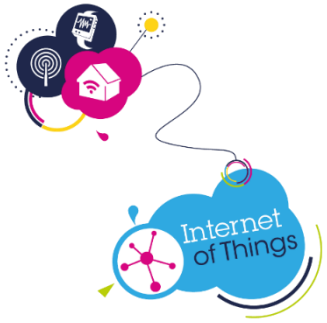
Power Semiconductors for New Energies

September 2019

Alfredo Arno



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ST Developers Conference | September 12th, 2019
Santa Clara Convention Center - Mission City Ballroom
Santa Clara, CA

Power Semiconductors for New Energies

High Power Modules
&
Drivers

Intelligent Power
Modules
SLIMM

Si
HV & LV

SiC & GaN

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New Energies World Scenario

Potential Saving

- Energy saving via improvements in conversion efficiency is the best way to reduce power consumption and, consequently, minimize energy waste.

Transportation consumes More than

20%

of world energy

By 2020 more than

30

billion

Smart Things needing power

Electric lighting uses

20%

of global electricity

Industry consumes More than

50%

of world energy

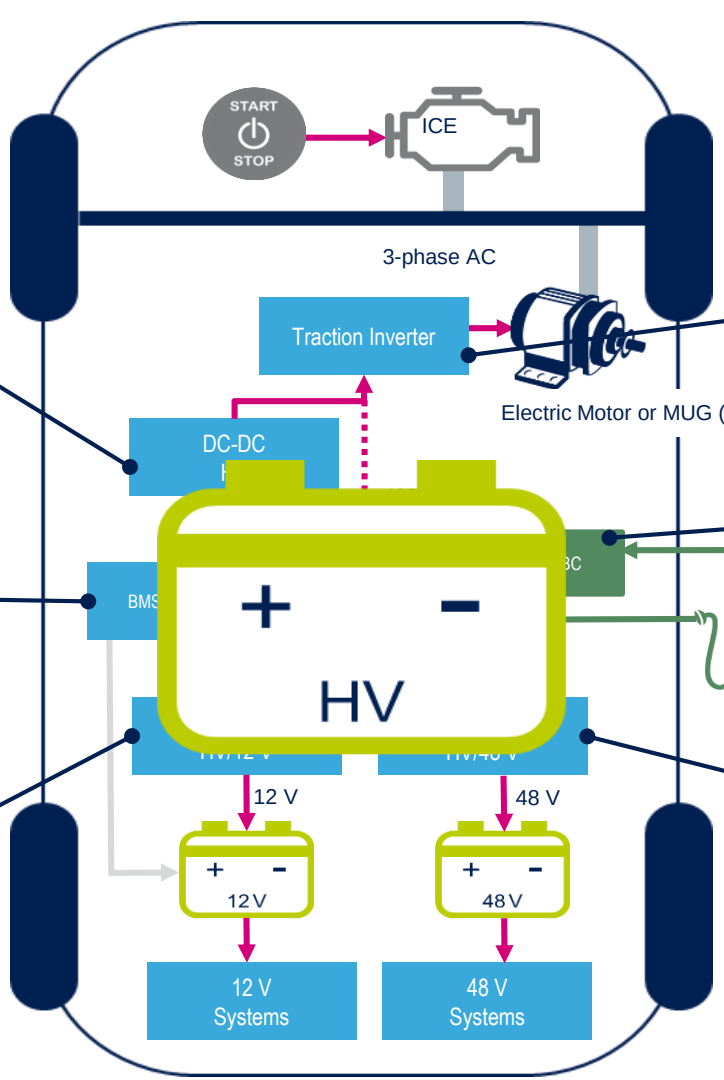
Electric motors use

60%

of industry electricity

Power Discrete in HEV EV

Key Elements in Electric Vehicle



DC-DC HV
- HV MOSFET DM2
- SiC MOSFET
- Modules
- TVS

Battery Management Systems (BMS)
- LV MOSFET
- Schottky
- TVS

DC-DC HV to 12V
- HV MOSFET DM2/DM6
- LV MOSFET
- TVS

Traction Inverter
- SiC MOSFET and IGBT
- Modules
- TVS

On-Board Charger (OBC)
- HV - SCR, Diodes, SiC Diodes & MOSFETs, M5/ DM2/DM6
- LV – MOSFETs and Diodes
- Modules
- TVS

DC-DC HV to 48V
- HV MOSFET DM2/DM6
- LV MOSFET
- TVS

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Automotive Discrete Products

Diodes, Thyristors & TVS | MOSFETs & IGBTs | Filters & Protection | New: SiC, FERD, Flat Packages & Modules

Safety

- Airbag
- Camera
- RADAR

Door Zone

- Doors
- Mirror

Body & Convenience

- BCM & gateways
- Dashboard
- HVAC
- LED
- Roof & Seat Control

Powertrain for HEV

- Bidirectional Aux Power Converter
- Electric Traction
- AC/DC (On Board Charger)
- Main Inverter
- Start-stop

Infotainment & Telematics

- Infotainment
- Sound system
- Telematics
- Vehicle-to Everything (V2X)

Chassis

- ABS and ESC
- Active suspension
- Electric power steering
- Electric park and brake

Powertrain for ICE

- CNG/LPG engine control
- Direct Injection
- Transmission

Discrete Products 20% content of Auto Electronics (60% of Auto Power Electronics)

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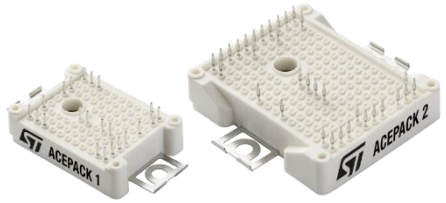
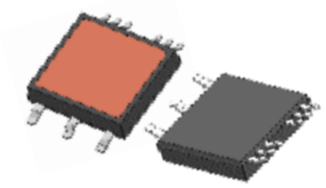
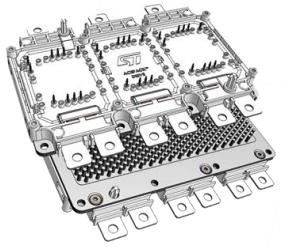
ACEPACK™ Modules

Adaptable, **C**ompact and **E**asier **PACK**age

ACEPACK	Key features	Configurations	Target Applications
1 & 2	 • 100% controlled by ST for silicon (SiC, MOSFET, IGBT and Diodes) • Compact design and cost-effective system approach for a plug & play system solution • Configuration flexibility • 2500Vrms electrical isolation	• CIB • Six-pack • Three level Boost • ….	
SMIT	 • SMD assembly • Top side cooling • Low thermal resistance • Reduced parasitic inductance and capacitance • 2500Vrms electrical isolation	• Bridge rectifier • Half Bridge • Boost • ….	
DRIVE	 • Optimized for 200 kW inverters • 1200V SiC MOSFET based switch • Improved light load power losses for extended EV driving ranges • Extreme low conduction losses • Short circuit ruggedness • Direct Cooled Cu Base Plate with pin fins	• Six-pack	

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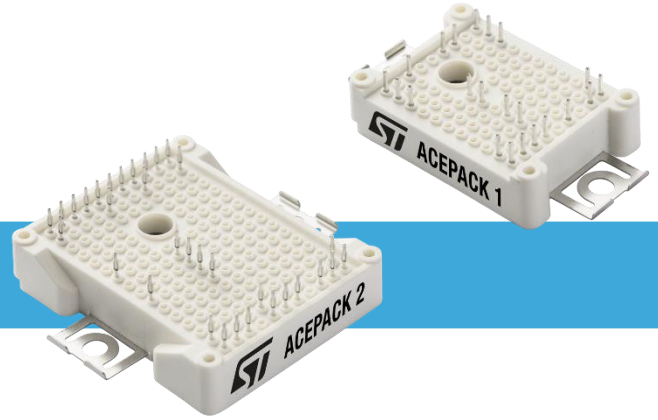
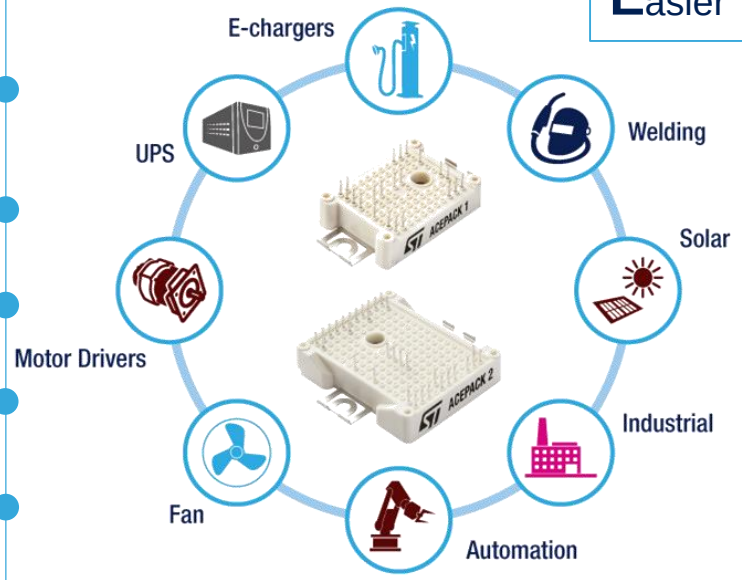


ACEPACK™ 1 & 2

Features and Benefits

- Press FIT and solder pins options, configuration flexibility
- Up to 1200V breakdown voltage
- Integrated screw clamps
- All power switches in a module including NTC
- Several current ratings available

Adaptable
Compact
Easier



- Several configurations (CIB, 6pack ..) available and low stray inductance
- High reliability and robustness, miniaturized power side board occupation
- Simplified and stable screwing
- Compact design and cost-effective system approach
- Very high power density

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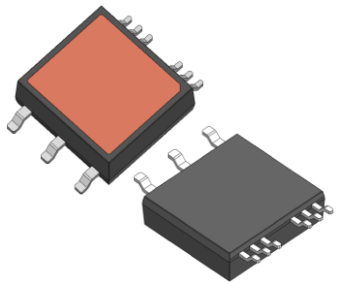
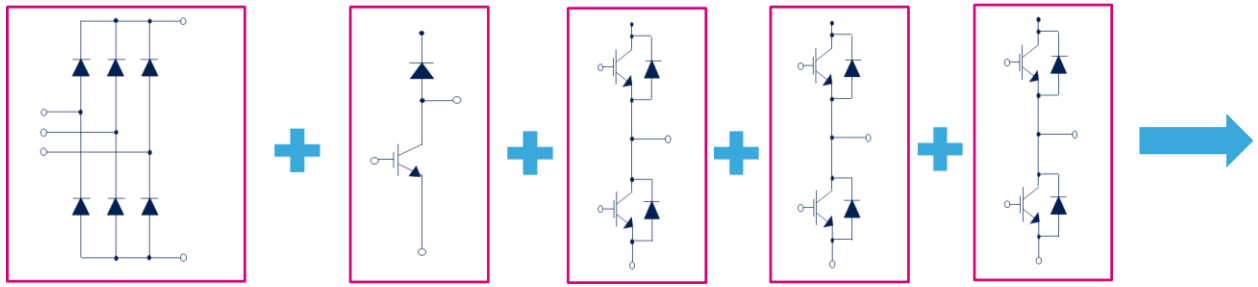
ACEPACK™ SMIT

Features and Benefits

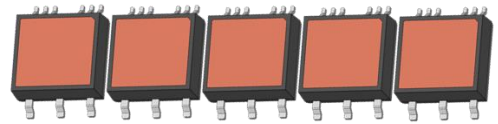
- 2500Vrms electrical isolation
- SMD assembly
- Dice chips on *Direct Bond Copper (DBC) substrate*
- Reduced parasitic inductance and capacitance
- Suitable for several switching technologies



- Several configurations available and low stray inductance
- High reliability and robustness, miniaturized power side board occupation
- Compact design and cost effective system approach
- Very high power density
- Ideal to realize a complete system



High level of modularity



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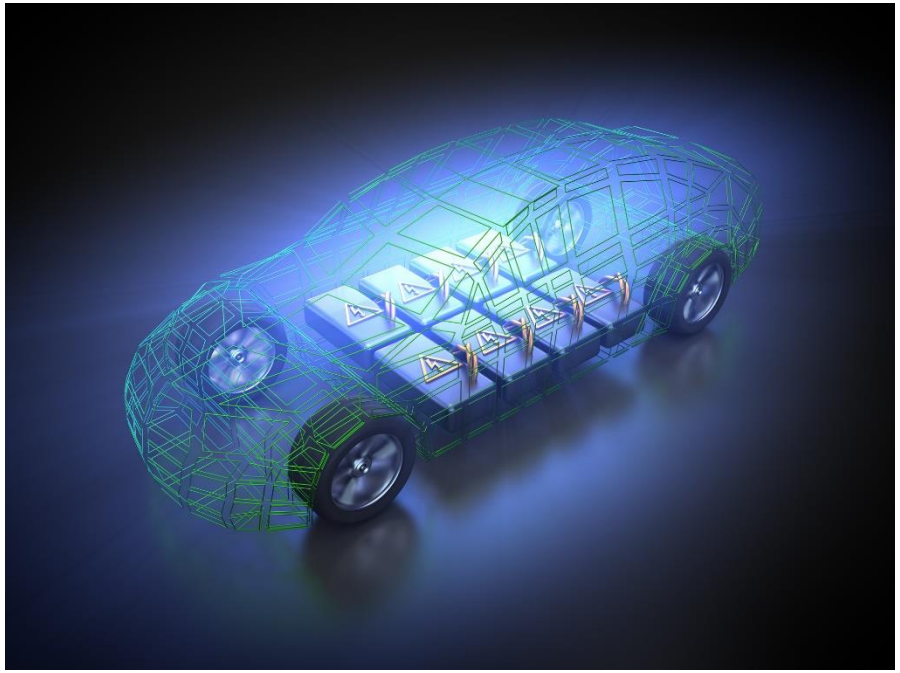
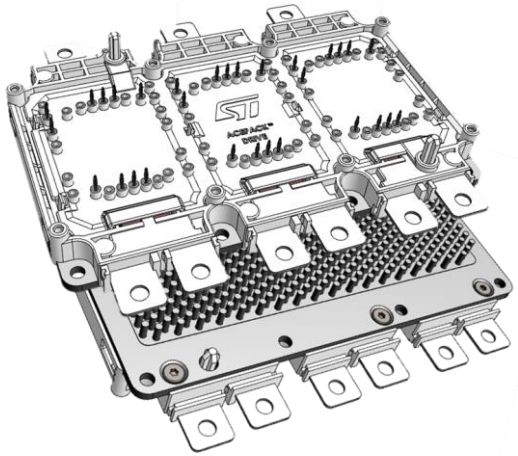
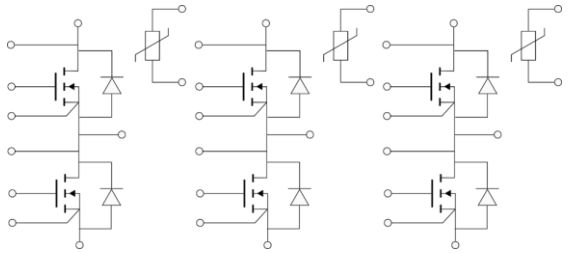
ACEPACK™ Drive

Compact Solution for Traction Inverter

Very High Power Density with Direct Cooling for EV and HEV







Main Features & Benefits

- Large output power range >200 kW
- 750V - 1200V SiC MOSFET based switch
- Improved light load power losses for extended EV driving ranges
- Extremely low conduction losses
- Direct Cooled Copper Base Plate with pin fins

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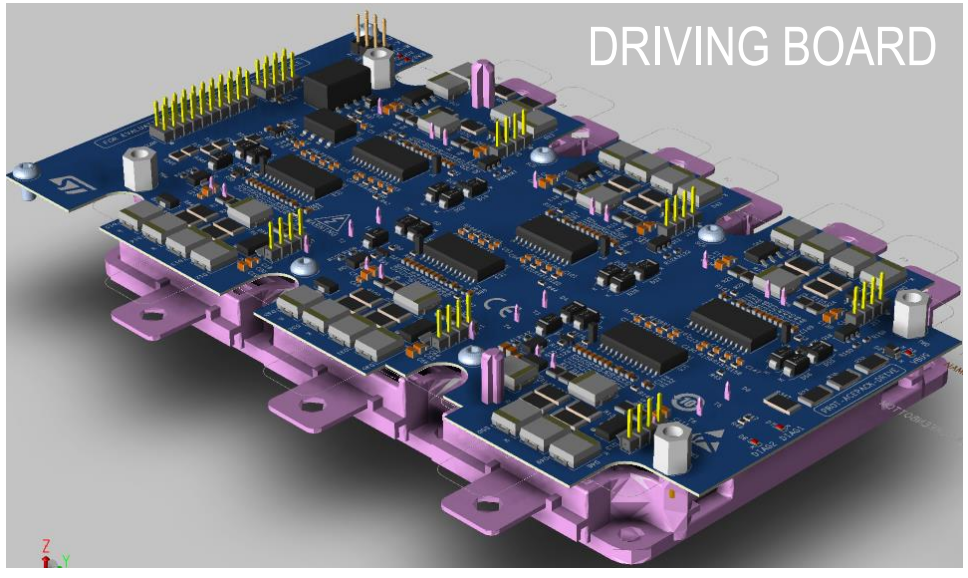
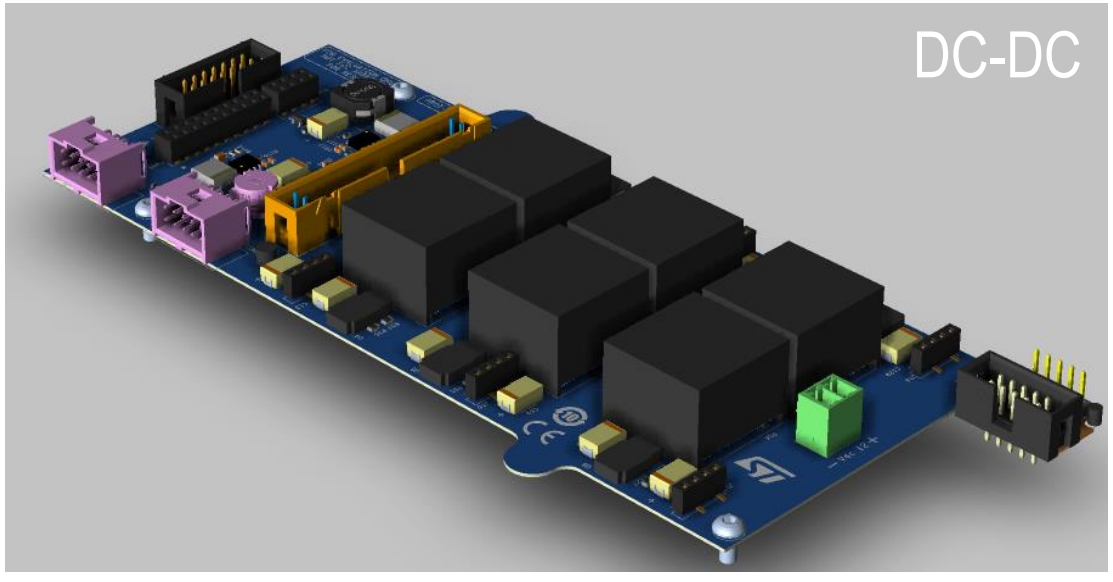
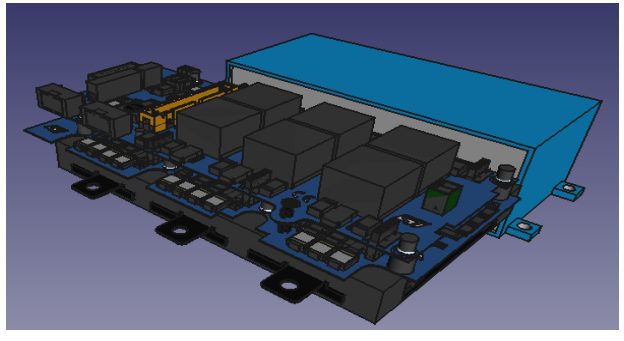
ACEPACK™ Drive

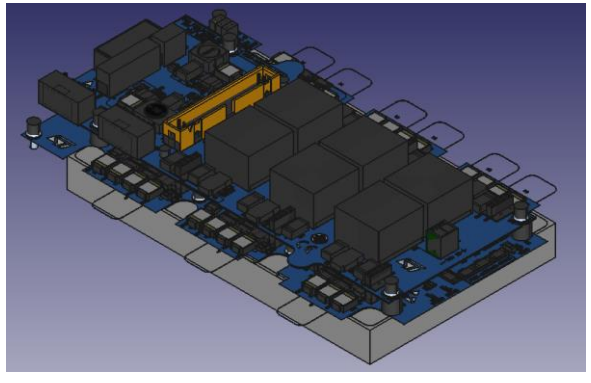
Evaluation Kit

Very High Power Density with Direct Cooling for EV and HEV









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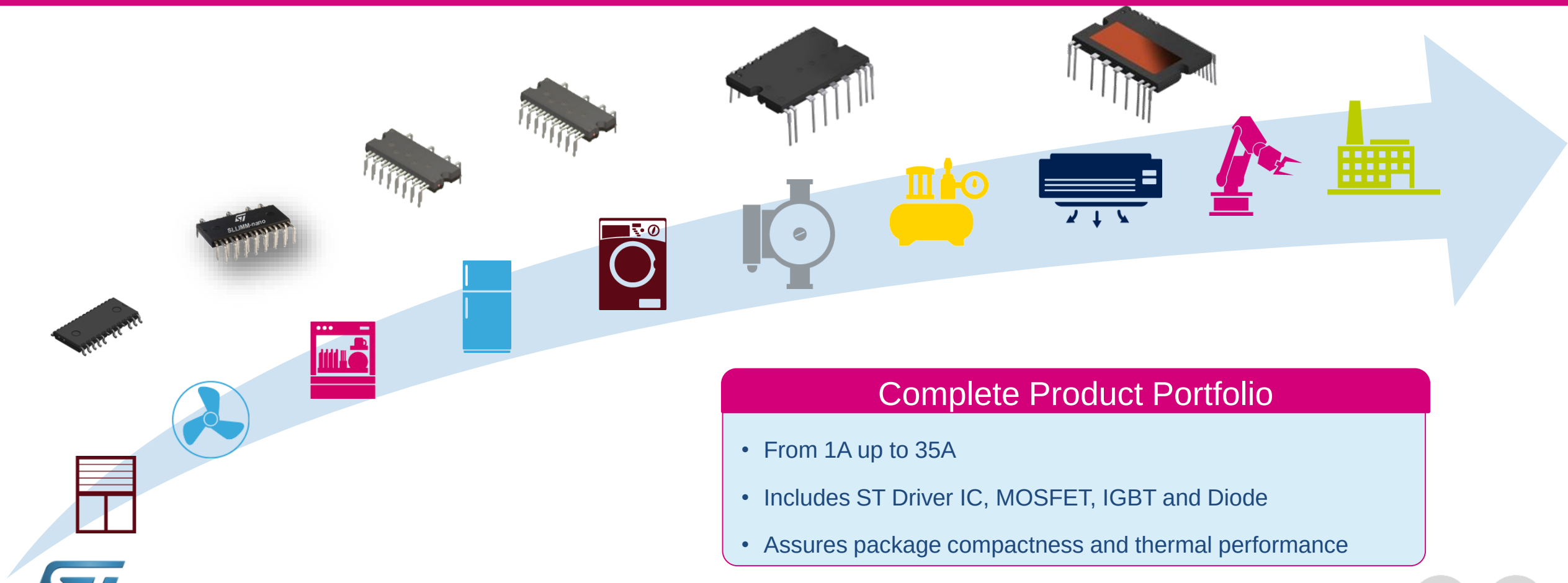
Intelligent Power Module Portfolio

Wide Current Range Scalability



Complete Product Portfolio

- From 1A up to 35A
- Includes ST Driver IC, MOSFET, IGBT and Diode
- Assures package compactness and thermal performance

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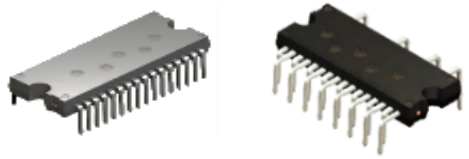
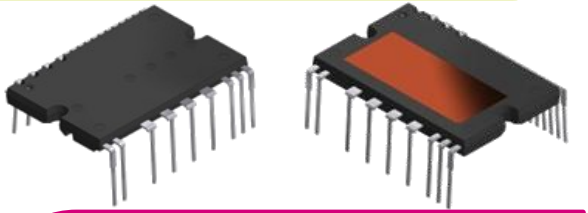
IPMs – SLLIMM™ Family

Small Low Loss Intelligent Molded Module

SLLIMM nano series	SLLIMM nano 2nd series	SLLIMM 2nd series
600V IGBT 500V MOSFET 1 up to 3A	600V IGBT 600V **SJ-MOSFET** 3 up to 8A	600V IGBT 600V **SJ-MOSFET** 8 up to 35A
		
NDIP (TH) NSDIP (SMD) 12.45 x 29.15 x 3.10 mm	N2DIP (TH) 12.45 x 32.15 x 4.10 mm	SDIP2F-26L SDIP2B-26L 24 x 38 x 3.5 mm

20W 100W 500W 3000W

Power

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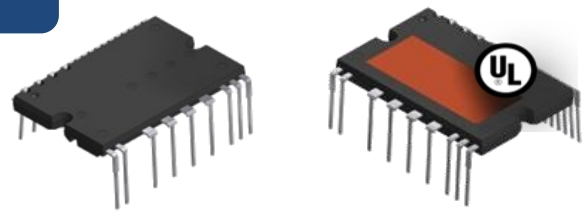
SLLIMM™ 2nd Series

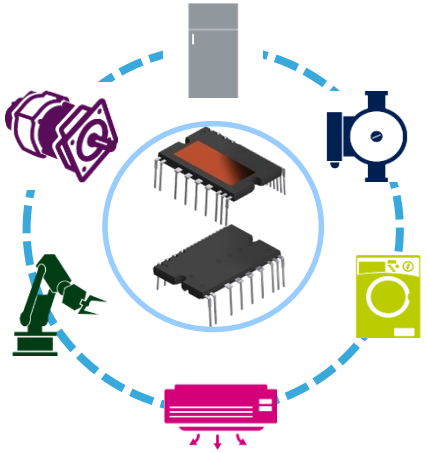
Product



Switch type	IGBT		SJ MOSFET
Voltage rating	600V		
Current capability	8A, 10A, 15A	12A, 15A, 20A, 25A, 35A	10A,15A
Package	SDIP2F-26L	SDIP2B-26L	

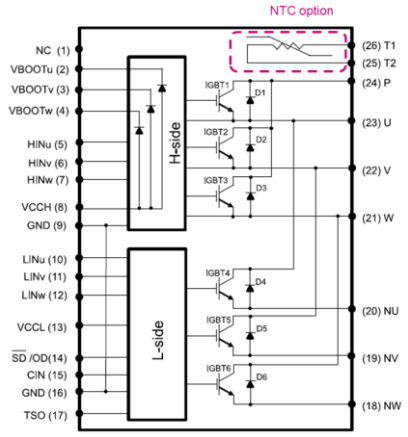
Application

- Washing machines
- Refrigerators
- Air conditioners
- Sewing machines
- Pumps
- Compressor
- Servo motors
- Any inverter system up to 3kW



Features

- TFS IGBT and SJ MOSFET based technologies
- High current scalability
- Full molded and DBC package
- Thermal sensor and NTC thermistor option
- Comparator, UVLO, Shutdown function



Benefits

- Improved thermal performances
- Best R_{th} value in the market
- Temperature monitoring
- Protection embedded inside the power module
- High efficiency at low load applications

1.1 °C/W

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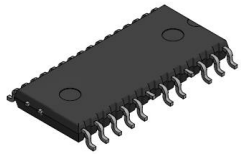
SLLIMM™ Nano Series

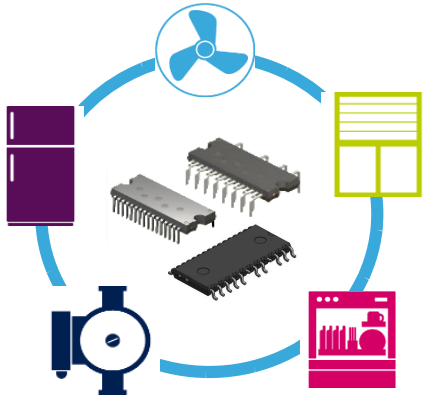
Product



Switch type	MOSFET	IGBT	MOSFET	IGBT
Voltage rating	500 V	600 V	500 V	600 V
Current capability	1A, 2A	3A	1A, 2A	3A
Package	NDIP (12.45x29.15)		NSDIP (12.45x29.15)	

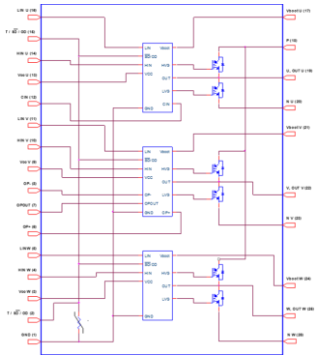
Application

- Small fans
- Roller shutters
- Dish washer
- Compressor
- Pumps
- Refrigerators



Features

- IGBT and MOSFET based technologies
- Optimized voltage drop in conduction
- Through-hole (TH) and SMD packages
- In line or zig-zag leads
- NTC thermistor option
- Comparator, UVLO, Interlocking function



Benefits

- High flexibility and robustness
- Improved efficiency and reliability
- Package compactness
- Temperature monitoring
- Protection embedded inside the power module

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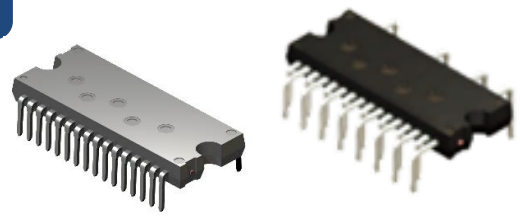
SLLIMM™ Nano 2nd series

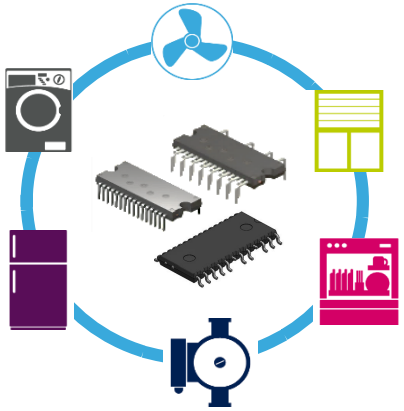
Product



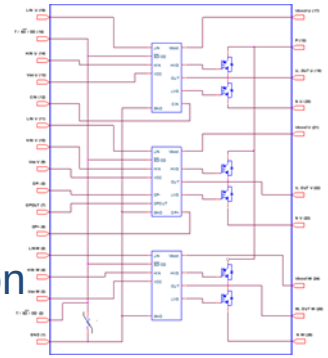
Switch type	**SJ-MOSFET**	IGBT(planar, **TFS**)
Voltage rating	600 V	
Current capability	3A, 5A	3A, **5A, 8A**
Package	N2DIP (12.45x29.15)	

Application

- Small fans
- Roller shutters
- Dish washer
- Compressor
- Pumps
- Refrigerators
- Washing machines



Features



- TFS IGBT and SJ-MOSFET
- based technologies
- Optimized voltage drop in conduction
- In line or zig-zag leads w/wo stand-off option
- Slots for heatsink screw
- NTC thermistor option
- Comparator, UVLO, Interlocking function

Benefits

- High flexibility, robustness and improved efficiency
- Improved isolation voltage up to 1.5 kVrms/min
- Package compactness and thermal performances
- Temperature monitoring
- Protection embedded inside the power module
- High efficiency at low load applications

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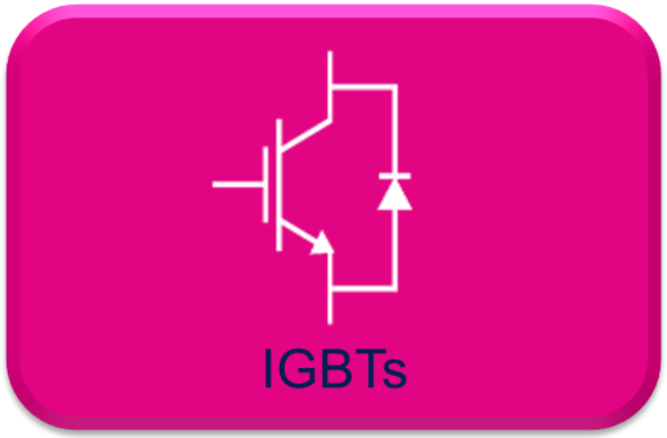
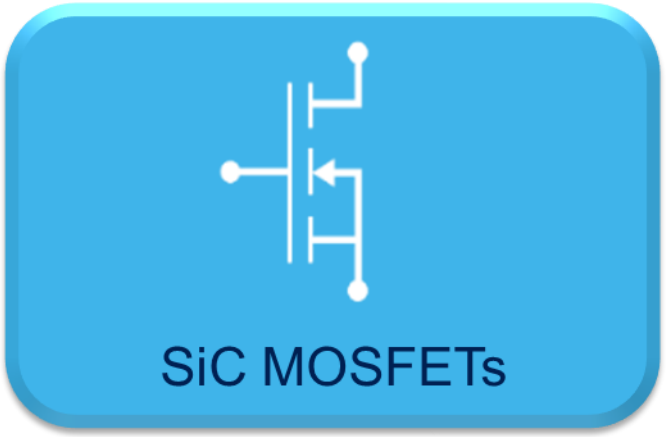
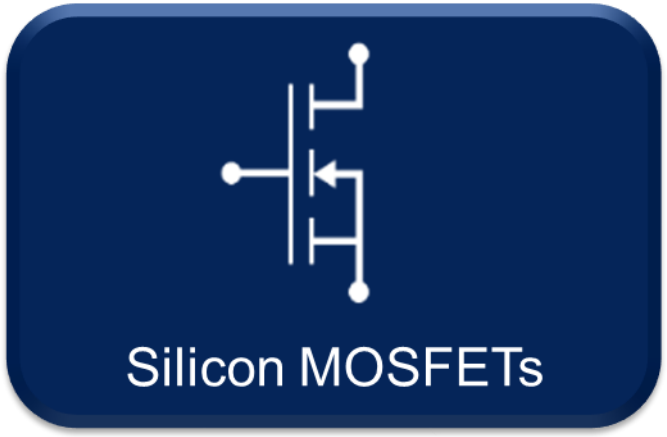
Power Semiconductors for New Energies







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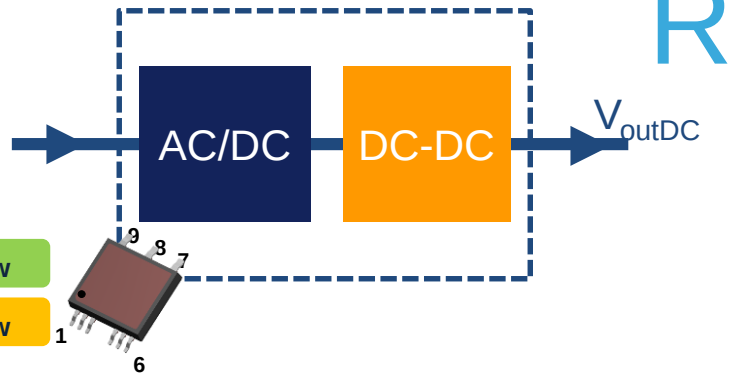
Rectification On Board Charger

Bridge and Bridgeless



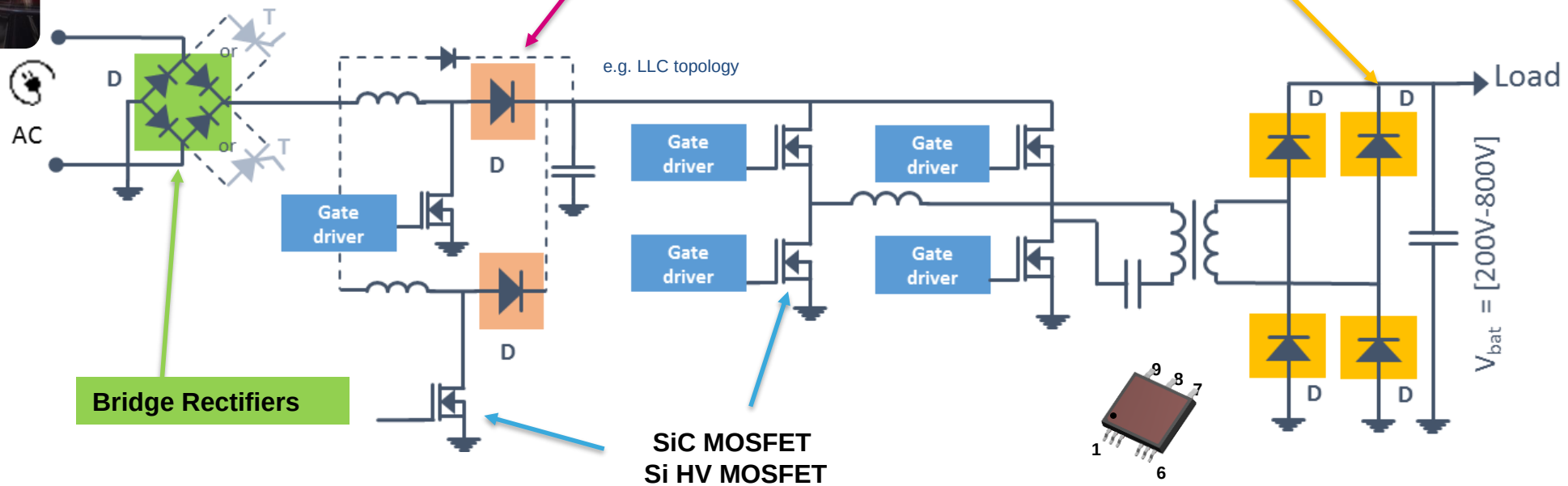
Soft Start ICL

Thyristors TVS

SiC Diodes

SiC Diodes

Rapid Quiet Rectifiers



Bridge Rectifiers

SiC MOSFET
Si HV MOSFET
(M5, DM6, DM2)

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High-Voltage Power MOSFET

Superjunction Technology

Breakdown Voltage

600V	650V	800V – 1700V

MDmesh series

M2	M6	DM2	DM6	M5	DM2	DM6	K5

Focus Applications

Flyback, PFC/LLC **resonant converter –** Charger adapters Led lighting	Flyback, PFC/LLC high efficiency **resonant converter –** Charger adapters	Half/full bridge topologies, **ZVS, LLC** Solar, Server, Telecom SMPS	Half/full bridge **ZVS, LLC high efficiency** topologies Solar, Server, Telecom SMPS	Hi-end-power PFC and **hard switching topologies** Solar, Server, Telecom SMPS	Half/full bridge topologies, ZVS, LLC High power level Solar, Server, Telecom SMPS	Half/full bridge ZVS, LLC high efficiency topologies High power level Solar, Server, Telecom SMPS	Flyback topology LED driver, LED lighting, auxiliary SMPS

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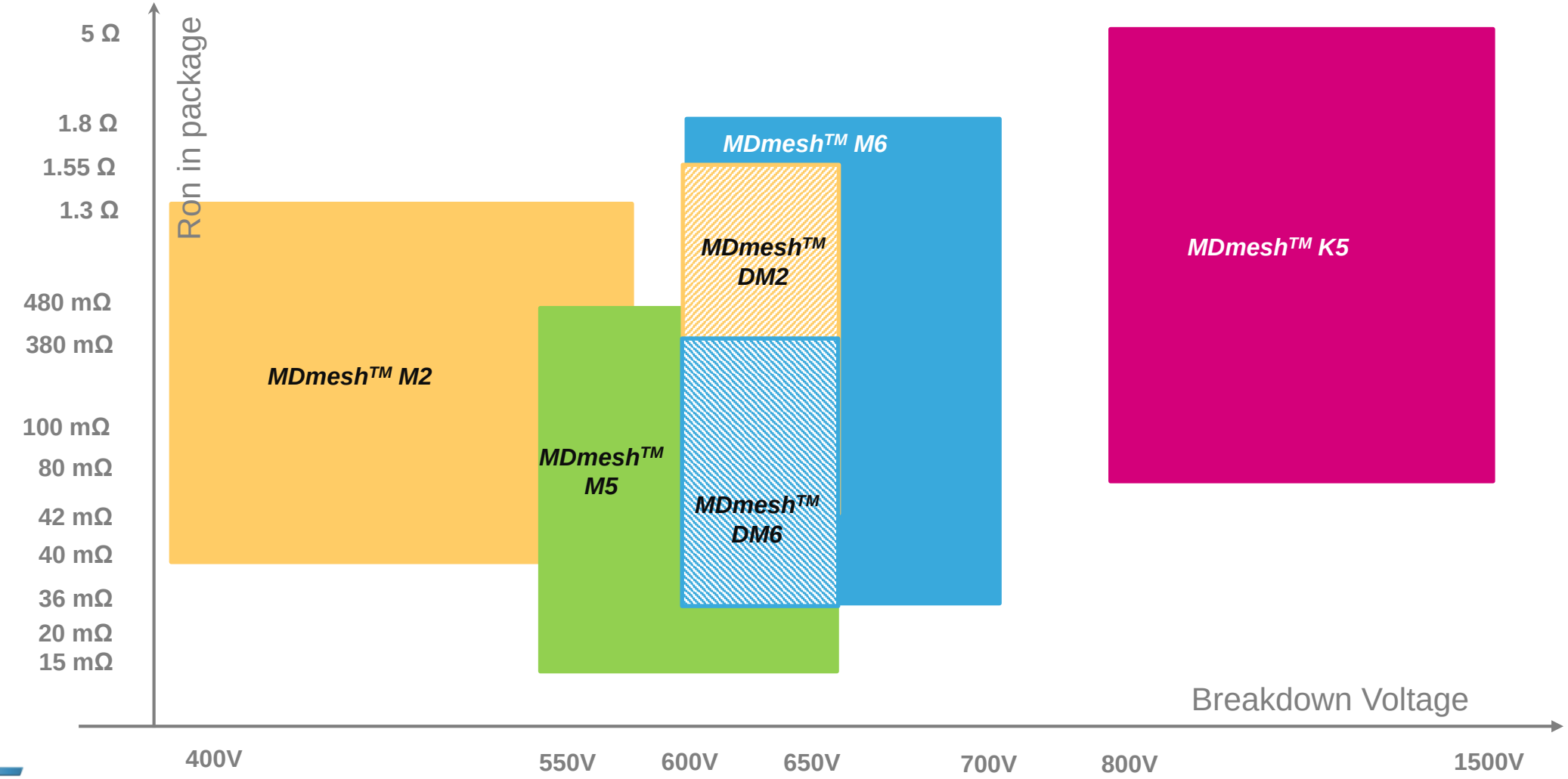
High-Voltage MOSFET Series



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MDmesh™ Technology Overview

High-Voltage MOSFETs

MDmesh™ M5 (550V ÷ 650V)

Permits reduction of switching losses and targets higher power density

- Enabler for High-Power PFC

MDmesh™K5 (800V ÷ 1700V)

Allows operation over very-high voltage range

- Enablers for High Efficiency

MDmesh™ M2/DM2 (600V ÷ 700V)

Optimized switching characteristics with very low turn-off switching losses, suitable for most high-frequency converters

- Enabler for FlyBack

MDmesh™ M6/DM6 (600V ÷ 700V)

Allows higher levels of efficiency (Platinum, Titanium) Due to its ideal performance – Saves Energy to achieve climate goals

- Enablers for Converters

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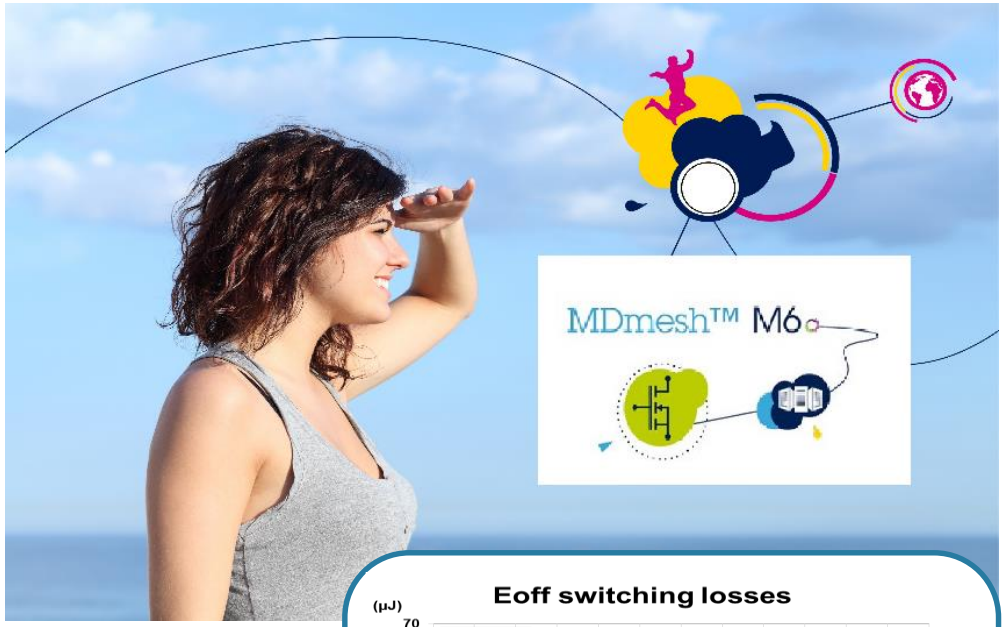
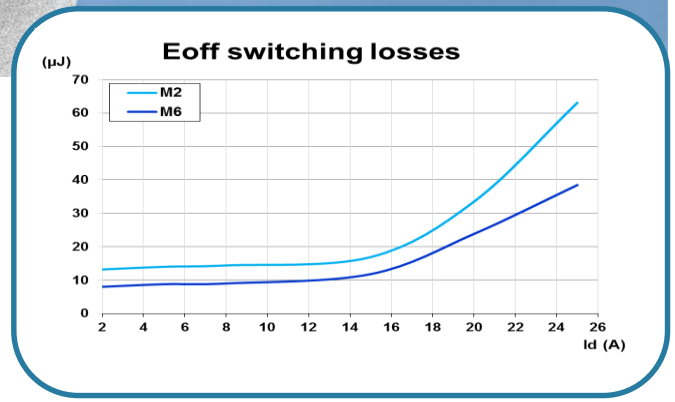
MDmesh™ M6:
New Super-Junction MOSFET Family

600V - 650V - 700V MDmesh™ M6: Advance in high-efficiency topologies





The ideal switch to boost efficiency

- **Latest** HV MOSFET (600V - 650V - 700V) series
- **Targeted** for ZVS & LLC Bridge topologies
- **Improved** Efficiency at light load conditions

Power Management

Telecom Power

Solar

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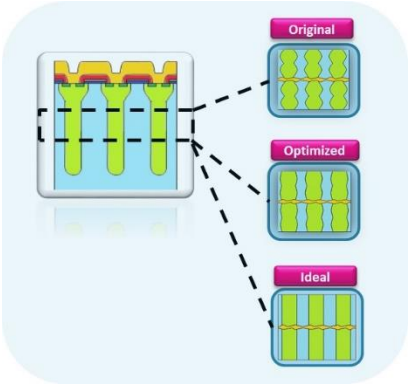
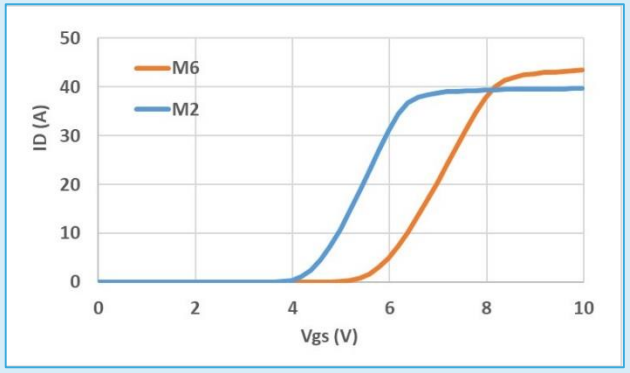
MDmesh™ M6:

Technology Features for Resonant Converters

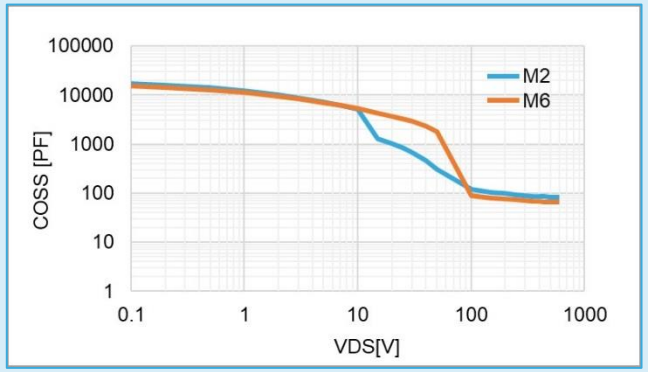


- New diffusion process and the optimization of MDmesh™ M2
- Thermal SPICE model also available on web
- Optimized diffusion process to enhance resonant converter performance

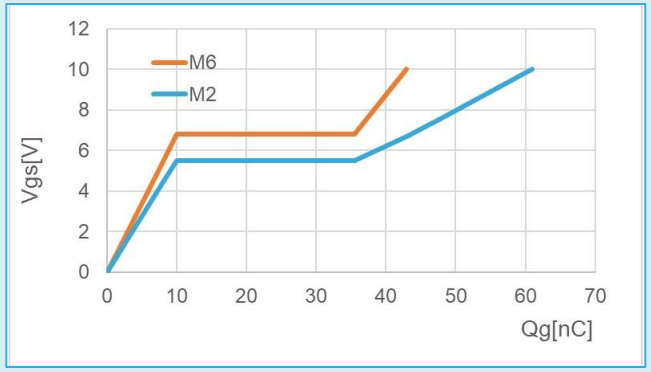
Optimized threshold voltage



Optimized Coss



Low gate charge



Reduced switching losses

Increase Power Efficiency at light load

High-frequency operation

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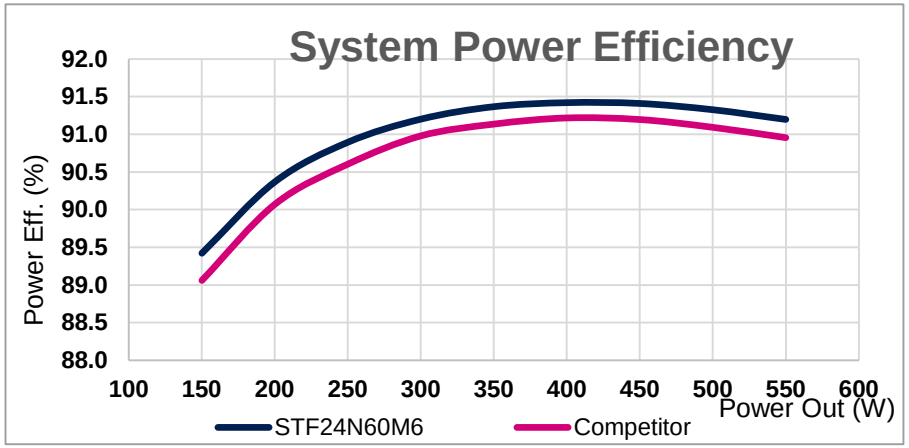
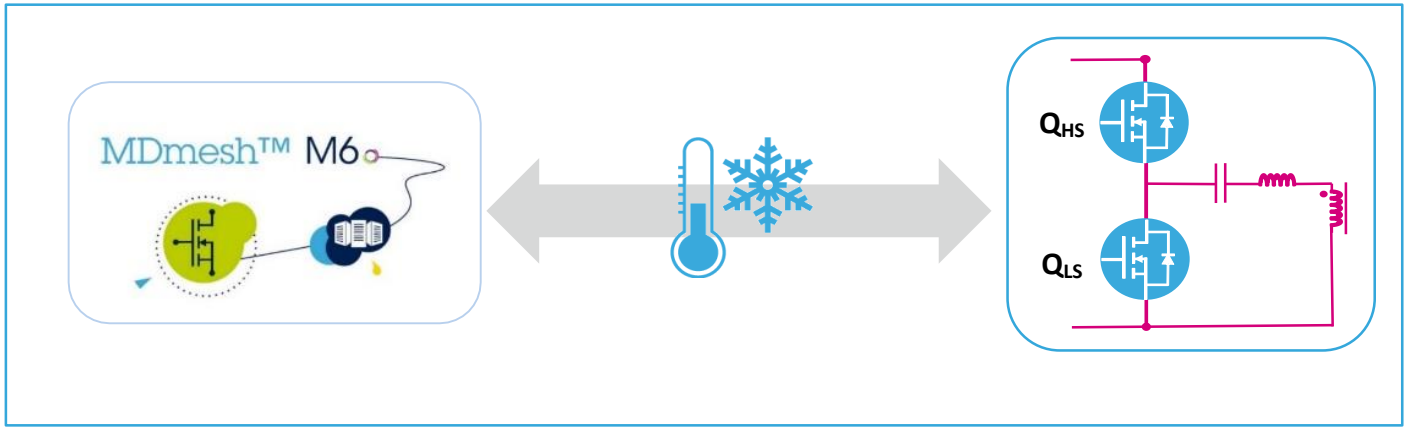
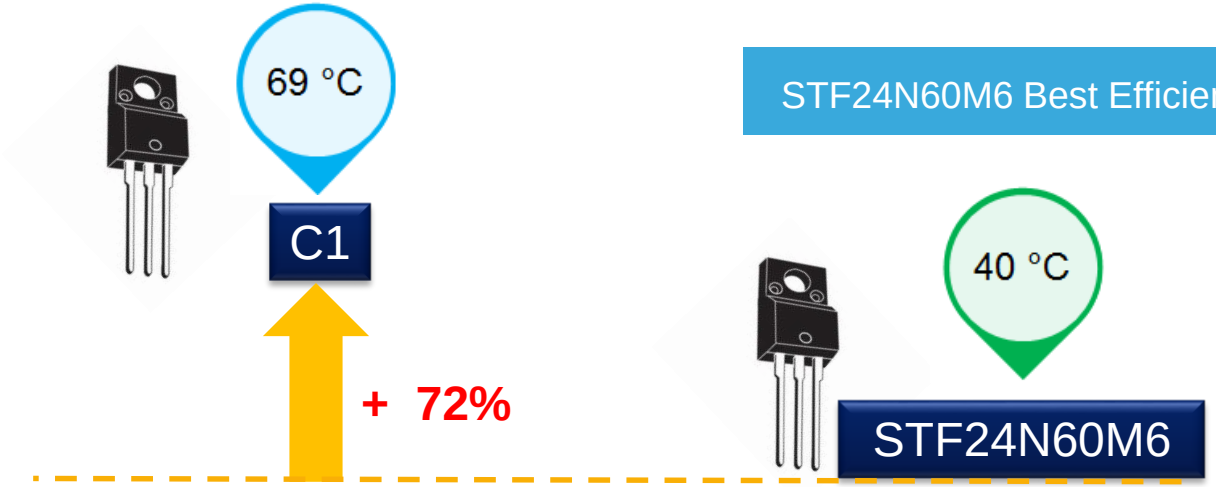
MDmesh™ M6:

Advantages in Resonant Topologies







STF24N60M6 Best Efficiency and Tcase Across Load

Average of the Tcase values measured on two couples of the same p/n

	STF24N60M6	C1
Parameters		
* BV_{dss} min (V)	600	600
* R_{DS}(on)max (mΩ)	190	180
*V_{GS}(th) typ (V)	4	3.5

* Datasheet values

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Already on WEB

MDmesh™ M6

Promotion

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600 to 700V MDmesh™ M6

High-voltage, SJ MOSFETs

To boost the efficiency

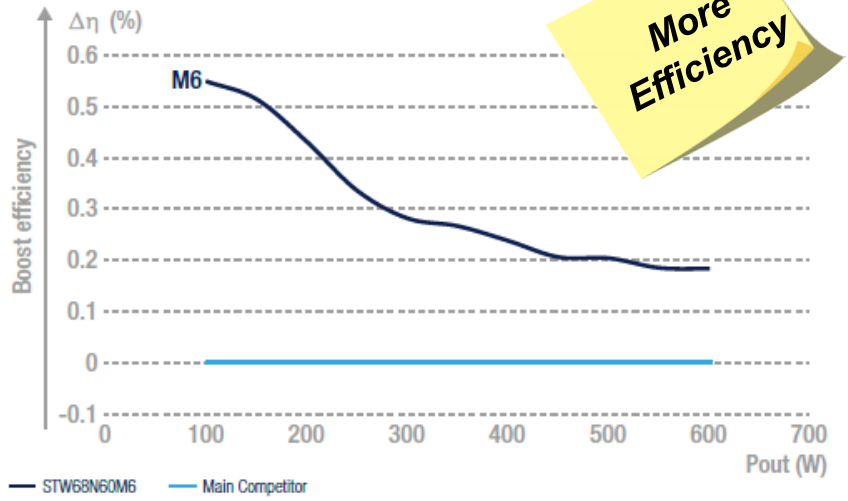
MDmesh™ M6 technology offers improved PFC and LLC efficiency especially at light load conditions for increased power density

MDMESH™ M6 SERIES

600V – 650V – 700V BVdss rated

ST's latest super-junction technology optimized for resonant topologies. With a breakdown voltage ranging from 600 to 700 V, MDmesh™ M6 MOSFETs are available in a wide range of package options including a TO-Leadless (TOLL) package solution, allowing efficient thermal management.

Efficiency test performed in open loop 700 W LLC system



GET IT ON Google Play

Available on the App Store

Wandoujia

PORTFOLIO available on your mobile

To explore the complete MDmesh™ M6 product portfolio, visit www.st.com or use our ST-MOSFET-Finder mobile app for Android and iOS

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600V & 650V IGBTs Series

in Trench Gate Field Stop

Higher performances in home appliances as well as high frequency converter

- ✓ Best Trade-off Static-Dynamic Characteristics
- ✓ Max junction temperature of 175˚C
- ✓ Tail-less switching off waveforms
- ✓ Very fast freewheeling diode for very low E_{on}

Breakdown Voltage					
600V		650V			
Current					
5 to 20 A	20 to 80 A	4 to 200 A	20 to 80 A	40 A	40 A, 50 A
Switching frequency					
8 to 30 kHz	50 to 100 kHz	2 to 20 kHz	16 to 60 kHz		
IGBT series					
H	V	M	HB	HB2 *	IH *
Focus Applications					
Home appliances (fans, pumps, washing machines and dryers)	Welding, high frequency converters, PFC, solar, UPS, charger	Industrial motor control, automotive traction inverter, GPI, Air-Con	High frequency converters, PFC, solar, UPS, charger, welding and induction heating		Induction heating and soft switching

* Enlargement in development

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≥1200V IGBTs Series

in Trench Gate Field Stop

For rugged, efficient and reliable industrial power drives and more

- ✓ Best trade-off Static-Dynamic Characteristics
- ✓ Max junction temperature (T_j max) of 175˚C
- ✓ From 2 up to 100 kHz
- ✓ Very fast freewheeling diode option

Breakdown Voltage			
1200V			1250V
Current			
15 to 75 A	8 to 75 A	15 to 40 A	20 A, 30 A
Switching frequency			
Up to 8 kHz	2 to 20 kHz	20 to 100 kHz	16 to 60 kHz
IGBT series			
S	M	H	IH
Focus Applications			
Industrial motor control, GPI, Air-Con		PFC, welding, high frequency converters, solar, UPS, charger	Induction heating, microwave and soft switching

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STripFET™ F7

40-100V Power MOSFET Technology

Key Characteristics

- Among the best RDS(on) in the market
- Minimal RDS(on) x Qg (FoM)
- Low input capacitances
- Optimized Crss/Ciss capacitance ratio
- High avalanche ruggedness
- Low intrinsic diode recovery charge

Application

- Power Tools
- Fork Lifts
- Electric Light Transportation
- TELECOM and SERVER
- SMPS
- Adapter/Battery Charger
- UPS
- Solar Inverter
- Lighting/Display

Features

- Extremely Low Rds(on)
- Optimized body diode (low Qrr)
- Intrinsic capacitances (Optimal capacitance Crss/Ciss ratio)
- ST provides several package solutions, including PowerFLAT 5x6 and H^2PAK

Benefits

- Low conduction losses
- Excellent switching performance (higher efficiency)
- No EMI issue
- A more complete solution provided to the customer

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STripFET™ F8

30-150V Power MOSFET for High End > 500KHz

Applications

- Power Tools
- Fork Lifts
- Electric Light Transportation
- Telecom and Servers

- SMPS
- Adapter/Battery Charger
- UPS
- Solar Inverter
- Lighting/Display

Features

- Lower R_{DS}(on) x Area (-40% Vs. F7)
- Extremely Low Qg/Qgd
- Qrr & Soft switching F7 like
- Extremely low thermal resistance

Benefits

- Reduced conduction power losses
- Reduced switching losses and passive sizes
- Reduced noise immunity
- Improved current capability and power dissipation
- Low EMI & turn on losses
- Extended package offer to enhance silicon performance

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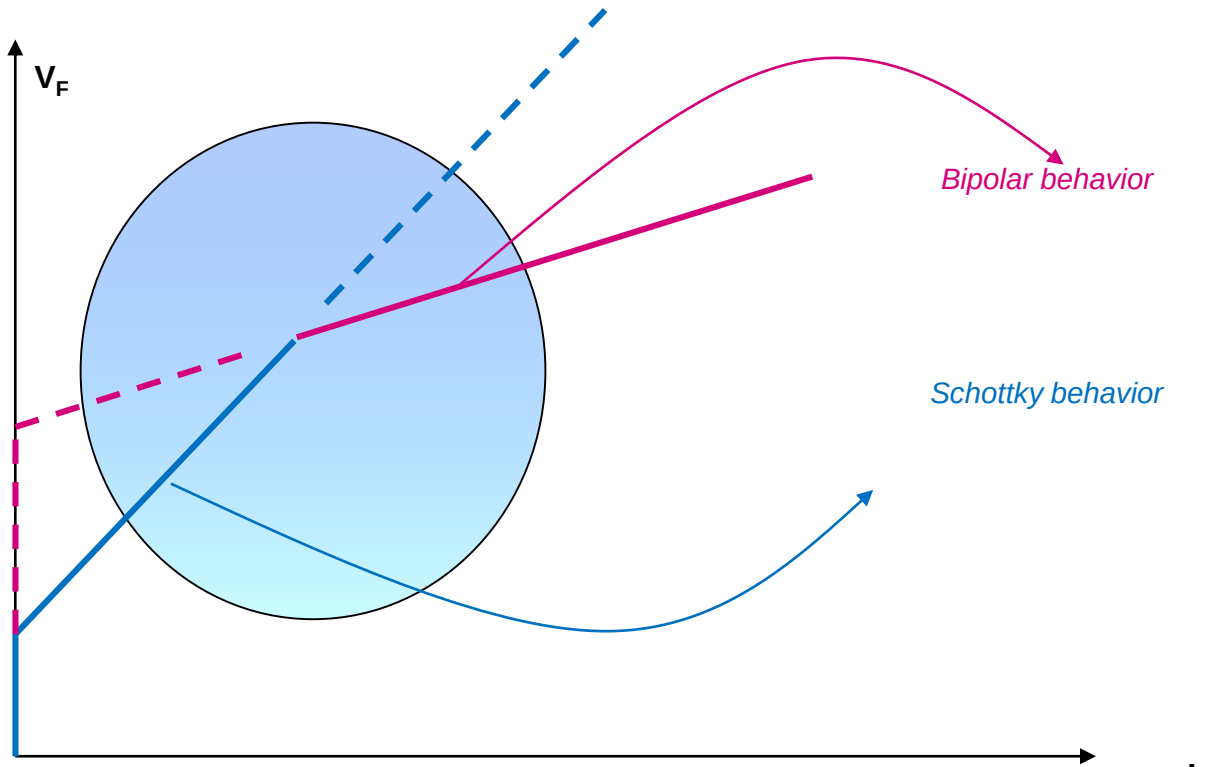
650V-1200V G2 SiC Rectifiers for EV

SiC 650V G2 and 1200V Technology: using JBS (Junction-Barrier Schottky)

- **Soft switching behavior**
- **Low forward conduction losses**
  Low switching losses
- **High forward surge capability**
- **High power integration**



The addition of P+ implantation in the Schottky structure creates P/N junctions.The surge forward current capability can be increased while keeping $T_J < T_{J(MAX)}$

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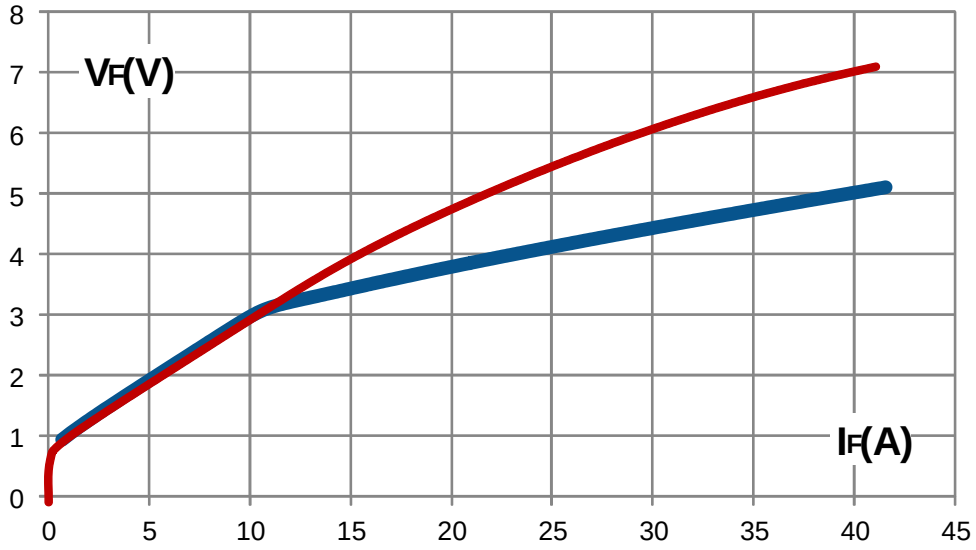
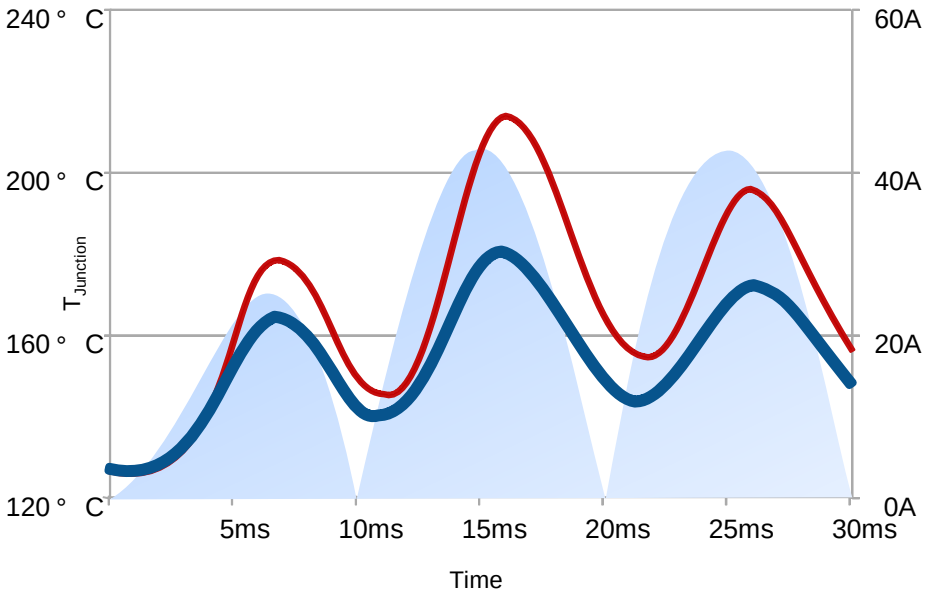
650V-1200V G2 SiC

Superior performances vs competition





SUPERIOR FORWARD SURGE CAPABILITY

More efficient clamping effect vs. best Competitor

SMALLER TEMPERATURE SWING

Better clamping effect and lower V_F reduces the $T_{junction}$ during transient phases in the application.

ST **Best Competitor**

1000W PFC start-up Pspice simulation
90V, 70kHz, Cout = 600µF, L = 270µH, Tc = 125°C

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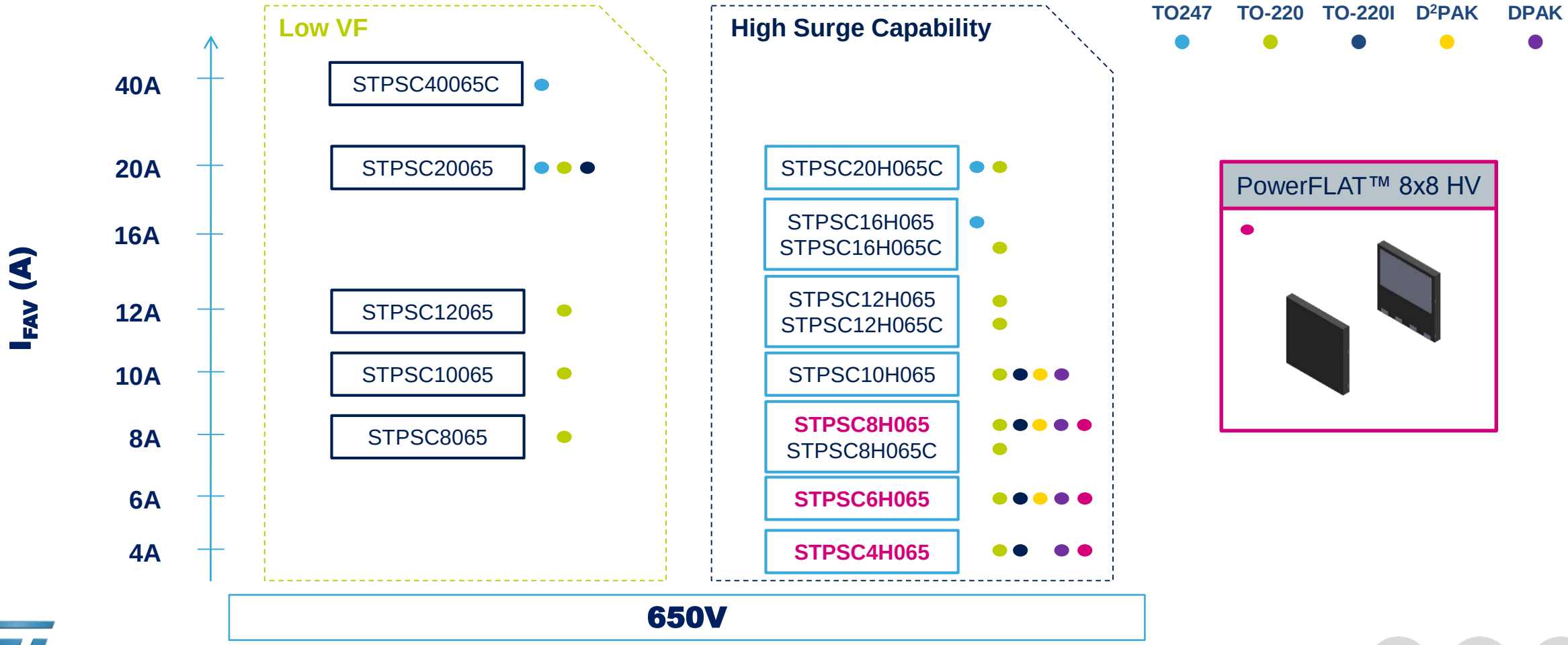
650V SiC Diode Portfolio

Extend Package Portfolio with Flat Package



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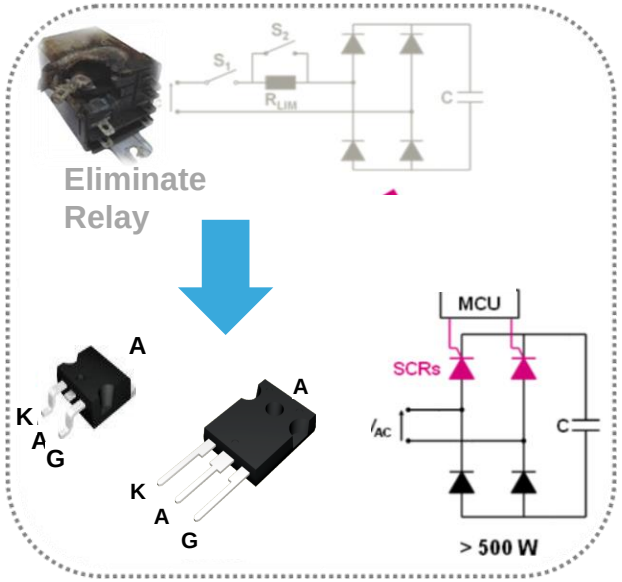
AG Thyristors for EV Charging

In-rush current limiting SCR for OBC

Features	TN5050H	TN3050H
V_{DRM} / V_{RRM}	1,200V over T_J range	
Max T_J	-40°C to +150°C	
V_{DSM} / V_{RSM}	1300V	1400V
I_{TRMS} (T_C=125°C)	80A	30A
I_{TSM} (10ms,25°C)	580A	300A
V_{TO} (150°C)	0.88V	0.88V
R_D (150°C)	6 mΩ	14 mΩ
I_{GT} (25°C)	10 to 50 mA	10 to 50 mA
dV/dt (800V-150°C)	1 kV/µs	



Design Value

- AEC-Q101 PPAP Available on request
- High switching life expectancy
- Enable systems to resist 6kV surge
- High speed power up / line drop recovery

A smart way to turn on your system

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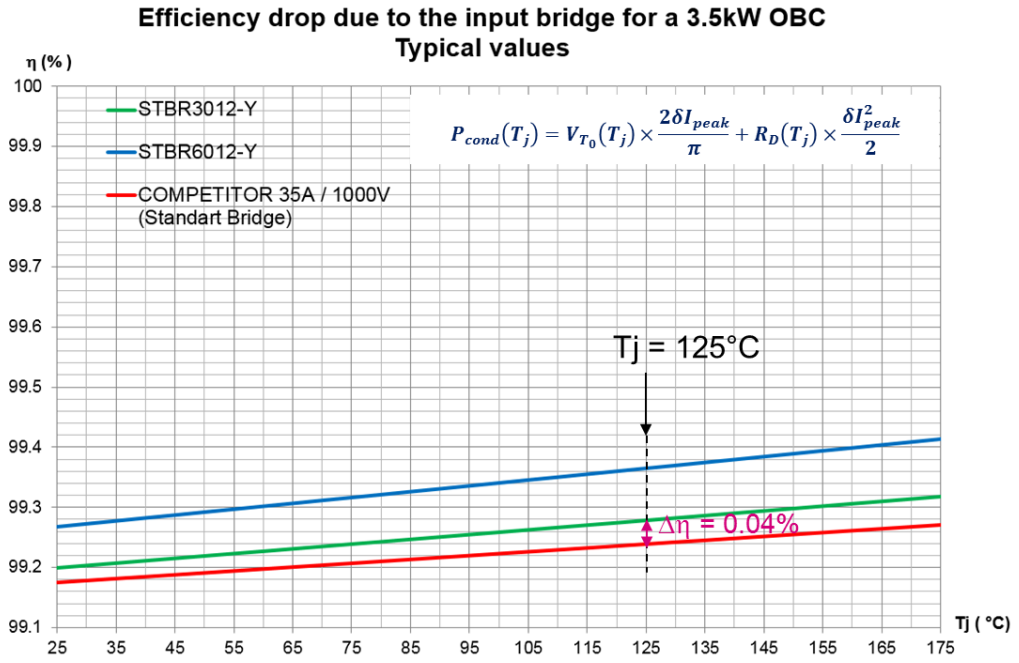
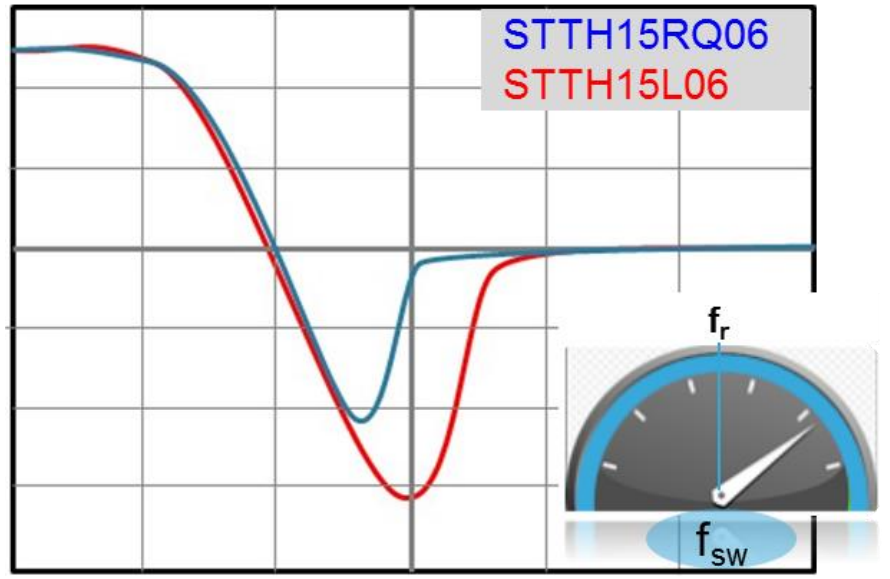
ST Fast Rectifier for EV Charging

ST Rectifiers for Input Bridge & Output Resonant



STBR: Lower V_F / Lower drop



STRQ: Q_{RR} better by factor of 2 and Soft switching

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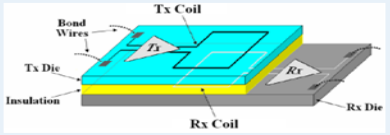
Existing Isolation Technologies

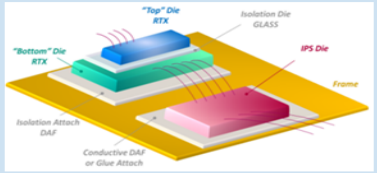
Isolation technologies

Polymeric/Ceramic Isolation

Isolation: film of **polymer** (or other dielectric such as DAF, glass). Custom assembly process required.

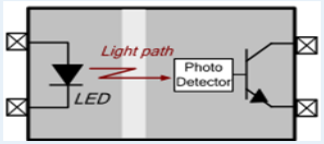
RF Couplers

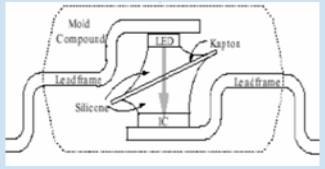




- Good **parametric stability** over time
- **Good CMTI immunity**
- **Limited** communication **speed**
- **Assembly complexity**

Optocouplers



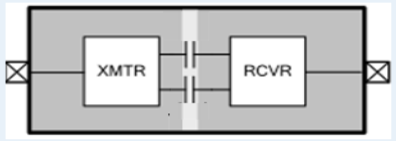


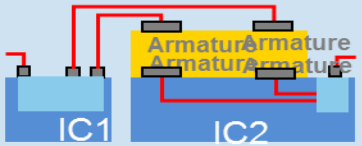
- Dielectric **ageing**: **parametric instability** over time
- **Limited CMTI immunity**

Thick Oxide Isolation

Isolation: **Silicon Oxide** grown on top of active silicon area (standard silicon IC technologies)

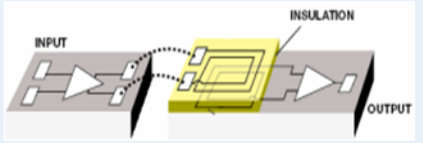
capacitive coupling

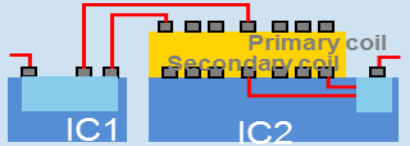




- Good **parametric stability** over time
- **Limited CMTI immunity**
- **Sensitive** to electric fields

magnetic coupling





- Good **parametric stability** over time
- **Very good CMTI immunity**
- Good **immunity to magnetic and electric fields**

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gapDRIVE™: Galvanically Isolated Gate Driver

Galvanically Isolated Gate Driver technology

- Automotive (Hybrid\Electric Vehicles)
  - Motor Control
  - DC/DC Converters
  - Battery Chargers

- Industrial
  - 600/1200V Inverters
  - Automation, Motion Control
  - Welding

- Power Conversion
  - Solar Inverters
  - UPS Systems
  - AC/DC, DC/DC Converters
  - Windmills

- Home/Consumer
  - Induction Cooking
  - White goods

The STGAP1S ***galvanically isolated*** gate driver features advanced **controls**, **protection** and **diagnostics.**

- **CONTROL:** A SPI interface to enable, disable and configure several features → Optimize your driving conditions.
- **PROTECTION:** Several features to mange anomalous conditions (OCP, DESAT, 2LTO, VCE_Clamp) and to prevent them (UVLO, OVLO, ASC, MillerCLAMP)
- **DIAGNOSTIC:** The SPI interface allows access to registers containing information about the status of the device.

Main Applications

Industrial Drive

EV / HEV

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STGAP1S – Main Features

Galvanically Isolated Gate Driver technology

AEC-Q100 grade 1
Wide operating range (-40°C -125°C)

+

SPI Interface
Parameters programming and diagnostics
Daisy chaining possibility

+

Advanced features
5A Active Miller clamp, Desaturation,
2-level turn-off, VCEClamp, ASC

+

Short propagation delay
(100 ns typ.; 130 ns max over temperature)
5A sink/source current

+

Fully protected – System safety
UVLO, OVLO, Over-Current, INFilter,
Thermal Warning and Shut-Down

+

High Voltage Rail up to 1.5 kV
Positive drive voltage up to 36V
Negative Gate drive ability (-10V)

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STGAP1S Isolation Characteristics

Conforms with IEC60664-1, IEC60747-5-2 and UL1577 standards

Parameter	Symbol	Test Conditions	Characteristic	Unit
Maximum Working isolation Voltage	V_{IORM}		1500	V_{PEAK}
Input to Output test voltage	V_{PR}	Method a, Type and sample test $V_{PR} = V_{IORM} \times 1.6$, $t_m = 10$ s Partial discharge < 5 pC	2400	V_{PEAK}
		Method b, 100% Production test $V_{PR} = V_{IORM} \times 1.875$, $t_m = 1$ s Partial discharge < 5 pC	2815	V_{PEAK}
Transient Overvoltage	V_{IOTM}	Type test; $t_{ini} = 60$ s	4000	V_{PEAK}
Maximum Surge isolation Voltage	V_{IOSM}	Type test;	4000	V_{PEAK}
Isolation Resistance	R_{IO}	$V_{IO} = 500V$ at T_S	$> 10^9$	Ω
Isolation Withstand Voltage	V_{ISO}	1 min. (type test)	2500\3536	$V_{rms\ PEAK}$
Isolation Test Voltage	$V_{ISO,test}$	1 sec. (100% production)	3000\4242	$V_{rms\ PEAK}$

Parameter	Symbol	Value	Unit	Conditions
Creepage (Minimum External Tracking)	CPG	8	mm	Measured from input terminals to output terminals, shortest distance path along body
Comparative Tracking Index (Tracking Resistance)	CTI	≥ 400		DIN IEC 112/VDE 0303 Part 1
Isolation group		II		Material Group (DIN VDE 0110, 1/89, Table1)

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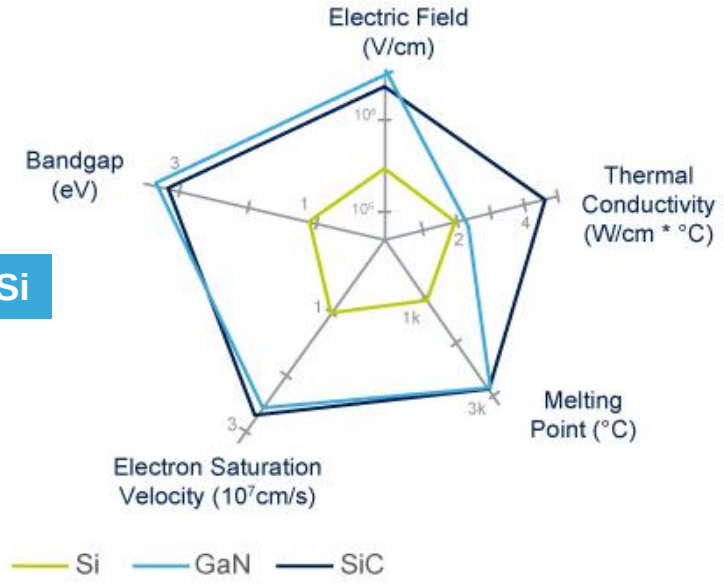
650V &1200V SiC MOSFETs

The real boost for efficient designs

Lower Losses, High Efficiency, Reduced Footprint: Breakthrough in High-Voltage Converters

- Leading to new technology platform with awesome Figure Of Merit
- Very low on-state resistance
- 200°C Max junction temperature
- Very fast and robust intrinsic body diode
- Industrial and Automotive Grade qualified
- Outstanding system efficiency and reduced cooling requirements

WBG and Si



Applications

- Traction inverters
- On board chargers
- DC-DC converters
- SMPS
- Auxiliary power supplies
- UPS
- Solar
- Welding

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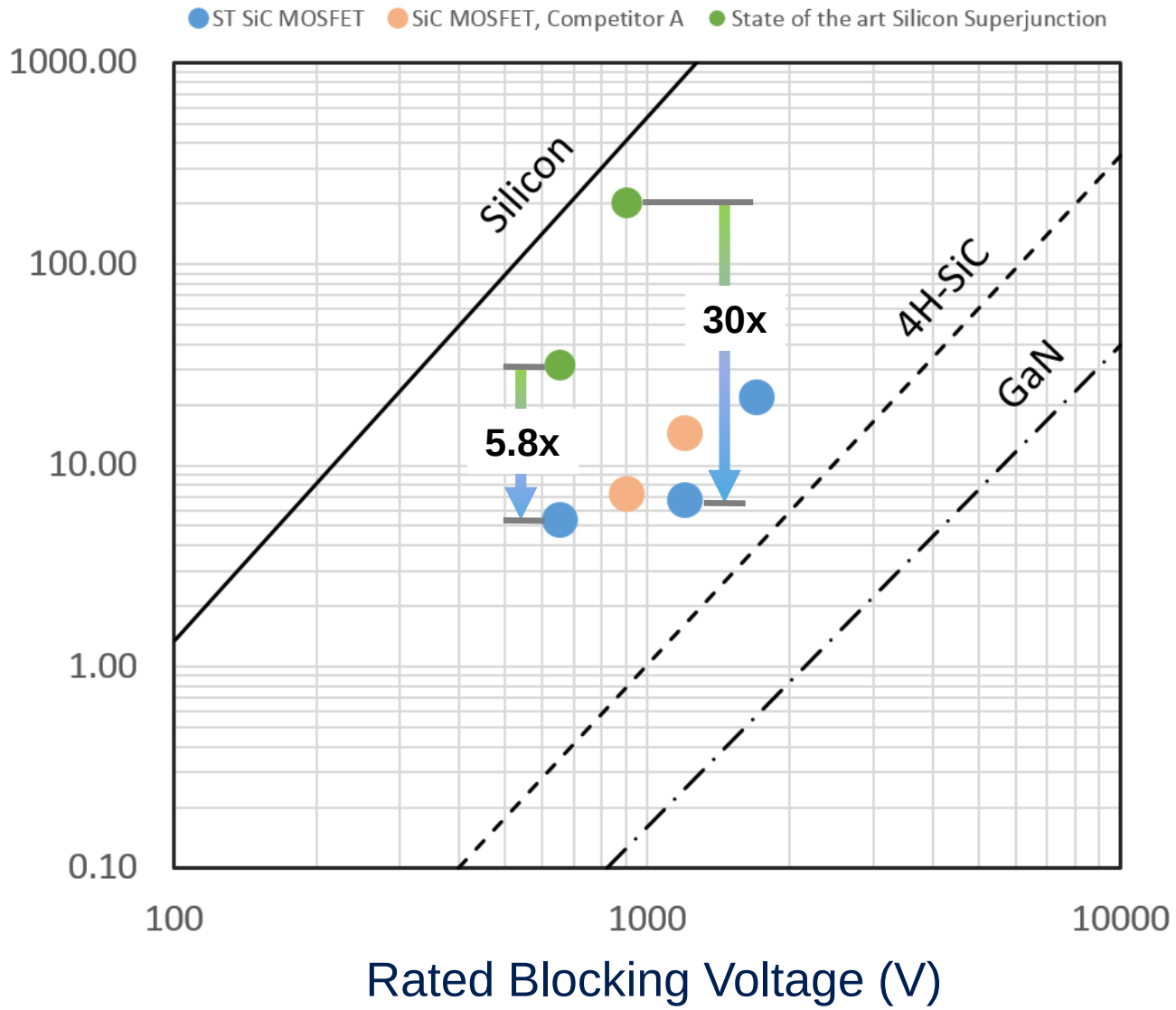
MOSFET $R_{DS(on)}$ Figure of Merit at T_J=150ºC



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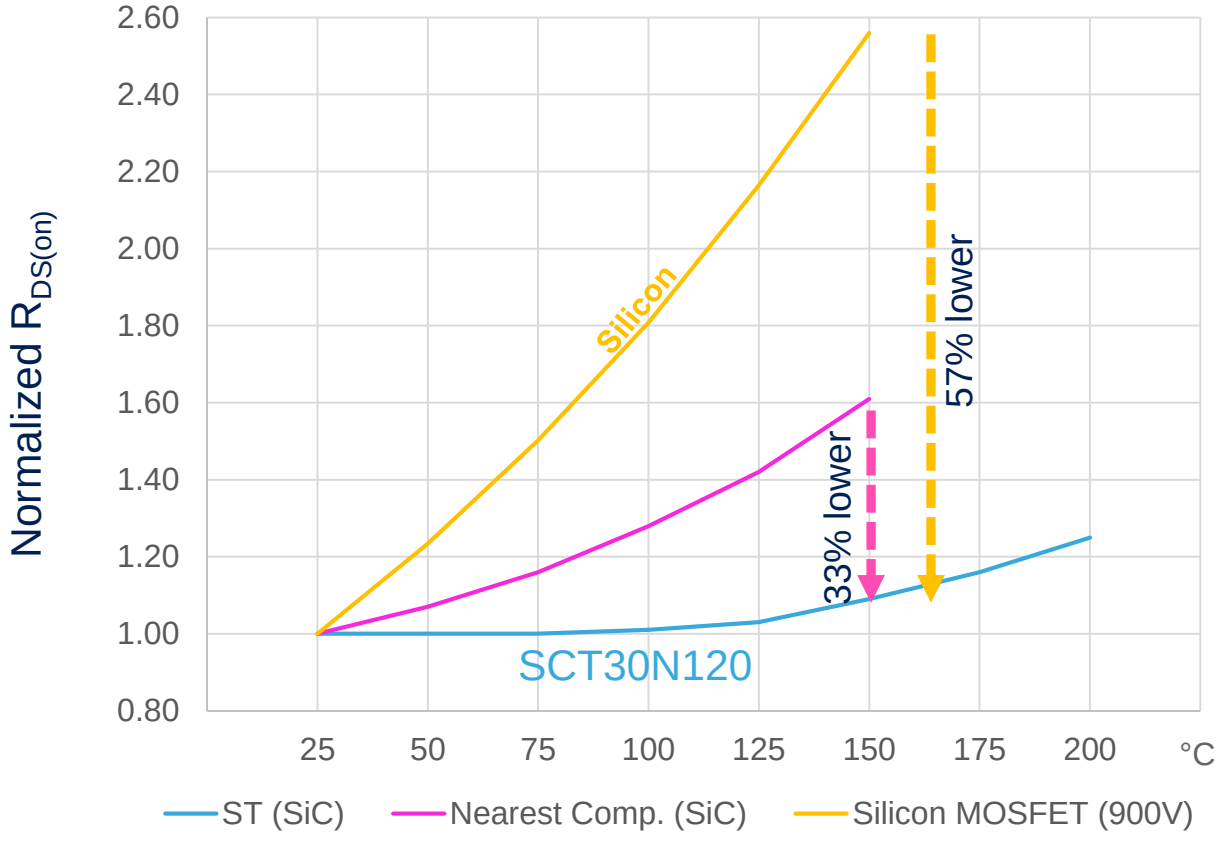
$R_{DS(on)}$ Variation with Temperature

1200V SiC MOSFET



ST is the only supplier to guarantee max Tj as high as 200°C in plastic package

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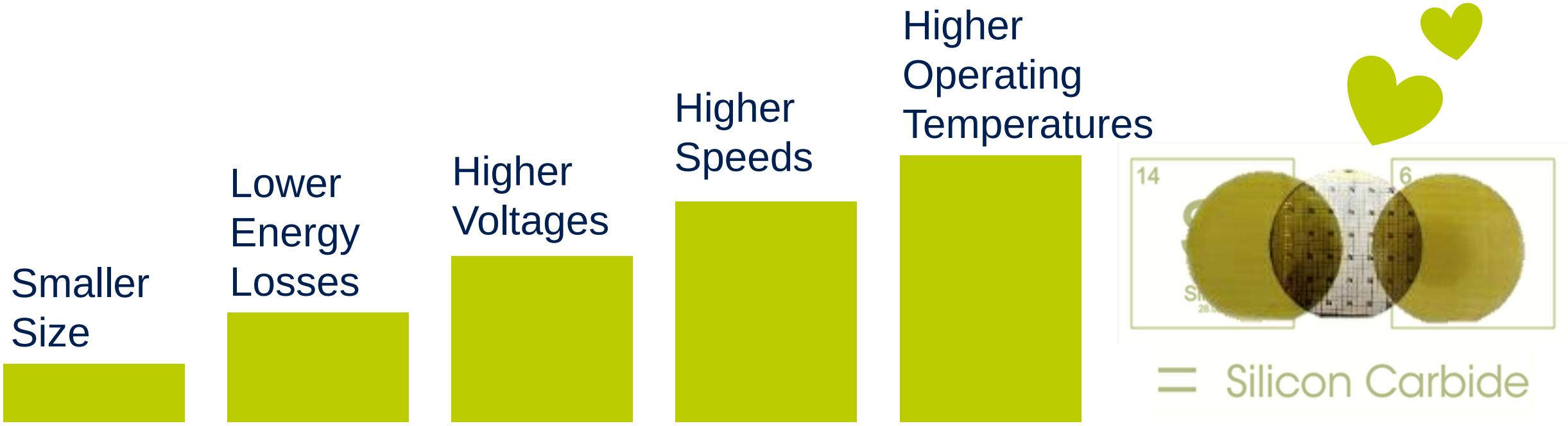
Why Silicon Carbide?

It's all about the Bandgap

Silicon Carbide allows Power Devices to go beyond the limits of Silicon...



...and makes high-voltage power-applications smarter

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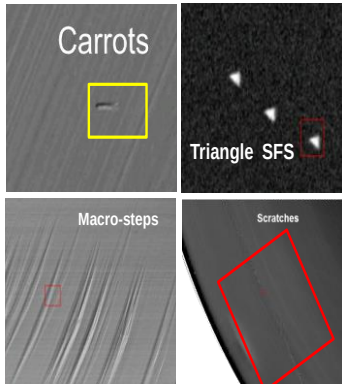
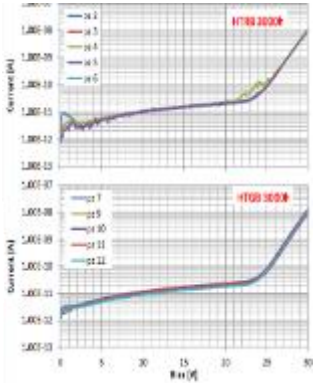
Challenges for Silicon Carbide

Technical

Defectivity



Reliability



Manufacturing


EPI SiC


Defectivity monitoring on epi and starting substrates

HT ion implanter


Very HT furnce


Line defectivity monitoring

Metal sputtering


lift-off tool

Capacity

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ST Silicon Carbide

20-Year History

April 1998
1st contract on SiC with CNR-IMETEM (Dr. V. Raineri)

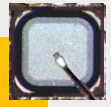
June 1996
Collaboration with Physics Dept. (Prof. G. Foti)

February 2003
ETC Epitaxial reactor prototype installed in ST

May 2002
Schottky Diode Demonstrator (CNR line)

November 2003
First ST internal product request

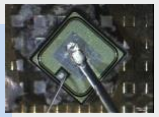
May 2004
Schottky Diode Demonstrator (ST line)



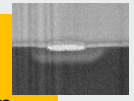
October 2007
1st Gen Diode Start Production

December 2005
Schottky Diode Mat 20

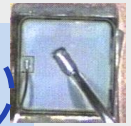
March 2009
Power MOSFET 3" Demonstrator



May 2012
2nd Gen Diode Start Production



September 2014
1st Gen MOSFET Start Production



June 2014
3rd Gen 3 Diode Start Production

June 2017
2nd Gen MOSFET AG 6" Start Production

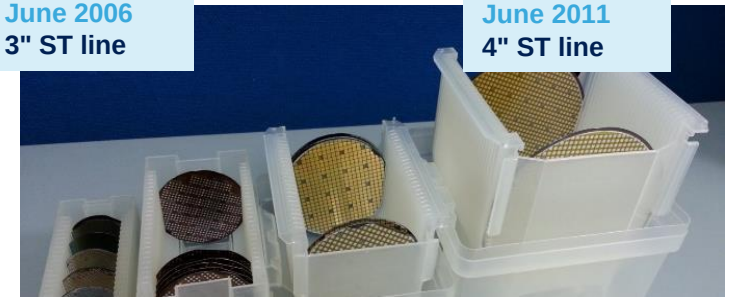
1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016…

Pioneers...

June 2003
2" ST line

June 2006
3" ST line

June 2011
4" ST line



June 2016
6" ST line

...to mass production

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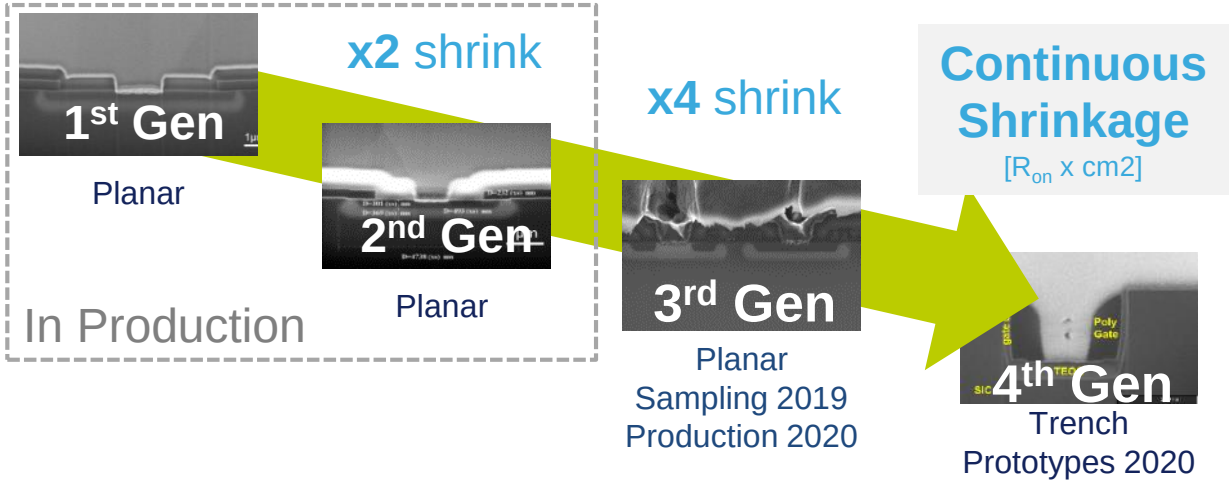
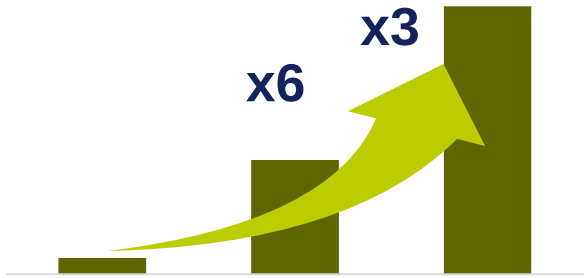
SiC MOSFET Facts at Glance

Front-end Evolution



Continuous Shrinkage
[R_{on} x cm2]

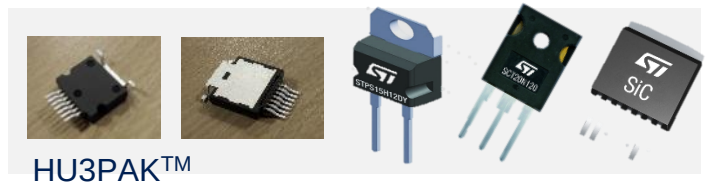
SiC adoption faster than expected



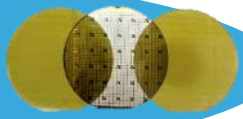
650 V to **1200 V**
MOSFETs and DIODEs

Package offer - Discrete - Mini-module - Modules

Discrete Packages

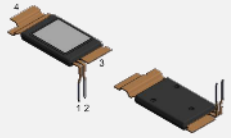


Bare Dice Strategic offer for Key Players



SiC Module focus for Largest Market

In Production

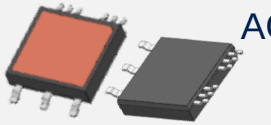


STPAK™

ACEPACK™ 1

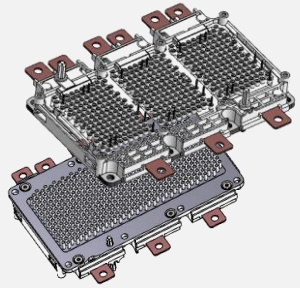
ACEPACK™ 2

Ramp-up by H1'19



ACEPACK™ SMIT

Production 2020



ACEPACK™ DRIVE

Production 2020

Traction Inverter

Advantages of SiC in Traction Inverters

Drive Train Electrification : Enabled by SiC Technology

	Silicon IGBT + Diode	SiC MOSFET
Die area for 100A nominal current [mm^2]	150	30
Max Junction temperature [°C]	175	200
Normalized switching energy	8	1
Normalized Power Loss(*) (Typical Mission profile)	7	1
Average junction temperature at nominal power [°C] (*)	100	80

Traction Inverter - End User Value Proposition

- Power Semiconductors size: Up to 70% smaller
- Cooling System: Up to 70% smaller
- Passive Components: Up to 80% smaller (**)

→ Up to 75% Overall size reduction

→ Up to 10% Mileage Extension

→ Extended life in use

1200V

(*) 210kWpeak, 350Arms peak, 200Arms continuous Traction Inverter, 750V bus, f_{PWM}=10kHz, T_{fluid} = 60°C
(**) applicable to High Power DC to DC converter when present

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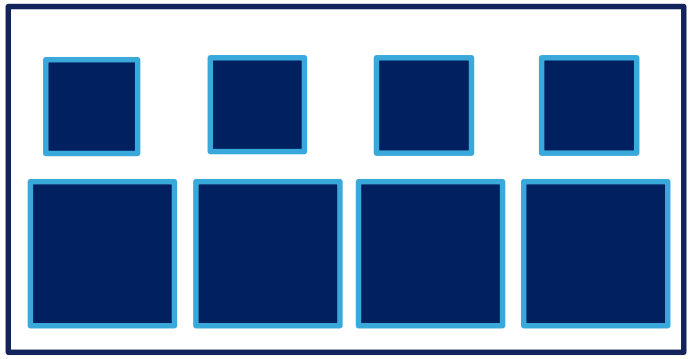
Si IGBT vs. SiC MOSFET – 1200V

Silicon Solution: IGBT+ Diode

4x100 mm² + 4x50 mm²

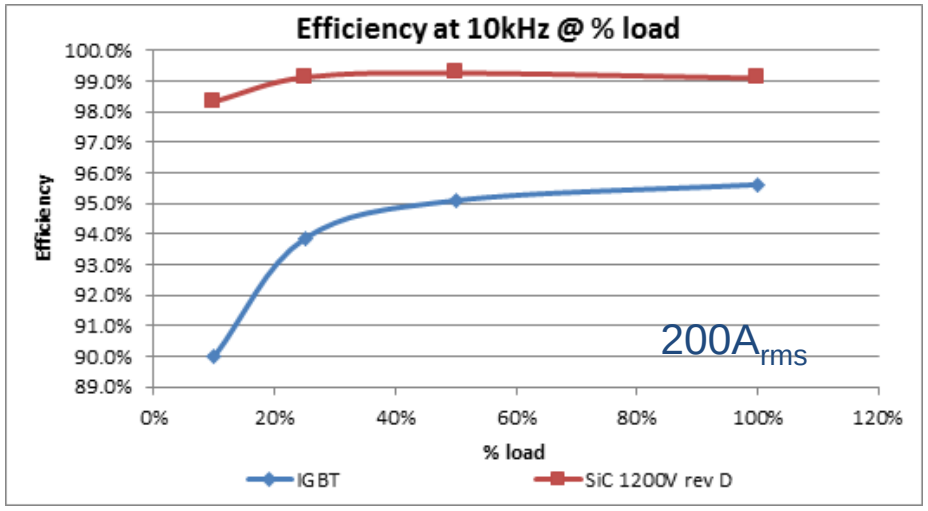


5x smaller semiconductor area

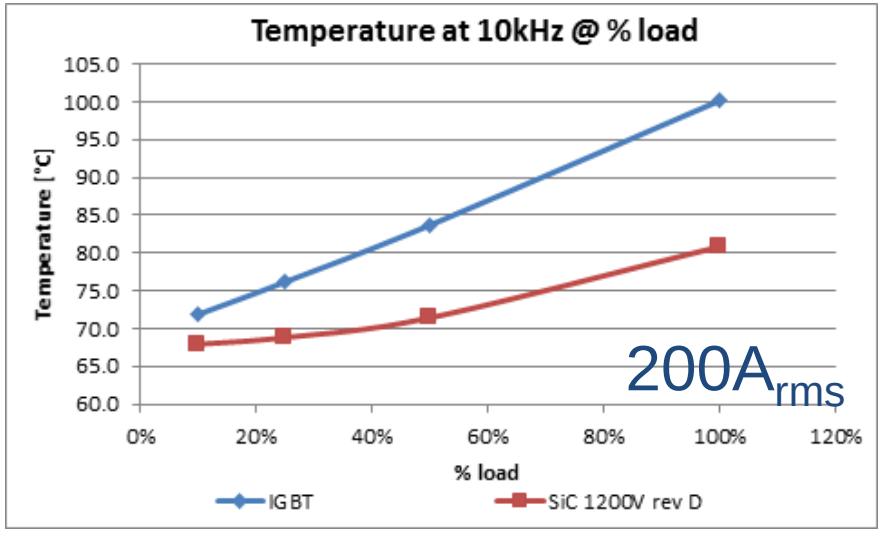
SiC MOSFET gen 3

Solution:6x20 mm2

Vbus = 750V, 200kW peak !!



DC-link voltage: 750V$_{dc}$, Switching frequency: 10 kHz, T$_{fluid}$ = 65°C, mi=0-5



From 3.5 to 10% higher efficiency

Si IGBT → SiC MOSFET

Lower temperature for higher reliability

Higher efficiency for extra mileage

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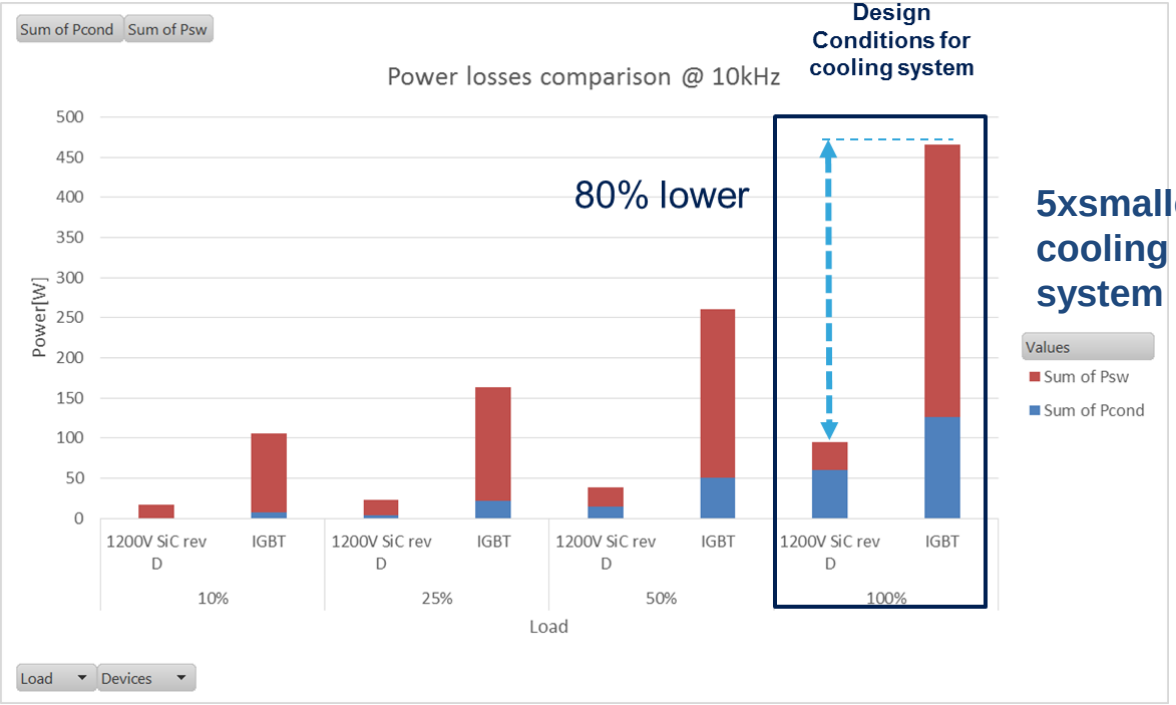
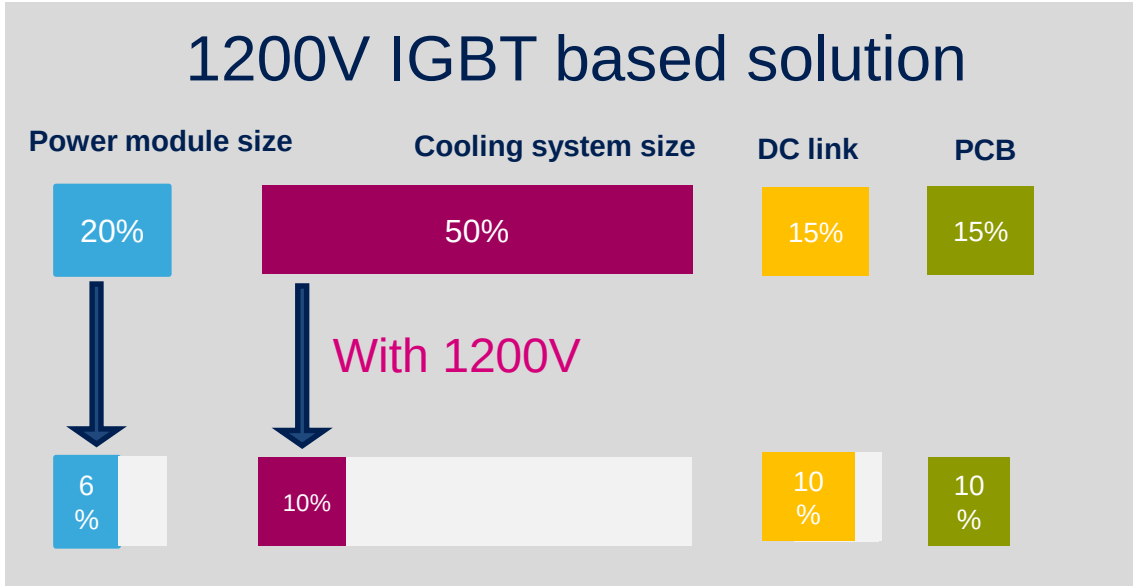
350A$_{rms}$ peak – 210kW, 200A$_{rms}$ nominal, DC-link voltage: 750V$_{dc}$, Switching frequency: 10 kHz, T$_{fluid}$ = 65°C

SiC MOSFET System Benefits – 1200V

Reducing PCU size





- $200A_{rms}$ continuous
- DC-link voltage: $750V_{dc}$
- Switching frequency: 10 kHz
- T_{fluid} = 65°C

Up to 70% smaller PCU

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Advantages of SiC in Traction Inverters

Drive Train Electrification : Enabled by SiC Technology

	Silicon IGBT + Diode	SiC MOSFET
Die area for 100A nominal current [mm^2]	100	26
Max Junction temperature [°C]	175	200
Normalized switching energy	6	1
Normalized Power Loss(*) (Typical Mission profile)	4	1
Average junction temperature at nominal power [°C] (*)	100	90

Traction Inverter - End User Value Proposition

- Power Semiconductors size: Up to 60% smaller
- Cooling System: Up to 50% smaller
- Passive Components: Up to 60% smaller (**)

→ Up to 50% Overall size reduction

→ Up to 6% Mileage Extension

→ Extended life in use

750V

(*) 170kWpeak, 525Arms peak, 300Arms continuous Traction Inverter, 400V bus, f_{PWM}=10kHz, T_{fluid} = 65°C
(**) applicable to DC to DC converter when present

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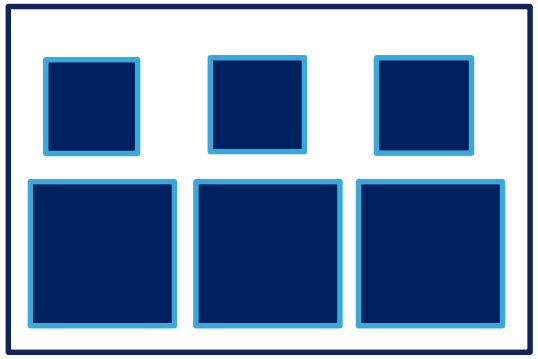
Si IGBT vs. SiC MOSFET – 750V

Silicon Solution: IGBT+ Diode

3x100 mm² + 3x50 mm²

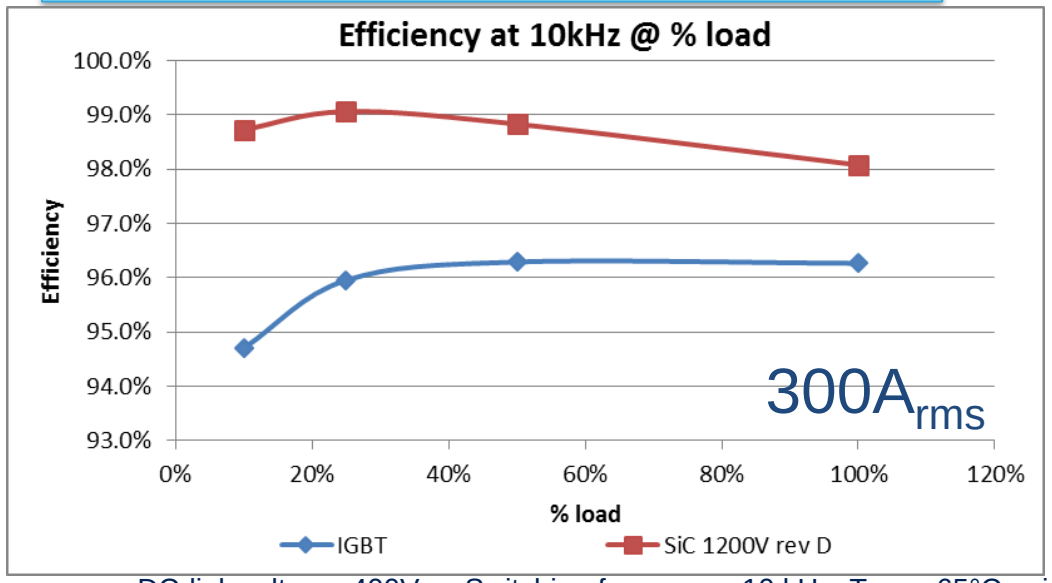


~4x smaller semiconductor area

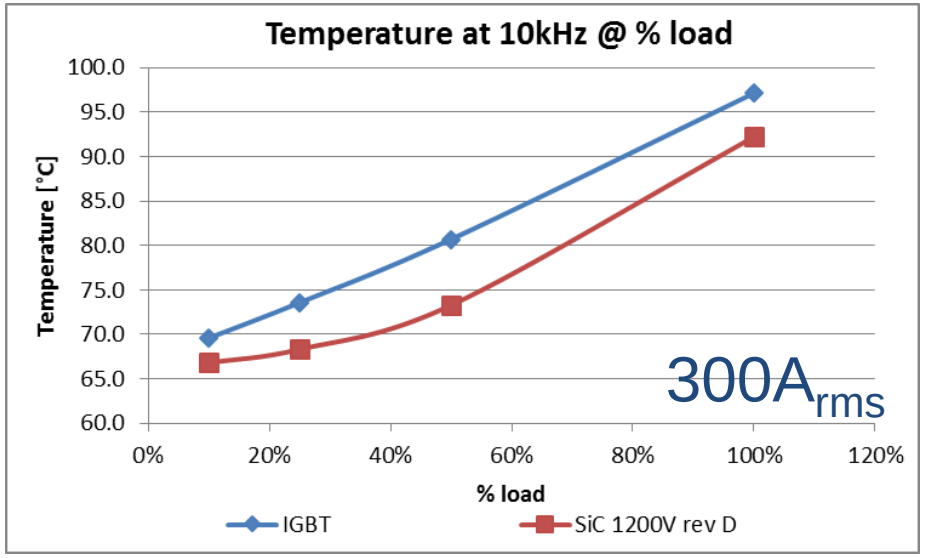
SiC MOSFET gen 3

Solution:6x20 mm2

Vbus = 400V 160kW peak !!



DC-link voltage: 400V_{dc} , Switching frequency: 10 kHz, T_{fluid} = 65°C, mi=0-5



From 2 to 4% higher efficiency

Si IGBT → SiC MOSFET

Higher efficiency for extra mileage

Lower temperature for higher reliability

525A_{rms} peak – 170kW, 300A_{rms} nominal, DC-link voltage: 400V_{dc} ,
Switching frequency: 10 kHz, T_{fluid} = 65°C

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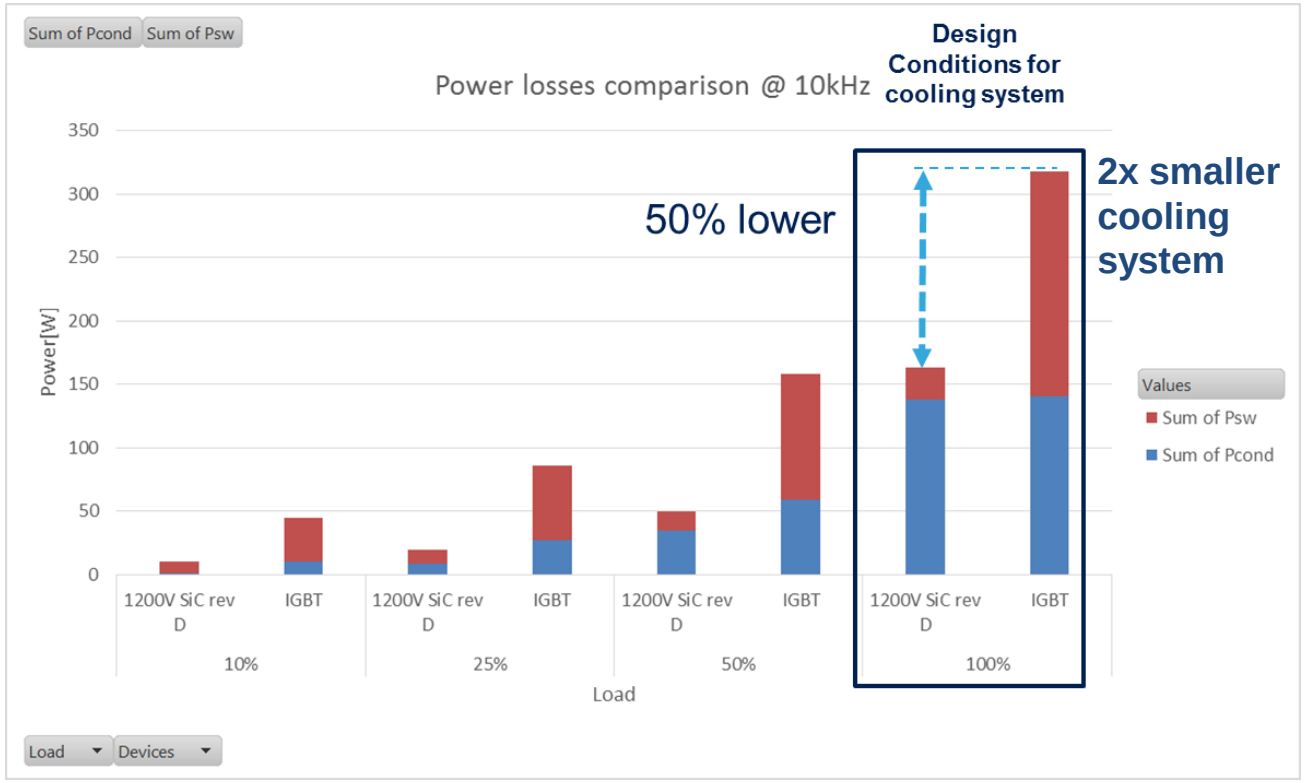
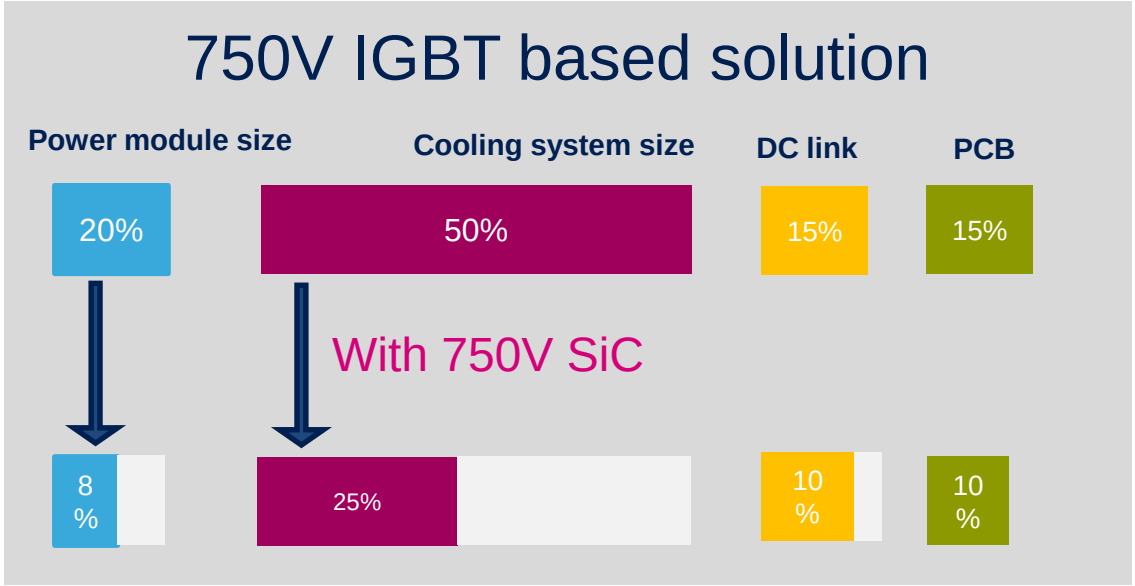
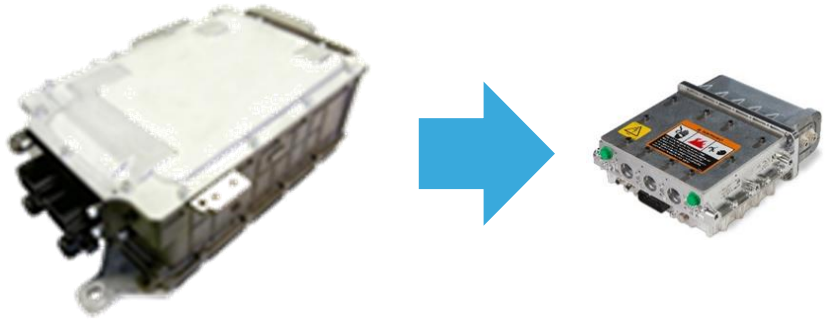
SiC MOSFET System Benefits – 750V

Reducing PCU size





- 300A_{rms} continuous
- DC-link voltage: 400V_{dc}
- Switching frequency: 10 kHz
- T_{fluid} = 65°C



Up to 50% smaller PCU

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Case Study 11kW, 3-Phase OBC

SiC Advantages in On-Board Battery Chargers

	Silicon IGBT + Diode	SiC MOSFET + Diode	OBC - End User Value Proposition
Losses [W]	300	216	Reduce heatsink size
Switching Frequency [kHz]	25	100/150	Reduce passive component size
Volume* [cm^3]	4593	1986	Reduce congestion and decrease car weight
Weight* [g]	7708	3074	
Efficiency** [%]	96.9	97.7	Higher Efficiency

60% weight, volume reduction

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*including heatsink , passive components, [illegible]
**only due to semi-conductor components

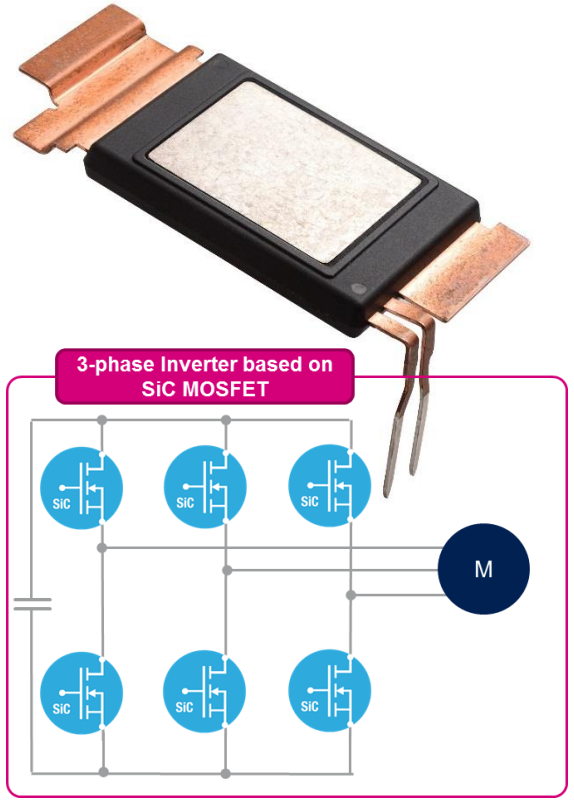
STPAK™: Multi-Sintering Package

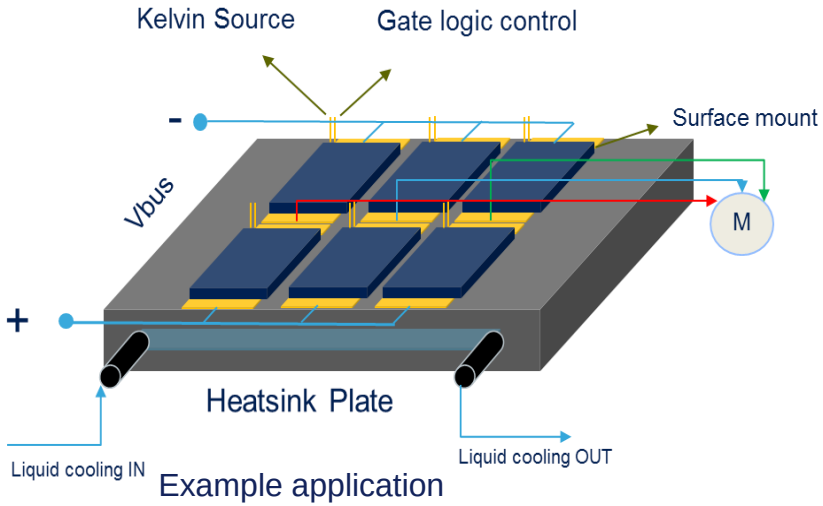
Ideal for Electric Vehicle applications

High Power Density for Traction Inverter

Main Features & Benefits

- Multi sintering solution for better performance and higher reliability
- AEC-Q101 qualified, Tj (max) =175°C
- 650V / 1200V Voltage rated
- Suitable for silicon IGBT and SiC Power MOSFET technologies
- Compact and modular design approach
- High power density
- Improved thermal performance due to direct sintering to the bottom of the heatsink
- Sense pin for enhanced control





Example application

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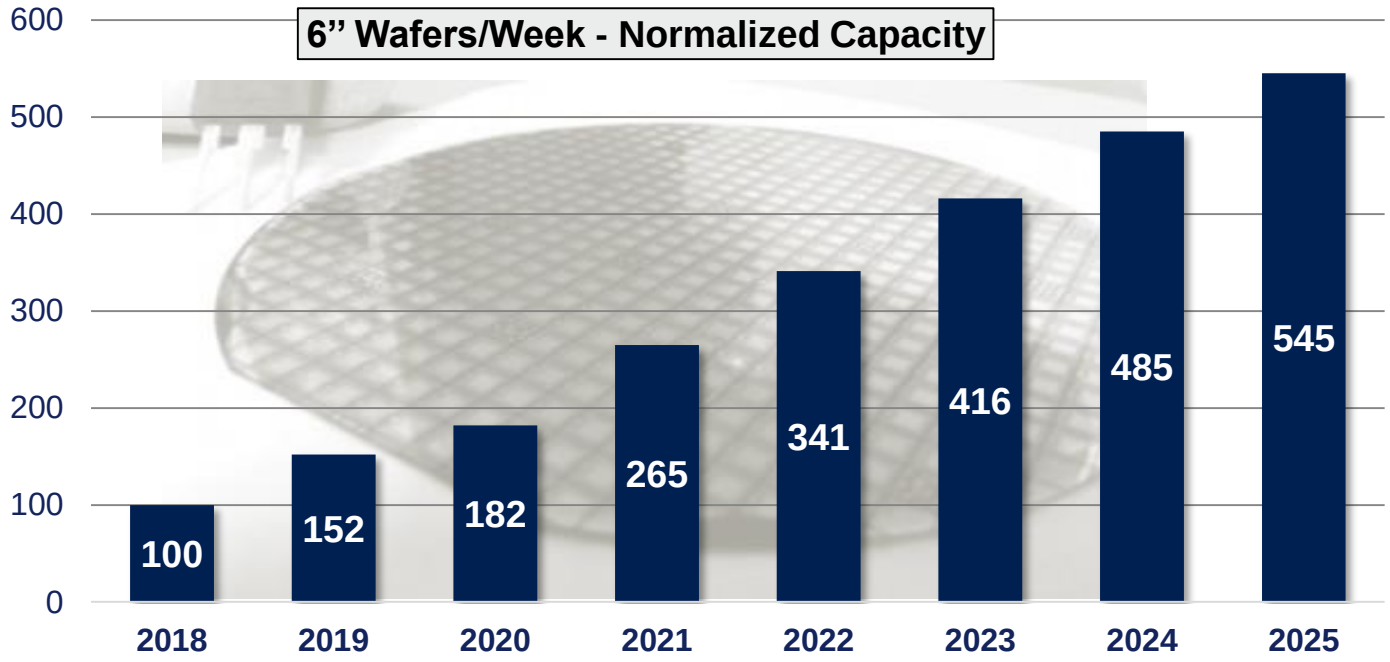
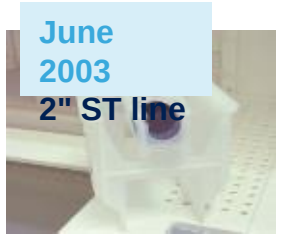
ST Silicon Carbide Manufacturing Evolution

Catania 6” wafer size capacity



Pioneers..



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2003 – 2” line startup → 2006 – 3” line startup → 2011 – 4” line startup → 2016 – 6” line startup

SiC-Substrate Supply-Management Strategy

- **Current Suppliers**
  - **4 Suppliers** already qualified and in full production
    - LTA already finalized with a key supplier:

Cree and STMicroelectronics Announce Multi-Year Silicon Carbide Wafer Supply Agreement

Agreement to boost commercial expansion of SiC in automotive and industrial applications

DURHAM, N.C. and GENEVA /07 Jan 2019

Cree, Inc. (**Nasdaq: CREE**) announces that it signed a multi-year agreement to produce and supply its Wolfspeed® silicon carbide (SiC) wafers to STMicroelectronics (NYSE: STM), a global semiconductor leader serving customers across the spectrum of electronics applications. The agreement governs the supply of a quarter billion dollars of Cree's advanced 150mm silicon carbide bare and epitaxial wafers to STMicroelectronics during this period of extraordinary growth and demand for silicon carbid e power devices.

"ST is the only semiconductor company with automotive-grade silicon carbide in mass production today, and we want to press forward to grow our SiC business both in terms of volume and breadth of applications served, targeting leadership in a market estimated at more than $3B in 2025," said Jean-Marc Chery, president and CEO of STMicroelectronics. "This agreement with Cree will improve our flexibility, sustain our ambition and plans, and contribute to boosting the pervasion of SiC in automotive and industrial applications

- **Long term Plan (Toward a full Vertically Integration)**
  - A strategic partnership with a new Supplier has just been closed (beg 2019) :

STMicroelectronics to Acquire Majority Stake in Silicon Carbide Wafer Manufacturer Norstel AB

Acquisition will extend ST's silicon carbide ecosystem and strengthen ST's flexibility to serve fast growing automotive and industrial applications

Geneva, Switzerland / 06 Feb 2019

STMicroelectronics (NYSE: STM), a global semiconductor leader serving customers across the spectrum of electronics applications, today announced it has signed an agreement to acquire a majority stake in Swedish silicon carbide (SiC) wafer manufacturer **Norstel AB ("Norstel")**. After closing, ST will control the entire supply chain for a portion of its SiC devices at a time of constrained global capacity and positions itself for a significant growth opportunity. ST will acquire 55% of Norstel's share capital, with an option to acquire the remaining 45% subject to certain conditions, which, if exercised, will result in total consideration of $137.5 million, funded with available cash.

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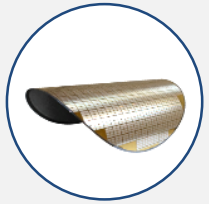
life.augmented NORSTEL

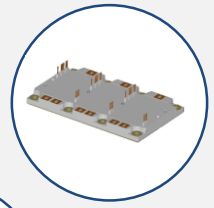
SiC Technology Summary



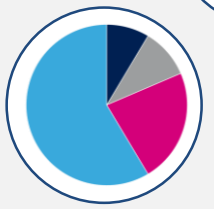
6” wafer production and EPI process step in-house in ST

AEC-Q101 Automotive Grade

MOSFET and Diode products available and significantly growing for 1200V and 650V



Bare Die, Discrete Package and Module offer



Standard product offer and customized solutions

- **Battery Electric Vehicles** are disrupting the automotive market
- **SiC Technology** enables an optimized total cost of ownership model, for both automotive (traction Inverters on-board chargers) as well as Industrial (Solar, UPS, energy storage) domains
- **Introducing** the new material in **Automotive** is challenging but our experience shows it’s manageable
- **Ramp up** of SiC Technology in STMicroelectronics is much faster than market expectation

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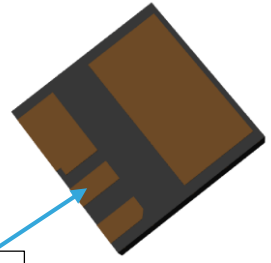
Gallium Nitride (GaN): a new member of

ST's Wide Band-Gap family

Enables increased power density, higher frequency operation and improved efficiency

First product under development:
SGT120R65ALD*

PowerFLAT™ 8x8

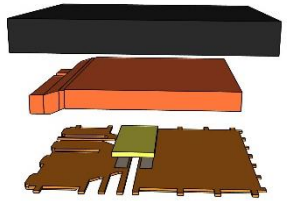


Kelvin pin for optimized Gate Driving

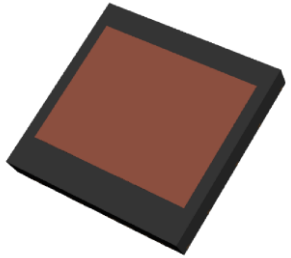
Product Features

RDS(on) = 120 mΩ @10 A

- BVdss > 650 V



Package section



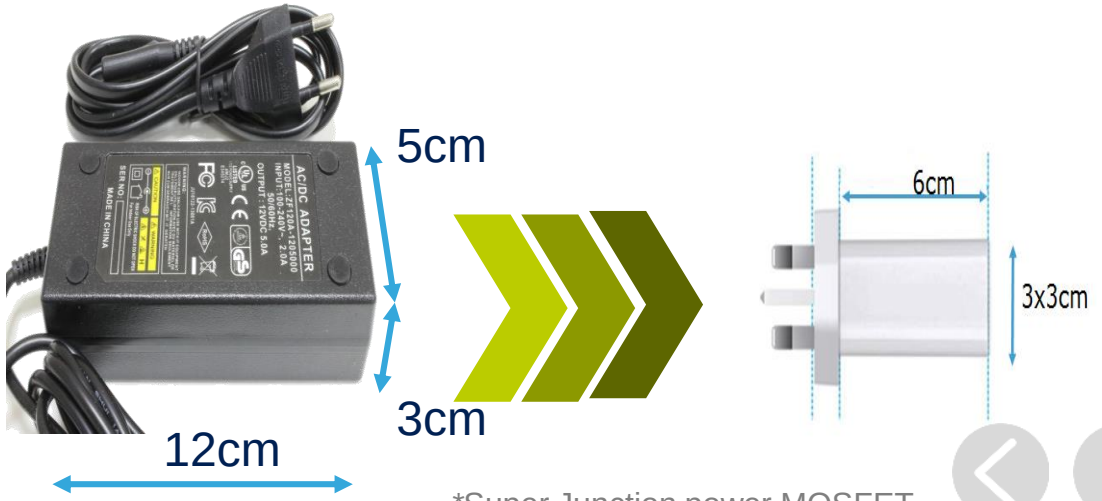
Top Side Cooling

Key Benefits

- Main breakthrough for High-Voltage Power conversion
- Compact Design
- Smaller form factor and increased Power density

Conventional adaptor based on Silicon switch*

Adaptor based on GaN switch



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*Under Development

*Super Junction power MOSFET

ST App finder

MOSFET

IGBT

Brand new finders, to allow an easier and faster recollect of the most important information about any power transistor in ST's portfolio.

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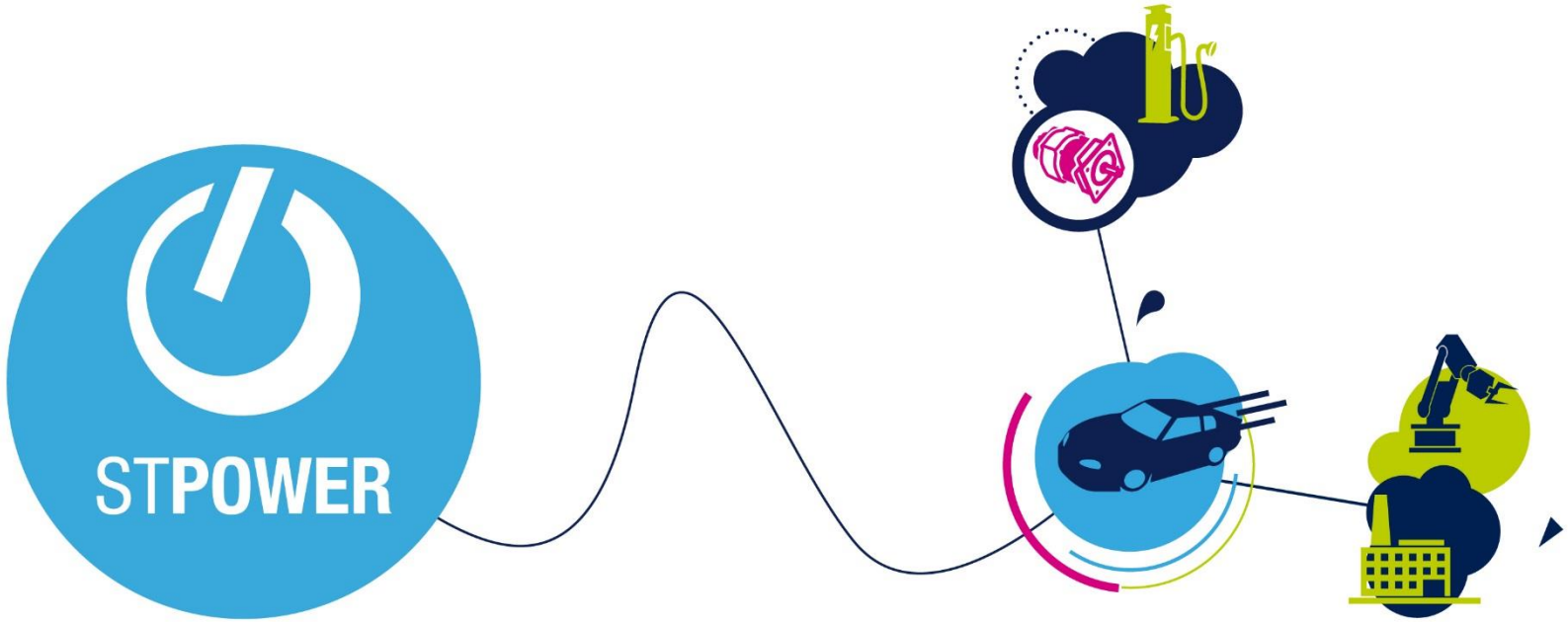

www.st.com/stpower

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