F80C

Address offset: 0x00

Read only = 0xXXXX where X is factory-programmed

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLASH_SIZE															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 15:0 **FLASH_SIZE[15:0]**: Flash memory size
This field indicates the size of the device Flash memory expressed in Kbytes.
As an example, 0x1000 corresponds to 4096 Kbytes.

72.3 Package data register

Base address: 0x08FF F80E

Address offset: 0x00

Read only = 0xXXXX where X is factory-programmed

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKG[4:0]				
											r	r	r	r	r

Bits 15:5 Reserved, must be kept at reset value.

Bits 4:0 **PKG[4:0]**: Package type
00010: LQFP100
00100: LQFP144
00111: LQFP176
00011: UFBGA176+25
00110: UFBGA169
01010: LQFP100 SMPS
01100: LQFP144 SMPS
01101: LQFP176 SMPS
01011: UFBGA176+25 SMPS
01110: UFBGA169 SMPS
10101: UFBGA144
10110: UFBGA144 SMPS
11000: WLCSP100 SMPS USBPHY
11001: UFBGA176_25 SMPS USBPHY
11010: LQFP176 SMPS USBPHY
11011: TFBGA225 SMPS USBPHY
11100: LQFP144 USBPHY
Others: reserved

Note: Refer to the product datasheet for availability of packages on a specific device.

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74 Revision history

Table 871. Document revision history

Date	Revision	Changes
20-Feb-2026	1	Initial release.

Index

A

ADC_AWD2CR 1368
ADC_AWD3CR 1368
ADC_CALFACT 1370
ADC_CCR 1373
ADC_CDR 1376
ADC_CFGR 1348
ADC_CFGR2 1353
ADC_CR 1345
ADC_CSR 1371
ADC_DIFSEL 1369
ADC_DR 1363
ADC_IER 1343
ADC_ISR 1341
ADC_JDRy 1367
ADC_JSQR 1363
ADC_OFRy 1366
ADC_OR 1370
ADC_SMPR1 1355
ADC_SMPR2 1356
ADC_SQR1 1359
ADC_SQR2 1360
ADC_SQR3 1361
ADC_SQR4 1362
ADC_TR1 1357
ADC_TR2 1358
ADC_TR3 1359
ADF_BSMX0CR 1617
ADF_CKGCR 1613
ADF_DFLT0CICR 1619
ADF_DFLT0CR 1617
ADF_DFLT0DR 1628
ADF_DFLT0IER 1622
ADF_DFLT0ISR 1623
ADF_DFLT0RSFR 1620
ADF_DLY0CR 1621
ADF_GCR 1613
ADF_SADANLVR 1628
ADF_SADCFGR 1626
ADF_SADCR 1624
ADF_SADSDLVR 1627
ADF_SITF0CR 1615
AES_CR 1797
AES_DINR 1800
AES_DOUTR 1801
AES_ICR 1808
AES_IER 1806
AES_ISR 1807
AES_IVR0 1803
AES_IVR1 1803
AES_IVR2 1803
AES_IVR3 1804
AES_KEYR0 1801
AES_KEYR1 1802
AES_KEYR2 1802
AES_KEYR3 1802
AES_KEYR4 1804
AES_KEYR5 1804
AES_KEYR6 1805
AES_KEYR7 1805
AES_SR 1799
AES_SUSPxR 1805
AP0_CSWR 3793
AP1_CSWR 3794
APx_BASER 3796
APx_BDnR 3796
APx_DRWR 3796
APx_IDR 3797
APx_TAR 3795

B

BPU_CIDR0 3848
BPU_CIDR1 3848
BPU_CIDR2 3849
BPU_CIDR3 3849
BPU_COMPxR 3844
BPU_CTRLR 3844
BPU_DEVARCHR 3845
BPU_DEVTYPER 3845
BPU_PIDR0 3846
BPU_PIDR1 3847
BPU_PIDR2 3847
BPU_PIDR3 3848
BPU_PIDR4 3846

C

C1ROM_CIDR3 . . . . . 3806, 3811, 3816
CCB_CR 1741
CCB_REFTAGRx 1744
CCB_SR 1742
CEC_CFGR 3764
CEC_CR 3763
CEC_IER 3768
CEC_ISR 3766
CEC_RXDR 3766

CEC_TXDR 3766
COMP_CFGR1 1468
COMP_CFGR2 1470
COMP_ICFR 1468
COMP_SR 1467
CORDIC_CSR 955
CORDIC_RDATA 958
CORDIC_WDATA 957
CPUROM_CIDR0 3814
CPUROM_CIDR1 3815
CPUROM_CIDR2 3815
CPUROM_CIDR3 3815
CPUROM_MEMTYPER 3812
CPUROM_PIDR0 3812
CPUROM_PIDR1 3813
CPUROM_PIDR2 3813
CPUROM_PIDR3 3814
CPUROM_PIDR4 3812
CRC_CR 938
CRC_DR 937
CRC_IDR 937
CRC_INIT 939
CRC_POL 939
CRS_CFGR 613
CRS_CR 611
CRS_ICR 616
CRS_ISR 614
CTI_APPCLEAR 3894
CTI_APPPULSER 3895
CTI_APPSETR 3894
CTI_CHINSTSR 3897
CTI_CHOUTSTSR 3898
CTI_CIDR0 3902
CTI_CIDR1 3902
CTI_CIDR2 3902
CTI_CIDR3 3903
CTI_CONTROLR 3893
CTI_DEVIDR 3899
CTI_DEVTYPER 3899
CTI_GATER 3898
CTI_INENxR 3895
CTI_INTACKR 3893
CTI_OUTENxR 3896
CTI_PIDR0 3900
CTI_PIDR1 3900
CTI_PIDR2 3901
CTI_PIDR3 3901
CTI_PIDR4 3899
CTI_TRGISTSR 3896
CTI_TRGOSTSR 3897

D

DAC_CCR 1432
DAC_CR 1421
DAC_DHR12L1 1426
DAC_DHR12L2 1427
DAC_DHR12LD 1429
DAC_DHR12R1 1425
DAC_DHR12R2 1427
DAC_DHR12RD 1428
DAC_DHR8R1 1426
DAC_DHR8R2 1428
DAC_DHR8RD 1429
DAC_DOR1 1430
DAC_DOR2 1430
DAC_MCR 1433
DAC_SHHR 1435
DAC_SHRR 1436
DAC_SHSR1 1434
DAC_SHSR2 1435
DAC_SR 1431
DAC_SWTRGR 1424
DBGMCU_AHB1FZR 3914
DBGMCU_APB1HFZR 3911
DBGMCU_APB1LFZR 3909
DBGMCU_APB2FZR 3911
DBGMCU_APB3FZR 3912
DBGMCU_CIDR0 3921
DBGMCU_CIDR1 3922
DBGMCU_CIDR2 3922
DBGMCU_CIDR3 3923
DBGMCU_CR 3908
DBGMCU_DBG_AUTH_ACK 3918
DBGMCU_DBG_AUTH_DEVICE 3918
DBGMCU_DBG_AUTH_HOST 3917
DBGMCU_EDBGRQ 3916
DBGMCU_IDCODE 3907
DBGMCU_PIDR0 3919
DBGMCU_PIDR1 3920
DBGMCU_PIDR2 3920
DBGMCU_PIDR3 3921
DBGMCU_PIDR4 3919
DBGMCU_SR 3917
DCACHE_CMDREADDRR 436
DCACHE_CMDRSADDRR 436
DCACHE_CR 431
DCACHE_FCR 434
DCACHE_IER 433
DCACHE_RHMONR 434
DCACHE_RMMONR 435
DCACHE_SR 432
DCACHE_WHMONR 435
DCACHE_WMMONR 435

DCMI_CR 1642
DCMI_CWSIZE 1651
DCMI_CWSTRT 1650
DCMI_DR 1651
DCMI_ESCR 1649
DCMI_ESUR 1649
DCMI_ICR 1648
DCMI_IER 1646
DCMI_MIS 1647
DCMI_RIS 1645
DCMI_SR 1645
DLYB_CFGR 1256
DLYB_CR 1255
DMA2D_AMTCR 821
DMA2D_BGCLUTx 836
DMA2D_BGCMAR 816
DMA2D_BGCOLR 816
DMA2D_BGMAR 812
DMA2D_BGMSR 813
DMA2D_BGOR 813
DMA2D_BGPFCCR 814
DMA2D_CLCR 830
DMA2D_CLSR 831
DMA2D_CR 801
DMA2D_FGCLUTx 835
DMA2D_FGCMAR 812
DMA2D_FGCOLR 811
DMA2D_FGMAR 807
DMA2D_FGMSR 808
DMA2D_FGOR 808
DMA2D_FGPFCCR 809
DMA2D_GPFCR 827
DMA2D_GPFR 828
DMA2D_GPFRR 829
DMA2D_GPFSR 829
DMA2D_IER 804
DMA2D_IFCR 806
DMA2D_ISR 802
DMA2D_LBCAR 835
DMA2D_LBCBAR 834
DMA2D_LBCSR 834
DMA2D_LWR 820
DMA2D_NLR 820
DMA2D_OCOLR 818
DMA2D_OMAR 819
DMA2D_OOR 819
DMA2D_OPFCCR 817
DMA2D_RBBAR 833
DMA2D_RBHPR 833
DMA2D_RBWPR 834
DMA2D_SBCR 821
DMA2D_SBMAR 822
DMA2D_SBMSR 823
DMA2D_SBOR 822
DMA2D_SCR 825
DMA2D_SNLR 825
DMA2D_SPR 826
DMA2D_SSR 826
DMA2D_TBCR 824
DP_ABORTR 3785
DP_CTRLSTATR 3786
DP_DLCR 3787
DP_DLPIDR 3788
DP_DPIDR 3785
DP_RDBUFFR 3790
DP_RESENDR 3789
DP_SELECTR 3789
DP_TARGETIDR 3788
DTS_CFGR1 1389
DTS_DR 1392
DTS_ICIFR 1395
DTS_ITENR 1394
DTS_ITR1 1392
DTS_OR 1396
DTS_RAMPVALR 1391
DTS_SR 1393
DTS_T0VALR1 1391
DWT_CIDR0 3829
DWT_CIDR1 3830
DWT_CIDR2 3830
DWT_CIDR3 3831
DWT_COMPxR 3822
DWT_CPICNTR 3820
DWT_CTRLR 3818
DWT_CYCCNTR 3819
DWT_DEVARCHR 3826
DWT_DEVTYPER 3827
DWT_EXCCNTR 3820
DWT_FOLDCNTR 3821
DWT_FUNCTR0 3822
DWT_FUNCTR1 3823
DWT_FUNCTR2 3824
DWT_FUNCTR3 3825
DWT_LSUCNTR 3821
DWT_PCSR 3821
DWT_PIDR0 3828
DWT_PIDR1 3828
DWT_PIDR2 3828
DWT_PIDR3 3829
DWT_PIDR4 3827
DWT_SLPCNTR 3820

E

ETH_DMACCARXBR 3636
ETH_DMACCARXDR 3636
ETH_DMACCATXBR 3636
ETH_DMACCATXDR 3635
ETH_DMACCR 3624
ETH_DMACIER 3631
ETH_DMACMFCR 3639
ETH_DMACRXCR 3626
ETH_DMACRXDLAR 3628
ETH_DMACRXDTPR 3629
ETH_DMACRXIWTR 3634
ETH_DMACRXRLR 3630
ETH_DMACSR 3637
ETH_DMACTXCR 3625
ETH_DMACTXDLAR 3627
ETH_DMACTXDTPR 3629
ETH_DMACTXRLR 3630
ETH_DMADSR 3623
ETH_DMAISR 3622
ETH_DMAMR 3620
ETH_DMASBMR 3621
ETH_MAC_IACR 3718
ETH_MAC_TMRQR 3719
ETH_MAC1USTCR 3681
ETH_MACA0HR 3696
ETH_MACACR 3729
ETH_MACARPAR 3694
ETH_MACATSNR 3730
ETH_MACATSSR 3731
ETH_MACAxHR 3697
ETH_MACAxLR 3696
ETH_MACCR 3651
ETH_MACCSRSWCR 3694
ETH_MACDR 3682
ETH_MACECR 3656
ETH_MACHT0R 3662
ETH_MACHT1R 3663
ETH_MACHWF0R 3683
ETH_MACHWF1R 3685
ETH_MACHWF2R 3687
ETH_MACHWF3R 3689
ETH_MACIER 3674
ETH_MACISR 3672
ETH_MACIVIR 3668
ETH_MACL3A00R 3711
ETH_MACL3A01R 3716
ETH_MACL3A10R 3711
ETH_MACL3A11R 3716
ETH_MACL3A20R 3712
ETH_MACL3A21R 3717
ETH_MACL3A30R 3712
ETH_MACL3A31R 3717
ETH_MACL3L4C0R 3708
ETH_MACL3L4C1R 3713
ETH_MACL4A0R 3710
ETH_MACL4A1R 3715
ETH_MACLCSR 3678
ETH_MACLETR 3681
ETH_MACLMIR 3742
ETH_MACLTCR 3680
ETH_MACMDIOAR 3691
ETH_MACMDIODR 3693
ETH_MACPCSR 3676
ETH_MACPFR 3658
ETH_MACPOCR 3740
ETH_MACPPSCR 3734, 3736
ETH_MACPPSIR 3739
ETH_MACPPSTTNR 3738
ETH_MACPPSTTSR 3737
ETH_MACPPSWR 3739
ETH_MACPRSTIMR 3695
ETH_MACPRSTIMUR 3695
ETH_MACQTXFCR 3669
ETH_MACRWKPFR 3678
ETH_MACRXDTI 3727
ETH_MACRXFCR 3671
ETH_MACRXTXSR 3675
ETH_MACSPI0R 3741
ETH_MACSPI1R 3741
ETH_MACSPI2R 3741
ETH_MACSSIR 3722
ETH_MACSTNR 3723
ETH_MACSTNUR 3724
ETH_MACSTSR 3723
ETH_MACSTSUR 3724
ETH_MACTSAR 3725
ETH_MACTSCR 3720
ETH_MACTSEACR 3732
ETH_MACTSECNR 3733
ETH_MACTSELR 3734
ETH_MACTSIACR 3731
ETH_MACTSICNR 3732
ETH_MACTSILR 3733
ETH_MACTSSR 3726
ETH_MACTXDTI 3728
ETH_MACTXTSSNR 3728
ETH_MACTXTSSSR 3729
ETH_MACVHTR 3666
ETH_MACVIR 3667
ETH_MACVR 3682
ETH_MACVTR 3664
ETH_MACWJBTR 3660
ETH_MMC_CONTROL 3698

ETH_MMC_RX_INTERRUPT 3699
ETH_MMC_RX_INTERRUPT_MASK 3701
ETH_MMC_TX_INTERRUPT 3700
ETH_MMC_TX_INTERRUPT_MASK 3702
ETH_MTLISR 3643
ETH_MTLOMR 3642
ETH_MTLQICSR 3646
ETH_MTLRXQDR 3649
ETH_MTLRXQMPOCR 3648
ETH_MTLRXQOMR 3647
ETH_MTLTXQDR 3645
ETH_MTLTXQOMR 3643
ETH_MTLTXQUR 3644
ETH_RX_ALIGNMENT_ERROR_PACKETS . . . 3705
ETH_RX_CRC_ERROR_PACKETS 3704
ETH_RX_LPI_TRAN_CNTR 3707
ETH_RX_LPI_USEC_CNTR 3707
ETH_RX_UNICAST_PACKETS_GOOD . . .3705
ETH_TX_LPI_TRAN_CNTR 3706
ETH_TX_LPI_USEC_CNTR 3706
ETH_TX_MULTIPLE_COLLISION_-GOOD_PACKETS 3704
ETH_TX_PACKET_COUNT_GOOD 3704
ETH_TX_SINGLE_COLLISION_GOOD_PACK-ETS 3703
ETM_AUTHSTATR 3871
ETM_CCCTLR 3856
ETM_CIDR0 3874
ETM_CIDR1 3875
ETM_CIDR2 3875
ETM_CIDR3 3876
ETM_CLAIMCLR 3870
ETM_CLAIMSETR 3870
ETM_CNTRLDVR0 3857
ETM_CONFIGR 3852
ETM_DEVARCHR 3871
ETM_DEVTYPER 3872
ETM_EVENTCTL0R 3853
ETM_EVENTCTL1R 3854
ETM_IDR0 3861
ETM_IDR1 3862
ETM_IDR10 3859
ETM_IDR11 3859
ETM_IDR12 3859
ETM_IDR13 3860
ETM_IDR2 3862
ETM_IDR3 3863
ETM_IDR4 3864
ETM_IDR5 3865
ETM_IDR8 3858
ETM_IDR9 3858
ETM_IMSPECR0 3860
ETM_PDCR 3868
ETM_PDSR 3869
ETM_PIDR0 3873
ETM_PIDR1 3873
ETM_PIDR2 3873
ETM_PIDR3 3874
ETM_PIDR4 3872
ETM_PRGCTLR 3851
ETM_RSCTLR2 3866
ETM_RSCTLR3 3866
ETM_SSCCR0 3867
ETM_SSCSR0 3867
ETM_SSPCICR0 3868
ETM_STALLCTLR 3854
ETM_STATR 3852
ETM_SYNCPR 3855
ETM_TRACEIDR 3856
ETM_VICTLR 3856
EXTI_EMR1 926
EXTI_EMR2 928
EXTI_EMR3 930
EXTI_EXTICR1 915
EXTI_EXTICR2 918
EXTI_EXTICR3 920
EXTI_EXTICR4 923
EXTI_FPR1 896
EXTI_FPR2 906
EXTI_FPR3 913
EXTI_FTSR1 894
EXTI_FTSR2 899
EXTI_FTSR3 910
EXTI_IMR1 926
EXTI_IMR2 927
EXTI_IMR3 929
EXTI_LOCKR 925
EXTI_PRIVCFGR1 897
EXTI_PRIVCFGR2 909
EXTI_PRIVCFGR3 915
EXTI_RPR1 895
EXTI_RPR2 904
EXTI_RPR3 912
EXTI_RTSR1 893
EXTI_RTSR2 897
EXTI_RTSR3 909
EXTI_SECCFGR1 896
EXTI_SECCFGR2 908
EXTI_SECCFGR3 914
EXTI_SWIER1 894
EXTI_SWIER2 901
EXTI_SWIER3 911

F

FDCAN_CCCR 3079
FDCAN_CKDIV 3104
FDCAN_CREL 3076
FDCAN_DBTP 3076
FDCAN_ECR 3084
FDCAN_ENDN 3076
FDCAN_HPMS 3095
FDCAN_IE 3090
FDCAN_ILE 3093
FDCAN_ILS 3092
FDCAN_IR 3087
FDCAN_NBTP 3080
FDCAN_PSR 3085
FDCAN_RWD 3078
FDCAN_RXF0A 3097
FDCAN_RXF0S 3096
FDCAN_RXF1A 3098
FDCAN_RXF1S 3097
FDCAN_RXGFC 3093
FDCAN_TDCR 3087
FDCAN_TEST 3077
FDCAN_TOCC 3083
FDCAN_TOCV 3084
FDCAN_TSCC 3082
FDCAN_TSCV 3082
FDCAN_TXBAR 3100
FDCAN_TXBC 3098
FDCAN_TXBCF 3102
FDCAN_TXBCIE 3103
FDCAN_TXBCR 3101
FDCAN_TXBRP 3099
FDCAN_TXBTIE 3102
FDCAN_TXBTO 3101
FDCAN_TXEFA 3104
FDCAN_TXEFS 3103
FDCAN_TXFQS 3099
FDCAN_XIDAM 3095
FLASH_ACR 350
FLASH_BOOTR_PRG 378
FLASH_ECCCORR 386
FLASH_ECCDETR 387
FLASH_ECCDR 388
FLASH_EDATA1R_CUR 384
FLASH_EDATA1R_PRG 384
FLASH_EDATA2R_CUR 393
FLASH_EDATA2R_PRG 394
FLASH_HDP1R_CUR 385
FLASH_HDP1R_PRG 385
FLASH_HDP2R_CUR 394
FLASH_HDP2R_PRG 395
FLASH_HDPEXTR 369
FLASH_NSBOOTR_CUR 376
FLASH_NSBOOTR_PRG 376
FLASH_NSCCR 364
FLASH_NSCR 359
FLASH_NSEPOCHR_CUR 373
FLASH_NSKEYR 351
FLASH_NSOBKCFGR 366
FLASH_NSOBKKEYR 352
FLASH_NSSR 355
FLASH_OPSR 353
FLASH_OPTCR 354
FLASH_OPTKEYR 352
FLASH_OPTSR_CUR 369
FLASH_OPTSR_PRG 371
FLASH_OPTSR2_CUR 374
FLASH_OPTSR2_PRG 375
FLASH_OTPBLR_CUR 379
FLASH_OTPBLR_PRG 379
FLASH_PRIVBB1Rx 381
FLASH_PRIVBB2Rx 390
FLASH_PRIVCFGR 366
FLASH_SECBB1Rx 381
FLASH_SECBB2Rx 390
FLASH_SECBOOTR_CUR 378
FLASH_SECCCR 365
FLASH_SECCR 361
FLASH_SECEPOCHR_CUR 373
FLASH_SECKEYR 351
FLASH_SECOBKCFGR 367
FLASH_SECOBKKEYR 353
FLASH_SECSR 357
FLASH_SECWM1R_CUR 382
FLASH_SECWM1R_PRG 382
FLASH_SECWM2R_CUR 391
FLASH_SECWM2R_PRG 391
FLASH_WRP11R_CUR 383
FLASH_WRP11R_PRG 383
FLASH_WRP12R_CUR 380
FLASH_WRP12R_PRG 380
FLASH_WRP21R_CUR 392
FLASH_WRP21R_PRG 392
FLASH_WRP22R_CUR 389
FLASH_WRP22R_PRG 389
FMAC_CR 982
FMAC_PARAM 981
FMAC_RDATA 985
FMAC_SR 983
FMAC_WDATA 984
FMAC_X1BUFCFG 979
FMAC_X2BUFCFG 979
FMAC_YBUFCFG 980
FMC_BCRx 1062

FMC_BTRx 1065
FMC_BWTRx 1067
FMC_ECCR 1080
FMC_PATT 1079
FMC_PCR 1075
FMC_PCSCNTR 1069
FMC_PMEM 1078
FMC_SDCMR 1095
FMC_SDCRx 1092
FMC_SDRTR 1096
FMC_SDSR 1098
FMC_SDTRx 1093
FMC_SR 1077

G

GFXTIM_AFCC1R 871
GFXTIM_AFCR 870
GFXTIM_ALCC1R 871
GFXTIM_ALCC2R 871
GFXTIM_ALCR 870
GFXTIM_ATR 869
GFXTIM_CGCR 855
GFXTIM_CR 854
GFXTIM_EVCR 859
GFXTIM_EVSR 859
GFXTIM_FCCRR 869
GFXTIM_ICR 864
GFXTIM_IER 866
GFXTIM_ISR 863
GFXTIM_LCCRR 869
GFXTIM_RFC1R 872
GFXTIM_RFC1RR 872
GFXTIM_RFC2R 873
GFXTIM_RFC2RR 873
GFXTIM_TCR 857
GFXTIM_TDR 858
GFXTIM_TSR 868
GFXTIM_WDGCR 873
GFXTIM_WDGPAR 874
GFXTIM_WDGRR 874
GFXTIM_WDGTCR 861
GPDMA_CxBR1 747-748
GPDMA_CxBR2 754
GPDMA_CxCR 737
GPDMA_CxDAR 752
GPDMA_CxFCR 735
GPDMA_CxLBAR 734
GPDMA_CxLLR 755, 757
GPDMA_CxSAR 751
GPDMA_CxSR 736
GPDMA_CxTR1 739
GPDMA_CxTR2 743
GPDMA_CxTR3 753
GPDMA_MISR 733
GPDMA_PRIVCFGR 732
GPDMA_RCFGLOCKR 732
GPDMA_SECCFGR 731
GPDMA_SMISR 734
GPIOx_AFRH 633
GPIOx_AFRL 633
GPIOx_BRR 634
GPIOx_BSRR 631
GPIOx_HSLVR 635
GPIOx_IDR 630
GPIOx_LCKR 632
GPIOx_MODER 628
GPIOx_ODR 631
GPIOx_OSPEEDR 629
GPIOx_OTYPER 629
GPIOx_PUPDR 630
GPIOx_SECCFGR 635
GTZC1_MPCBB1_PRIVCFGRx 263
GTZC1_MPCBB1_SECCFGRx 261
GTZC1_MPCBB2_PRIVCFGRx 263
GTZC1_MPCBB2_SECCFGRx 262
GTZC1_MPCBB3_PRIVCFGRx 264
GTZC1_MPCBB3_SECCFGRx 262
GTZC1_MPCBBz_CFGLOCK1 261
GTZC1_MPCBBz_CR 260
GTZC1_TZIC_FCR1 247
GTZC1_TZIC_FCR2 250
GTZC1_TZIC_FCR3 252
GTZC1_TZIC_FCR4 255
GTZC1_TZIC_IER1 228
GTZC1_TZIC_IER2 230
GTZC1_TZIC_IER3 233
GTZC1_TZIC_IER4 235
GTZC1_TZIC_SR1 238
GTZC1_TZIC_SR2 240
GTZC1_TZIC_SR3 242
GTZC1_TZIC_SR4 245
GTZC1_TZSC_CR 206
GTZC1_TZSC_MPCWMxACFGR 222
GTZC1_TZSC_MPCWMxAR 224
GTZC1_TZSC_MPCWMxBCFGR 223
GTZC1_TZSC_MPCWMxBR 225
GTZC1_TZSC_PRIVCFGR1 214
GTZC1_TZSC_PRIVCFGR2 217
GTZC1_TZSC_PRIVCFGR3 219
GTZC1_TZSC_SECCFGR1 206
GTZC1_TZSC_SECCFGR2 209
GTZC1_TZSC_SECCFGR3 211

H

HASH_CR 1880
HASH_CSRx 1888
HASH_DIN 1882
HASH_HRAx 1885
HASH_HRx 1885
HASH_IMR 1886
HASH_SR 1886
HASH_STR 1883

I

I2C_CR1 2629
I2C_CR2 2632
I2C_ICR 2640
I2C_ISR 2637
I2C_OAR1 2634
I2C_OAR2 2634
I2C_PECR 2641
I2C_RXDR 2641
I2C_TIMEOUTR 2636
I2C_TIMINGR 2635
I2C_TXDR 2642
I3C_BCR 2742
I3C_CEVR 2729
I3C_CFGR 2708
I3C_CR 2704, 2706
I3C_CRCAPR 2745
I3C_DCR 2743
I3C_DEVR0 2732
I3C_DEVRx 2734
I3C_EPIDR 2748
I3C_EVR 2723
I3C_GETCAPR 2744
I3C_GETMXDSR 2746
I3C_IBIDR 2717
I3C_IER 2727
I3C_MAXRLR 2736
I3C_MAXWLR 2737
I3C_MISR 2731
I3C_RDR 2713
I3C_RDWR 2714
I3C_RMR 2722
I3C_SER 2720
I3C_SR 2719
I3C_TDR 2715
I3C_TDWR 2716
I3C_TGTTDR 2718
I3C_TIMINGR0 2738
I3C_TIMINGR1 2739
I3C_TIMINGR2 2741
ICACHE_CR 413
ICACHE_CRRx 416
ICACHE_FCR 415
ICACHE_HMONR 416
ICACHE_IER 415
ICACHE_MMONR 416
ICACHE_SR 414
ITM_CIDR0 3840
ITM_CIDR1 3841
ITM_CIDR2 3841
ITM_CIDR3 3842
ITM_DEVARCHR 3837
ITM_DEVTYPER 3838
ITM_PIDR0 3839
ITM_PIDR1 3839
ITM_PIDR2 3839
ITM_PIDR3 3840
ITM_PIDR4 3838
ITM_STIMRx 3834
ITM_TCR 3836
ITM_TER 3835
ITM_TPR 3835
IWDG_EWCR 2464
IWDG_KR 2461
IWDG_PR 2461
IWDG_RLR 2462
IWDG_SR 2462
IWDG_WINR 2464

J

JPEG_CFR 1711
JPEG_CONFR0 1705
JPEG_CONFR1 1706
JPEG_CONFR2 1707
JPEG_CONFR3 1707
JPEG_CONFRx 1708
JPEG_CR 1709
JPEG_DHTMEMx 1716
JPEG_DIR 1712
JPEG_DOR 1712
JPEG_HUFFBASEx 1714
JPEG_HUFFENC_ACx_y 1716
JPEG_HUFFENC_DCx_y 1717
JPEG_HUFFMINx_y 1713-1714
JPEG_HUFFSYMBx 1715
JPEG_QMEMx_y 1713
JPEG_SR 1710

L

LPTIM_ARR 2443
LPTIM_CCMR1 2445
LPTIM_CCR1 2442

LPTIM_CCR2 2448
LPTIM_CFGR 2438
LPTIM_CFGR2 2444
LPTIM_CNT 2443
LPTIM_CR 2441
LPTIM_RCR 2445
LPTIM4_DIER 2433
LPTIM4_ICR 2430
LPTIM4_ISR 2425
LPTIMx_DIER 2435-2436
LPTIMx_ICR 2431-2432
LPTIMx_ISR 2426, 2428
LPUART_BRR 2885
LPUART_CR1 . . . . . .2872, 2875
LPUART_CR2 2878
LPUART_CR3 . . . . . .2880, 2883
LPUART_ICR 2894
LPUART_ISR 2886, 2891
LPUART_PRESC 2896
LPUART_RDR 2895
LPUART_RQR 2885
LPUART_TDR 2895
LTDC_AWCR 1680
LTDC_BCCR 1683
LTDC_BPCR 1679
LTDC_CDSR 1687
LTDC_CPSR 1686
LTDC_GCR 1681
LTDC_ICR 1685
LTDC_IER 1684
LTDC_ISR 1685
LTDC_LIPCR 1686
LTDC_LxBFCR 1692
LTDC_LxCACR 1691
LTDC_LxCFBAR 1693
LTDC_LxCFBLNR 1694
LTDC_LxCFBLR 1693
LTDC_LxCKCR 1690
LTDC_LxCLUTWR 1694
LTDC_LxCR 1687
LTDC_LxDCCR 1691
LTDC_LxPFCR 1690
LTDC_LxWHPCR 1688
LTDC_LxWVPCR 1689
LTDC_SRCR 1683
LTDC_SSCR 1679
LTDC_TWCR 1681

M

MCUROM_CIDR0 3809
MCUROM_CIDR1 3810
MCUROM_CIDR2 3810
MCUROM_CIDR3 3810
MCUROM_MEMTYPER 3807
MCUROM_PIDR0 3807
MCUROM_PIDR1 3808
MCUROM_PIDR2 3808
MCUROM_PIDR3 3809
MCUROM_PIDR4 3807
MDF_BSMXxCR 1537
MDF_CKGCR 1534
MDF_DFLT0IER 1547
MDF_DFLT0ISR 1550
MDF_DFLTxCICR 1540
MDF_DFLTxCR 1538
MDF_DFLTxDR 1554
MDF_DFLTxIER 1549
MDF_DFLTxINTR 1543
MDF_DFLTxISR 1552
MDF_DFLTxRSFR 1542
MDF_DLYxCR 1546
MDF_GCR 1533
MDF_OECxCR 1553
MDF_OLDxCR 1543
MDF_OLDxTHHR 1545
MDF_OLDxTHLR 1545
MDF_SCDxCR 1546
MDF_SITFxCR 1536
MDF_SNPSxDR 1554

O

OCTOSPI_ABR 1148
OCTOSPI_AR 1143
OCTOSPI_CCR 1145
OCTOSPI_CR 1133
OCTOSPI_DCR1 1136
OCTOSPI_DCR2 1138
OCTOSPI_DCR3 1139
OCTOSPI_DCR4 1140
OCTOSPI_DLR 1142
OCTOSPI_DR 1143
OCTOSPI_FCR 1141
OCTOSPI_HLCR 1156
OCTOSPI_IR 1148
OCTOSPI_LPTR 1149
OCTOSPI_PIR 1145
OCTOSPI_PSMAR 1144
OCTOSPI_PSMKR 1144
OCTOSPI_SR 1140
OCTOSPI_TCR 1147
OCTOSPI_WABR 1156
OCTOSPI_WCCR 1153

OCTOSPI_WIR 1155
OCTOSPI_WPABR 1152
OCTOSPI_WPCCR 1149
OCTOSPI_WPIR 1152
OCTOSPI_WPTCR 1151
OCTOSPI_WTCR 1155
OCTOSPIM_CR 1168
OPAMP1_CSR 1453
OPAMP1_HSOTR 1456
OPAMP1_OTR 1455
OTFDEC_CR 1938
OTFDEC_ICR 1946
OTFDEC_IER 1947
OTFDEC_ISR 1945
OTFDEC_PRIVCFGR 1939
OTFDEC_RxCFGR 1939
OTFDEC_RxENDADDR 1941
OTFDEC_RxKEYR0 1943
OTFDEC_RxKEYR1 1944
OTFDEC_RxKEYR2 1944
OTFDEC_RxKEYR3 1945
OTFDEC_RxNONCER0 1942
OTFDEC_RxNONCER1 1943
OTFDEC_RxSTARTADDR 1941
OTG_CID 3165, 3324
OTG_DAINT 3188, 3348
OTG_DAINTMSK 3189, 3349
OTG_DCFG 3181, 3341
OTG_DCTL 3182, 3343
OTG_DEACHINT 3190
OTG_DEACHINTMSK 3190
OTG_DIEPCTL0 3193
OTG_DIEPCTLx 3195, 3197, 3351, 3353
OTG_DIEPDMAx 3357
OTG_DIEPEACHM 3191
OTG_DIEPEMPMSK 3189, 3350
OTG_DIEPINTx 3199, 3355
OTG_DIEPMSK 3186, 3346
OTG_DIEPTSIZ0 . . . . . 3200, 3356
OTG_DIEPTSIZx 3201, 3358
OTG_DIEPTXF0 . . . . . 3162, 3321
OTG_DIEPTXFx 3170, 3329
OTG_DOEPCTL0 . . . . . 3202, 3358
OTG_DOEPCTLx 3206, 3208, 3363, 3365
OTG_DOEPDMAx 3363
OTG_DOEPEACHMSK1 3192
OTG_DOEPINTx 3204, 3360
OTG_DOEPMSK 3187, 3347
OTG_DOEPTSIZ0 . . . . . 3205, 3362
OTG_DOEPTSIZx 3210, 3367
OTG_DSTS 3185, 3345
OTG_DTHRCTL 3349
OTG_DTXFSTSx 3201, 3357
OTG_GAHBCFG 3141, 3298
OTG_GCCFG 3164, 3323
OTG_GINTMSK 3154-3155, 3313-3314
OTG_GINTSTS 3146, 3150, 3304, 3308
OTG_GLPMCFG 3165, 3325
OTG_GOTGCTL 3138, 3295
OTG_GOTGINT 3140, 3297
OTG_GRSTCTL 3143, 3301
OTG_GRXFSIZ 3161, 3320
OTG_GRXSTSP 3159-3160, 3318-3319
OTG_GRXSTSR 3157-3158, 3316-3317
OTG_GUSBCFG 3142, 3299
OTG_HAINT 3174, 3333
OTG_HAINTMSK 3174, 3333
OTG_HCCHARx 3177, 3336
OTG_HCDMAx 3341
OTG_HCFG 3171, 3330
OTG_HCINTMSKx 3179, 3339
OTG_HCINTx 3178, 3338
OTG_HCSPLTx 3337
OTG_HCTSIZx 3180, 3340
OTG_HFIR 3171, 3330
OTG_HFNUM 3172, 3331
OTG_HNPTXFSIZ 3162, 3321
OTG_HNPTXSTS 3163, 3322
OTG_HPRT 3175, 3334
OTG_HPTXFSIZ 3170, 3329
OTG_HPTXSTS 3173, 3332
OTG_PCGCCTL 3211, 3368
OTG_PCGCCTL1 . . . . . 3212, 3369

P

PKA_CLRFR 1926
PKA_CR 1922
PKA_SR 1924
PLAY_CFGCR 1007
PLAY_FILTxCFG 1009
PLAY_FLCLR 1016
PLAY_FLCTL 1017
PLAY_FLIER 1016
PLAY_FLSET 1015
PLAY_FLSTAT 1014
PLAY_ICR 1019
PLAY_IER 1020
PLAY_ISR 1018
PLAY_LExCFG1 1010
PLAY_LExCFG2 1010
PLAY_MSR 1018
PLAY_OSR 1014
PLAY_OUTxCFG 1011

PLAY_PRIVCFGR 1008
PLAY_SECCFGR 1007
PLAY_SWIN 1012
PLAY_SWINCLR 1013
PLAY_SWINSET 1012
PSSI_CR 1661
PSSI_DR 1665
PSSI_ICR 1665
PSSI_IER 1664
PSSI_MIS 1664
PSSI_RIS 1663
PSSI_SR 1662
PWR_BDCR 474
PWR_BDSR 476
PWR_DBPCR 476
PWR_IORETR 483
PWR_PMCR 470
PWR_PMSR 472
PWR_PRIVCFGR 485
PWR_SCCR 478
PWR_SECCFGR 484
PWR_UCPDR 477
PWR_USBSCR 479
PWR_VMCR 478
PWR_VMSR 480
PWR_VOSCR 473
PWR_VOSSR 474
PWR_WUCR 482
PWR_WUSCR 481
PWR_WUSR 481

R

RAMCFG_M2WPR1 273
RAMCFG_M2WPR2 273
RAMCFG_M2WPR3 274
RAMCFG_M2WPR4 275
RAMCFG_MxCR 269
RAMCFG_MxDEAR 272
RAMCFG_MxECCKEYR 273
RAMCFG_MxERKEYR 274
RAMCFG_MxICR 272
RAMCFG_MxIER 270
RAMCFG_MxISR 271
RAMCFG_MxSEAR 271
RCC_AHB1ENR 557
RCC_AHB1LPENR 570
RCC_AHB1RSTR 545
RCC_AHB2ENR 559
RCC_AHB2LPENR 573
RCC_AHB2RSTR 546
RCC_AHB4ENR 562
RCC_AHB4LPENR 576
RCC_AHB4RSTR 549
RCC_APB1HENR 566
RCC_APB1HLPENR 580
RCC_APB1HRSTR 553
RCC_APB1LENR 563
RCC_APB1LLPENR 577
RCC_APB1LRSTR 550
RCC_APB2ENR 567
RCC_APB2LPENR 581
RCC_APB2RSTR 554
RCC_APB3ENR 569
RCC_APB3LPENR 582
RCC_APB3RSTR 556
RCC_BDCR 594
RCC_CCIPR1 584
RCC_CCIPR2 586
RCC_CCIPR3 588
RCC_CCIPR4 590
RCC_CCIPR5 592
RCC_CFGR1 526
RCC_CFGR2 528
RCC_CICR 544
RCC_CIER 541
RCC_CIFR 542
RCC_CR 521
RCC_CRRCR 525
RCC_CSICFGR 525
RCC_HSICFGR 524
RCC_PLL1CFGR 530
RCC_PLL1DIVR 535
RCC_PLL1FRACR 537
RCC_PLL2CFGR 532
RCC_PLL2DIVR 537
RCC_PLL2FRACR 538
RCC_PLL3CFGR 534
RCC_PLL3DIVR 539
RCC_PLL3FRACR 540
RCC_PRIVCFGR 600
RCC_RSR 597
RCC_SECCFGR 598
RNG_CR 1758
RNG_DR 1761
RNG_HTCRx 1762
RNG_NSCR 1762
RNG_SR 1760, 1763-1764
RTC_ALRABINR 2527
RTC_ALRBBINR 2527
RTC_ALRMAR 2517
RTC_ALRMASSR 2519
RTC_ALRMBR 2520
RTC_ALRMBSSR 2521

RTC_CALR 2513
RTC_CR 2505
RTC_DR 2500
RTC_ICSR 2502
RTC_MISR 2523
RTC_OR 2526
RTC_PRER 2504
RTC_PRIVCFGR 2509
RTC_SCR 2525
RTC_SECCFGR 2511
RTC_SHIFTR 2514
RTC_SMISR 2524
RTC_SR 2522
RTC_SSR 2501
RTC_TR 2499
RTC_TSDR 2516
RTC_TSSSR 2517
RTC_TSTR 2515
RTC_WPR 2512
RTC_WUTR 2505

S

SAES_CR 1851
SAES_DINR 1855
SAES_DOUTR 1856
SAES_ICR 1863
SAES_IER 1861
SAES_ISR 1862
SAES_IVR0 1858
SAES_IVR1 1858
SAES_IVR2 1858
SAES_IVR3 1859
SAES_KEYR0 1856
SAES_KEYR1 1857
SAES_KEYR2 1857
SAES_KEYR3 1857
SAES_KEYR4 1859
SAES_KEYR5 1859
SAES_KEYR6 1860
SAES_KEYR7 1860
SAES_SR 1854
SAES_SUSPxR 1860
SAI_ACLRFR 3025
SAI_ACR1 3014
SAI_ACR2 3017
SAI_ADR 3026
SAI_AFRCR 3019
SAI_AIM 3021
SAI_ASLOTR 3020
SAI_ASR 3023
SAI_BCLRFR 3036
SAI_BCR1 3026
SAI_BCR2 3029
SAI_BDR 3037
SAI_BFRCR 3031
SAI_BIM 3033
SAI_BSLOTR 3032
SAI_BSR 3034
SAI_GCR 3014
SAI_PDMCR 3038
SAI_PDMDLY 3039
SBS_CCCSR 656
SBS_CCSWCR 658
SBS_CCVALR 657
SBS_CFGR2 659
SBS_CNSLCKR 660
SBS_CSLCKR 661
SBS_DBGCR 651
SBS_DBGLOCKR 651
SBS_ECCNMIR 662
SBS_EPOCHSELCR 652
SBS_FPUIMR 655
SBS_HDPLCR 649
SBS_HDPLSR 650
SBS_MESR 656
SBS_NEXTHDPLCR 650
SBS_OTGHSPHYTUNER2 662
SBS_PMCR 654
SBS_RSSCMDR 652
SBS_SECCFGR 653
SDMMC_ACKTIMER 1245
SDMMC_ARGR 1230
SDMMC_CLKCR 1228
SDMMC_CMDR 1230
SDMMC_DCNTR 1236
SDMMC_DCTRL 1235
SDMMC_DLENR 1234
SDMMC_DTIMER 1233
SDMMC_FIFORx 1249
SDMMC_ICR 1240
SDMMC_IDMABAR 1248
SDMMC_IDMABASER 1247
SDMMC_IDMABSIZER 1246
SDMMC_IDMACTRLR 1245
SDMMC_IDMALAR 1247
SDMMC_MASKR 1242
SDMMC_POWER 1227
SDMMC_RESPCMDR 1232
SDMMC_RESPxR 1233
SDMMC_STAR 1237
SPI_CFG1 2957
SPI_CFG2 2961
SPI_CR1 2955

SPI_CR2 2957
SPI_CRCPOLY 2969
SPI_I2SCFGR 2971
SPI_IER 2963
SPI_IFCR 2967
SPI_RXCRC 2970
SPI_RXDR 2968
SPI_SR 2964
SPI_TXCRC 2969
SPI_TXDR 2968
SPI_UDRDR 2971
SYSROM_CIDR0 3804
SYSROM_CIDR1 3805
SYSROM_CIDR2 3805
SYSROM_CIDR3 3805
SYSROM_MEMTYPER 3802
SYSROM_PIDR0 3802
SYSROM_PIDR1 3803
SYSROM_PIDR2 3803
SYSROM_PIDR3 3804
SYSROM_PIDR4 3802

T

TAMP_ATCR1 2557
TAMP_ATCR2 2560
TAMP_ATOR 2559
TAMP_ATSEEDR 2559
TAMP_BKPxR 2577
TAMP_COUNT1R 2575
TAMP_CR1 2550
TAMP_CR2 2552
TAMP_CR3 2554
TAMP_FLTCR 2555
TAMP_IER 2566
TAMP_MISR 2570
TAMP_OR 2575
TAMP_PRIVCFGR 2565
TAMP_RPCFGR 2576
TAMP_SCR 2573
TAMP_SECCFGR 2563
TAMP_SMISR 2571
TAMP_SR 2568
TIM12_ARR 2276
TIM12_CCER 2274
TIM12_CCMR1 2270-2271
TIM12_CCR1 2277
TIM12_CCR2 2277
TIM12_CNT 2275
TIM12_CR1 2263
TIM12_CR2 2265
TIM12_DIER 2267
TIM12_EGR 2269
TIM12_PSC 2276
TIM12_SMCR 2265
TIM12_SR 2268
TIM12_TISEL 2278
TIM15_AF1 2366
TIM15_AF2 2368
TIM15_ARR 2359
TIM15_BDTR 2361
TIM15_CCER 2355
TIM15_CCMR1 2351-2352
TIM15_CCR1 2360
TIM15_CCR2 2361
TIM15_CNT 2358
TIM15_CR1 2342
TIM15_CR2 2343
TIM15_DCR 2369
TIM15_DIER 2347
TIM15_DMAR 2370
TIM15_DTR2 2364
TIM15_EGR 2350
TIM15_PSC 2358
TIM15_RCR 2359
TIM15_SMCR 2345
TIM15_SR 2348
TIM15_TISEL 2365
TIM17_OR1 2394
TIMx_AF1 . . . . . .2085, 2205, 2391
TIMx_AF2 . . . . . .2088, 2206, 2394
TIMx_ARR 2071, 2195, 2229, 2289, 2385
TIMx_BDTR 2075, 2387
TIMx_CCER 2066, 2192, 2287, 2381
TIMx_CCMR1 . . 2057, 2059, 2184, 2186, 2284-2285, ... 2378-2379
TIMx_CCMR2 . . . . . .2062-2063, 2188-2189
TIMx_CCMR3 2081
TIMx_CCR1 . . . . . 2072, 2196-2197, 2290, 2386
TIMx_CCR2 . . . . . 2072, 2197-2198
TIMx_CCR3 . . . . . 2073, 2199-2200
TIMx_CCR4 . . . . . 2074, 2201-2202
TIMx_CCR5 2079
TIMx_CCR6 2080
TIMx_CNT . 2070, 2193-2194, 2228, 2288, 2384
TIMx_CR1 . . . . . .2043, 2173, 2225, 2281, 2373
TIMx_CR2 . . . . . .2044, 2174, 2227, 2374
TIMx_DCR 2090, 2207, 2395
TIMx_DIER 2052, 2180, 2227, 2282, 2375
TIMx_DMAR 2092, 2208, 2396
TIMx_DTR2 . . . . . .2082, 2390
TIMx_ECR 2083, 2203
TIMx_EGR 2056, 2183, 2228, 2283, 2377
TIMx_PSC 2070, 2194, 2229, 2289, 2384

TIMx_RCR 2071, 2385
TIMx_SMCR 2048, 2176
TIMx_SR 2053, 2181, 2228, 2282, 2376
TIMx_TISEL 2084, 2204, 2290, 2391
TPIU_ACPR 3881
TPIU_CIDR0 3888
TPIU_CIDR1 3889
TPIU_CIDR2 3889
TPIU_CIDR3 3890
TPIU_CLAIMCLR 3885
TPIU_CLAIMSETR 3884
TPIU_CSPSR 3881
TPIU_DEVIDR 3885
TPIU_DEVTYPER 3886
TPIU_FFCR 3883
TPIU_FFSR 3882
TPIU_PIDR0 3887
TPIU_PIDR1 3887
TPIU_PIDR2 3887
TPIU_PIDR3 3888
TPIU_PIDR4 3886
TPIU_PSCR 3884
TPIU_SPPR 3882
TPIU_SSPSR 3881

U

UCPD_CFGR1 3456
UCPD_CFGR2 3458
UCPD_CR 3459
UCPD_ICR 3465
UCPD_IMR 3461
UCPD_RX_ORDEXTR1 3469
UCPD_RX_ORDEXTR2 3470
UCPD_RX_ORDSETR 3468
UCPD_RX_PAYSZR 3468
UCPD_RXDR 3469
UCPD_SR 3462
UCPD_TX_ORDSETR 3466
UCPD_TX_PAYSZR 3467
UCPD_TXDR 3467
USART_BRR 2822
USART_CR1 . . . . . .2804, 2808
USART_CR2 2811
USART_CR3 . . . . . .2815, 2819
USART_GTPR 2823
USART_ICR 2837
USART_ISR 2826, 2832
USART_PRESC 2839
USART_RDR 2838
USART_RQR 2825
USART_RTOR 2824
USART_TDR 2839

V

VREFBUF_CCR 1442
VREFBUF_CSR 1441

W

WWDG_CFR 2472
WWDG_CR 2471
WWDG_SR 2473

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