Getting started with X-CUBE-OUT3 industrial digital output software for STM32 Nucleo

Introduction

The X-CUBE-OUT3 expansion software package for STM32Cube runs on the STM32 microcontroller and includes a driver to control the IPS2050H and/or the IPS2050H-32 high efficiency dual high-side switches with extended diagnostics and smart driving for capacitive loads.

The software provides an affordable and easy-to-use solution for the development of 2.5 A (X-NUCLEO-OUT03A1) or 5.7 A (X-NUCLEO-OUT04A1) digital output modules, letting you easily evaluate the driving and diagnostic capabilities of IPS2050H and IPS2050H-32 with industrial loads.

The expansion is built on STM32Cube software technology to ease portability across different STM32 microcontrollers.

The software comes with a sample implementation of a dual channel driver running on the X-NUCLEO-OUT03A1 or X-NUCLEO-OUT04A1 expansion board connected to a NUCLEO-F401RE or NUCLEO-G431RB development board.

You can stack up to four expansion boards, X-NUCLEO-OUT03A1 and/or X-NUCLEO-OUT04A1 with shared or independent supply rail and independent loads, to evaluate up to an eight-channel digital output module.

When two or more boards are stacked, the configuration resistors between signals and Arduino connectors of the second, third or fourth board must be properly placed in alternate positions to guarantee the desired control of the hardware.

RELATED LINKS

Visit the STM32Cube ecosystem web page on www.st.com for further information

1 Acronyms and abbreviations

Table 1. List of acronyms

Acronym	Description
API	Application programming interface
BSP	Board support package
CMSIS	Cortex® microcontroller software interface standard
HAL	Hardware abstraction layer
IDE	Integrated development environment
SPI	Serial peripheral interface

2 X-CUBE-OUT3 software expansion for STM32Cube

2.1 Overview

The X-CUBE-OUT3 software package expands the functionality provided by STM32Cube .

The key features of the package are:

- Complete software to build applications for IPS2050H and IPS2050H-32 high efficiency dual high-side switch
- GPIOs, PWMs and IRQs
- Fault/Diagnostics interrupt handling
- Sample implementation available on the X-NUCLEO-OUT03A1 or X-NUCLEO-OUT04A1 expansion boards when connected to a NUCLEO-F401RE or NUCLEO-G431RB development boards
- Easy portability across different MCU families, thanks to STM32Cube
- Free, user-friendly license terms

This software enables control of the digital output channel of a dual channel expansion board (X-NUCLEO-OUT03A1 or X-NUCLEO-OUT04A1) or of up to four appropriately configured expansion boards (X-NUCLEO-OUT03A1 and/or X-NUCLEO-OUT04A1) stacked on a NUCLEO-F401RE or NUCLEO-G431RB development board.

It also allows you to program the expansion boards to be independently switched on and off using PWM with a specific frequency in the 0-100 Hz range (0.1 Hz resolution), and specific duty cycle in the 0-100% range (1% resolution).

The package includes an example to test device functionality while driving the channels in steady state and PWM.

2.2 Architecture

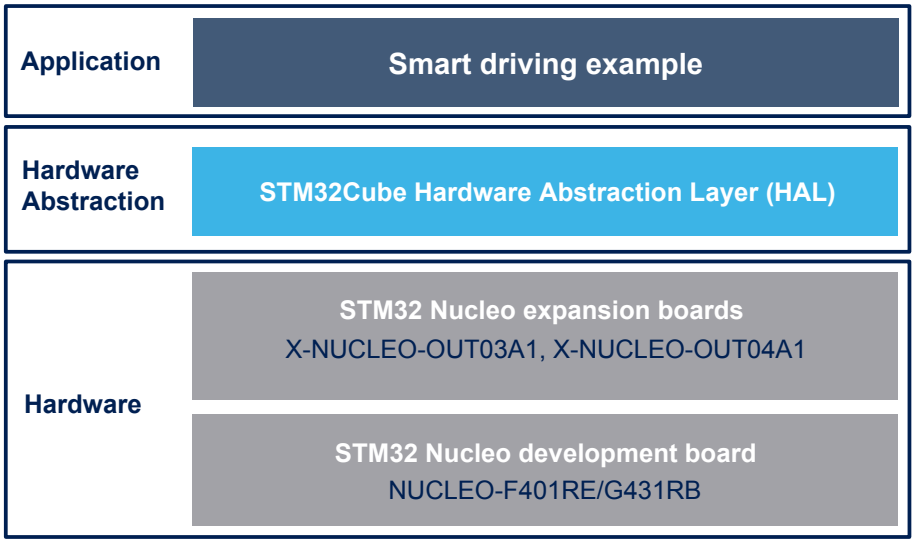
This software is a fully compliant expansion of STM32Cube architecture for the development of applications for single high-side driver intelligent power switch (IPS) digital output modules.

The software is based on the STM32CubeHAL hardware abstraction layer for the STM32 microcontroller. The package extends STM32Cube by providing a board support package (BSP) for the digital output expansion boards based on IPS2050H and IPS2050H-32.

The software layers used by the application software to access and use the industrial digital output expansion boards are:

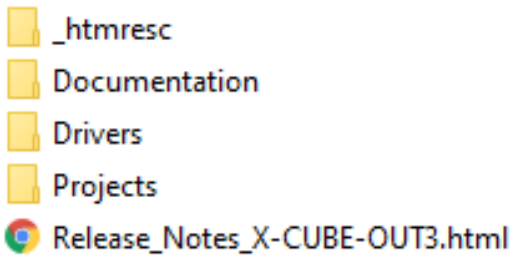
- **STM32Cube HAL layer**: consists of simple, generic and multi-instance APIs (application programming interfaces) which interact with the upper layer applications, libraries and stacks. These generic and extension APIs are based on a common framework so that overlying layers like middleware can function without requiring specific microcontroller unit (MCU) hardware information. This structure improves library code reusability and guarantees easy portability across other devices.
- **Board support package (BSP) layer**: provides software support for the STM32 Nucleo board peripherals, excluding the MCU. These specific APIs provide a programming interface for certain board specific peripherals like LEDs, user buttons, etc., and can also be used to fetch individual board version information. It also provides support for initializing, configuring and reading data.

Figure 1. **X-CUBE-OUT3 software architecture**



2.3 Folder structure

Figure 2. **X-CUBE-OUT3 package folder structure**



The following folders are included in the software package:

- **_htmresc** contains graphics for html pages.
- **Documentation** contains a compiled HTML file generated from the source code, detailing the software components and APIs.
- **Drivers** contains:
  - **STM32Cube HAL** sub-folders, located in the subfolders (STM32G4xx_HAL_Driver and STM32F4xx_HAL_Driver). These files are not specific to the X-CUBE-OUT3 software but come directly from the STM32Cube framework and represent the Hardware Abstraction Layer code for the STM32 MCUs.
  - a **CMSIS** folder which contains the Cortex® microcontroller software interface standard files from ARM. These files are vendor-independent hardware abstraction layer for the Cortex-M processor series. This folder comes also unchanged from the STM32Cube framework.
  - a **BSP** folder containing the codes required for the X-NUCLEO-OUT03A1 and X-NUCLEO-OUT04A1 configuration, the IPS2050H and IPS2050H-32 drivers and the switch API functions.
- **Projects** contains sample applications for IPS2050H and IPS2050H-32, provided for NUCLEO-F401RE and NUCLEO-G431RB platforms.

2.3.1 BSPs

For the X-CUBE-OUT3 software, different BSPs are used:

1. STM32F4xx-Nucleo/STM32G4xx_Nucleo
2. IPS1025H_2050H
3. OUT0xA1

2.3.1.1 *STM32F4xx-Nucleo/STM32G4xx_Nucleo*

Depending on the STM32 Nucleo development board used, these BSPs provide an interface to configure and use the development board peripherals with the X-NUCLEO-OUT03A1 and X-NUCLEO-OUT04A1 expansion boards.

Each STM32XXxx-Nucleo sub-folder contains couples of .c/.h files (stm32XXxx_nucleo.c/h) which come from the STM32Cube framework without modification and provide the functions to handle the corresponding user button and LEDs of the corresponding development board.

2.3.1.2 *IPS1025H_2050H*

The IPS1025H_2050H BSP component provides the driver functions for the STMicroelectronics intelligent power switch devices in the X-CUBE_IPS\Drivers\BSP\Components\ips1025h_2050h folder, which contains:

- **ips1025h_2050h.c**: core functions of the IPS2050H and IPS2050H-32 drivers
- **ips1025h_2050h.h**: declaration of the IPS2050H and IPS2050H-32 driver functions and their associated definitions

2.3.1.3 *OUT0xA1*

The OUT0xA1 BSP component contains board support package files for X-NUCLEO-OUT0xA1 board family (X-NUCLEO-OUT03A1, X-NUCLEO-OUT04A1, etc.), which are dedicated to the functions necessary to drive the power switches in steady-state and in PWM mode using GPIOs.

The files are also used to obtain the status of diagnostics and output feedback pins. Through these functions, the channel can be set and reset or configured in PWM mode with a specific frequency and duty cycle.

2.3.2 Projects

For each STM32 Nucleo platform, an example project is available in the folders:

- Projects\STM32F401RE-Nucleo\Examples\Out03_04
- Projects\STM32G431RB-Nucleo\Examples\Out03_04

Each example has a folder dedicated to the targeted IDE:

- **EWARM** containing the project files for IAR
- **MDK-ARM** containing the project files for Keil
- **STM32CubeIDE** containing the project files for OpenSTM32

Each example also contains the following code files:

- **Projects\STM32F401RE-Nucleo\Examples\Out03_04**
  - **Inc\main.h** - Header for main.c module
  - **Inc\out03_04a1_conf.h** - Header for BSP/OUT0xA1 driver configuration
  - **Inc\app_switch.h** - Header for app_switch.c module
  - **Inc\stm32f4xx_hal_conf.h** - HAL configuration file for STM32F4xx
  - **Inc\stm32f4xx_it.h** - Interrupt handlers header file for STM32F4xx
  - **Inc\stm32f4xx_nucleo_errno.h** - Error codes for STM32F4xx-Nucleo
  - **Inc\ips2050h_conf.h** - Header for BSP/Components/ips1025h_2050h driver configuration
  - **Src\main.c** - Main program
  - **Src\app_switch.c** - Code for application example customization
  - **Src\stm32f4xx_hal_msp.c** - HAL MSP module for STM32F4xx
  - **Src\stm32f4xx_it.c** - Interrupt handlers for STM32F4xx
  - **Src\system_stm32f4xx.c** - System source file for STM32F4xx

- **Projects\STM32G431RB-Nucleo\Examples\Out03_04**
  - **Inc\main.h** - Header for main.c module
  - **Inc\out03_04a1_conf.h** - Header for BSP/OUT0xA1 driver configuration
  - **Inc\app_switch.h** - Header for app_switch.c module
  - **Inc\stm32g4xx_hal_conf.h** - HAL configuration file for STM32G4xx
  - **Inc\stm32g4xx_it.h** - Interrupt handlers header file for STM32G4xx
  - **Inc\stm32g4xx_nucleo_conf.h** - Configuration file for STM32G4xx-Nucleo
  - **Inc\ips2050h_conf.h** - Header for BSP/Components/ips1025h_2050h driver configuration
  - **Src\main.c** - Main program
  - **Src\app_switch.c** - Code for application example customization
  - **Src\stm32g4xx_hal_msp.c** - HAL MSP module for STM32G4xx
  - **Src\stm32g4xx_it.c** - Interrupt handlers for STM32G4xx
  - **Src\system_stm32g4xx.c** - System source file for STM32G4xx

2.4 Software required resources and board configuration

The MCU controls IPS2050H and IPS2050H-32 via GPIOs.

Thus, when using one X-NUCLEO-OUT03A1 expansion board or one X-NUCLEO-OUT04A1 expansion board, two GPIO signals (IN1 and IN2 pins) plus two GPIOs dedicated to the interrupt management (FLT1, FLT2 pins) are required.

The software also uses a PWM timer (TIM3) to generate the periodic patterns on the output channels for the expansion boards.

It is also possible to evaluate an eight channel digital output module by stacking up to four X-NUCLEO-OUT03A1 and\or X-NUCLEO-OUT04A1 with shared or independent supply rail and independent loads.

In this case, the additional expansion boards must be properly configured: for the second, third or fourth board, it is necessary to unsolder four resistors for each board from the default position and solder them in different positions related to the board number following the scheme described below.

Table 2. Configuration of a stack of four expansion boards

Board no.	IN1	IN2	FLT1	FLT2
Board 0	R101	R102	R103	R104
Board 1	R131	R132	R133	R134
Board 2	R111	R112	R113	R114
Board 3	R121	R122	R123	R124

Important:
When using Board 2 and Board 3, two jumpers must close the morpho connectors pins in the STM32 Nucleo board:

- *CN7.35-36 closed*
- *CN10.25-26 closed*

For further details, see the jumper configuration described in Section 3.4 Board setup and the documentation file (readme.txt).

2.5 APIs

The X-CUBE-OUT3 API software is defined in the Drivers\BSP\OUT0xA1\out0xa1.h file. Its functions are prefixed by `OUT03_05_SWITCH_`.

Detailed technical information about the APIs available to the user can be found in a compiled HTML Help (chm) file located inside the “Documentation” folder of the software package where all the functions and parameters are fully described.

2.6 Sample application description

A sample application using the X-NUCLEO-OUT03A1 or X-NUCLEO-OUT04A1 expansion board with either NUCLEO-F401RE or NUCLEO-G431RB boards is provided in the “Projects” directory. Ready to be built projects are available for multiple IDEs.

In this example, a sequence of commands is applied to the X-NUCLEO-OUT03A1 or X-NUCLEO-OUT04A1 IN channels. An operation change is requested by pressing the user button.

At start-up, the IN1 and IN2 channels are switched off. Each time the user button is pressed, the program performs a consecutive action as in the sequence below:

1. Switches ON IN1 channel on boards 0-2, switches ON IN2 channel on boards 1-3
2. Switches ON IN1 channel on boards 1-3, switches ON IN2 channel on boards 0-2
3. Switches OFF IN1 channel on boards 0-1, switches OFF IN2 channel on boards 2-3
4. Switches OFF IN1 channel on boards 2-3, switches OFF IN2 channel on boards 0-1
5. Switches ON IN1 and IN2 channels on all boards
6. Switches OFF IN1 and IN2 channels on all boards
7. Start PWM on both channels on all boards with different frequency and duty cycle settings:
   - IN1 boards 0-3: PWM ON with freq. 2 Hz, DC 25%
   - IN2 boards 1-2: PWM ON with freq. 2 Hz, DC 50%
   - IN1 boards 1-2: PWM ON with freq. 1 Hz, DC 25%
   - IN2 boards 0-3: PWM ON with freq. 1 Hz, DC 50%
8. Set DC 50% for IN1 on all boards
9. Set DC 75% for IN2 on all boards
10. Set DC 100% for IN1 on all boards
11. Set DC 100% for IN2 on all boards
12. Stop PWM on both channels on all boards

By pressing the user blue button, the firmware moves forward to the next function.

The sequence is cyclic: after the last step (12) it returns to the first one (1).

3 System setup guide

3.1 Hardware description

3.1.1 STM32 Nucleo

STM32 Nucleo development boards provide an affordable and flexible way for users to test solutions and build prototypes with any STM32 microcontroller line.

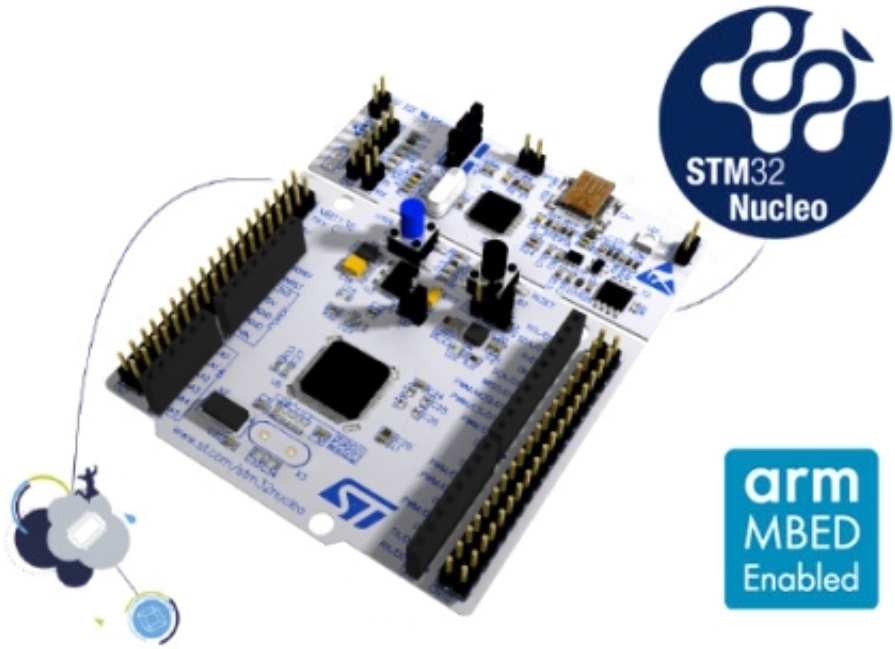
The Arduino connectivity support and ST morpho connectors make it easy to expand the functionality of the STM32 Nucleo open development platform with a wide range of specialized expansion boards to choose from.

The STM32 Nucleo board does not require separate probes as it integrates the ST-LINK/V2-1 debugger/ programmer.

The STM32 Nucleo board comes with the comprehensive STM32 software HAL library together with various packaged software examples for different IDEs (IAR EWARM, Keil MDK-ARM, STM32CubeIDE, mbed and GCC/ LLVM).

All STM32 Nucleo users have free access to the mbed online resources (compiler, C/C++ SDK and developer community) at www.mbed.org to easily build complete applications.

Figure 3. STM32 Nucleo board



3.1.2 X-NUCLEO-OUT03A1 expansion board

The X-NUCLEO-OUT03A1 industrial digital output expansion board for STM32 Nucleo provides a powerful and flexible environment for the evaluation of the driving and diagnostic capabilities of the IPS2050H (dual high-side smart power solid state relay) in a digital output module connected to 2.5 A (max.) industrial loads.

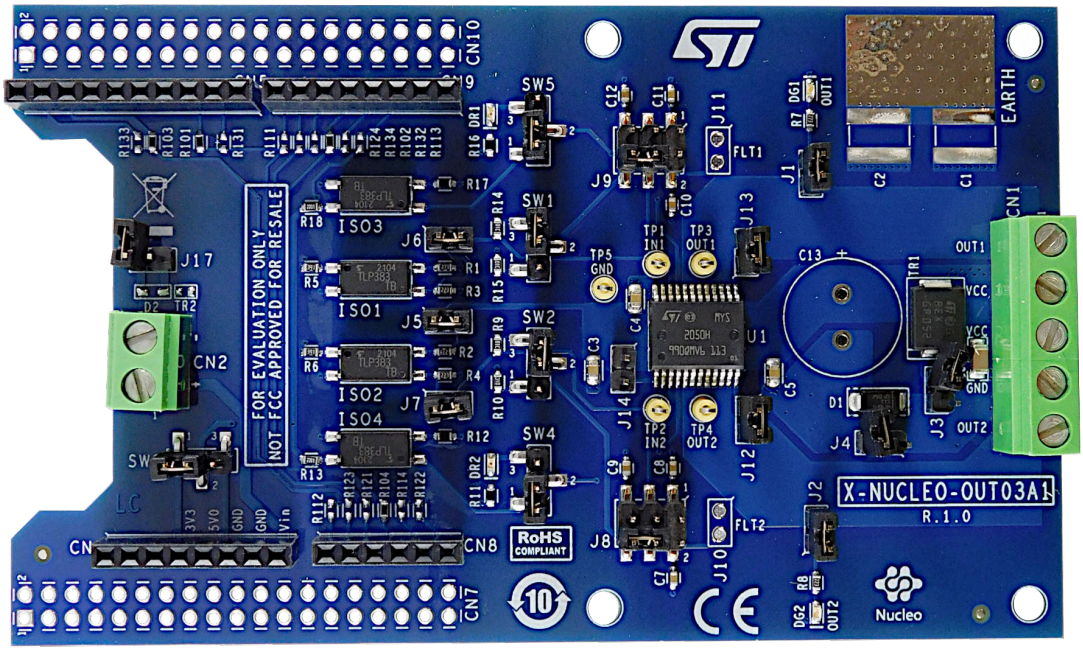
The X-NUCLEO-OUT03A1 interfaces with the microcontroller on the STM32 Nucleo via 5 kV optocouplers driven by GPIO pins, Arduino UNO R3 (default configuration) and ST morpho (optional, not mounted) connectors.

The expansion board can be connected to either a NUCLEO-F401RE or NUCLEO-G431RB development board.

It is also possible to evaluate a system composed by up to four stacked X-NUCLEO-OUT03A1 expansion boards.

As an example, a system with four X-NUCLEO-OUT03A1 expansion boards allows you to evaluate an eight-channel digital output module with 2.5 A (max.) capability each.

Figure 4. X-NUCLEO-OUT03A1 expansion board



3.1.3 X-NUCLEO-OUT04A1 expansion board

The X-NUCLEO-OUT04A1 industrial digital output expansion board for STM32 Nucleo provides a powerful and flexible environment for the evaluation of the driving and diagnostic capabilities of the IPS2050H-32 (dual high-side smart power solid state relay) in a digital output module connected to 5.7 A (max.) industrial loads.

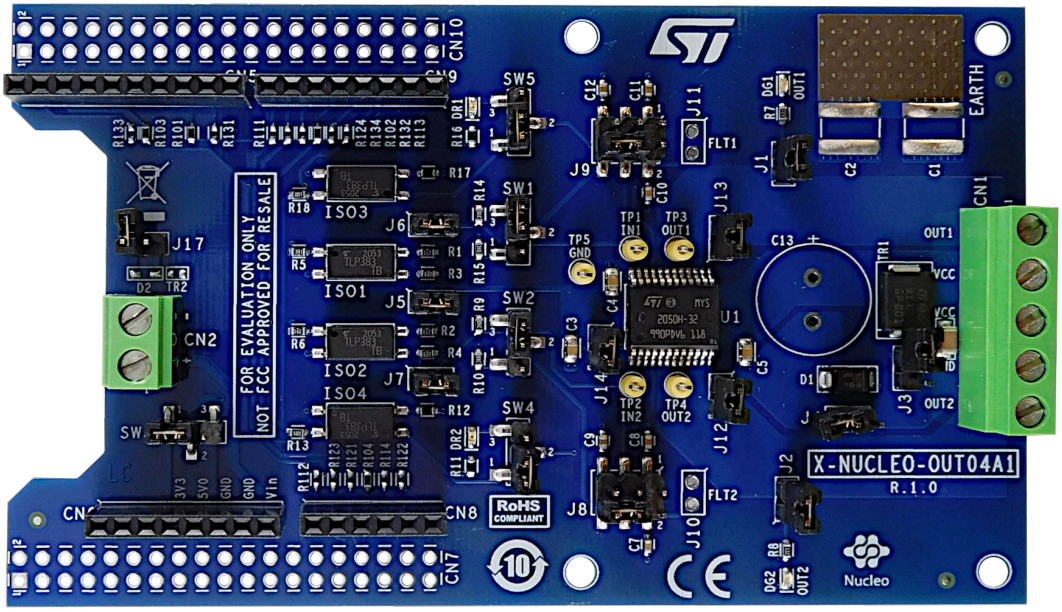
The X-NUCLEO-OUT04A1 interfaces with the microcontroller on the STM32 Nucleo via 5 kV optocouplers driven by GPIO pins, Arduino UNO R3 (default configuration) and ST morpho (optional, not mounted) connectors.

The expansion board can be connected to either a NUCLEO-F401RE or NUCLEO-G431RB development board.

It is also possible to evaluate a system composed by up to four stacked X-NUCLEO-OUT04A1 expansion boards.

As an example, a system with four X-NUCLEO-OUT04A1 expansion boards allows you to evaluate an eight-channel digital output module with 5.7 A (max.) capability each.

Figure 5. X-NUCLEO-OUT04A1 expansion board



3.2 Hardware setup

The following hardware components are required:

1. One USB type A to Mini-B USB cable to connect the STM32 Nucleo to the PC when using a NUCLEO-F401RE
2. One USB type A to Micro-B USB cable when using a NUCLEO-G431RB
3. An external power supply (8 - 33 V) and the associated wires to supply the X-NUCLEO-OUT03A1 or X-NUCLEO-OUT04A1 expansion boards

3.3 Software setup

The following software components are required to set up a suitable development environment for creating applications for the STM32 Nucleo equipped with the X-NUCLEO-OUT03A1 or X-NUCLEO-OUT04A1 industrial digital output expansion boards:

- X-CUBE-OUT3: an expansion for STM32Cube dedicated to application development which require the use of IPS2050H or IPS2050H-32. The X-CUBE-OUT3 firmware and related documentation is available on www.st.com.
- Development tool-chain and Compiler: the STM32Cube expansion software supports the three following environments:
  - IAR Embedded Workbench for ARM® (EWARM) toolchain + ST-LINK
  - RealView Microcontroller Development Kit (MDK-ARM-STR) toolchain + ST-LINK
  - STM32CubeIDE + ST-LINK

3.4 Board setup

The STM32 Nucleo must be configured with the following jumper positions:

- NUCLEO-F401RE
  - JP5 on U5V for firmware flashing
  - JP1 open
  - JP6 closed
  - CN2: closed 1-2, 3-4
  - CN3 open
  - CN4 open
  - CN11 closed
  - CN12 closed
- NUCLEO-G431RB
  - JP5 Closed 1-2 (5V_STLK for firmware flashing)
  - JP1, JP7 open
  - JP3, JP6 closed
  - JP8 closed 1-2
  - CN4 open
  - CN11 closed
  - CN12 closed

The X-NUCLEO-OUT03A1 or X-NUCLEO-OUT04A1 expansion board must be configured in the following way:

- SW1 1-2
- SW2 1-2
- SW3 1-2
- SW4
  - Close 1-2 to route FLT2 signal from device to microcontroller only
  - Close 2-3 to drive the DR2 red LED only
- SW5
  - Close 1-2 to route FLT1 signal from device to microcontroller only
  - Close 2-3 to drive the DR1 red LED only
- J1, J2, J5, J6, J7, J12, J13, J14 closed
- J3, J4, J10, J11, J17 open
- J8 closed 4-6
- J9 closed 4-6

Step 1. Plug the X-NUCLEO-OUT03A1 or X-NUCLEO-OUT04A1 expansion board on top of the STM32 Nucleo via the Arduino connectors.

Figure 6. X-NUCLEO-OUT03A1 expansion board connected to an STM32 Nucleo development board

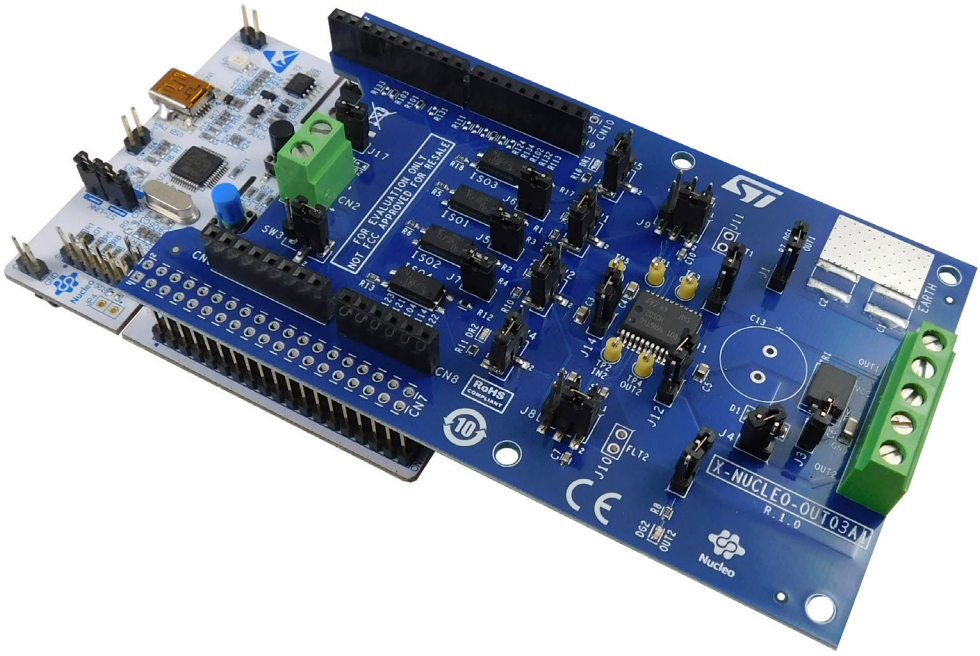
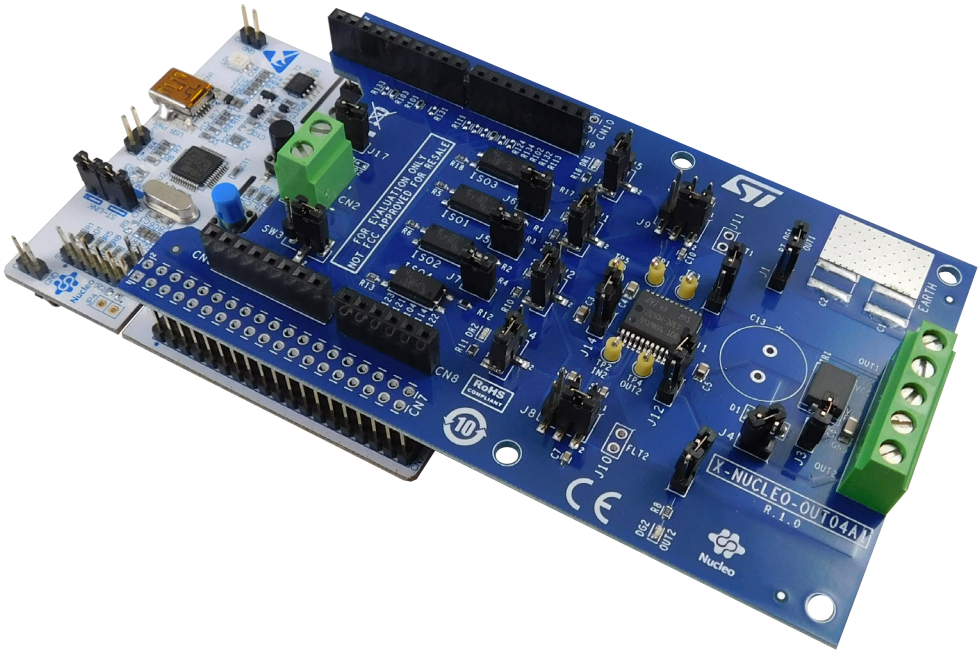


Figure 7. X-NUCLEO-OUT04A1 expansion board connected to an STM32 Nucleo development board



Step 2. Power on the STM32 Nucleo development board by connecting a USB cable between CN1 connector and a PC USB port.

Step 3. Power on the X-NUCLEO-OUT03A1 or X-NUCLEO-OUT04A1 expansion board by properly connecting CN1 connector pin 2 or 3 (V_{CC}) and 4 (GND) to the DC power supply (which must be set between 8 and 33 V).

Step 4. Open your preferred toolchain (MDK-ARM from Keil, EWARM from IAR, or STM32CubeIDE)

Step 5. Depending on the STM32 Nucleo development board used, open the software project from:

- Projects\STM32F401RE-Nucleo\Examples\Out03_04 for NUCLEO-F401RE
- Projects\STM32G431RB-Nucleo\Examples\Out03_04 for NUCLEO-G431RB

Step 6. Rebuild all files and load your image into target memory.

Step 7. Run the example.

Each time the user button is pressed, a new command is applied at the digital output as described in Section 2.6 Sample application description

Revision history

Table 3. **Document revision history**

Date	Revision	Changes
09-Nov-2021	1	Initial release.

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