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Wide bandgaps materials and power module solutions for new energy applications

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Technical Marketing

Power Discrete & Sub Analog Group

Agenda

1 WBG materials

2 SiC introduction and benefits

3 ST SiC technology overview

4 ST SiC product profile

5 ST SiC and module solution for new energy applications

6 Q&A

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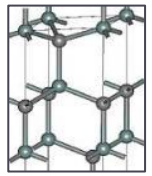
Why silicon carbide?

SiC power devices for performance beyond silicon

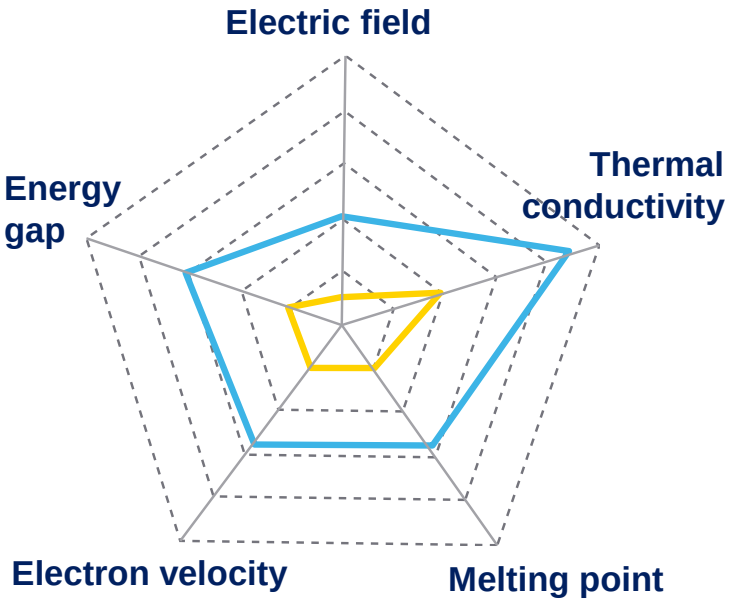


Silicon Carbide

Higher breakdown voltage: x10
Lower ON resistance & losses

Higher temperature
(operation & endurance)
Reduced cooling requirements

Higher switching frequency
Lower switching losses



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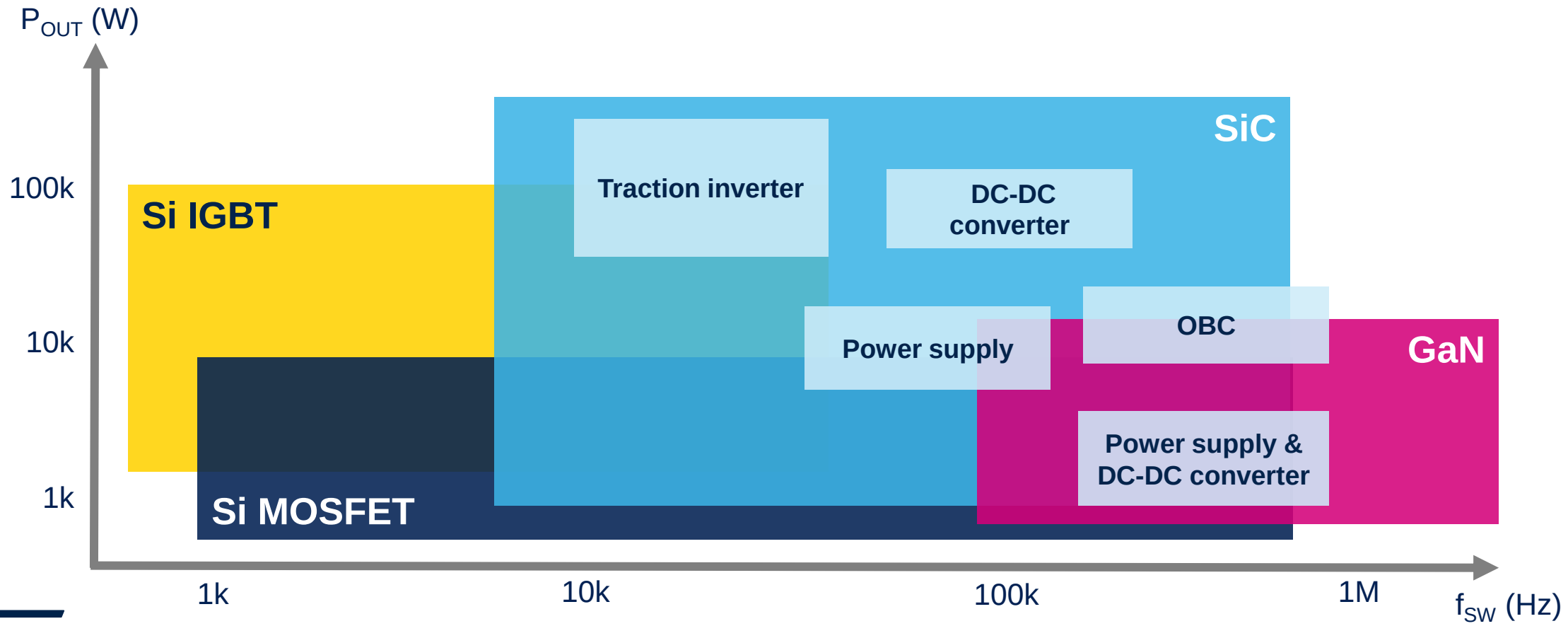
Power semiconductors for key applications

SiC MOSFET technology offers the best performance in high voltage, high frequency, and high-power system applications



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SiC benefits - Why SiC?

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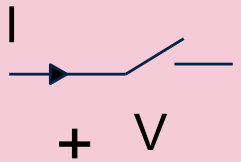
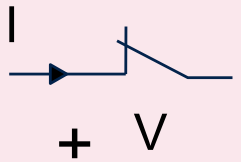
Combining all 3 features of an ideal switch

Lowest Rds(on), highest speed, highest operating temperature

OFF		I=0 for any V
ON		V=0 for any I

	SiC MOSFET (planar)	Silicon MOSFET	Silicon IGBT
$R_{DS(on)}$ x Area	1	30	3 (10 at low current)
Switching energy losses	1	>10	7
Max. junction temperature (°C)	≥200	150	175

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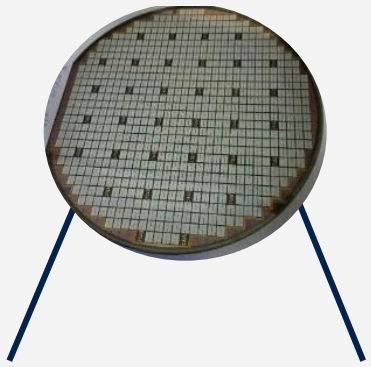
Key benefits of SIC Diode

Energy savings generated by sustainable technology

Power Losses



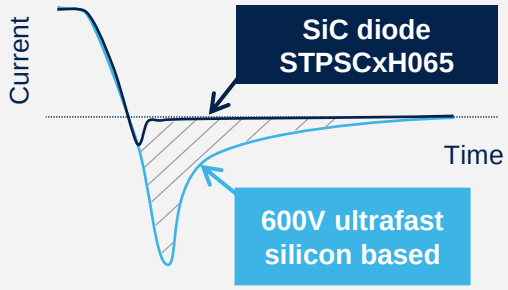
Recovery Losses

Conduction Losses

Si-based ultrafast diodes

Eliminate Recovery Losses

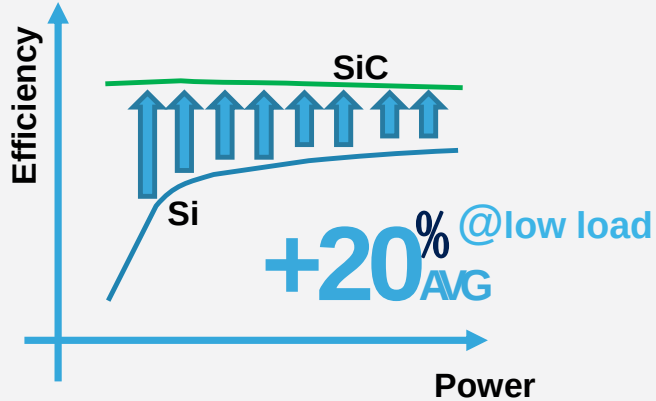
Switching performance comparison



SiC-based diodes

Reduced Dimensions

- 60%



More efficient power conversion

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SUSTAINABLE TECHNOLOGY

Key benefits of SiC MOSFETs

Extremely low energy losses and low R_{ON} especially at very high Tj

Higher operating frequency
for smaller and lighter systems

Thermal performance

High operating temperature (T_{jmax} = 200°C)
Reduced cooling requirements & heat-sink
Increased life time

Easy to drive

Fully compatible with
standard gate drivers

Very fast and robust intrinsic body diode

More compact inverter

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SiC MOSFET Value Proposition

SiC Technology Benefits
SiC vs Conventional Silicon IGBT

Higher Performance & Voltage Operation

- Extremely low power losses
- High efficiency at low current
- Intrinsic SiC body diode (4 quadrant operation)

Higher Operating Frequency

- Lower switching losses
- Excellent diode switching performance

Higher Operating Temperature

- Operating up to 200°C junction

SiC Advantages for Automotive

Electrification - mileage extension, smaller battery (or increased battery reliability), fast & efficient charging

Efficiency gain in average	Switching losses	Chip size	Total loss	Switching frequency
From ~2% (high load) to ~10% (low load)	~7x lower	~5x smaller	~50% lower	~ 5 ..10 times higher

Lower System Cost

~7x reduced form factor	~80% cooling system down sizing	~Simpler Sub-systems: smaller passives, no external freewheeling diode…

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ST SiC technology overview

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Silicon Carbide Manufacturing

Huge investments sustaining business growth

Device manufacturing

In volume production with 150 mm since 2017

- High yields and automotive-grade quality
- Capacity expanded almost 4X in 2020 vs. 2017

Further 2.5X expansion, 200 mm tools compatible

- Second fab in Singapore to be qualified in 2021
- Back-end at 2 sites: Shenzhen (China) and Bouskoura (Marocco)

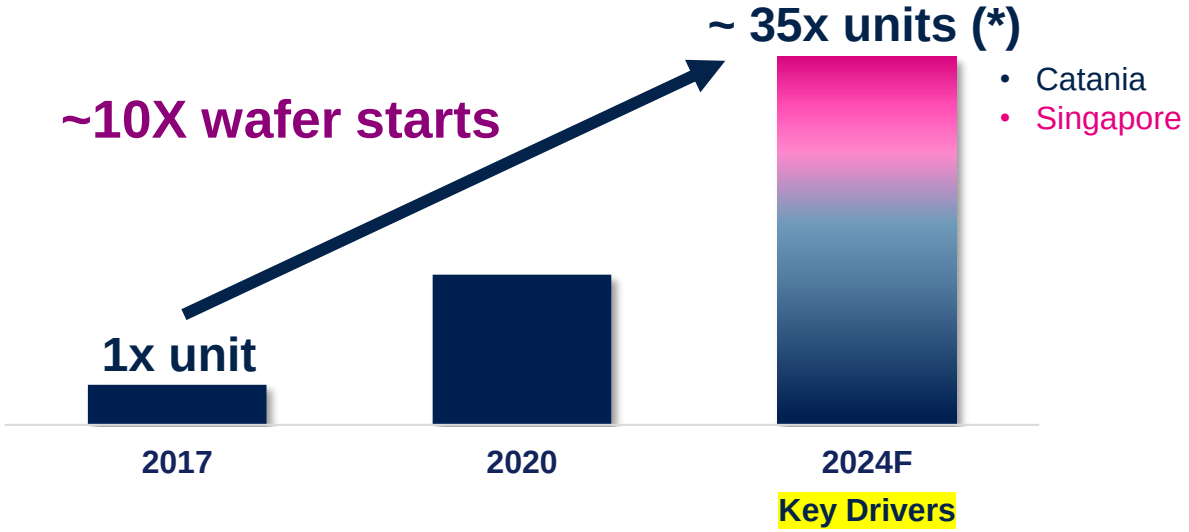
Substrates

- Extended Supply Chain capability through Multi-Year supply agreement

Vertical integration

- First internal supply of 150 mm from ST-Norstel, focus on 200 mm development
- Designing new plant to achieve > 40% internal sourcing by 2024

Normalized Front-end** capacity evolution



Key Drivers

- Technology Evolution (Gen4)
- 200mm wafer size
- Yield improvement

Catania (Italy)

Singapore

(*) with Technology shrinkage and yield improvement
(**) Front-end: wafer diffusion and manufacturing

ST SiC Diodes
More than 12 years experience

2008
SiC 600V
1st Gen
STPSCxx06x

2012
SiC 650V
H serie
STPSCxxH065x

2014
SiC 650V
H serie
Automotive Grade
STPSCxxH065x-Y

2016
SiC 650V
Low V_F
STPSCxx065x

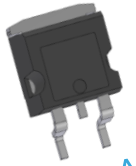
2017
SiC 1200V
Industrial &
Automotive Grade
STPSCxxH12x
STPSCxxH12x-Y

2018
New packages
Introduction

PowerFLAT8x8

2019
Module, Die Form,
New ratings

D²PAK HV



2020 & beyond…
Auto Grade
Portfolio
Extension

New Dev
650V-1200V

Silicon Carbide MOSFET technology executive strategy

Technology Roadmap

Planar

2014: Gen1
- **1200 V** (0-300kHz)
- **1700 V** (0-300kHz)
- 20 V driving voltage

2018: Gen2
- **650 V** (0-500kHz)
- **1200 V** (0-500kHz)
- 18 V driving voltage

2020: Gen3
- **750 V** (0->500kHz)
- **1200 V** (0->500kHz)
- 18 V* driving voltage

2023: Gen4
- **750 V** (0->1MHz)
- **1200 V** (0->1MHz)
- 15 V driving voltage

Continuous scale-down
[Ron x area]

x2 shrinkage

x4 shrinkage

x5 shrinkage

No Planar

2025: Gen 5
RADICAL INNOVATION

Product Status

Planar

Gen1	**In full production**
Gen2	**In full production**
3rd Gen	**Technology Qualified in Q4 2020**
4th Gen	**In development** Expected introduction in 2023

No Planar

Feasibility and simulation results in **2022**

* Suggested for best performance

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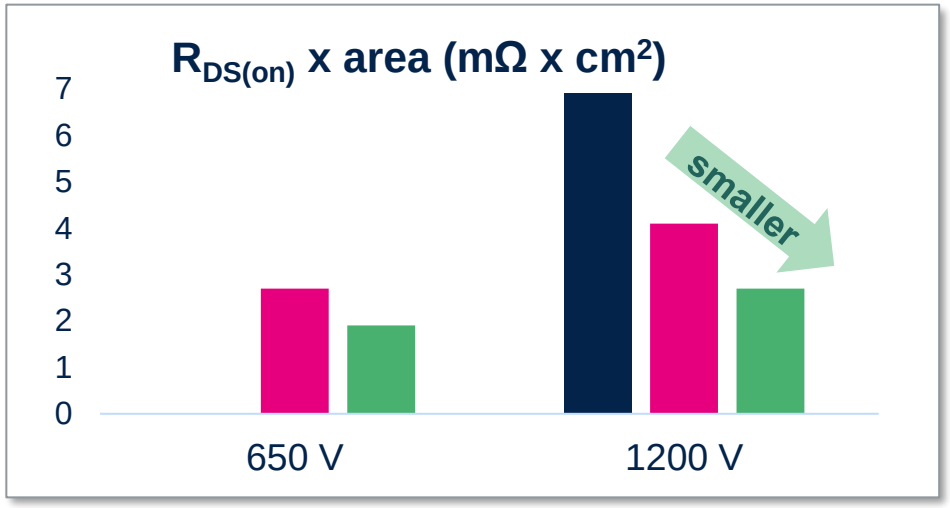
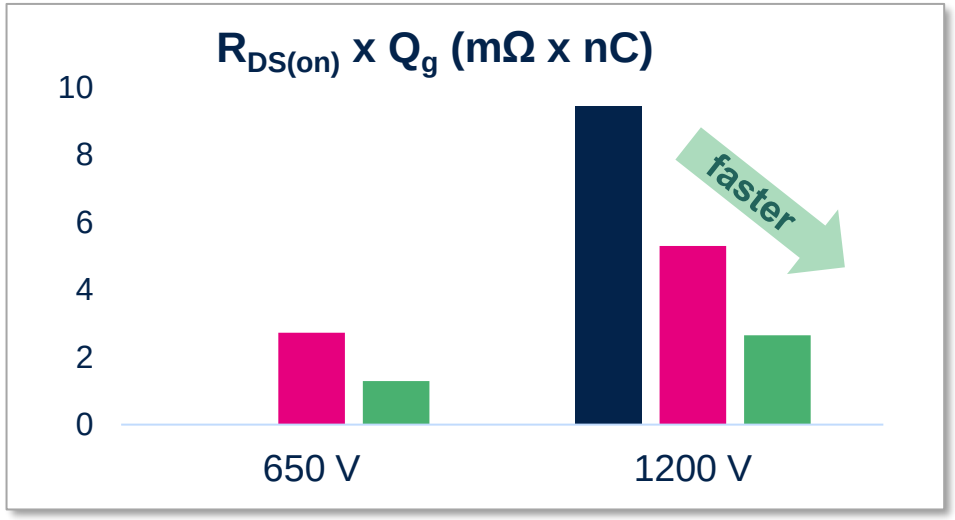
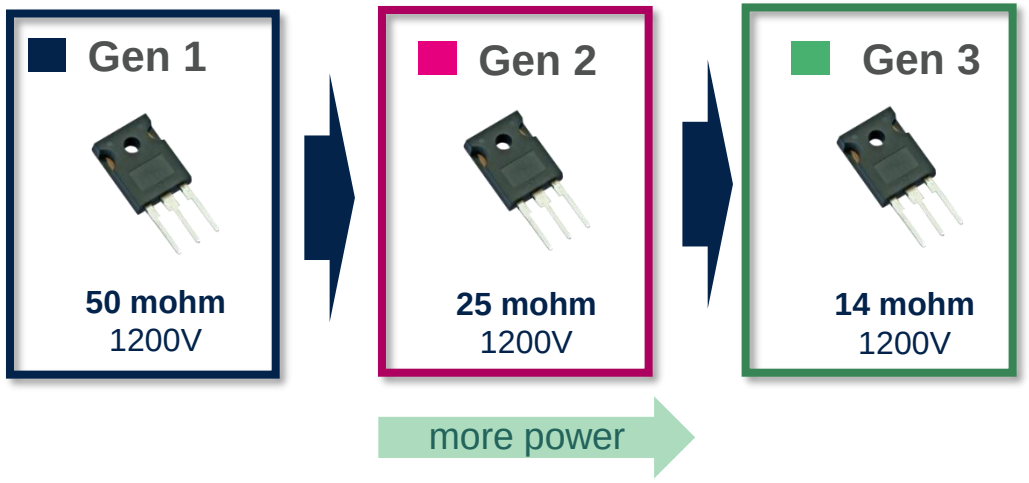
SiC MOSFET Advances in Technology Figure of Merits







improvement in MOSFET generations

- **Lower Ron x Area** → lower Ron for a given chip size or smaller chip size for a given Ron, higher current capability, lower conduction Losses → for a power module means **higher power achievable with the same form factor**
- **Lower Ron x Qg → lower switching losses, higher frequency (reduced board)**

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ST SiC Product Profile

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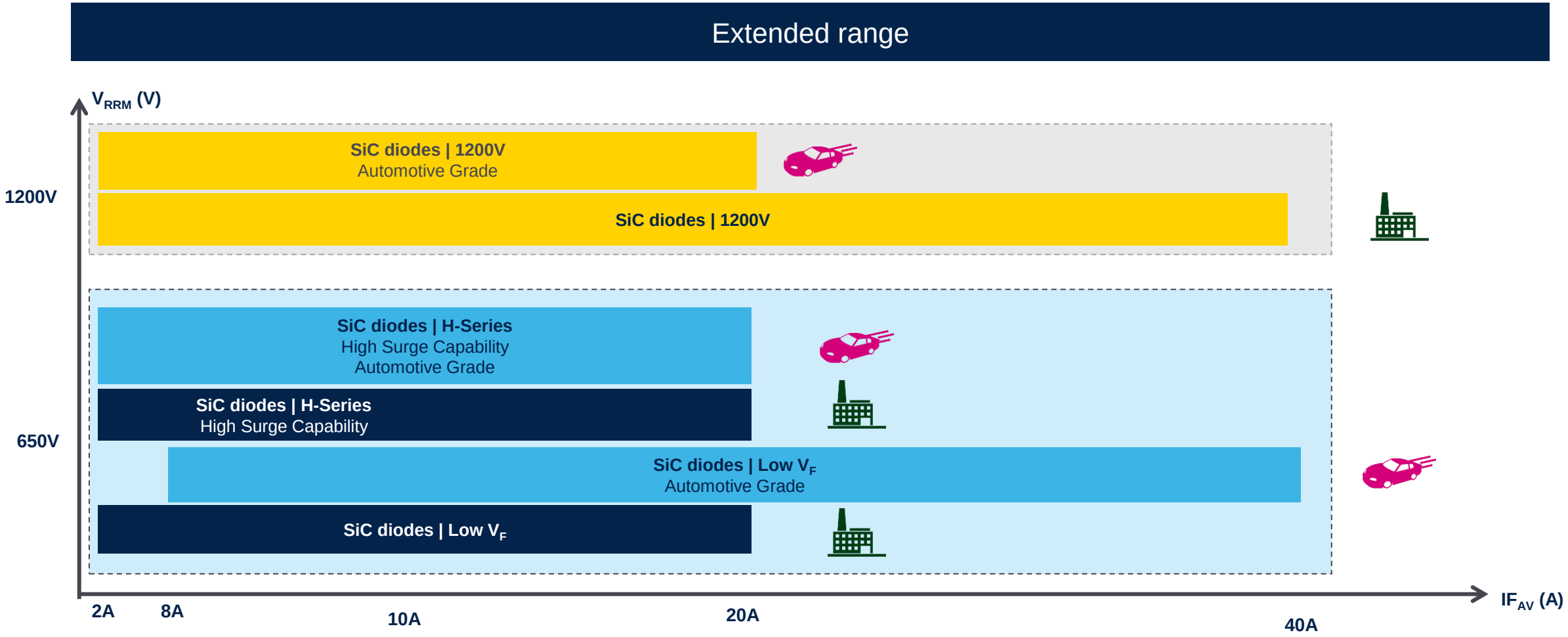
SiC Diode series overview



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SiC MOSFET Portfolio

Breakdown Voltage

650 V	750 V	1200 V	1700 V

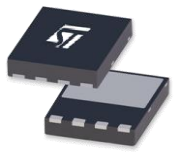
Series

Gen 2	Gen 3	Gen 3	Gen 1	Gen 2	Gen 3	Gen 1

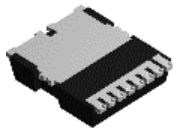
On-state resistance

18 mOhm to 55 mOhm	14 mOhm to 55 mOhm	11 mOhm	52 mOhm to 520 mOhm	21 mOhm to 75 mOhm	15 mOhm to 70 mOhm	1 Ohm and 65 mOhm

Packages



POWER FLAT 8x8



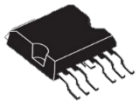
TOLL

TO-247 3L

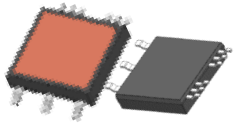
TO-247 3LL

TO-247 4L

HiP247
Rated at 200°C

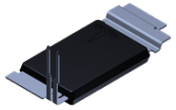


H2PAK 7L



SMIT

HU3PAK



STPAK

Premier pilot product at 2200V under test

Die Business

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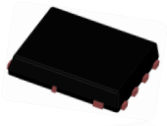
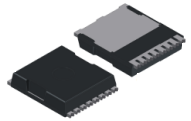
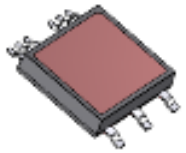
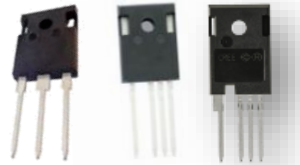
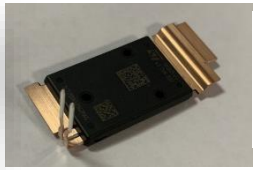
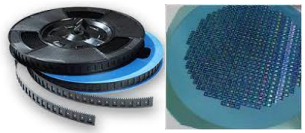
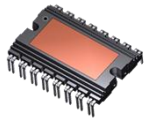
SiC MOSFET Package Roadmap

	Power FLAT 8x8 STD & DSC	TOLL	H2PAK-7L	HU3PAK	ACEPAK SMIT	HiP-247 3L 4L & 4L HC	STPAK	Bare Dice
Package								
	Surface Mounting					**Through-Hole**	**Special Package Solutions**	
Characteristics	▫ Very Thin (< 1mm) ▫ Well accepted in power conversion ▫ Dual side cooling option ▫ Leadless ▫ **Industrial domain**	▫ Leadless ▫ Industrial domain ▫ Kelvin Source for optimized driving ▫ Good thermal dissipation	▫ **AG qualified at 175dC** ▫ Kelvin Source for optimized driving ▫ High runner for Automotive customers	▫ **AG qualified at 175dC** ▫ **Top side cooling** ▫ Kelvin Source for optimized driving ▫ Very good thermal dissipation	▫ **AG qualified at 175dC** ▫ **Isolated Top side cooling** ▫ Suitable for different configurations (HB, Dual die, etc.) ▫ High Power ▫ Modular Approach	▫ **AG qualified at 200dC** ▫ **Very common Industry standard** ▫ Kelvin Source option for optimized driving ▫ High creepage version (1200V and 1700V) in development	▫ **Unique Solution for traction Inverter** ▫ **AG qualified at 200dC** ▫ **Very High thermal dissipation efficiency** ▫ Sense pin for optimized driving ▫ Multi-sintered package	▫ **WLBI & KGD** ▫ **T&R or RWF options** ▫ **Compliant with the most stringent Automotive Quality Requirements**

Power Module Solutions Overview for Industrial and Automotive

ACEPACK Power Module

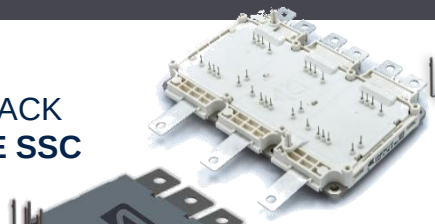
Silicon MOSFET & IGBT, Silicon Carbide MOSFET



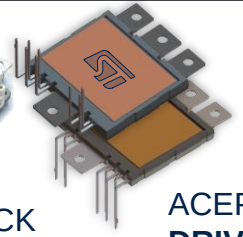
ACEPACK **DMT-32**

ACEPACK **SMIT**

ACEPACK **1 & 2**



ACEPACK **DRIVE SSC**



ACEPACK **DRIVE**

ACEPACK **DRIVE DSC**

5 kW — 10 kW — 30 kW — 150 kW — 340 kW →

Middle Power Applications

Solar Energy

Power Supply & UPS

HVAC

OBC

DC-DC Converter

Charging Station

Motor Drives

Grid and Infrastructure

Wind and renewable energy

High Power Applications

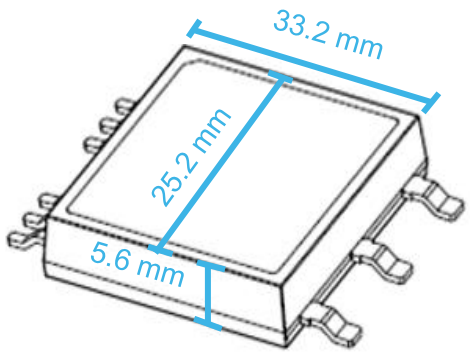
Traction Inverter

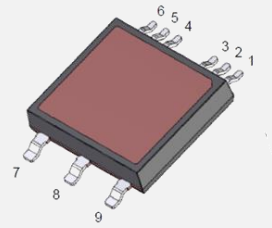
ACEPACK SMIT features and benefits

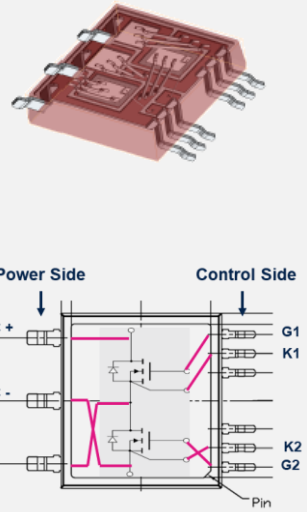
Surface Mounted Isolated Top-Side Cooled Package: ACEPACK SMIT

Features

- Surface Mount Device for automatic stack assembly
- Up to six dies on Direct Bond Copper (DBC) substrate
- Top side cooling with low thermal resistance < 0.2°C/W
- Backside Insulated Ceramic, UL recognized, > 3400VRMS
- Halogen free molding compound
- Improved creepage distances
- 6.6 mm minimum lead-to-lead





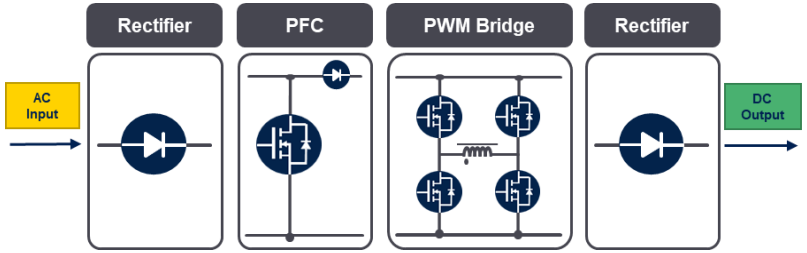


- This assembly is merely illustrative.
- Pin connections in real products may differ.

Benefits

- Top side cooling package
- Molded and isolated thermal pad
- Very high thermal dissipation
- Kelvin source pin enables higher efficiency
- Suitable for several switch technology
- Several topologies can be realized
- Automotive graded
- Available in T&R*

* Tape and Reel



Ideal to realize a complete system

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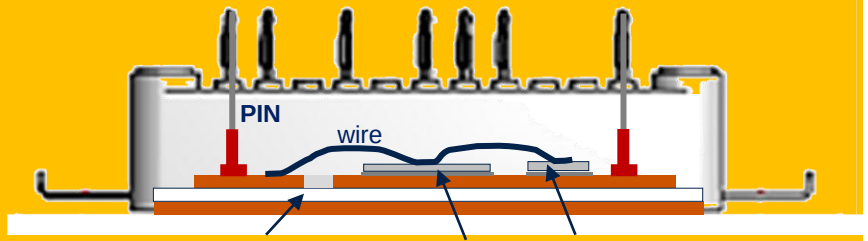
ACEPACK A1 & A2
Plastic Package Power Modules

Package Dimension
48x33.8

Package Dimension
48x56.7



High flexibility in pin positioning for different pin out and configurations

For all the industrial application with more than 3-5KW - ACEPACK 1-2 are the right choice

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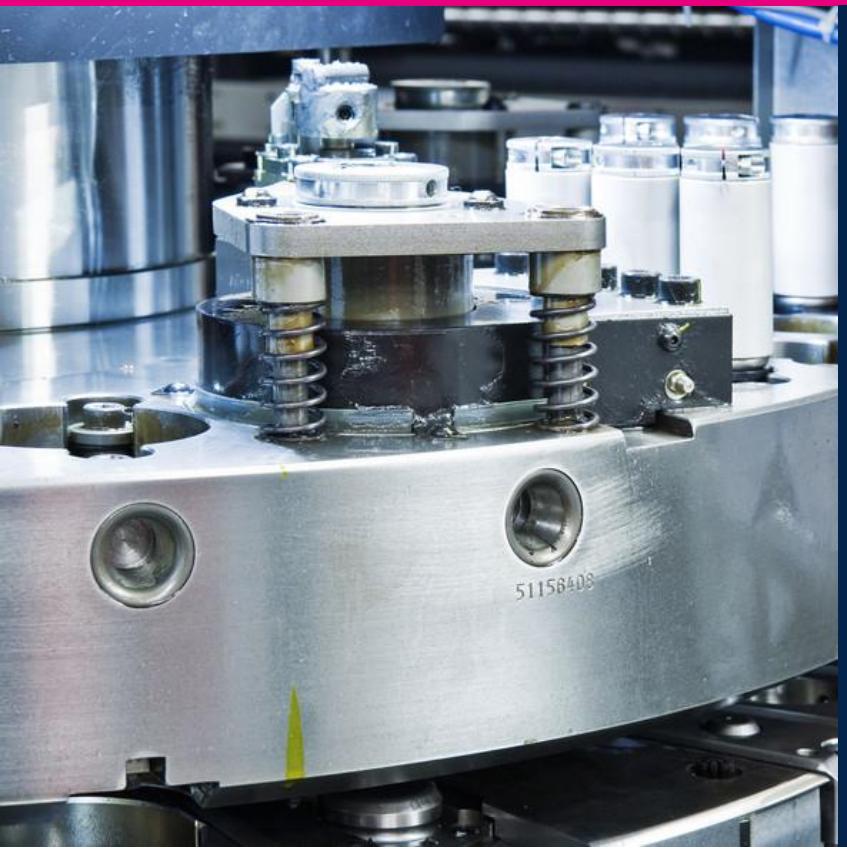
ACEPACK 1 and ACEPACK 2 key benefits

Industrial drives, motor control, UPS, and automotive EV ecosystems



ACEPACK 1 & 2

33.8 x 48 mm

48 x 56.7 mm

- Press fit and solder pin options for configuration flexibility
- Up to 1200V breakdown voltage
- Integrated screw clamps
- All power switches in a module including NTC
- Several current ratings available
- Several configuration options (CIB, six-pack, etc.)
- Low stray inductance
- High reliability and robustness, lower power-side board occupation
- Compact design and cost-effective system approach
- Very high power density

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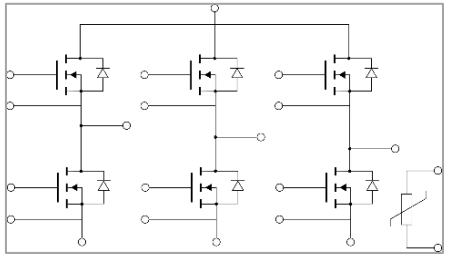
ACEPACK 1 & 2
Industrial-grade product developments

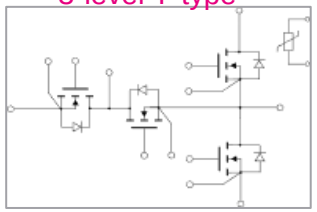
New SiC-based power modules

Part number	Dice	Topology	BV	$R_{DS(on)typ}$ @ 25°C (per switch)	Package	Available within
A1P25M12W2-1	SiC	Six-pack	1200V	25mΩ	ACEPACK 1	Q1-2023
A2U12M12W2-F1C	SiC	3-level T-type S2S with integrated capacitance	1200V	12mΩ	ACEPACK 2	In production
A2U12M12W2-F2	SiC	3-level T-type D2D	1200V	12mΩ	ACEPACK 2	In production
A2F12M12W2-F1	SiC	Four-pack	1200V	12mΩ	ACEPACK 2	In production
A1F25M12W2-F1	SiC	Four-pack	1200V	25mΩ	ACEPACK 1	Q4-2022
A2H6M12W3	SiC	Half-bridge	1200V	6mΩ	ACEPACK 2	Q1-2023
A1H12M12W2-F	SiC	Half-bridge	1200V	12mΩ	ACEPACK 1	Q1-2023

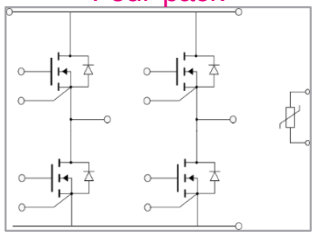
Six-pack



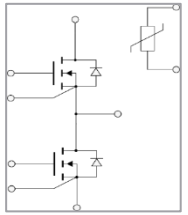
3-level T-type



Four-pack



Half-bridge



Date: Sept 2022
Timeline and prototype availability may be subject to variation without notification

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ST SiC and module solution for new energy application

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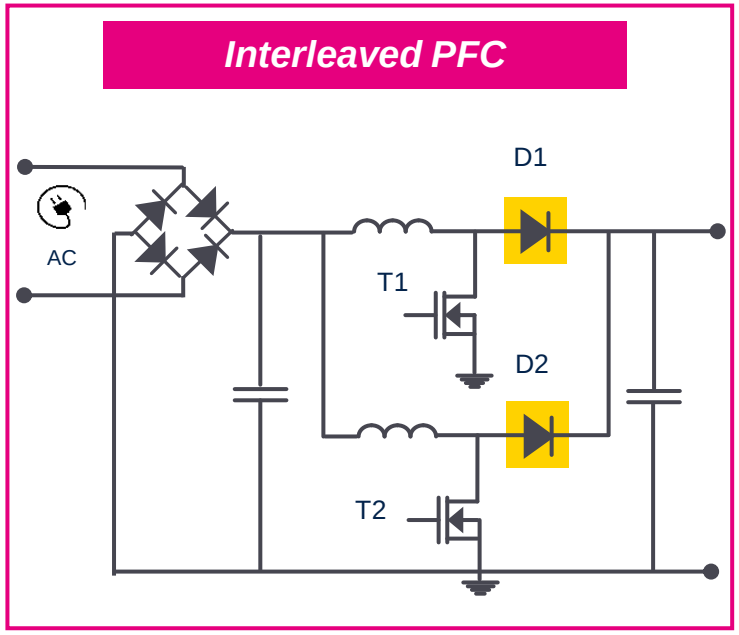
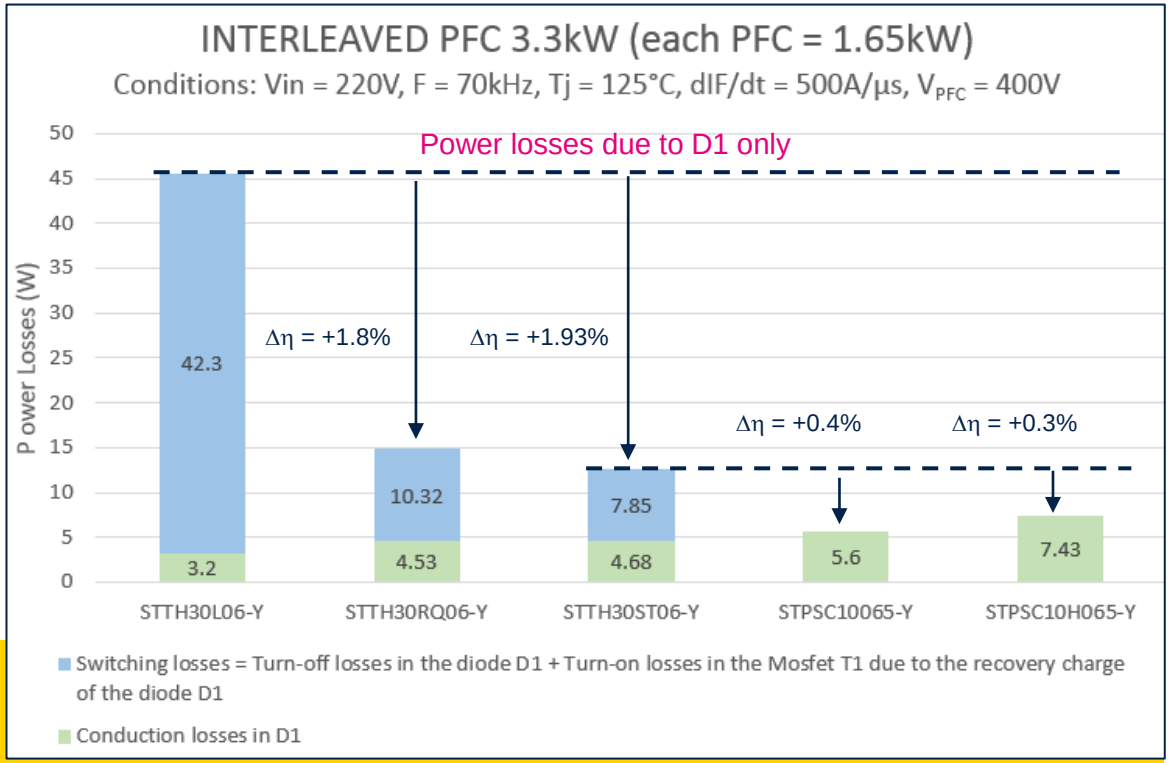
650V SiC diode performance vs Si

Interleaved PFC 3.3kW: power losses sharing





Main advantages

- **Best switching performance (fast and soft)**
- **Best efficiency in hard-switching applications thanks to best turn-off performance**

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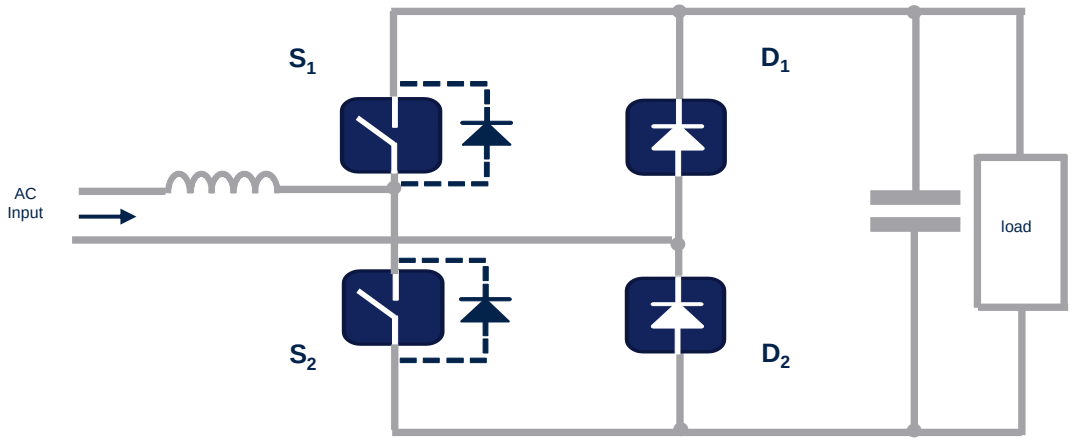
Totem-pole bridgeless PFC
Ideal reverse recovery diode benefits

Totem Pole Bridgeless PFC



Typical losses at V_{in}=220V_{ac}

Devices

- S_1 / S_2= ST SIC Mosfet 650V/55mohm/H2Pack
- S_1 / S_2= ST SI Mosfet: 650V/24mohm/TO247
- S_1 / S_2= ST 650V 40A IGBT
- D_1/D_2= 650V 30A Si rectifiers

Test conditions

- P_{out}= 3.6 kW
- $I_{in\ rms}$=16A
- V_{out}= 400 V
- F_{sw} = 100 kHz
- V_{in} = 220V_{ac}

SiC MOSFET outperforms both Si solutions

S_1 ,S_2 position	Conduction losses[W]	Switching losses[W]	S_1 + S_2 losses [W]	Efficiency*
SIC MOS	7.61	3.7	11.3	99.68%
Si MOS	12.56	34	46.56	98.7%
IGBT	15.6	40.7	56.1	98.44%

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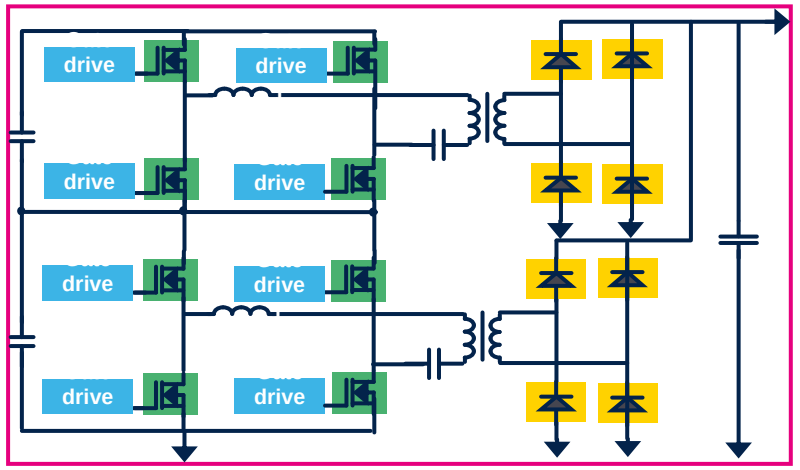
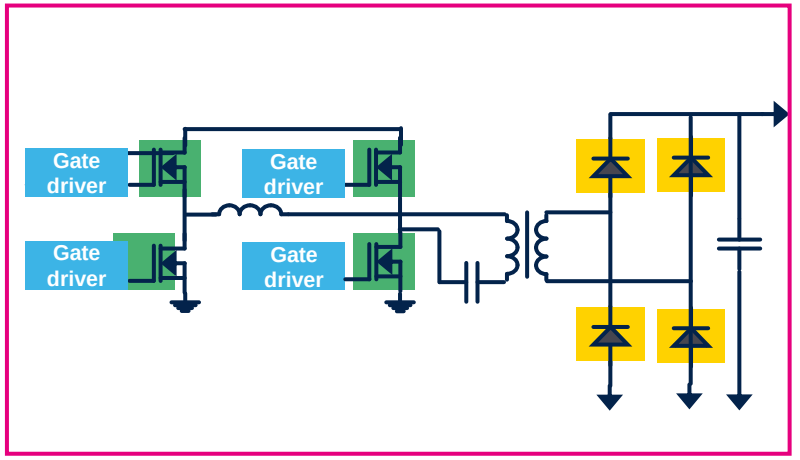
Benefits in LLC DC/DC secondary stage

Comparing efficiency in an 11 kW LLC DC/DC



ST 600V 70mohm SI Mosfet *8

VS



ST 1200V 62mohm SiC Mosfet *4

Test conditions

- P_{out}= 11kW
- $I_{Mos\text{-}rms}$= 12.7A
- V_{bus}= 800 V
- F_{sw_min} = 100 kHz (at max load)

DUT	$P_{cond\_DC/DC}$ [W]	$P_{sw\_DC/DC}$ [W]	$P_{tot\_DC/DC}$ [W]	Efficiency
ST SIC MOS 1200V 70mohm	62.15	48	110.15	98.98
ST SI MOS 650V 80mohm	202.4	28	230.4	97.87

1200V SiC MOSFET solution is more simplify and higher efficiency than 600V Si solution. 1200V Si would have much higher RDS(on) and not suite for this application.

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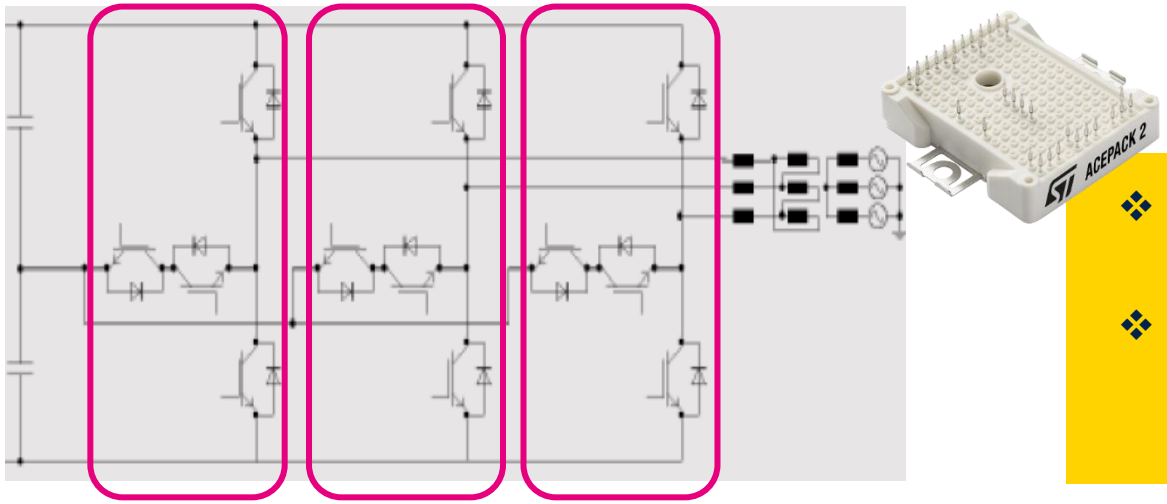
Benefits in DC/AC Inverter



A2U12M12W2-F2

Comparing efficiency in 40kW T-NPC DC/AC

- **50% power loss reduction for ST SiC module vs competitor IGBT module @19KHz**
- **27% power loss reduction and same Tj level @48Khz, and higher Fsw would reduce output inductor size**

Test conditions

- Input 1000Vdc, output 380Vac
- P_{out}= 40kW
- $I_{c\text{-}rms}$= 67A
- F_{sw_min} = 19/48 kHz
- Th=85 ℃
- Each module for one phase

DUT	P_{cond} [W]	P_{sw} [W]	P_{tot}[W]	Efficiency	Highest Tj, avg ℃
IGBT Module 1200V/80A @19Khz	164.31	138.07	302.38	98.98	140
ST SiC Module 1200V/75A @19KHz	93.62	50.14	143.76	99.03	115
ST SiC Module 1200V/75A @48KHz	93.62	125.35	218.97	98.53	141.6

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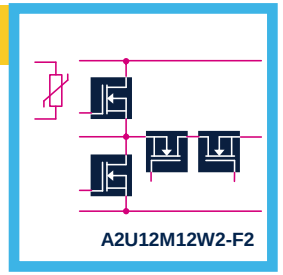
Example of 50kW converter with SiC ACEPACK 2 power modules

A2U12M12W2

- SiC MOSFET
- 3 Level T-Type topology, NPC2
- 13mΩ of typical $R_{DS(on)}$
- 1200V blocking voltage
- D2D (*-F2*) or S2S (*-F1C*) version available



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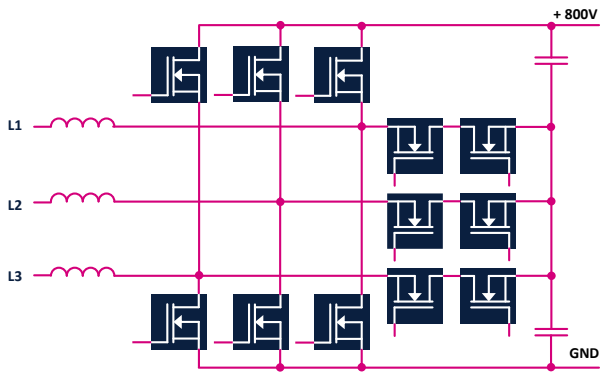
Main applications

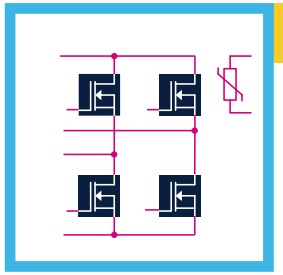
- **DC charging station**
- **UPS**
- **Energy storage**
- **Solar**



Active PFC stage

A2F12M12W2-F1

- SiC MOSFET
- Full Bridge topology
- 13mΩ of typical $R_{DS(on)}$
- 1200V blocking voltage



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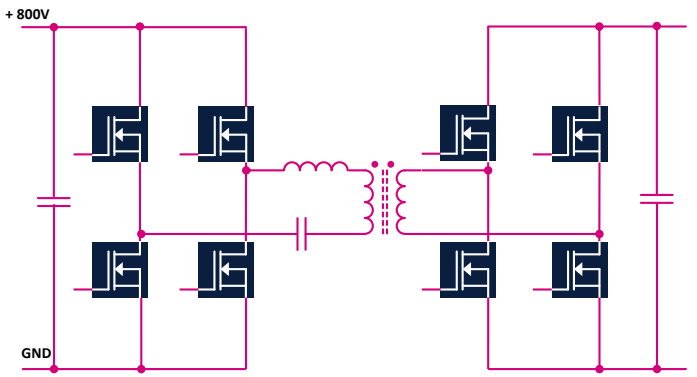

DC-DC isolated (DAB, LLC)

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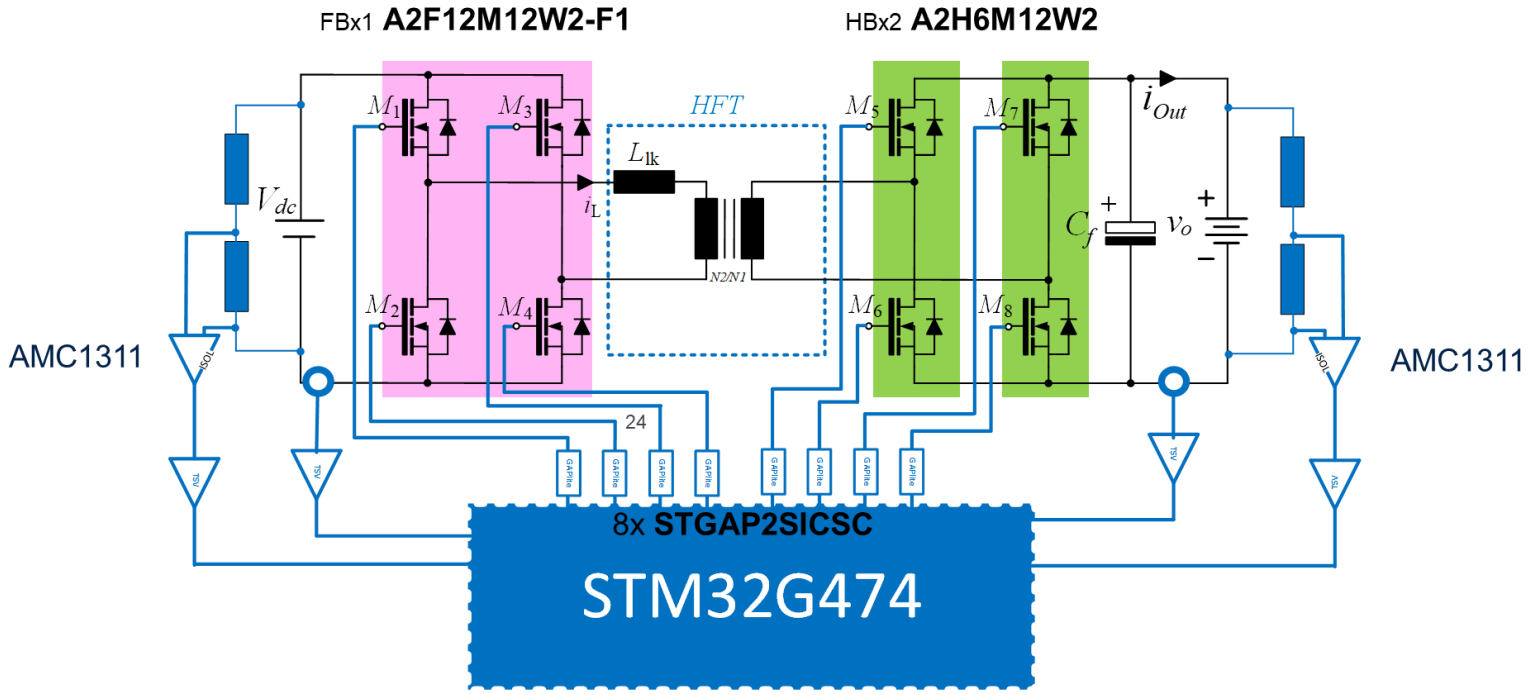
Reference Design
25kW Bidirectional DC/DC DAB –Dual Active Bridge

Project description

- The scope of this activity is to develop bidirectional DC/DC power platforms based on SiC based Power Modules and STM32G4.
- The selected topology is the «Dual Active Bridge – DAB».
- Main specifications:
  - Pout = 25kW
  - Vin = 800V
  - Vout = from 250V up to 650V
  - η>98% @ 80% load
  - Switching frequency = 100kHz

Addressed Market

- Charging stations
- Power Supply
- Energy Storage Systems



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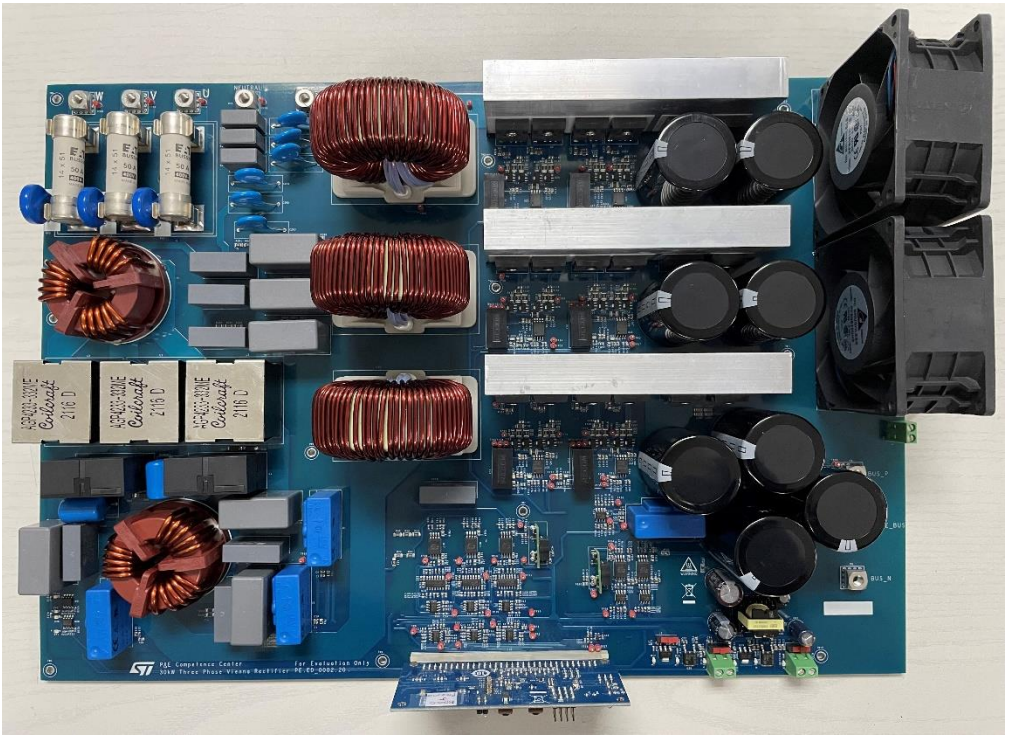
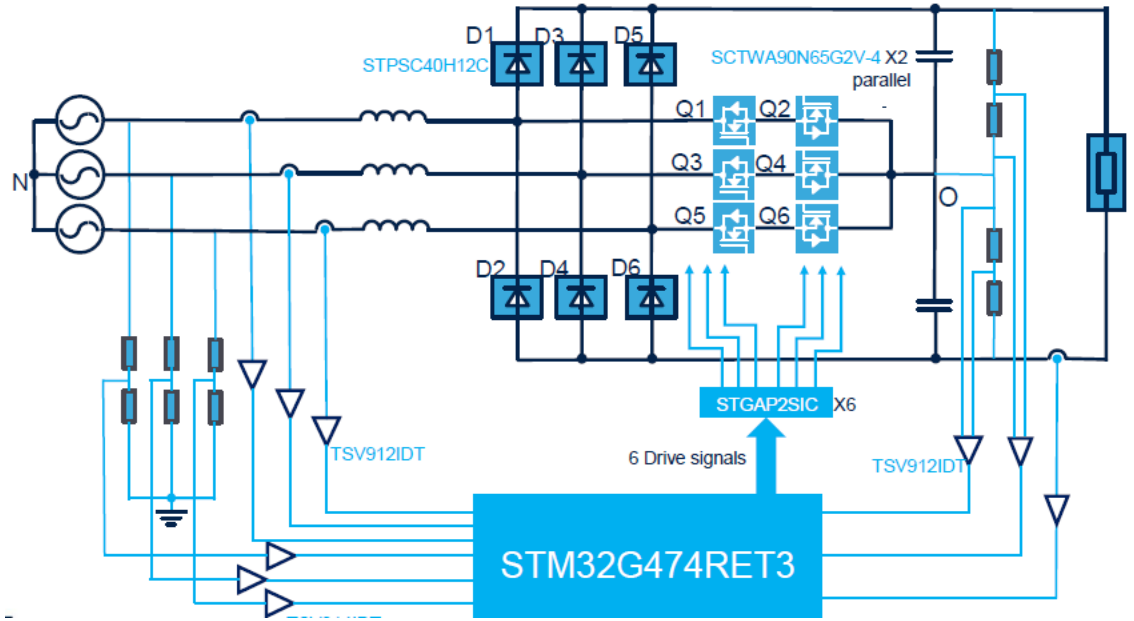
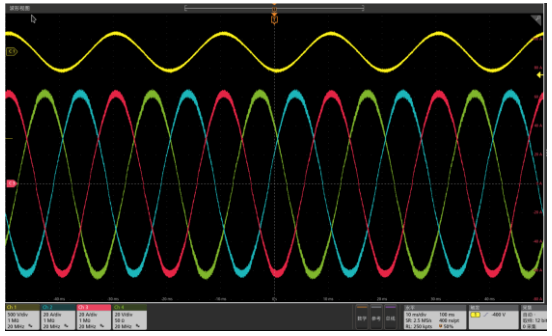
Reference Design
30kW Three Phase Vienna Rectifier

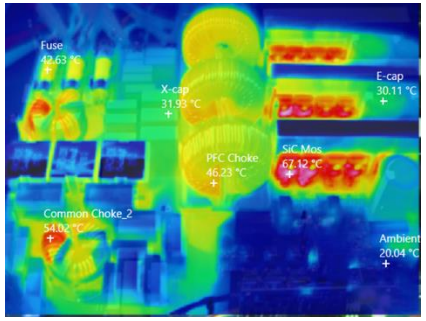
Main Features:

- 345-460Vac input AC line voltage and 700-850Vdc output DC voltage
- SiC MOSFET and Diode based solution achieves high efficiency:
  Peak efficiency 98.56%@800Vdc output; 98.73%@700Vdc output
- Control section based on STM32G474 microcontroller
- PF>0.99, THD<2%@400Vac input; 800Vdc output; 30kW









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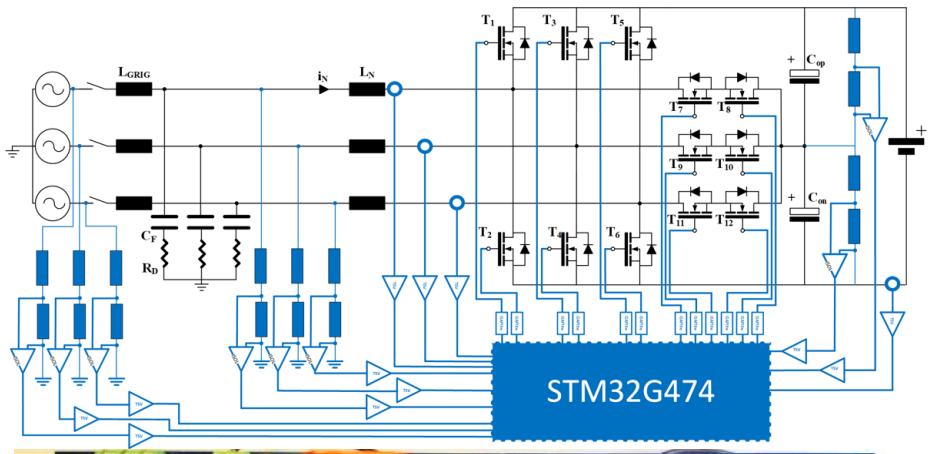
Reference design
15kW three phase AFE Bi-directional Converter



Key Specs

V_{in}	380 Vac
V_{out}	800 Vdc
P_{out}	15 kW
F_s	70 kHz
I_{ripple}	2.5A
V_{out_ripple}	10 Vpp
$PF_{@20\%}$	> 0.98
$THD_{@20\%}$	< 5%
$\eta_{@20\%}$	>97%

Key ST Products

- **STM32G474** (32-bit MCU)
- **SCTW40N120G2V** (6x 70mΩ 1200V SiC)
- **SCTW35N65G2V** (6x 55mΩ 650V SiC)
- **STGAP2S** (Galvanic Isolated Gate Driver)
- **STPS1L30A, STPS2H100A, STTH1L06A, STPS1150A, STPS2L60A** (Schottky and Ultrafast diodes)
- **VIPer26HD** (High Voltage Converter)

- **Webpage:**
- https://www.st.com/en/evaluation-tools/stdes-pfcbidir.html

Takeaways

ST is a leader in the SiC MOSFET industry through dedicated line. The ramp up of SiC Technology is faster than market expectation!

ST SiC technology innovation combined with the complete industrialization of new power packages leads to a strong product range for many power systems.

ST can offer a broad product range: discrete, bare dice, modules, and is investing continuously to expand capacity.

ST experts in new WBG materials and power solutions can replicate a new success story on GaN as already done with SiC

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