Techday
Taiwan | 2023
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Sub-track II –
Power & Energy Presentation

3 kW 5G telecom rectifier with SiC MOSFET and STM32G4 digital controller

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Power & Energy Competence Center

Agenda

1 Background

2 Introduction for 3 kW digital solution

3 EVM board performance

4 ST products introduction

5 Summary

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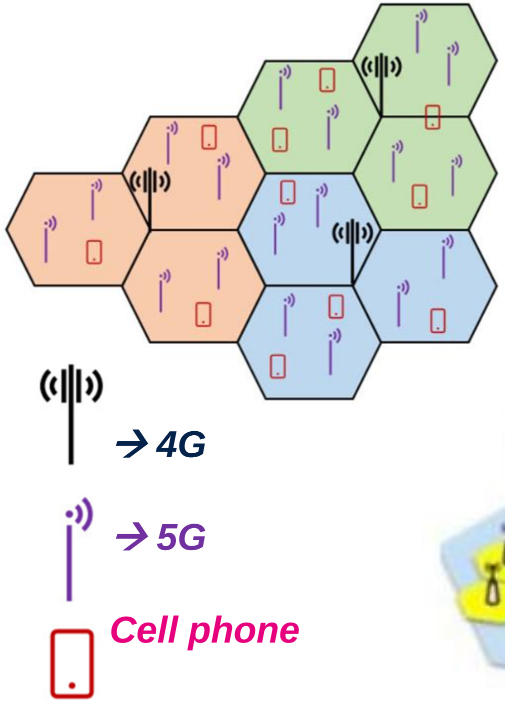
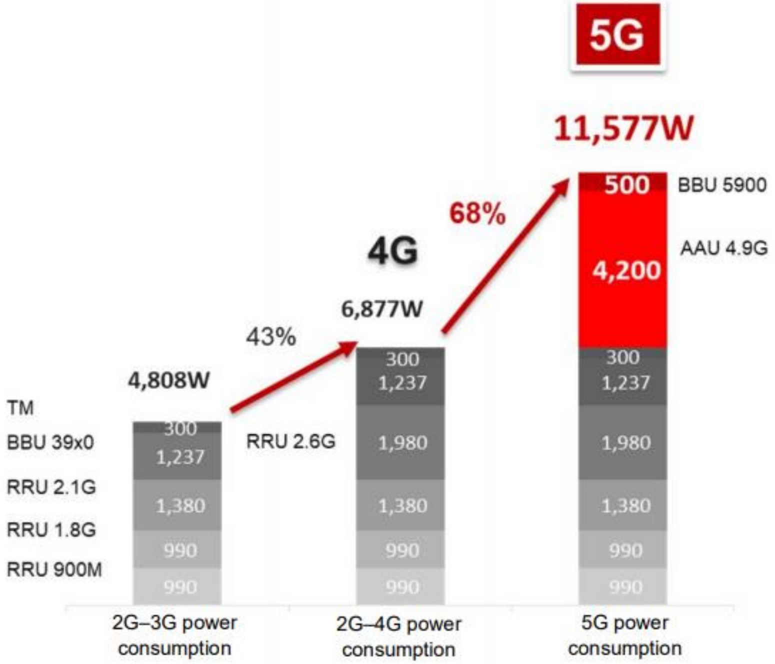
Background

5G telecom power requirements

Higher system integration is the Key for 5G power
Provides higher power density and higher efficiency!

- **Smaller coverage due to higher frequency radio:** to achieve high network speed and low latency
- **Higher power consumption in 5G usage:** to fulfill high traffic density and connection density



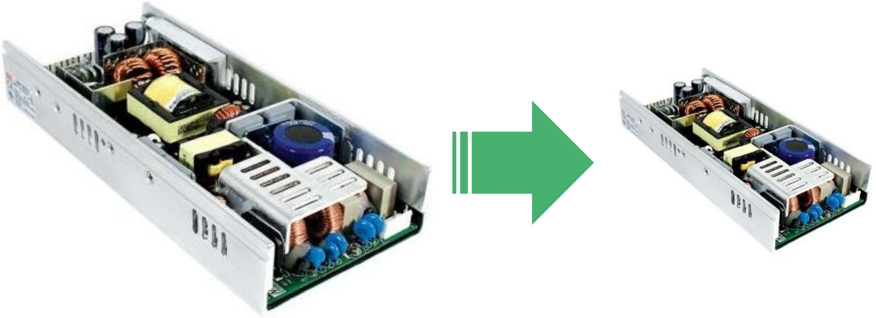


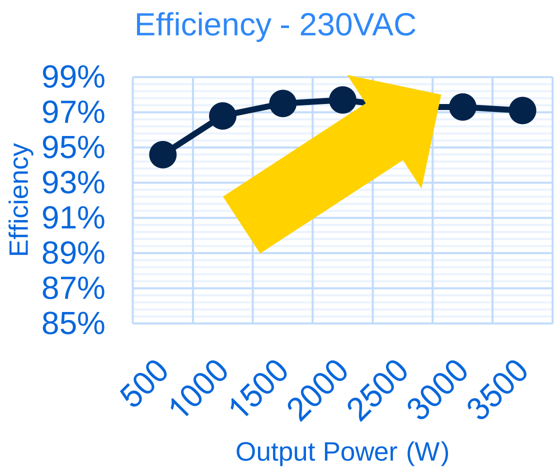
Source: Huawei

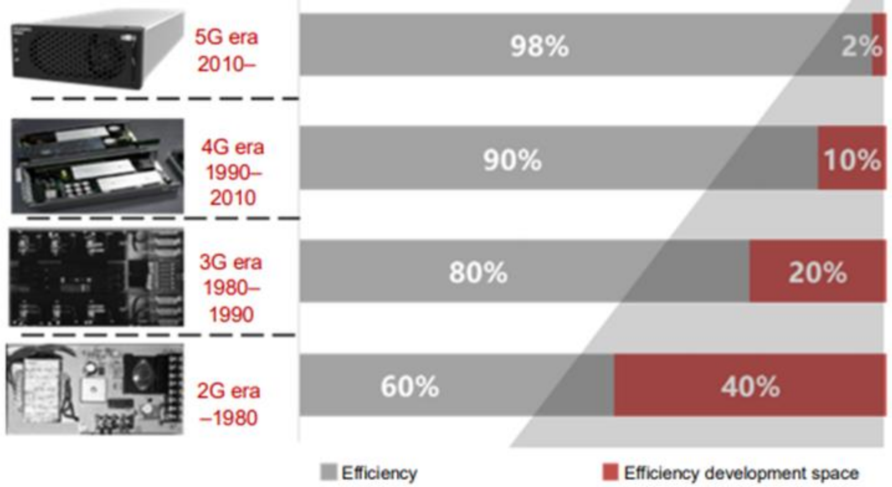
Digital solution for 5G power applications

To achieve high system integration, we need:

- High flexibility and good adaptability for advanced topologies to achieve high efficiency
- Provide benefit on downsizing and BOM reduction
- Support communication for real-time monitoring (safety)
- Less component variation (high reliability)







Source: Huawei

Introduction for 3 kW digital solution

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Telecom rectifier/datacenter/server

3 kW CCM TTP PFC + FB LLC + SR–telecom rectifier

PE.SP_0001.20

Physical Sample

ST 3 kW telecom Rectifier

Commercial 2.9 kW telecom Rectifier

Application key features:

- Fully digital AC-DC power supply
- Input AC voltage: 90–264 VAC
- Input AC frequency: 47–63 Hz
- DC output voltage: 53.5 VDC
- Peak efficiency > 96.5% @ 230 VAC
- Power Factor > 0.99 @ 100% load
- iTHD < 5% @ 100% load
- Hold up time: 10 ms
- Outline dimension: 100 x310 x 41 mm
- Power density up to 40 W/inch^3
- Peak inrush current <30 A

Key products

PFC:

- SCTW35N65G2V (SiC MOSFET),
- STY139N65M5 (SJ MOSFET),
- STGAP2D (galvanic insulated gate driver)
- STM32G4 (32-bit MCU)
- VIPER26HD (for aux. power of PFC stage)

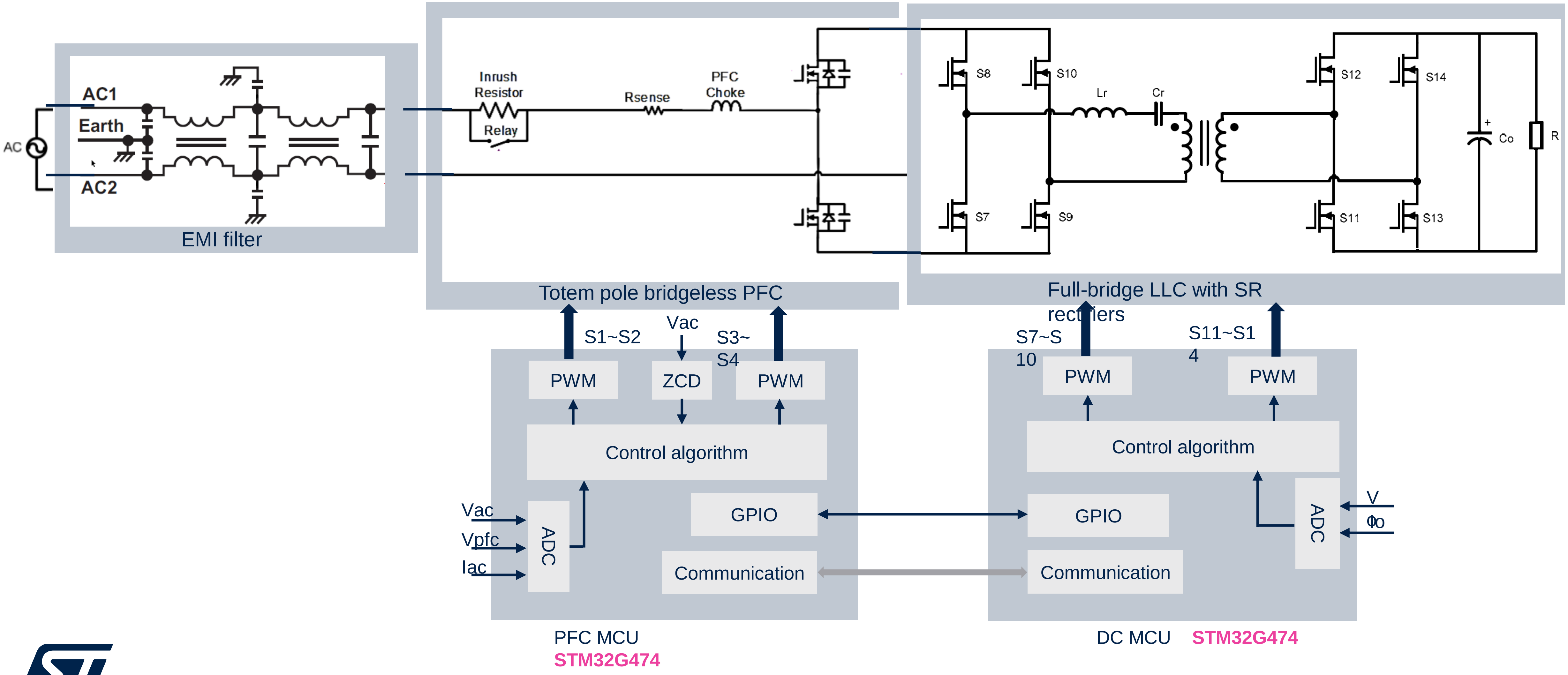
LLC:

- STW70N65DM6 (SJ MOSFET),
- STGAP2HS (galvanic insulated gate driver)
- STL130N8F7 (SR MOSFET)
- STM32G4 (32-bit MCU)
- VIPER38HD (for aux. power of LLC stage)

Key benefits

- Peak efficiency > 96.5%
- Power density up to 40W/inch^3

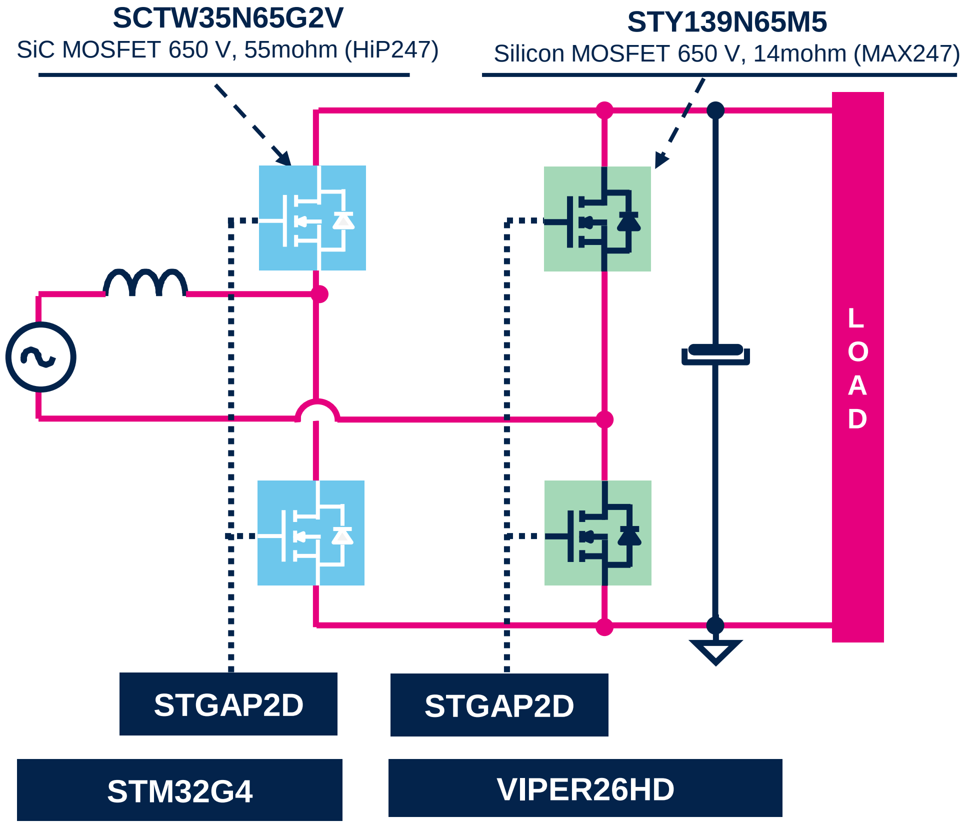
Simplified block diagram



3 kW CCM totem pole PFC solution

Key specs

- Input AC voltage: 90–264 VAC
- Input inrush current: <30 A
- Switching frequency: 70 kHz
- Operation mode: CCM
- Peak efficiency: 98.5% @ 230 VAC
- Power Factor > 0.99 @ 100% load
- iTHD < 5% @ 100% load
- STM32G4 digital power control



Key products:

- SCTW35N65G2V (SiC MOSFET)
- STY139N65M5 (SJ MOSFET)
- STGAP2D (galvanic insulated gate driver)
- STM32G4 (32-bit MCU)

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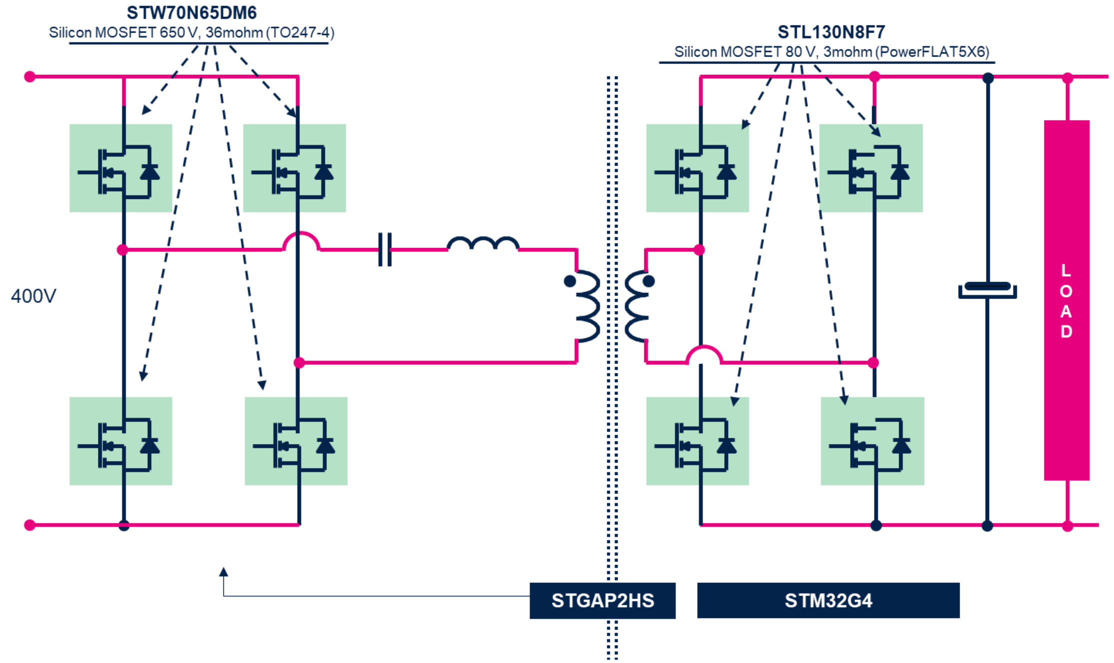
3 kW full-bridge LLC solution

Key specs

- Input DC voltage: 350–425 V
- Output voltage: 53.5 53.5 V
- Switching frequency: 80 kHz–150 kHz
- Resonant frequency: 115 kHz
- Peak efficiency: 98.2%
- Output voltage dynamic response: < 5%
- Digital (STM32G4) power control



Key products:

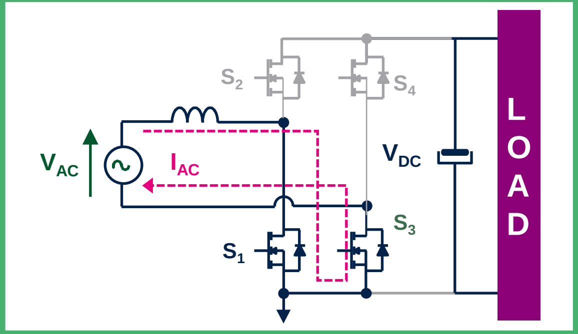
- STW70N65DM6 (HV MOSFET)
- STL130N8F7 (SR MOSFET)
- STGAP2HS (galvanic insulated gate driver)
- STM32G4 (32-bit MCU)
- VIPER38LD (converter for aux. PS)

Operation mode of totem pole PFC

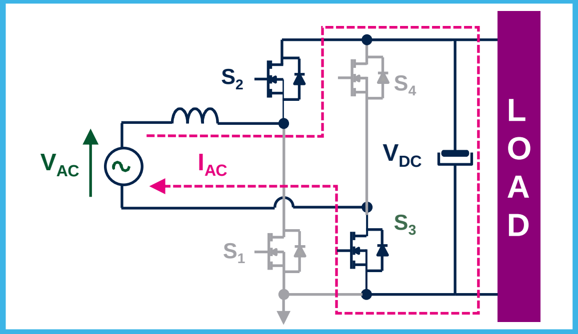
$V_{AC} > 0$

S1 controls PFC choke charging
S3 can be switched on to reduce voltage drop of the body diode

S1 on, inductor current rising



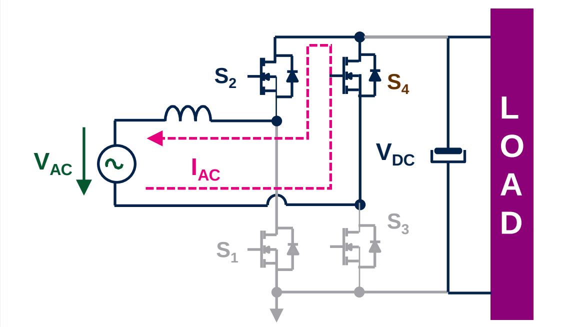
S1 off, inductor current falling



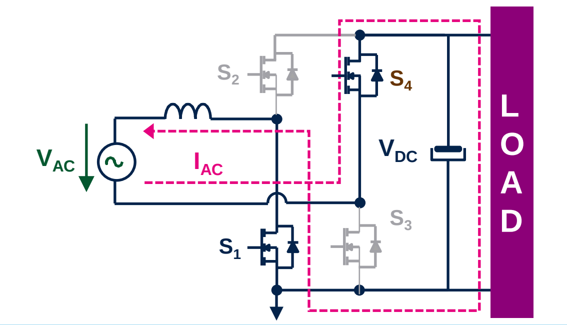
$V_{AC} < 0$

S2 controls PFC choke charging
S4 can be switched on to reduce voltage drop of the body diode

S2 on, inductor current rising

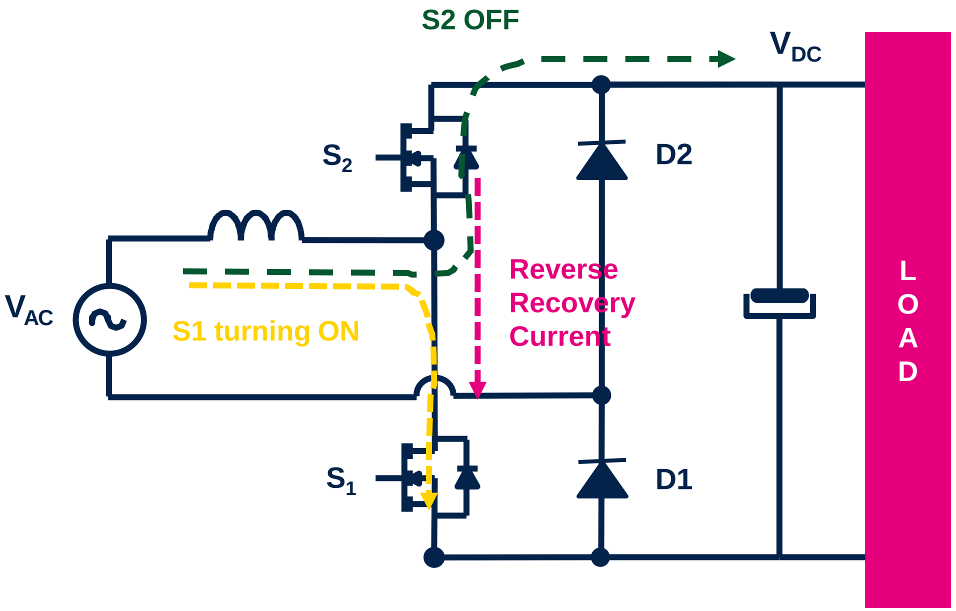


S2 off, inductor current falling

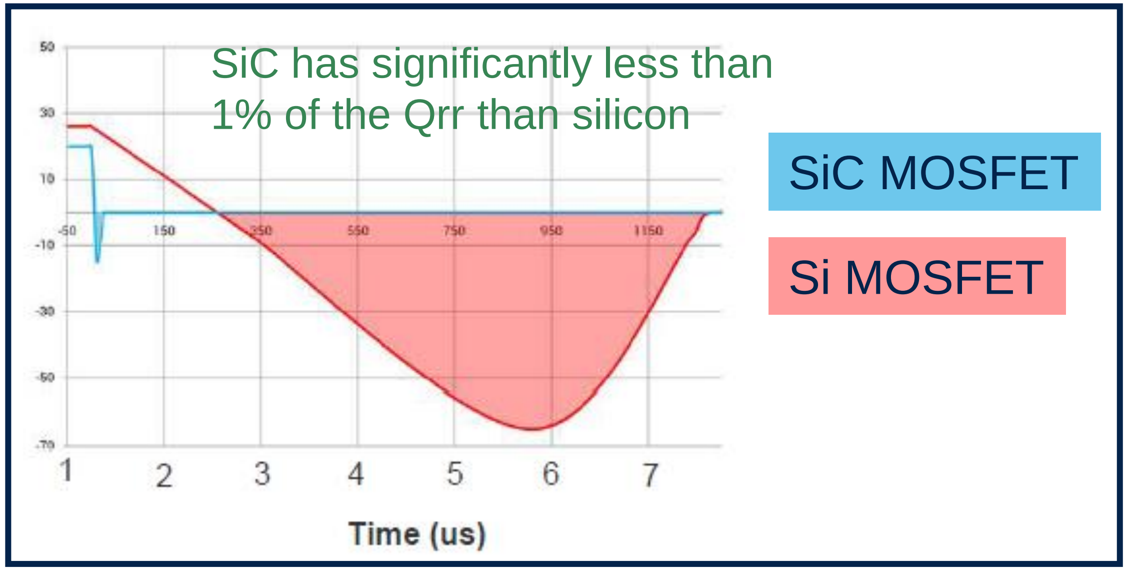


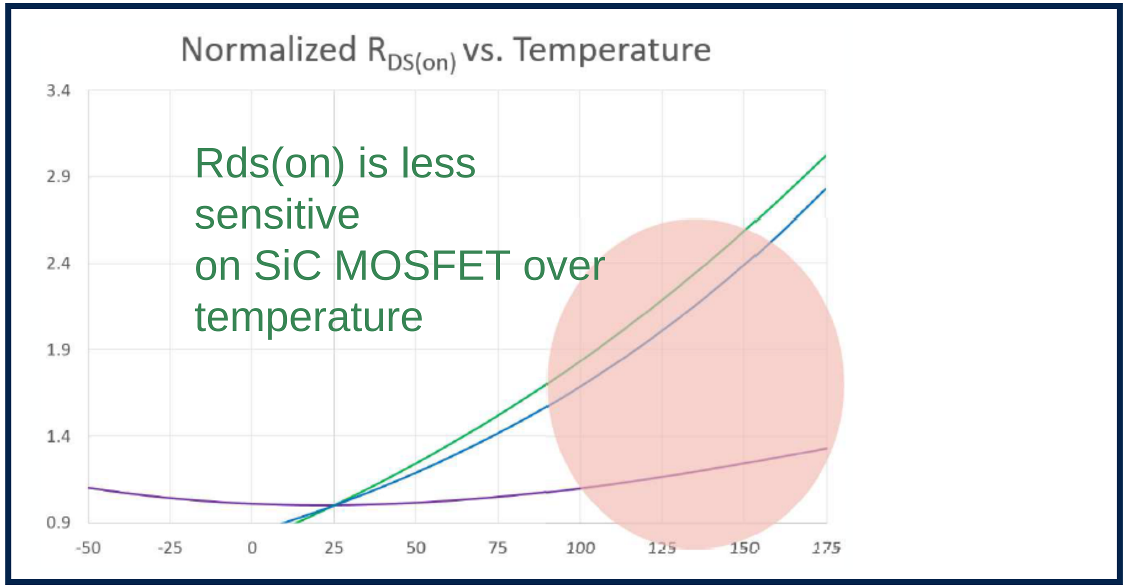
SiC MOSFET and driver IC

650 V Gen2 SiC MOSFET



- Low body diode reverse recovery.
- Low switching loss due to outstanding figure of merit
- Low power loss at high temperature due to less temperature dependence of on resistance





Resonant tank design

Magnetizing inductance Lm selection

Considerations:

- Select resonant frequency around 110-kHz-based power density target
- Main consideration is to achieve the optimal efficiency
- Primary MOSFET Eoff is related to Lm
- Primary MOSFET conducting loss is related to Lm
- Transformer copper loss is related to Lm
- Resonant inductor copper loss is related to Lm
- Power MOSFET ZVS is related to Lm

When operating at fs=fr=116 kHz, Lm=225 μH:
RMS magnetizing current is 2.17 A
MOSFET switching off current is 3.752 A
Voltage/current phase difference is Φ=0.309
Total zvs discharging capability is 800 nC

Calculation

Check maximum Lm to ensure MOSFET ZVS at light load:

$\mathrm{frt} := 150\mathrm{kHz}$ — *maximun switching frequency at steady status*

$\mathrm{Coss} := 286 \cdot (1 + 30\%)\mathrm{pF} = 371.8 \cdot \mathrm{pF}$ — *output capacitor of MOSFET (considering 30% tolerrance)*

$\mathrm{Td} := 400\mathrm{ns}$ — *deat time between MOSFETs conduction*

$\mathrm{Cstray} := 100\mathrm{pF}$ — *parastic capacitor*

the peak value of excitation current when Lm=Lm_zvs, suppose the switching off current of mosfet is peak excitation current, so the current should meet ZVS condition as below:

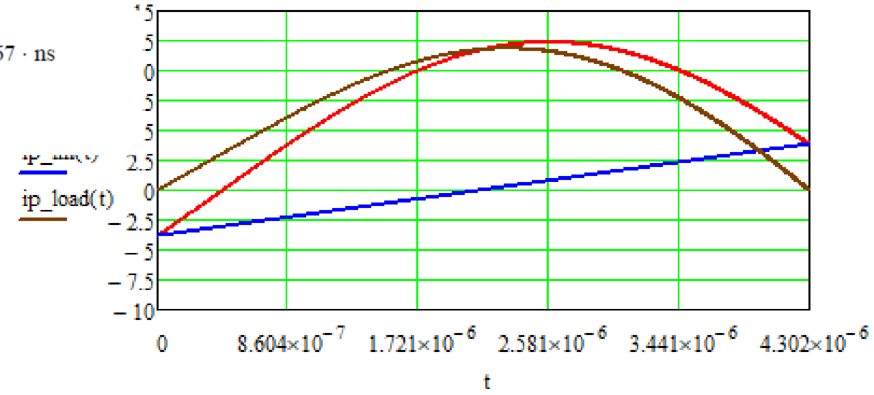
$$\mathrm{I(Lm\_zvs)} := \frac{\mathrm{Vpfc\_v} \cdot \left(\frac{1}{2\mathrm{frt}} - \mathrm{Td}\right)}{4\mathrm{Lm\_zvs}}$$

$$\mathrm{Lm\_zvs} := \mathrm{root}[\mathrm{I(Lm\_zvs)} \cdot \mathrm{Td} - (2\mathrm{Coss} + \mathrm{Cstray}) \cdot \mathrm{Vpfc\_t}, \mathrm{Lm\_zvs}, 1\mu\mathrm{H}, 500\mu\mathrm{H}] = 257.892 \cdot \mu\mathrm{H}$$

Select Lm=230 μH, then double check Td margin at full load:

$$\mathrm{Td\_max} := \frac{\phi}{\pi} \cdot \frac{1}{2\mathrm{fr}} = 423.467 \cdot \mathrm{ns}$$

Td<Td_max, ok



Resonant tank design

Resonant tank Cr, Lr selection

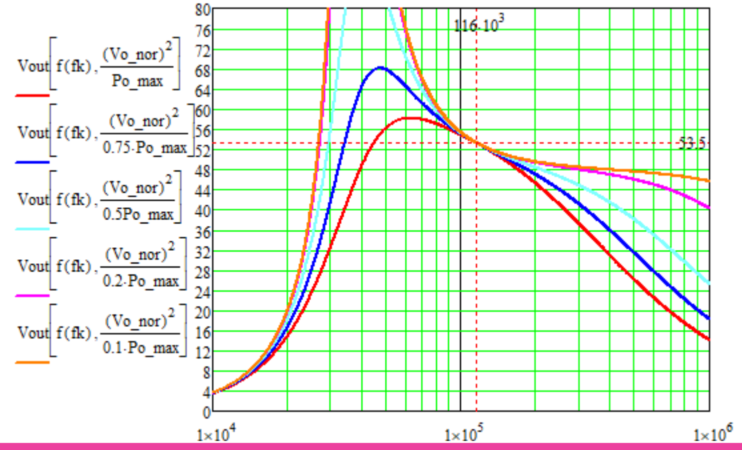
Considerations:

- Influence for efficiency, mainly Lr
- Output voltage range and its corresponding operating frequency range
- Smaller Lr can reduce total resonant inductor power loss
- Smaller Lr will reduce output capability @ low Vin and full load
- Influence for output maintain time during shutdown
- Smaller Lr means higher frequency is needed for output regulation @ high Vin and light load

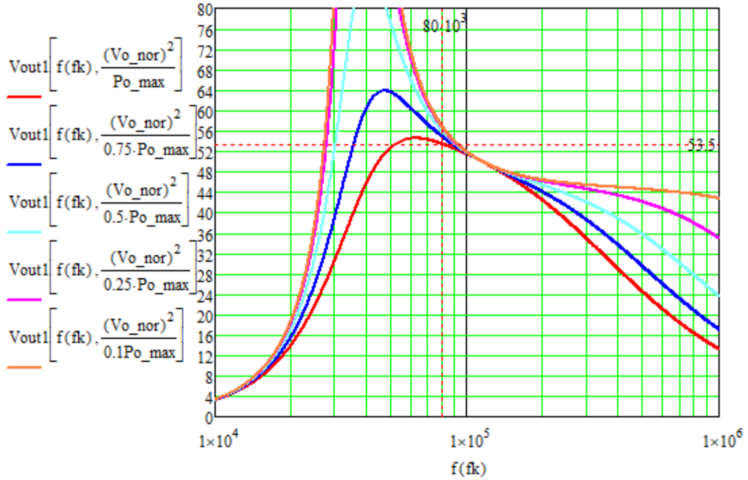
When operating with Lm=225 μH, Lr=25 μH, Cr=75 nF:
K=9,
Q=0.42 @ full load
fs=80 kHz @ Vin=375 V, Vout=53.5 V, full load
fs=165 kHz @ Vin=425 V, Vout=53.5 V, Iout=1 A

Calculation

Vout vs. fs @ Vin=400 Vdc, each load



Vout vs. fs @ Vin=375 Vdc, each load



EVM board performance

Contents

- Efficiency / iTHD / PF
- Soft startup
- Load transient response
- Load on with full power
- Hold-up time

Find more information from https://www.st.com/en/evaluation-tools/stdes-3kwtlcp.html

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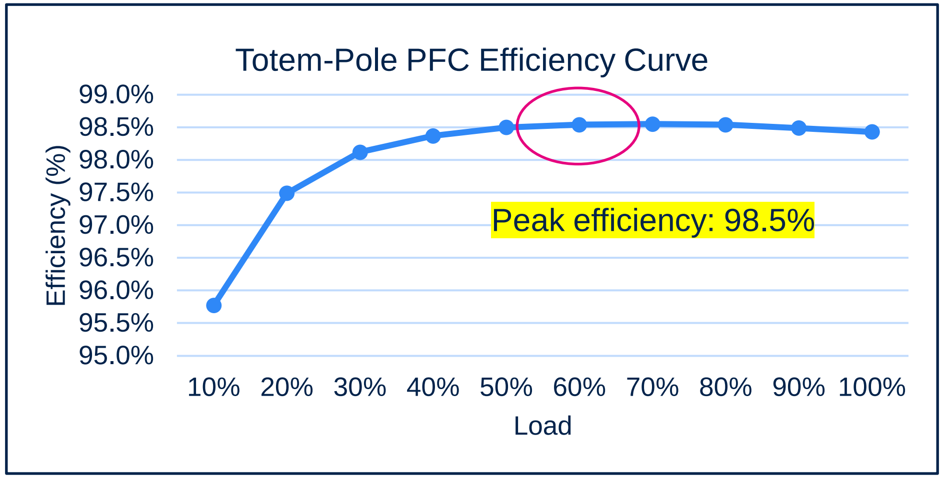
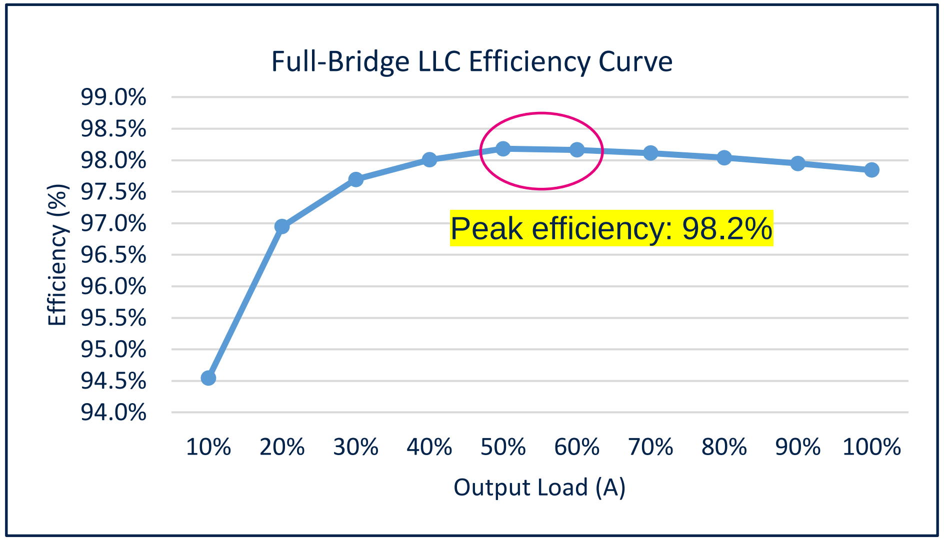
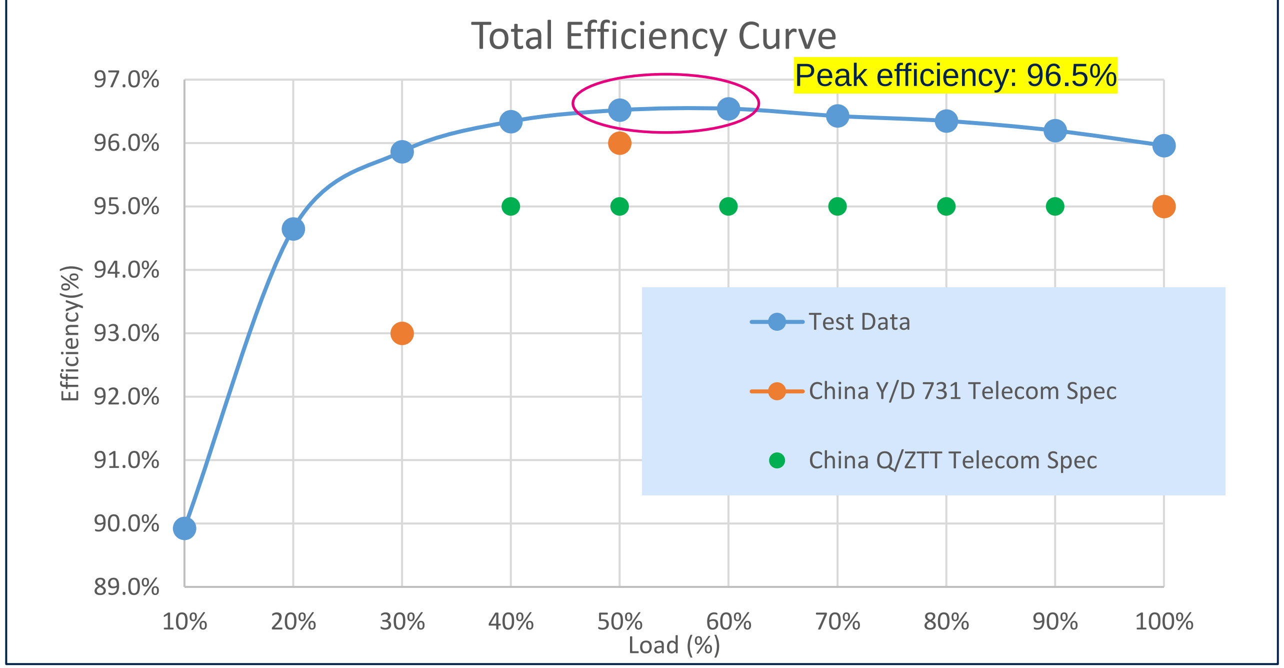
Efficiency curve





Total efficiency



Test condition: 230Vac/50Hz

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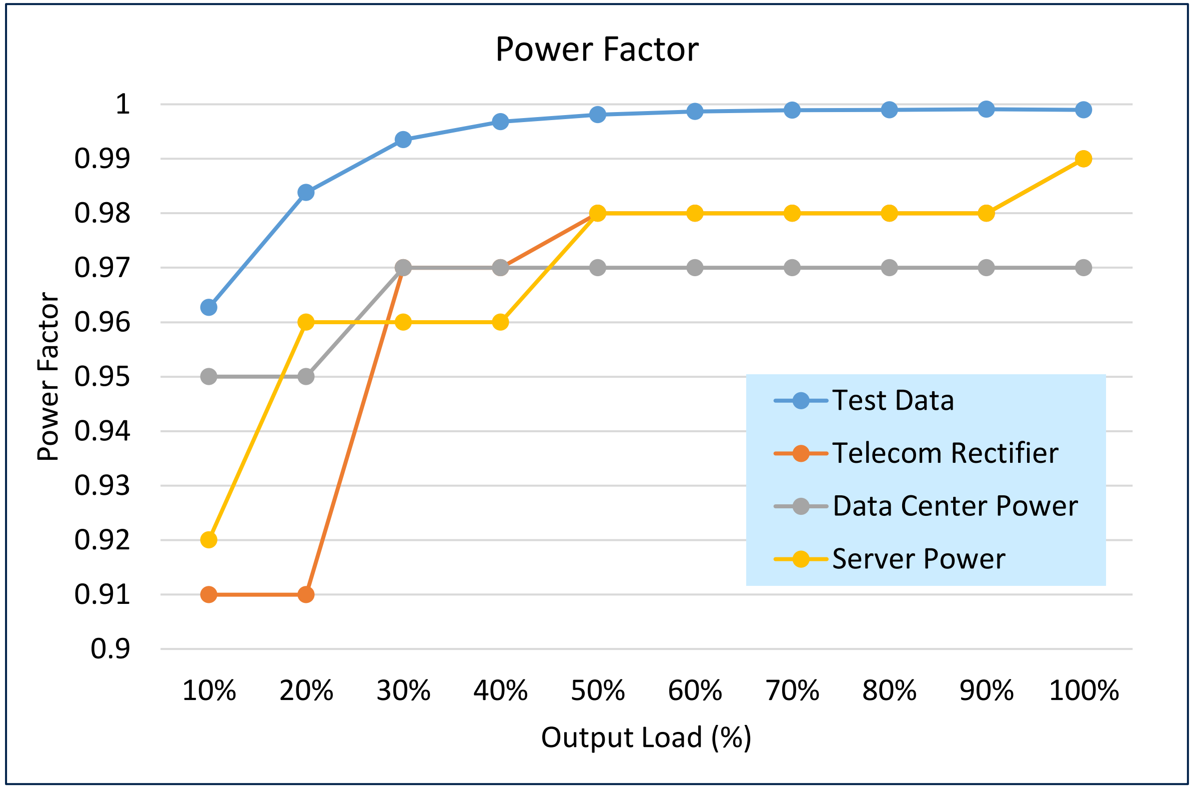
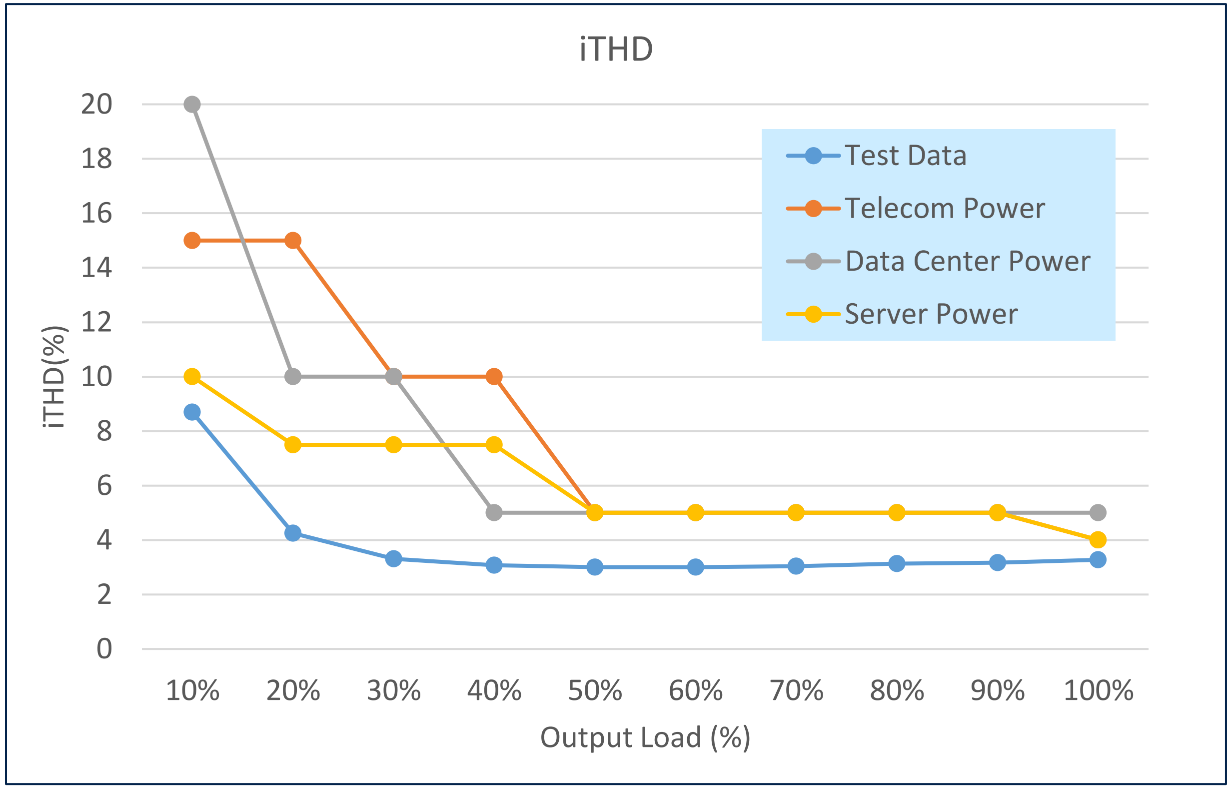
iTHD/power factor @ 230 Vac

PF



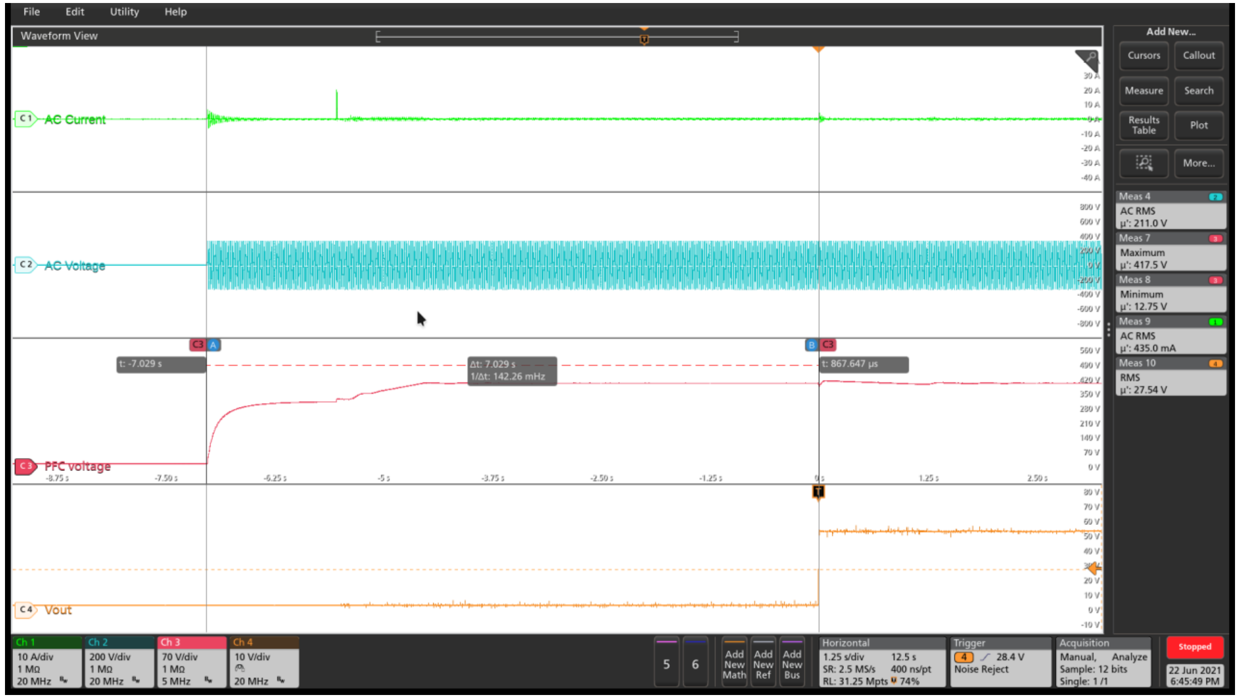
iTHD



Soft start @ 230 Vac/50 Hz

No load

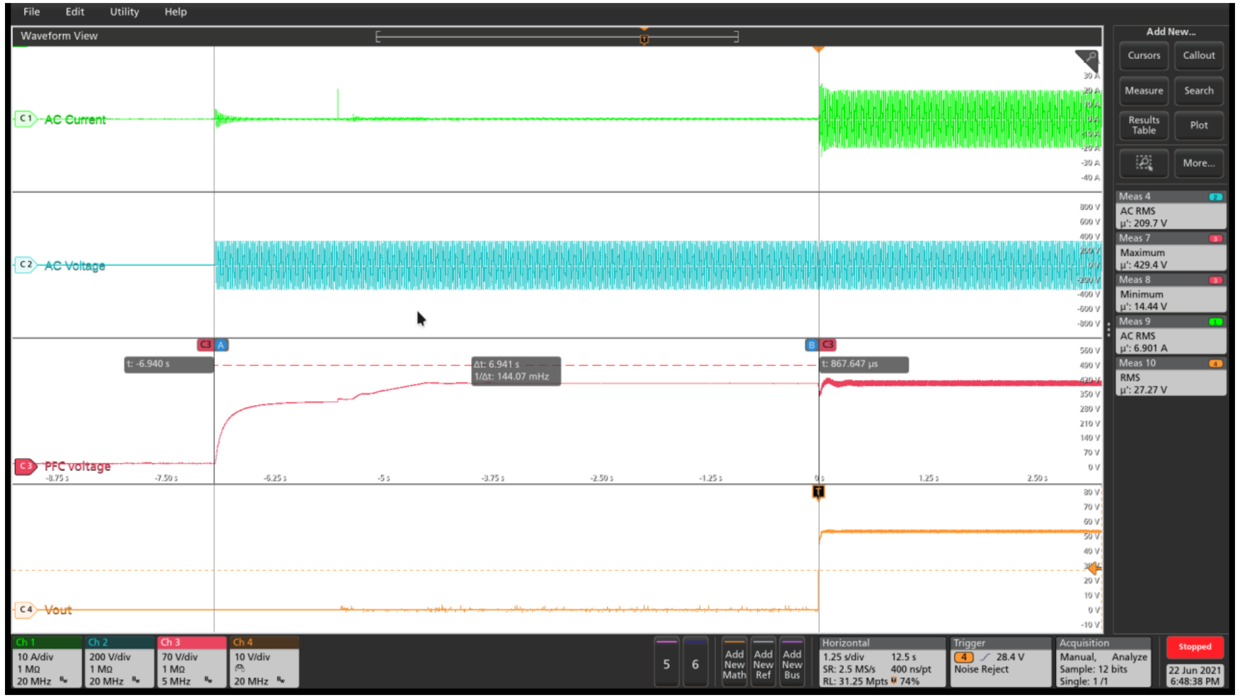
Tss=7.029 s



CH1: Input current (10 A/div)
CH2: Input voltage (200 V/div)
CH3: Bulk cap voltage (70 V/div)
CH4: Output voltage (10 V/div)

Full load

Tss=6.941 s



CH1: Input current (10 A/div)
CH2: Input voltage (200 V/div)
CH3: Bulk cap voltage (70 V/div)
CH4: Output voltage (10 V/div)

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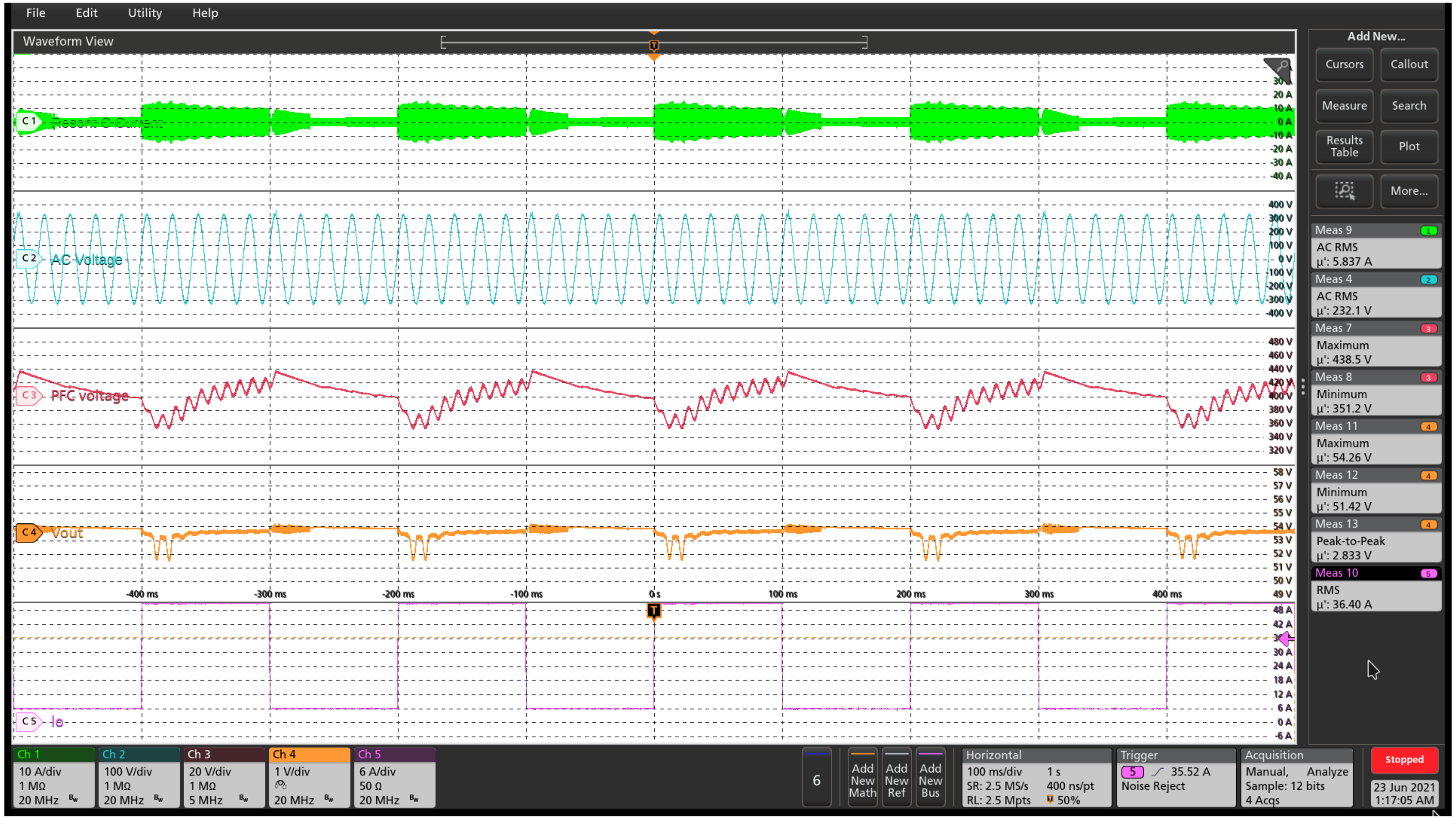
Load transient response @ 230 Vac / 50 Hz

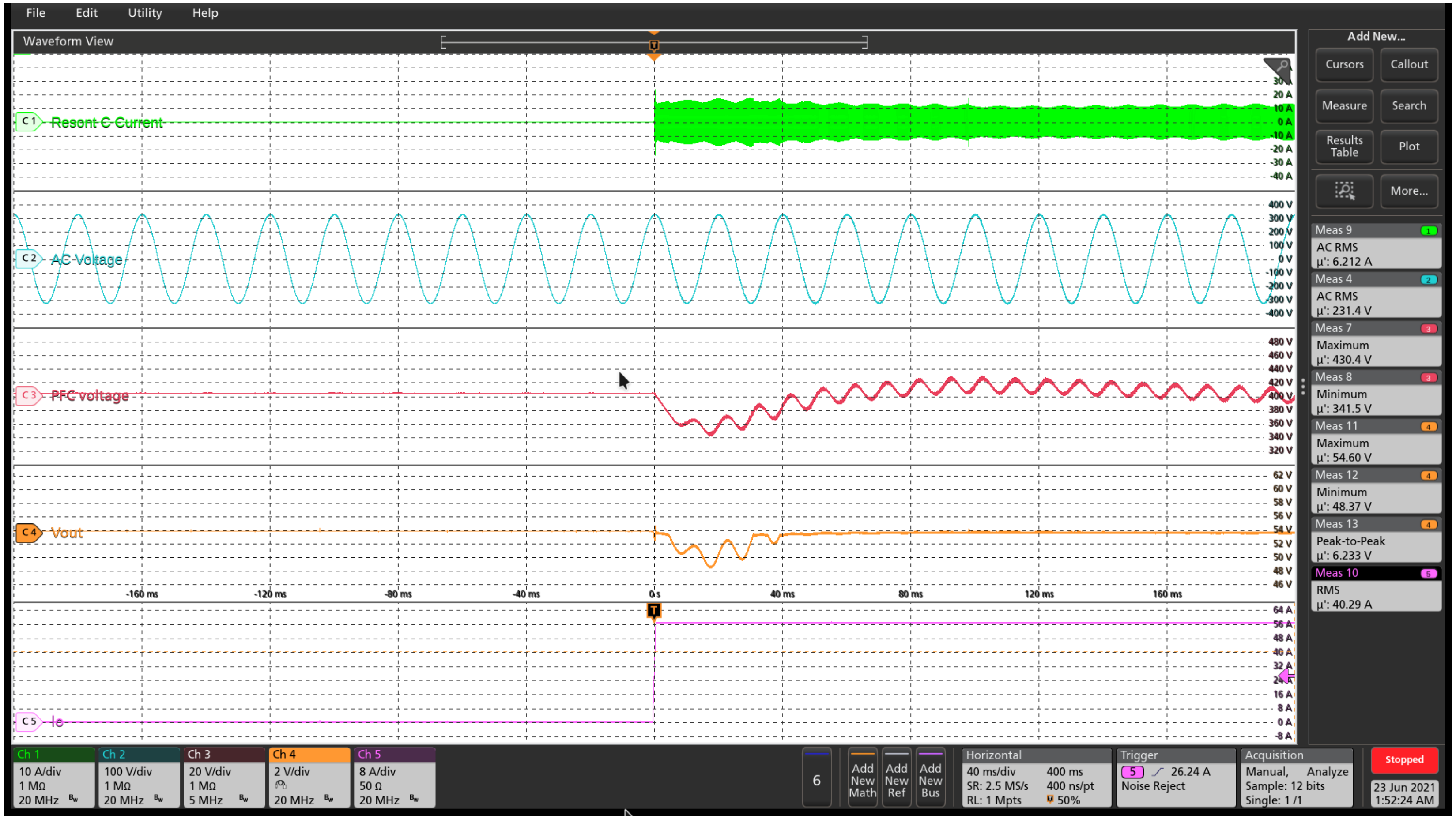
10%~90%~10% 0.1A/µs 100 ms



CH1: Resonant current (10 A/div)
CH2: Input voltage (100 V/div)
CH3: Bulk cap voltage (20 V/div Vos=400 V)
CH4: Output voltage (1 V/div Vos=53.5 V)
CH5: Load current (6 A/div)

Load on with full power @ 230 Vac/50 Hz

Load on with full power



CH1: Resonant current (10 A/div)
CH2: Input voltage (100 V/div)
CH3: Bulk cap voltage (20 V/div Vos=400 V)
CH4: Output voltage (2 V/div Vos=53.5 V)
CH5: Load current (8 A/div)

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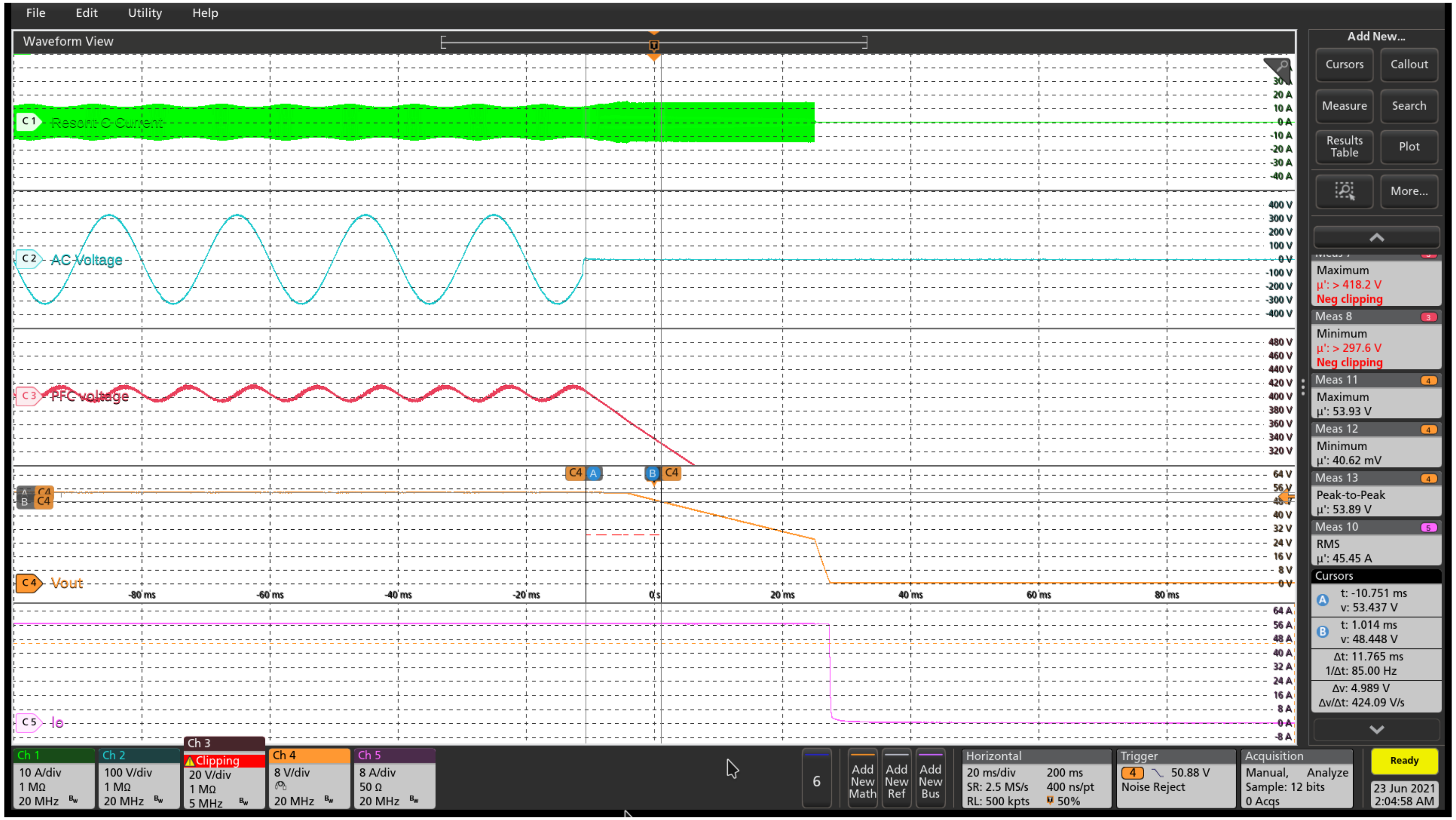
Hold up time @ 230 Vac/50 Hz

Holdup time

T_{holdup}=10.751 ms   from 53.5 V drop to 48.5 V



CH1: Resonant current (10 A/div)

CH2: Input voltage (100 V/div)

CH3: Bulk cap voltage (20 V/div Vos=400 V)

CH4: Output voltage (8 V/div)

CH5: Load current (8 A/div)

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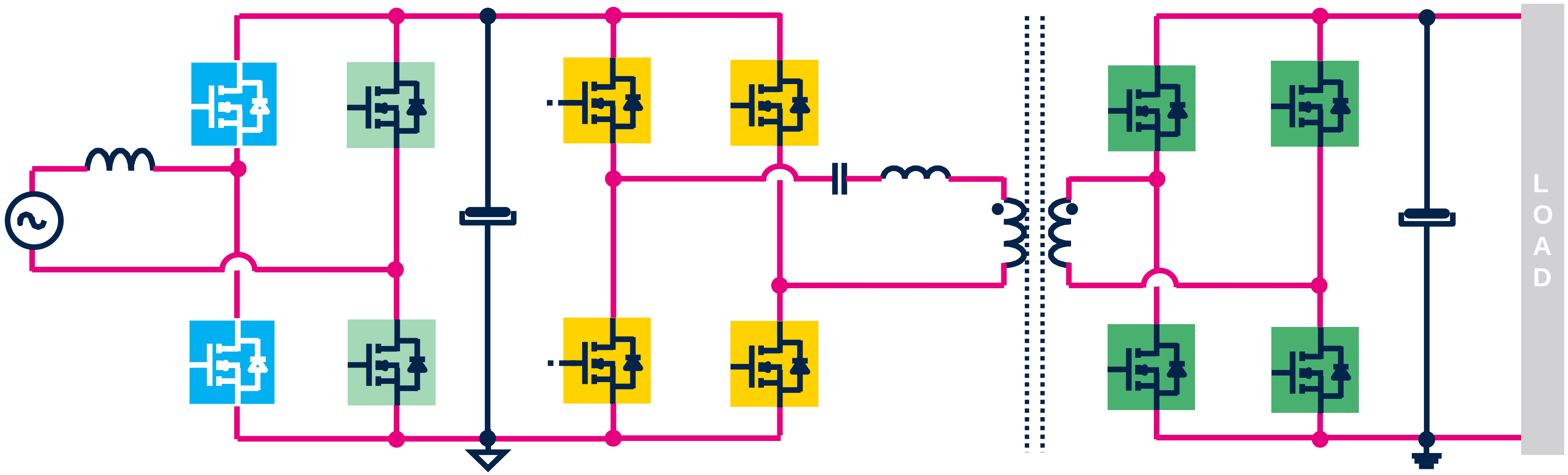
ST products

ST products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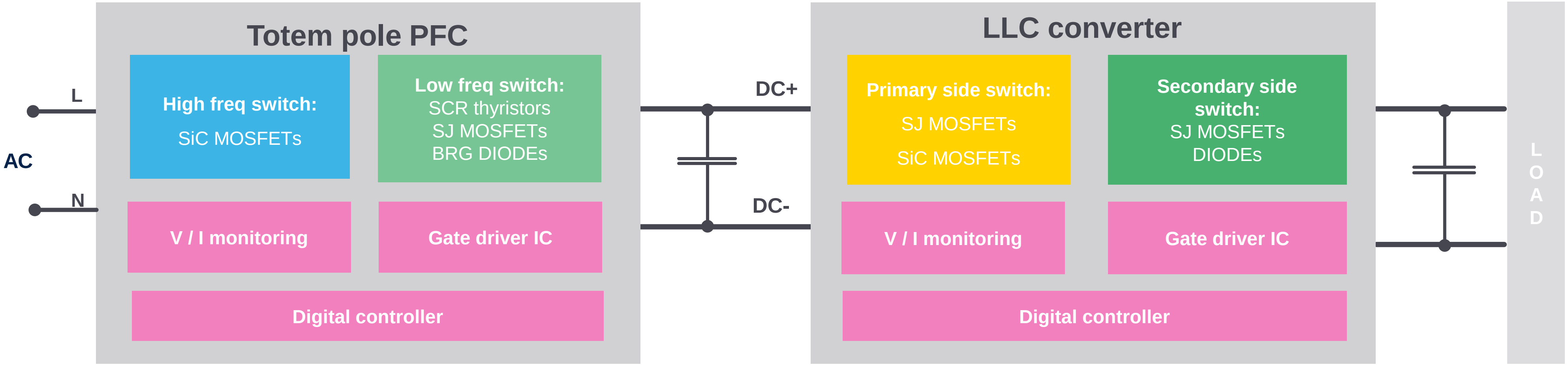
Totem pole PFC
L
AC
N
High freq switch:
SiC MOSFETs
Low freq switch:
SCR thyristors
SJ MOSFETs
BRG DIODEs
V / I monitoring
Gate driver IC
Digital controller
DC+
DC-
LLC converter
Primary side switch:
SJ MOSFETs
SiC MOSFETs
Secondary side switch:
SJ MOSFETs
DIODEs
V / I monitoring
Gate driver IC
Digital controller
L
O
A
D

STPOWER SiC MOSFET
Product families and applications

Breakdown voltage	650 V	650 V	750 V/900 V	1200 V	1200 V	1200 V	1700 V	2200 V
Series	G2	G3	G3	G1	G2	G3	G1	VHV
On-state resistance	18 mΩ to 55 mΩ	14-55 mΩ	11 mΩ	52 mΩ to 520 mΩ	25 mΩ to 75 mΩ	70 mΩ and 15 mΩ	1 Ω and 65 mΩ	31 mΩ
Focus applications	OBC & DC-DC Renewable energy Power supply Industrial drives	Traction OBC & DC-DC High density power supply	Traction inverter OBC & DC-DC High density power supply	Photovoltaic Power supply	OBC & DC-DC Inverter Charging stations Industrial drives	Traction inverter OBC & DC-DC HF power supply	DC-DC Power supply Renewable energy	DC-DC Power supply Renewable energy

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High-voltage superjunction MDmesh* series

MDmesh series

M2	M6	M5	M9	DM2	DM6	DM9	K5/DK5 - K6
400V to 650 V	600V to 650 V	550 V to 650 V	250 V to 650 V	400 V to 650 V	400 V to 650 V	600 V to 650 V	800 V to 1700 V

Focus topology

M2 / M6	M5	M9	DM2 / DM6 / DM9	K5/DK5 - K6
Flyback, PFC, LLC resonant	Hi-end-power PFC hard switching topologies, TTF	Hi-end-power PFC hard switching topologies, LLC soft switching topologies	Half Bridge, full Bridge, ZVS, LLC	Flyback topology

Focus applications

- TV SMPS, Fast chargers, adapters LED lighting, microinverters
- EV-Car/Charging
- Servers, telecom data centers, 5G power stations, solar, medical, motor control
- LED driver, LED lighting, auxiliary SMPS, EV-Car, medical

* is a registered and/or unregistered trademark of STMicroelectronics International NV or its affiliates in the EU and/or elsewhere.

Complete HV MOSFET series for higher efficiency

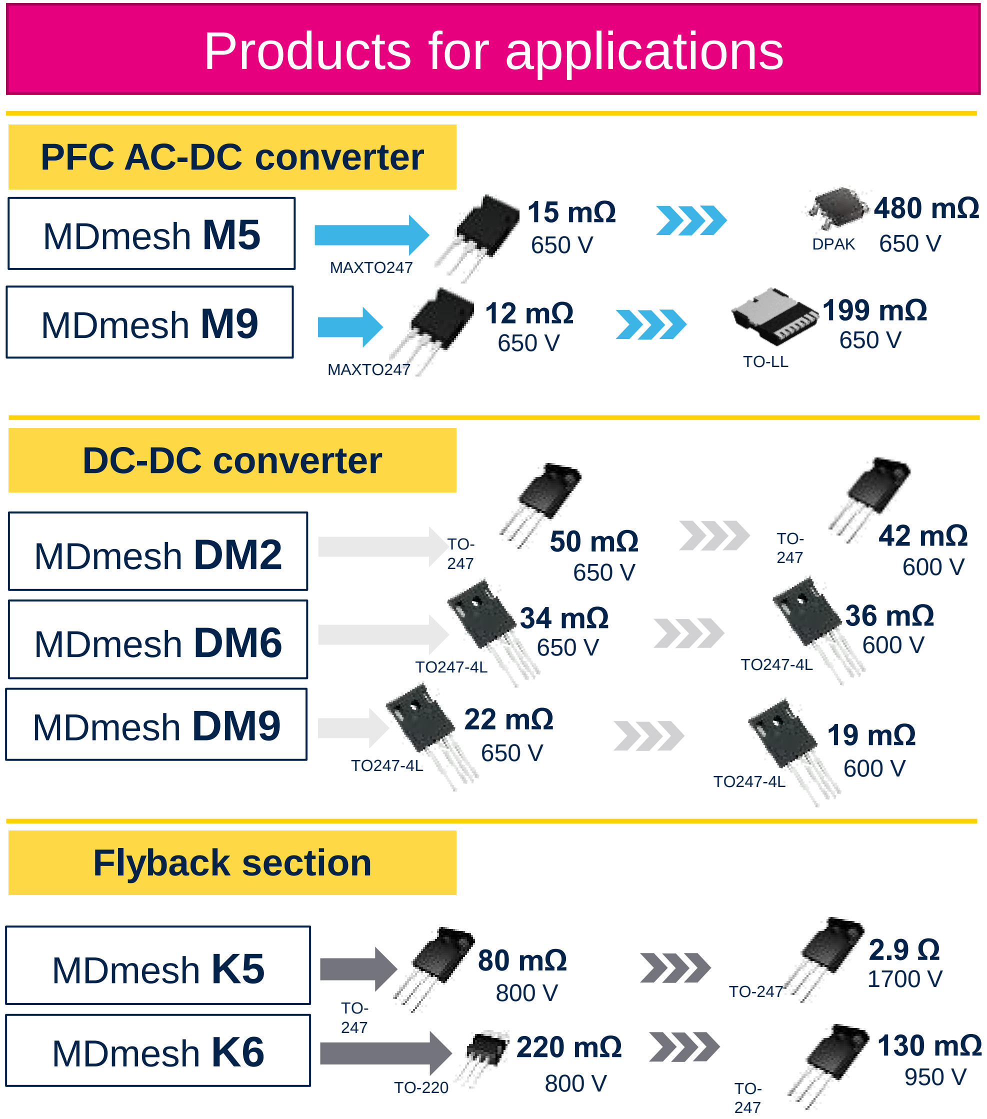
Energy generation & storage need higher & more efficient tailored topologies

Charging station: Complete solution up to 22 kW

Server and datacenter drive demand for better and higher power density systems

Telecom power: rapid increasing of smaller cells requires power system

Multiple SMD and through-hole package options



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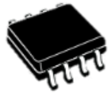
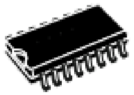
Isolated gate drive for SiC MOSFET

1700 V galvanic isolated single & dual channel



SO-8

STGAP2S
STGAP2SC
STGAP2SICSN
STGAP2SICSNC



SO-16

STGAP2D

Galvanic isolated, up to 1700 V high voltage rail

Extreme transient immunity up to ± 100 V / ns

Fast switching frequency (Tp 80 ns only)

High current capability 4A Isink / Isource

6000 V galvanic isolated single & dual channel

SO-8W

STGAP2HS
STGAP2HSC
STGAP2SICS
STGAP2SICSC

SO-36W

STGAP2HD
STGAP2SICD

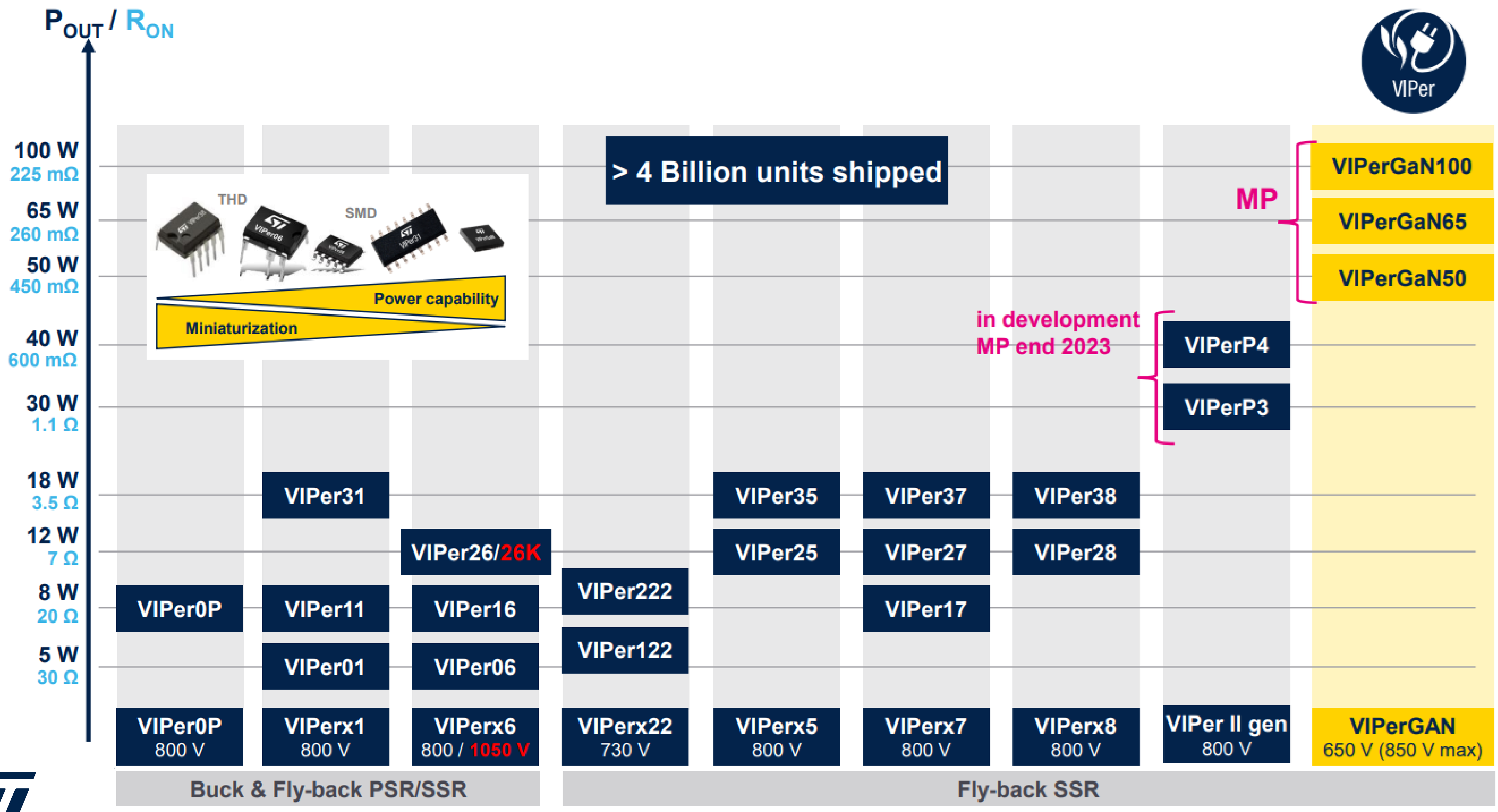
Galvanic isolated, up to 6000 V high voltage rail

Extreme transient immunity up to ± 100 V / ns

Fast switching frequency (Tp 80 ns only)

High current capability 4A Isink / Isource

VIPer family



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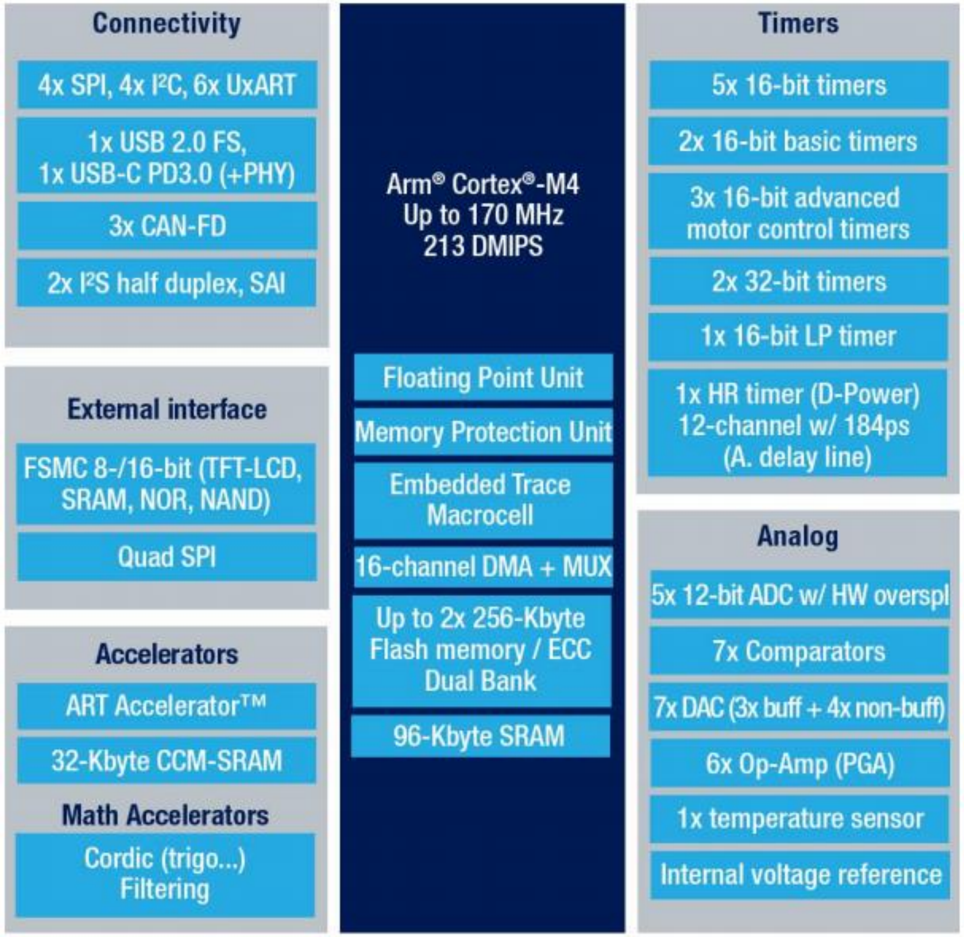
STM32G474 MCU

Based on a 32-bit Arm® Cortex® -M4 core with FPU and DSP instructions running at 170 MHz, ideal for digital power conversion

- 170 MHz 32-bit Arm Cortex®-M4 core with FPU
- Routine booster of CCM-SRAM up to 32 KB
- Mathematic hardware accelerators (CORDIC / FMAC)
- High-resolution timer (184 ps) for precise PWM control
- Rich advanced analog
- USB Type-C® Power Delivery (PD)
- ±1% internal clock



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Summary

Summary

- This digital solution with **STM32G4** will help you achieve **high efficiency / high power density** for 5G telecom power supply
- ST provides the latest technologies (SiC/STGAP/M6/STM32) for high power density and high efficiency solutions on 5G telecom power applications.
- This reference design offers:
  - Digital power solution for totem pole PFC converter and full-bridge LLC with synchronous rectifiers
  - Peak efficiency is greater than 96.5%, PFC section is 98.5%, DC-DC section is 98.2%
  - Power density up to 40 W/in^3
  - iTHD distortion lower than 5% and PF greater than 0.99
  - Adaptive SR control algorithm for efficiency optimization

Our technology starts with You

Find out more at www.st.com

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