Microchip Silicon Carbide (SiC) Power Solutions

A Leading Provider of Smart, Connected and Secure Embedded Solutions

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August 31, 2021

SMART | CONNECTED | SECURE

Agenda

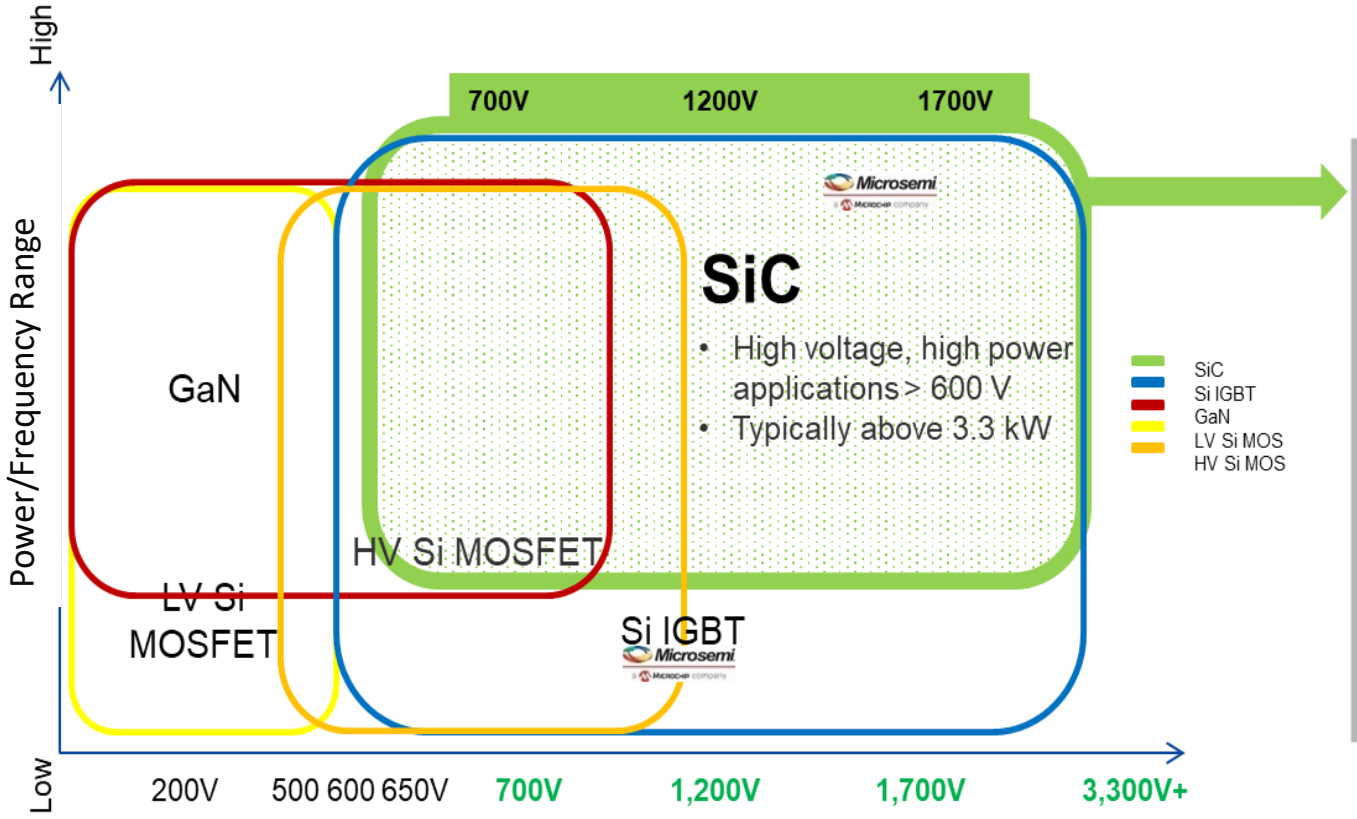
- SiC Technology Differentiation
- Reliability Considerations
- Target Markets and Applications
- SiC Power Solutions
- Quality, Supply and Support
- Key Takeaways

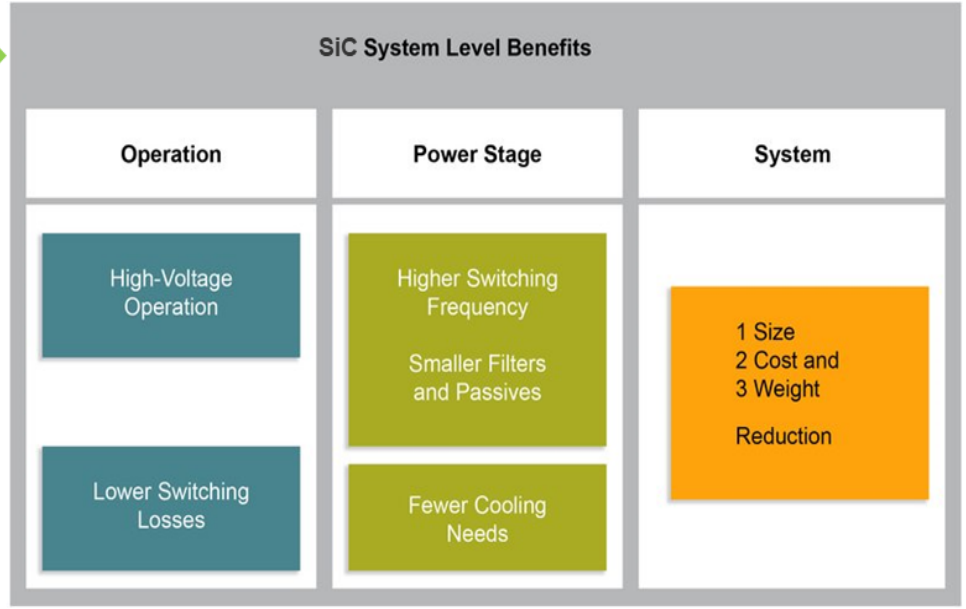
SiC Differentiation

Compared to Silicon and GaN

When to Consider SiC vs. Si and GaN

- **High-voltage power electronics applications using SiC power semiconductors to achieve maximum efficiency, power density and reliability**





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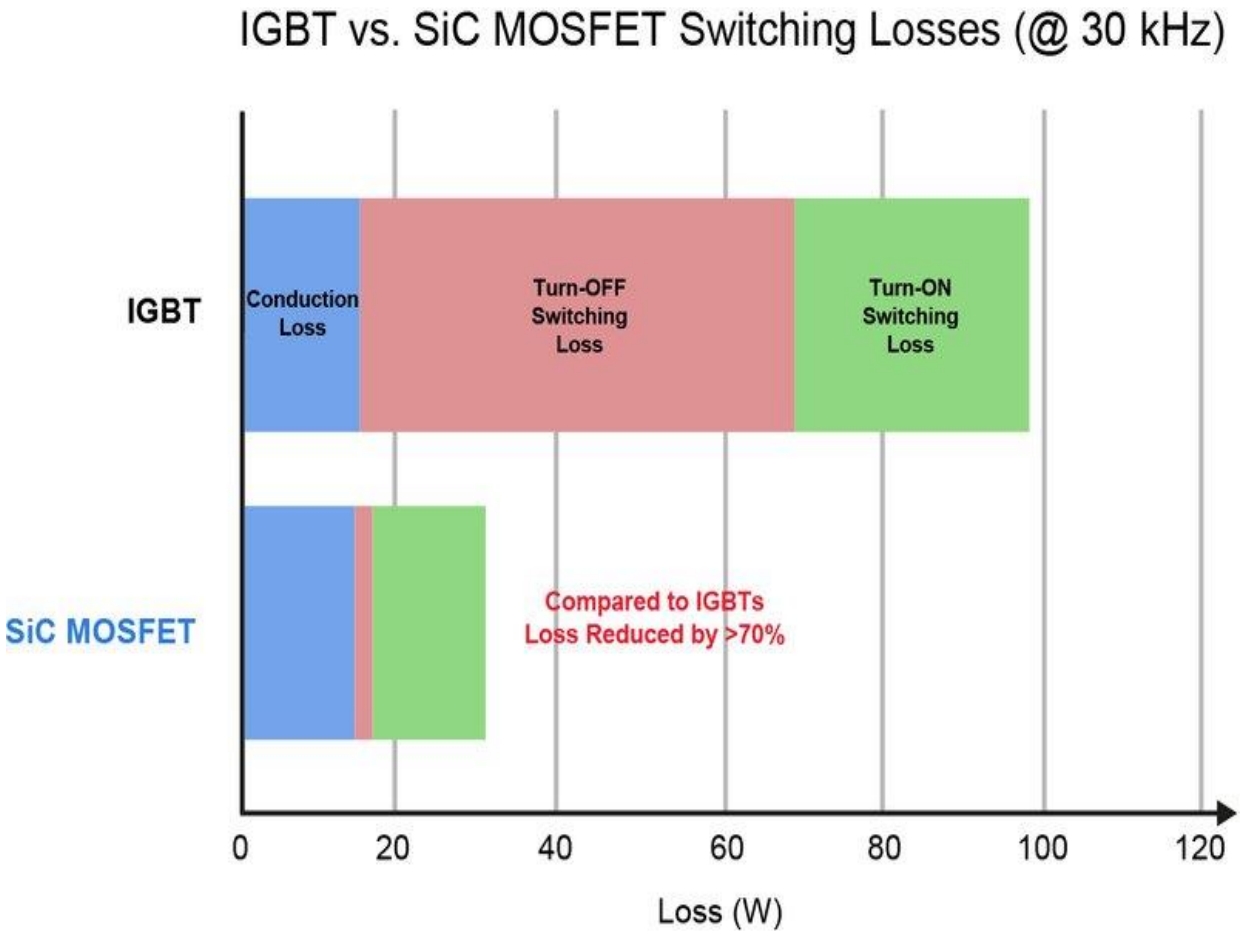
SiC Benefits Compared to Si and IGBT

SiC vs. IGBT



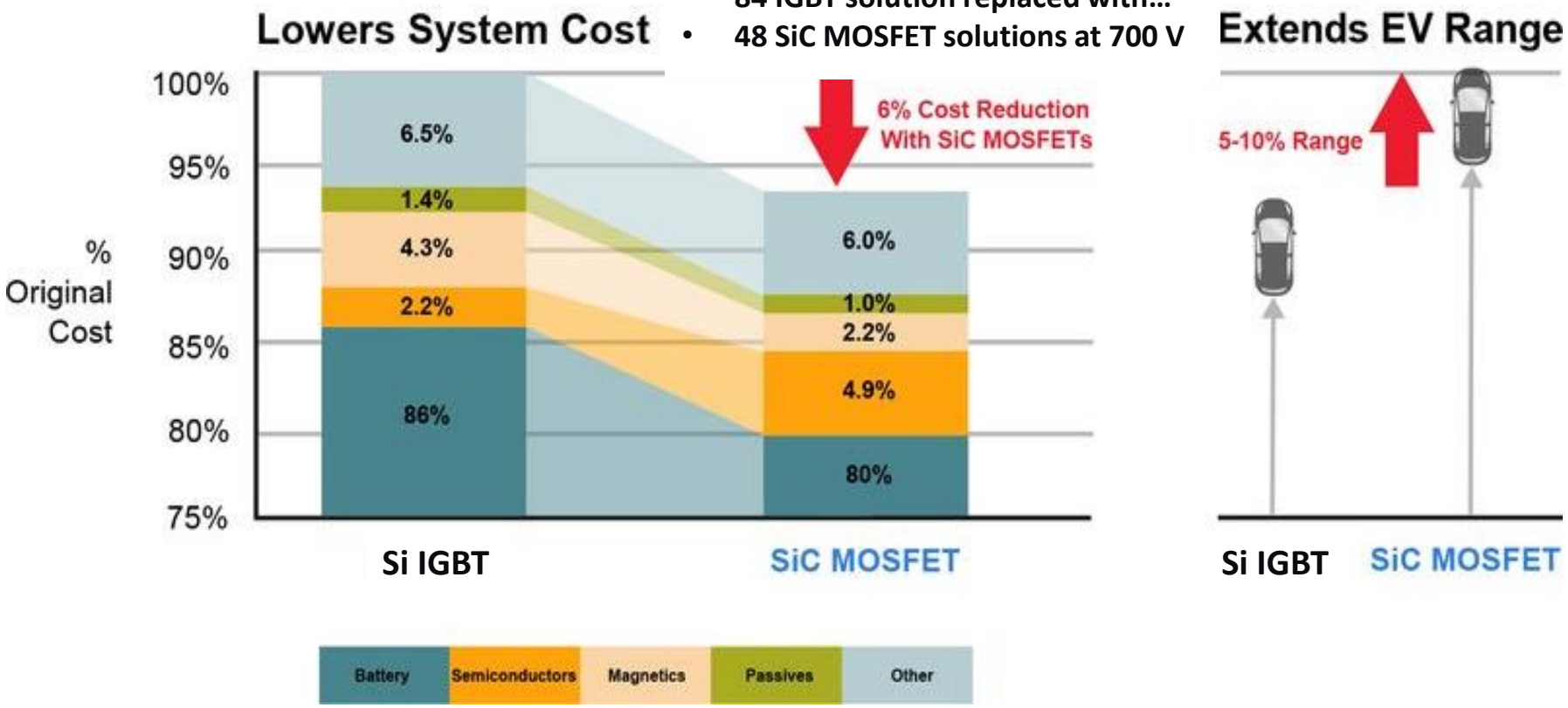
SiC vs. Si

Characteristics	SiC vs. Si	Results	Benefits
Breakdown field (MV/cm)	10x higher	Lower on-resistance	Higher efficiency
Electron sat. velocity (cm/s)	2x higher	Faster switching	Size reduction
Bandgap energy (ev)	3x higher	Higher junction temperature	Improved cooling
Thermal conductivity (W/m.K)	3x higher	Higher power density	Higher current capabilities

SiC Increases Efficiency, Lowers System Cost

- **Key takeaway: SiC offers better performance and overall lower system cost**

350 V Battery
225 kW 3-Phase Inverter
- **84 IGBT solution replaced with…**
- **48 SiC MOSFET solutions at 700 V**



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SiC Reliability Considerations

Why Ruggedness Matters in Power Conversion

Power conversion system should:

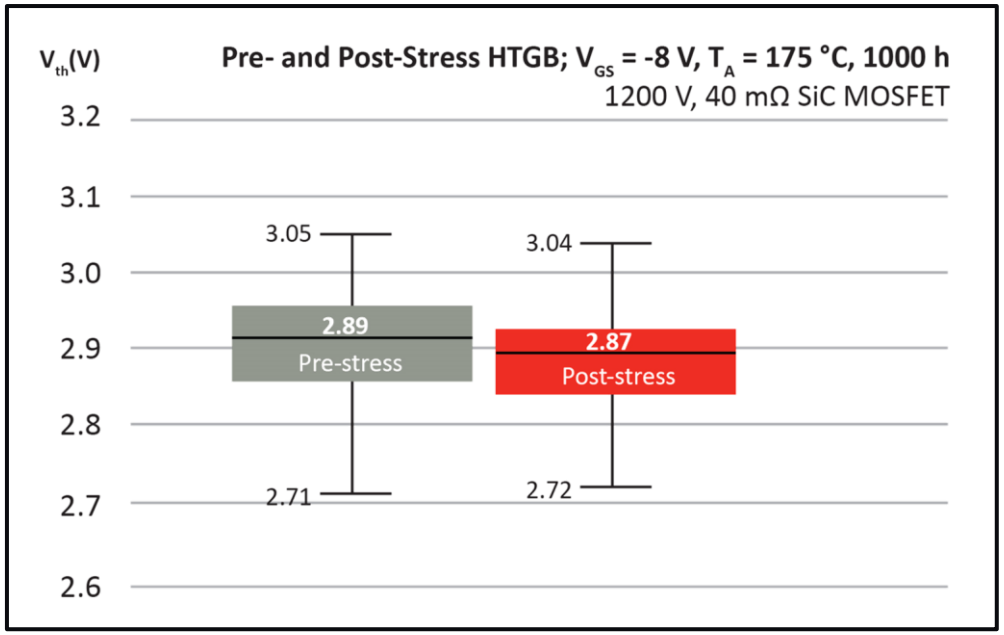
Operate routinely & reliably	Meet or exceed desired service lifetime	Survive electrical transients
Oxide stability	Oxide stability	Avalanche ruggedness
Oxide lifetime	Oxide lifetime	Short circuit withstand
Body diode stability	Body diode stability (also improves cost)	
Survivability		

You should care about:

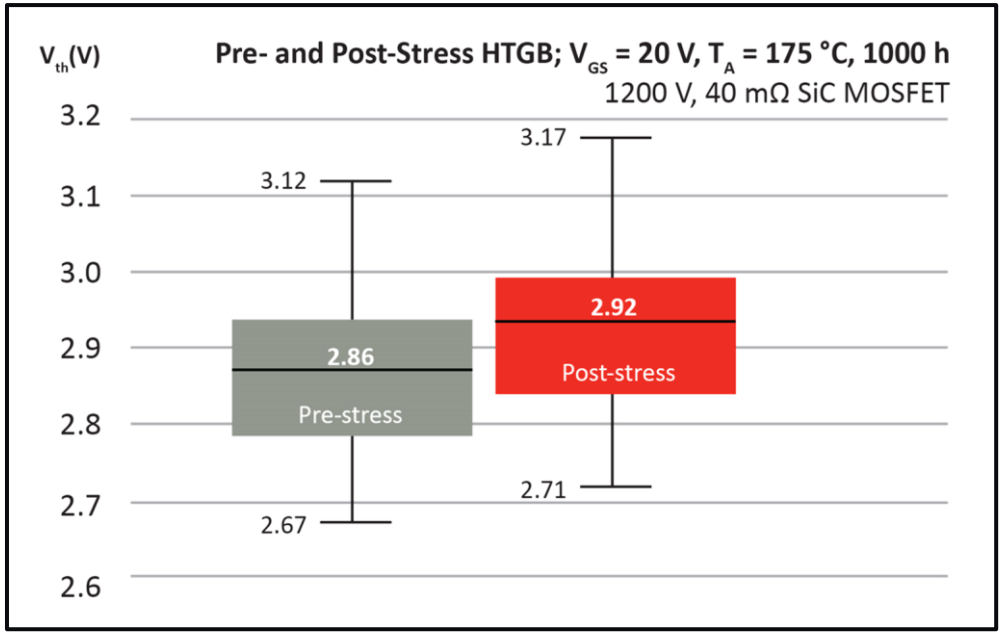
Not rugged?

Ruggedness | *Gate Oxide Stability*

Stress: V_{GS} = -8 V, 1000 h at T_A = 175 C | Change: -0.02 V



Stress: V_{GS} = 20 V, 1000 h at T_A = 175 C | Change: +0.06 V



V_{th} measurements before and after 1000 hours of high-temperature gate bias (HTGB) stress shows negligible shift

Application benefits

- Operate routinely & reliably
- Meet (exceed) desired service lifetime

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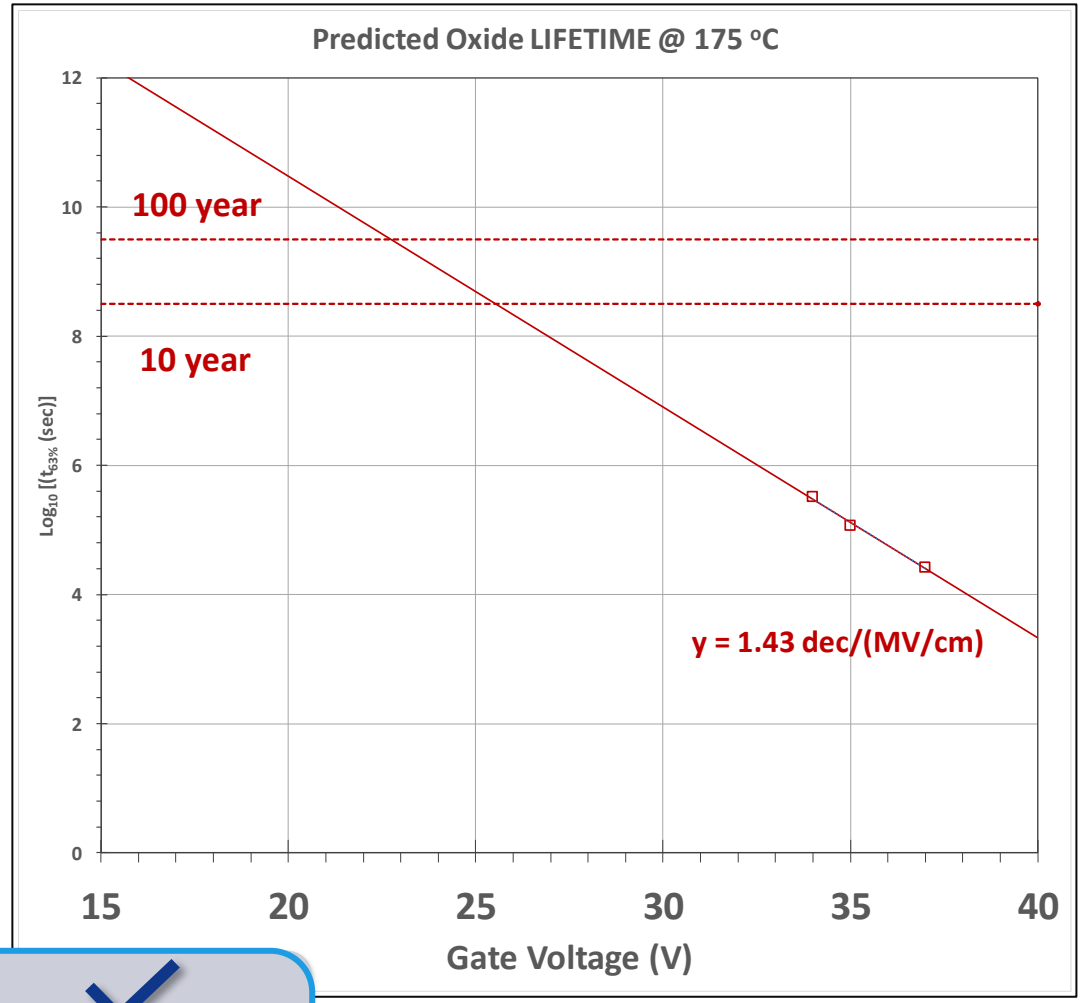
Ruggedness | *Gate Oxide Lifetime*

i. Oxide failure (breakdown) accelerated with temperature and electric field across the oxide
ii. Failure modes extracted from Weibull plots
iii. Arrhenius equation used to predict oxide lifetime

Data from production-grade 1200 V, 40 mOhm MOSFET

Oxide predicted to last more than 100 years at recommended V_{GS} and Tj = 175 C



Application benefits

- Operate routinely & reliably
- Meet (exceed) desired service lifetime
- Survive electrical transients

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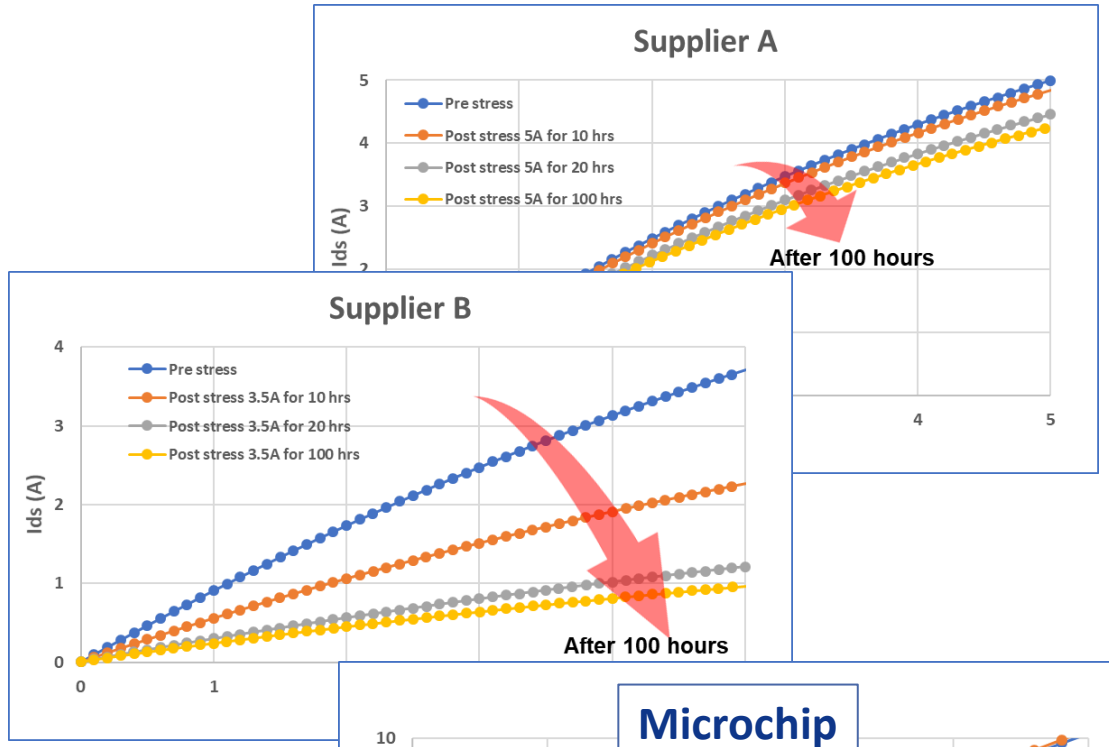
Ruggedness | *Body Diode Stability*

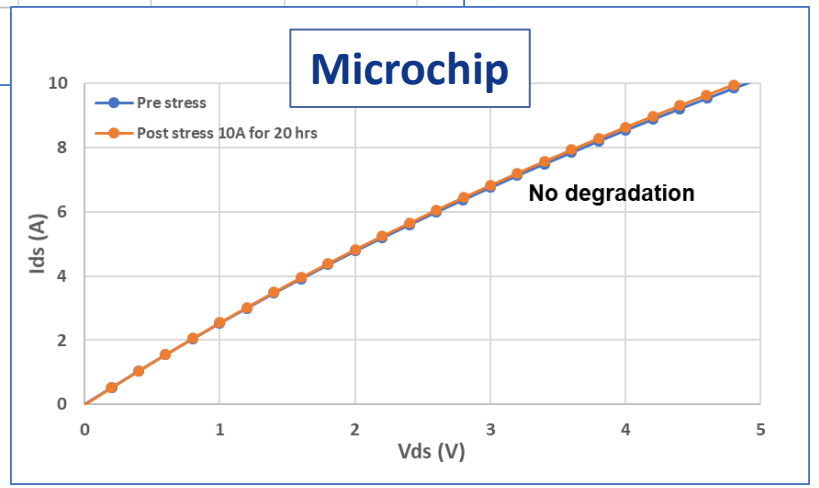
i. SiC MOSFET body diodes stressed with a constant forward current

ii. Body diode I-V curves and R_{DSon} measurements made before and after stress

Data from commercially available 1200 V, 80 mOhm MOSFETs*

*Courtesy: A. Agarwal and M. Kang, Ohio State University





No degradation observed in Microchip body diodes

Also, lower component cost by using body diode and eliminating Schottky

Application benefits

- Operate routinely & reliably
- Meet (exceed) desired service lifetime

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Ruggedness | *Short Circuit Capability*

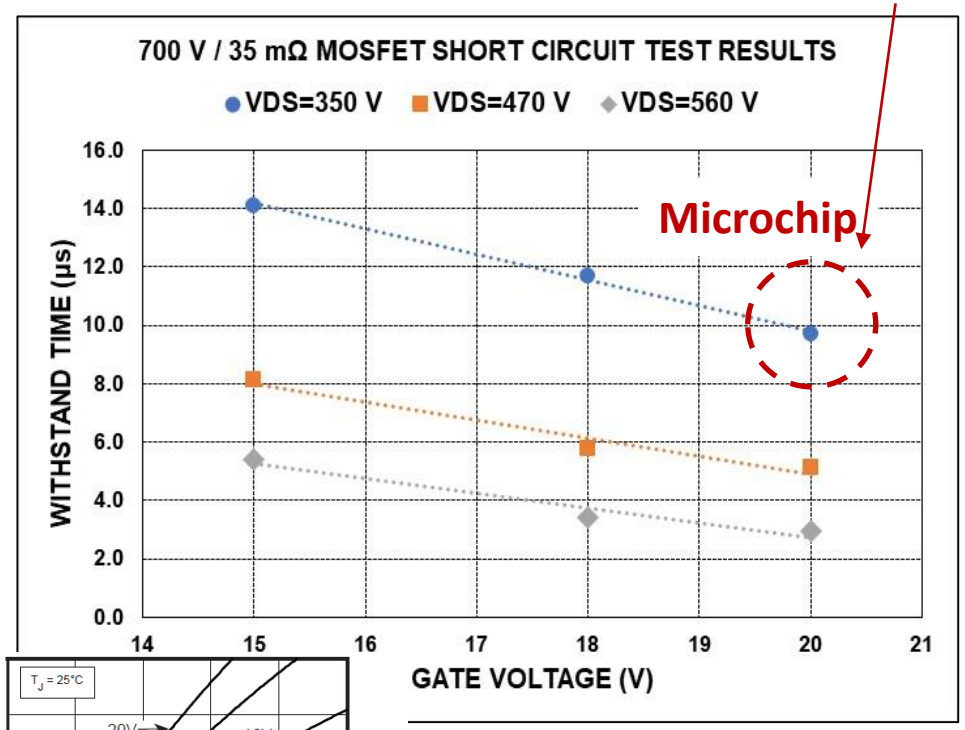
i. Short circuit emulates the application condition of shorting the MOSFET's drain-source across the dc link

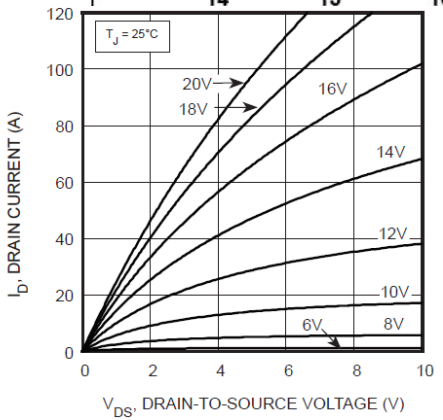
ii. Cells are enhanced (MOSFET is ON); peak current intended to distribute uniformly across die

Data from production-grade 700 V, 35 mOhm MOSFET

Designed to survive short circuit events, even at higher dc voltages (with adequate gate driver)

10 us
comparable
to IGBTs





Application benefits

Safely ride through harmful electrical transients

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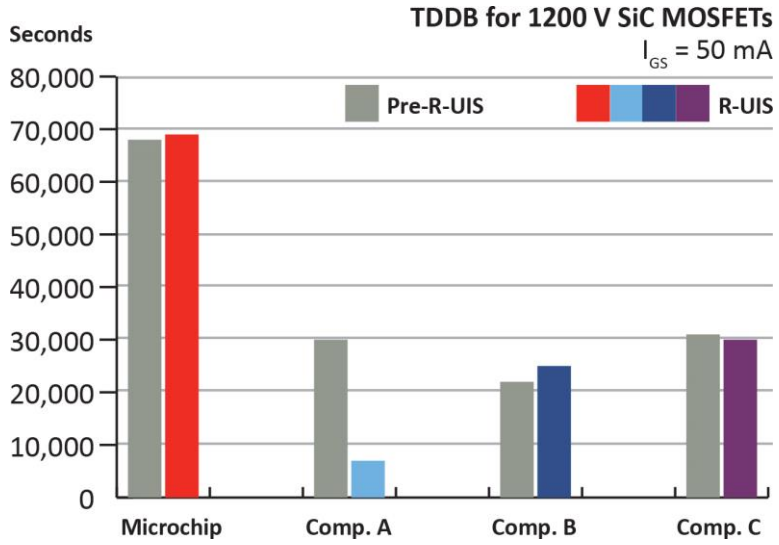
Ruggedness | *Avalanche / Repetitive-UIS*

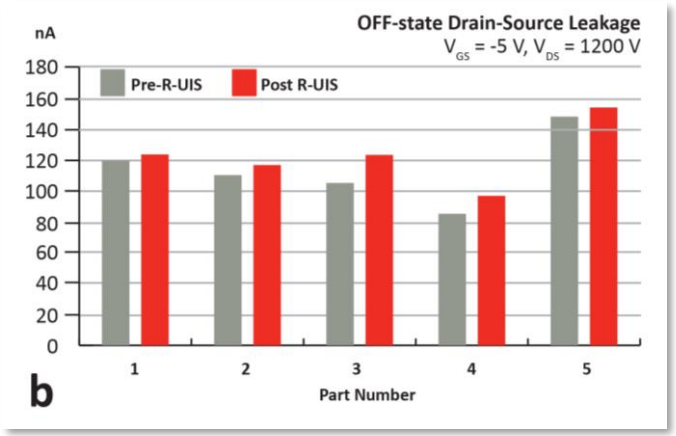
i. Measures the MOSFET's ability to repetitively sustain an avalanche current being switched off from an unclamped inductive load (R-UIS)

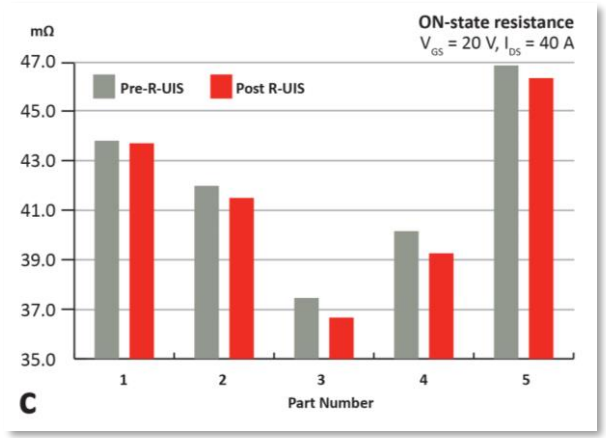
ii. Cells are not enhanced (MOSFET is OFF); peak current increases rapidly until $V_{DS} = V_{BR}$; avalanche current likely to crowd around die edge

Data from commercially available 1200 V, 80 mOhm MOSFETs



Microchip devices show excellent avalanche ruggedness and parametric stability following 100K pulses of R-UIS





Application benefits

Safely ride through harmful electrical transients

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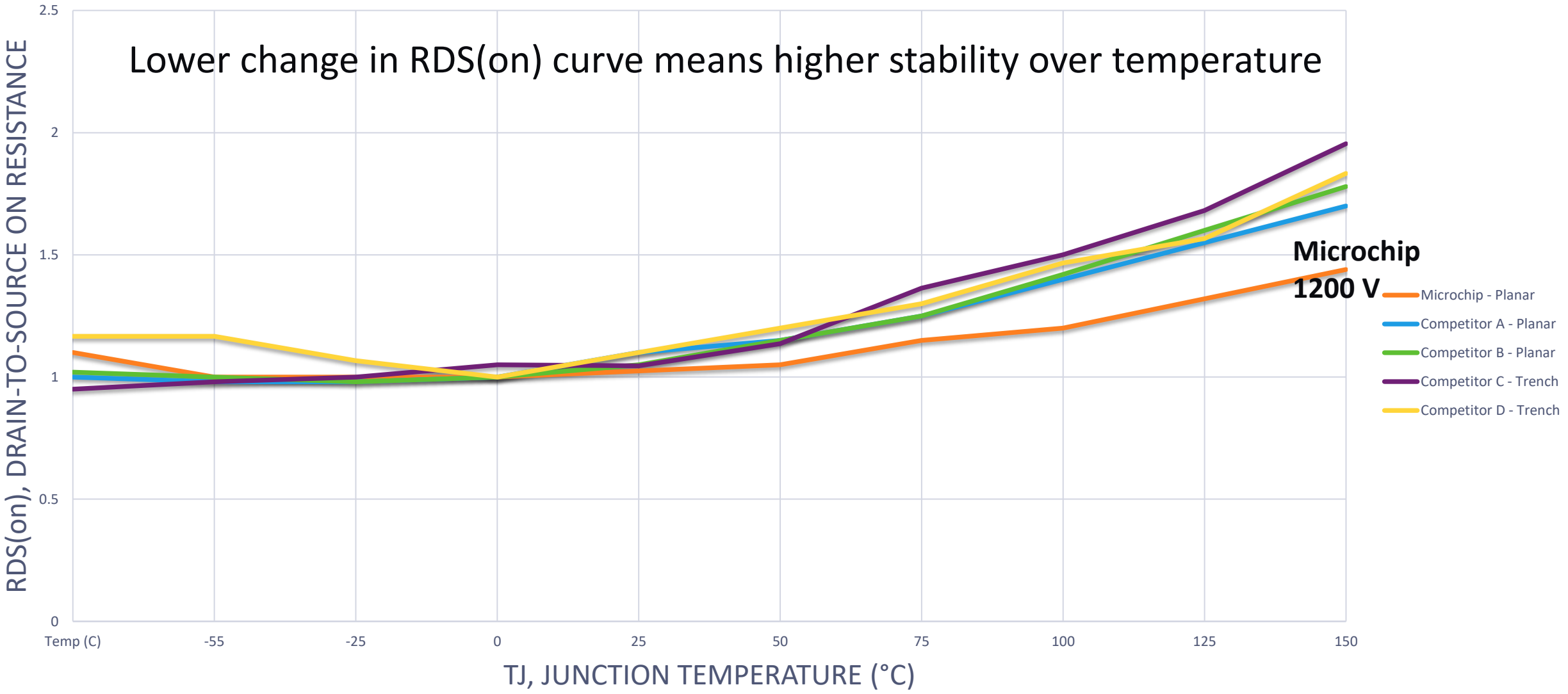
Ruggedness | *RDSon vs. Temperature*



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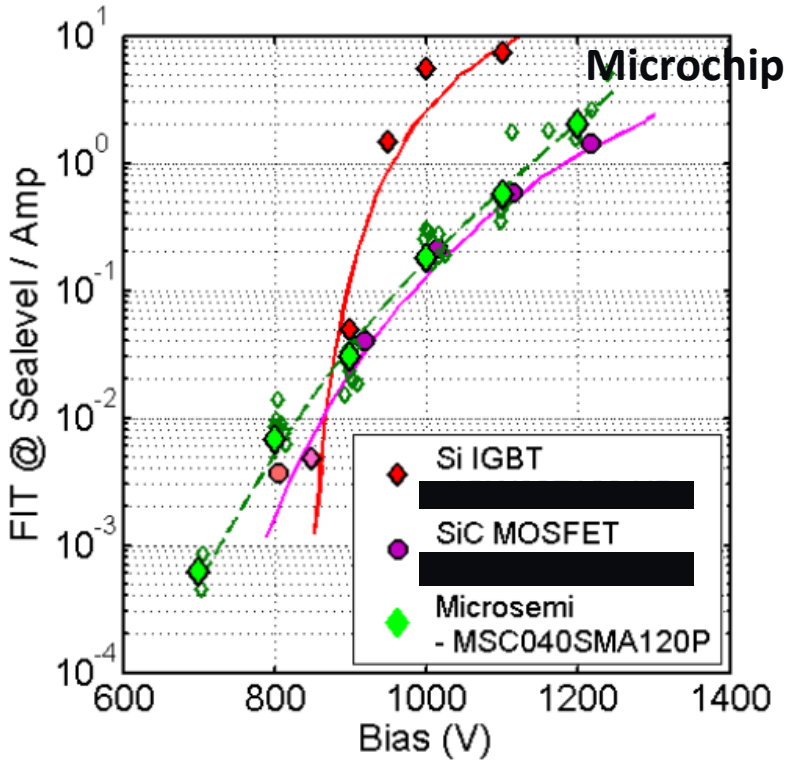
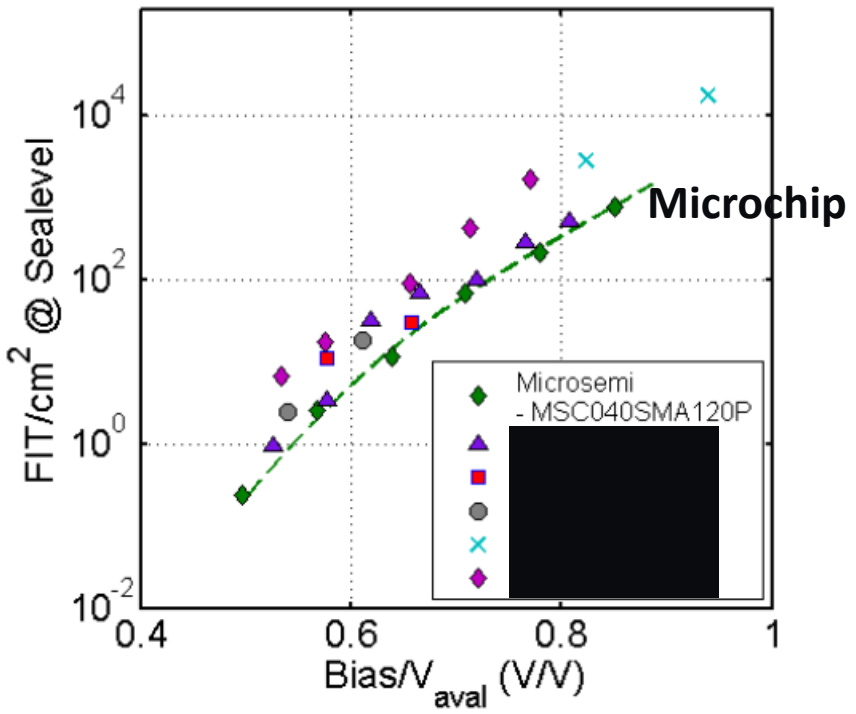
Terrestrial Neutron Susceptibility

- **Neutrons can damage or degrade system performance at sea level or in higher elevations**
- **<u>Application benefit</u>: Using SiC provides higher immunity to terrestrial radiation and lowers FIT rate across low to high elevations locations**



SiC MOSFETs have 10X lower FIT rate than comparable Si IGBTs @ rated voltage



Microchip SiC MOSFETs perform well against SiC competition regarding neutron irradiation

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SiC Markets and Portfolios

SiC Discrete, Module and Gate Driver Solutions

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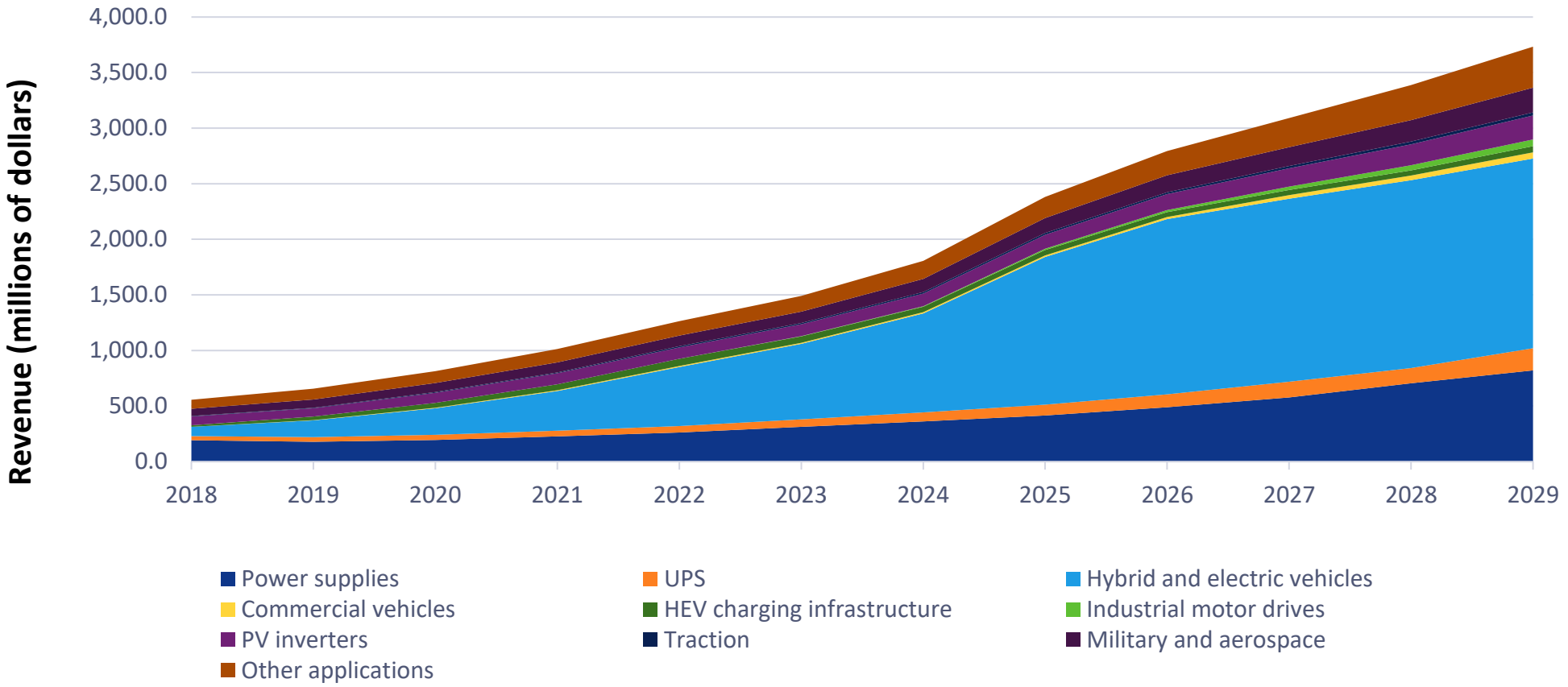
SiC Semiconductor Forecast by Applications



Source:Source: Omdia – SiC and GaN Power Semiconductors Report 2020

Target Markets and Applications

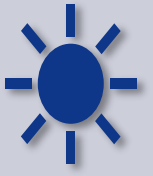
Transportation* – Traction APU, inverter, heavy duty vehicles

Data Center* – PFC, DC/DC PSU

Automotive* – OBC, DC/DC, traction inverter, E-fuse

Industrial – Induction heating, welding, SemiCap

Military/Aerospace – Power distribution, actuation



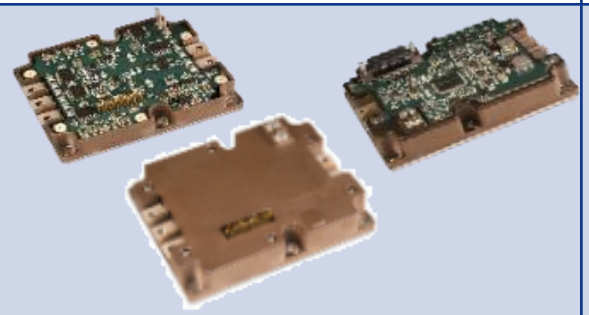
Renewable – PV inverters, wind

Grid – Solid state circuit breakers (E-fuse), charging infrastructure

Medical – Imaging, surgical power, implantable

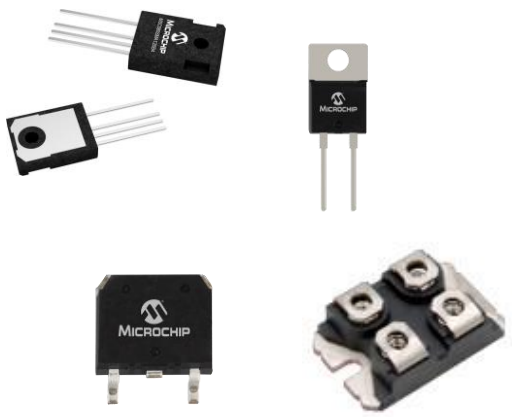
*Microchip Megatrend Markets

SiC Solutions Portfolios

Product Family	Product Package	Sub-product Family	Key Differentiation
Power Discretes		• SiC die • Discrete SiC MOSFETs • Discrete SBDs (Schottky Barrier Diodes)	• One of the broadest portfolios on the market • QSS (Quality, Supply, Support) • 30+ years in dev, design and support of power discretes
Power Modules		• SiC MOSFET power modules • SiC Diode power modules	• Standard packages and architectures available • Standard and Custom power modules • Flight proven heritage on both Boeing and Airbus Platforms = proven reliability in critical applications • High design flexibility
Integrated Power Solutions		• Power Control Module (PCM), Hybrid Power Drive Modules (HPD/HPE)	• Highest level of integration and reliability for flight critical applications • Standard SiC solution available as well as semi-custom SiC and IGBT offerings available • Partial discharge, current monitoring, over voltage, solenoid drive, short circuit protection, digital interface for control, screw and solder options
Digital Programmable Gate Drivers		• Gate Driver Cores • Module Adapter Boards • Plug & Play Gate Driver Boards	• Patented Augmented Switching™ reduces voltage overshoot, ringing, system noise, EMI • Robust Short Circuit protection rapidly detects and protects against overcurrent faults

www.microchip.com/sic

SiC Discretes: 700 – 1700 V



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Microchip Treelink Product Navigation

SiC Schottky Barrier Diodes (SBDs)

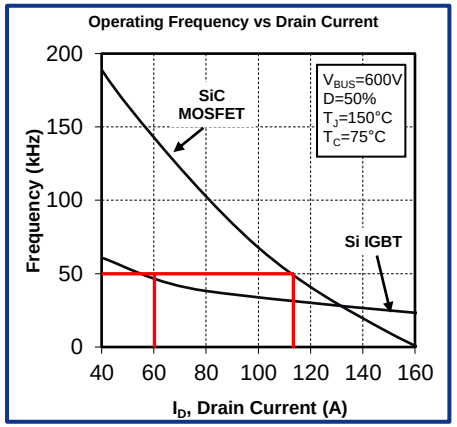
Voltage	$I_{F(avg)}$ Amps	V_F Volts	Part Number	Package
700	10	1.5	MSC010SDA070D/S	Die
			MSC010SDA070K	TO-220
			MSC010SDA070B	TO-247
	30	1.5	MSC030SDA070D/S	Die
			MSC030SDA070K	TO-220
			MSC030SDA070B	TO-247
			MSC030SDA070S	D³PAK
	50	1.5	MSC050SDA070D/S	Die
			MSC050SDA070B	TO-247
			MSC050SDA070S	D³PAK
1200	10	1.5	MSC010SDA120D/S	Die
			MSC010SDA120B	TO-247
			MSC010SDA120K	TO-220
	15	1.5	MSC015SDA120D/S	Die
			MSC015SDA120B	TO-247
			MSC015SDA120K	TO-220
	20	1.5	MSC020SDA120D/S	Die
			MSC020SDA120B	TO-247
			MSC020SDA120K	TO-220
	30	1.5	MSC030SDA120D/S	Die
			MSC030SDA120B	TO-247
			MSC030SDA120K	TO-220
			MSC030SDA120S	D³PAK
	50	1.5	MSC050SDA120D/S	Die
			MSC050SDA120B	TO-247
			MSC050SDA120S	D³PAK
1700	10	1.5	MSC010SDA170D/S	Die
			MSC010SDA170B	TO-247
	30	1.5	MSC030SDA170D/S	Die
			MSC030SDA170B	TO-247
	50	1.5	MSC050SDA170D/S	Die
			MSC050SDA170B	TO-247

SiC MOSFETs

Voltage	$R_{DS(On)}$ (typical)	Part Number	Package
700 V	90 mΩ	MSC090SMA070D/S	Die
		MSC090SMA070B	TO-247
		MSC090SMA070S	D3PAK
	60 mΩ	MSC060SMA070D/S	Die
		MSC060SMA070B	TO-247
		MSC060SMA070B4	TO-247-4L
		MSC060SMA070S	D3PAK
	35 mΩ	MSC035SMA070D/S	Die
		MSC035SMA070B	TO-247
		MSC035SMA070B4	TO-247-4L
		MSC035SMA070S	D3PAK
	15 mΩ	MSC015SMA070D/S	Die
		MSC015SMA070B	TO-247
		MSC015SMA070B4	TO-247-4L
		MSC015SMA070S	D3PAK
1200 V	80 mΩ	MSC080SMA120D/S	Die
		MSC080SMA120B	TO-247
		MSC080SMA120B4	TO-247-4L
		MSC080SMA120S	D3PAK
		MSC080SMA120J	SOT-227
	40 mΩ	MSC040SMA120D/S	Die
		MSC040SMA120B	TO-247
		MSC040SMA120B4	TO-247-4L
		MSC040SMA120S	D3PAK
		MSC040SMA120J	SOT-227
	25 mΩ	MSC025SMA120D/S	Die
		MSC025SMA120B	TO-247
		MSC025SMA120B4	TO-247-4L
		MSC025SMA120S	D3PAK
		MSC025SMA120J	SOT-227
	17 mΩ	MSC017SMA120D/S	Die
		MSC017SMA120B	TO-247
		MSC017SMA120B4	TO-247-4L
		MSC017SMA120S	D3PAK
		MSC017SMA120J	SOT-227
1700 V	750 mΩ	MSC750SMA170D/S	Die
		MSC750SMA170B	TO-247
		MSC750SMA170B4	TO-247-4L
		MSC750SMA170S	D3PAK
	35 mΩ	MSC035SMA170D/S	Die
		MSC035SMA170B	TO-247
		MSC035SMA170B4	TO-247-4L
		MSC035SMA170S	D3PAK

SiC Power Module for Higher Power Density

Parameter	Microchip APTGLQ300A120G	Microchip APTMC120AM20CT1AG	Comparison SiC vs. Si
Semiconductor type	Trench4 Fast IGBT	SiC MOSFET	
Ratings @ Tc=25°C	500 A/1200 V	143 A/1200 V	~3.5 x lower
Package type	SP6 – 108x62 mm	SP1 – 52x41 mm	~3.0 x smaller
Current @ 30 kHz Tc=75°C, D=50%, V=600 V	130 A	130 A	-
Current @ 50 kHz Tc=75°C, D=50%, V=600 V	60 A	115 A	~2.0 x higher
Eon+Eoff @ 100 A Tj=150°C, V=600 V	16.0 mJ	3.4 mJ	~5.0 x lower



MORE POWER @
HIGHER SWITCHING FREQUENCY
in
SMALLER VOLUME

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SiC Power Module Products Overview

Microchip SiC Die Inside!

SiC Diode Power Modules

STD Configurations	Voltage	Current (A) Tc=80 C	Package
3 phase bridge	700 V	50	SP1
Dual common cathode		100 to 200	D1P
Full bridge		50 to 200	SP1, SOT227 & SP6C
Phase leg		100 to 600	D1P & SP6C
3 phase bridge	1200 V	50	SP1
Dual common cathode		100 to 200	D1P
Full bridge		50 to 200	SP1, SOT227 & SP6C
Phase leg		100 to 600	D1P & SP6C
3 phase bridge	1700 V	50	SP1
Dual common cathode		100 to 200	D1P
Full bridge		50 to 200	SP1, SOT227 & SP6C
Phase leg		100 to 600	D1P & SP6C

Can't find the right module in the standard product portfolio?

We can modify an existing one (or create a full custom module) for you!

SiC MOSFET Power Modules

STD Configurations	Voltage	RDS(on) (mR)	Current (A) Tc=80 C	Package	
3 phase bridge	700 V	15	97	SP3F	
Boost chopper		15	97	SOT227	
Buck chopper		15	97	SOT227	
Full bridge		15	97	SP3F	
Phase leg		15 to 2.5	97 to 538	SP1, SP3F, D3, SP6C & SP6LI	
Triple phase leg		7.5 to 5	186 to 273	SP6P	
Vienna phase leg		15 to 7.5	97	SP3F & SP4	
3 phase bridge	1200 V	25	71	SP3F	
Boost chopper		40 to 11	44 to 202	SOT227 & SP3F	
Buck chopper		40 to 11	44 to 202	SOT227 & SP3F	
Full bridge		40 to 12.5	44 to 138	SP3F	
Phase leg		40 to 2.1	44 to 754	SP1, SP3F, D3, SP6C & SP6LI	
Triple phase leg		12.5 to 8.33	136 to 200	SP6P	
3 phase bridge	1700 V	35	50	SP3F	*NEW!*
Triple phase leg		17.5 to 11.7	96 to 140	SP6P	*NEW!*
Phase leg		35 to 2.9	50 to 530	SP1, SP3F, D3, SP6C & SP6LI	*NEW!*
Full bridge		35 to 17.5	50 to 97	SP3F	*NEW!*

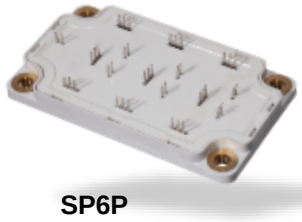
1700 V versions in Q3 CY2021


SOT-227


SP1

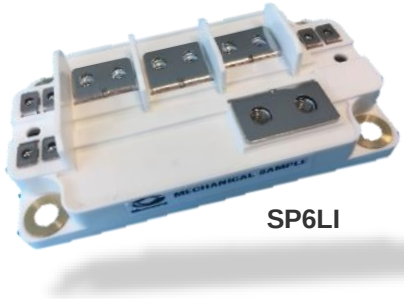

SP3F


D1P


SP6P


D3


SP6


SP6LI

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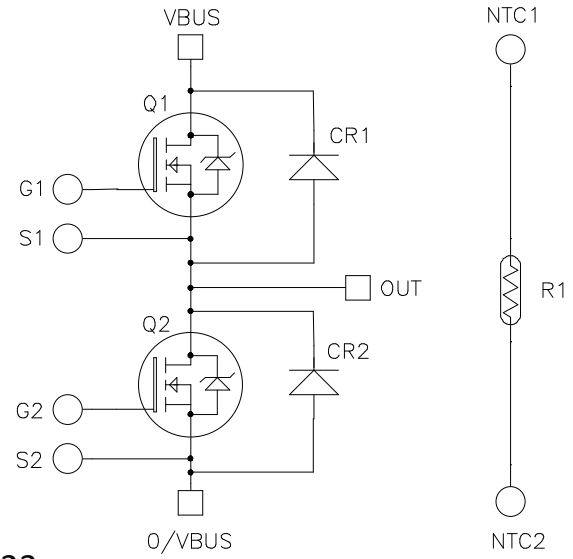
(Very) Low Inductance SP6LI Modules

Microchip SiC Die Inside!

PN	Voltage	Current Tc=80°C	RDSon Typ Tj=25°C	RDSon max. Tj=25°C	SiC Parallel Diode Ratings	
MSCSM70AM025CT6LIAG	700 V	538 A	2.5 mΩ	3.2 mΩ	300 A	
MSCSM120AM02CT6LIAG	1200 V	754 A	2.1 mΩ	2.58 mΩ	300 A	
MSCSM120AM03CT6LIAG	1200 V	641 A	2.5 mΩ	3.1 mΩ	250 A	
MSCSM120AM042CT6LIAG	1200 V	394 A	4.2 mΩ	5.2 mΩ	180 A	
MSCSM170AM029CT6LIAG	1700 V	530 A	2.9 mΩ	3.75 mΩ	300 A	*NEW!*
MSCSM170AM058CT6LIAG	1700 V	277 A	5.8 mΩ	7.5 mΩ	180 A	*NEW!*

SP6LI



- Excellent coupling between VBUS and 0/VBUS bus bars
- Parasitic loop inductance measured at very low 2.9 nH
- Full screw terminals inter-connection for signal and power
- SP6 package industrial standard 62 mm x 108 mm footprint
- Phase leg configuration
- AlN or Si3N4 substrate with copper or AlSiC baseplate and NTC monitoring
- Module phase legs are easy to parallel and connection to DC bus is achieved without parasitic inductance
- Possibility to interconnect 3 modules together in vertical or horizontal position

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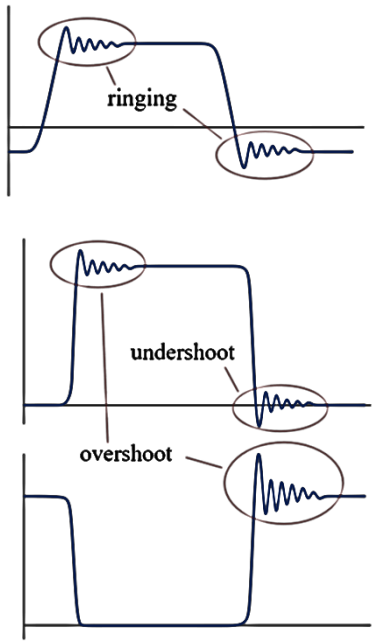
Solving SiC Implementation Issues with AgileSwitch® Digital Programmable Gate Drivers

Superior SiC Digital Programmable Gate Driver Solution vs. Analog Solution

Standard Analog Drivers

vs.

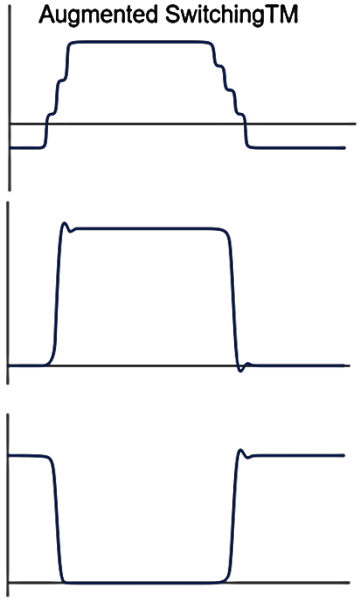
AgileSwitch® Gate Drivers featuring Augmented Switching™



Gate Voltage

Current

Voltage



- ✓ No False Faults
- ✓ Mitigates Ringing
- ✓ Lowers EMI

✓ Reduces Overshoot

✓ Reduces Undershoot

Reliable and efficient control of SiC MOSFETs – Noise, short circuits, overheating, overvoltage

- Up to 80% lower Vds overshoot
- Up to 50% lower switching losses
- Robust and fast short circuit protection

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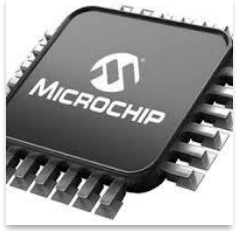
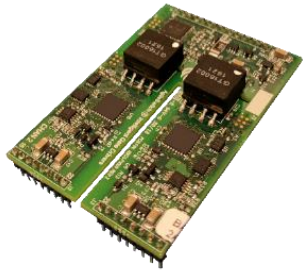
AgileSwitch® Digital Programmable Gate Drivers



ICs

In Development



Cores

1200 V

1700 V

Plug & Play

1200 V

1700 V

3300 V

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AgileSwitch® Development Kits (ASDAK)

2ASC-12A1HP - 62CA1

Part Number: ASDAK-2ASC-12A1HP-62
Status: New

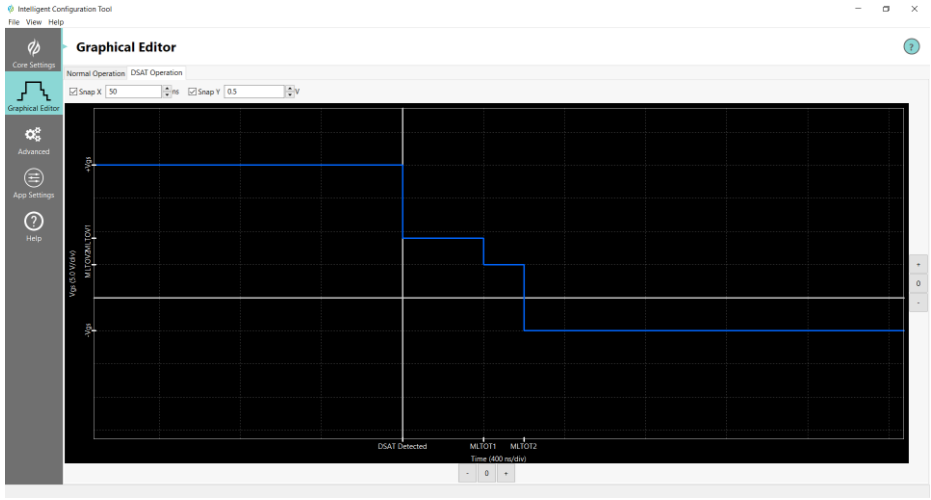
CONTENTS:

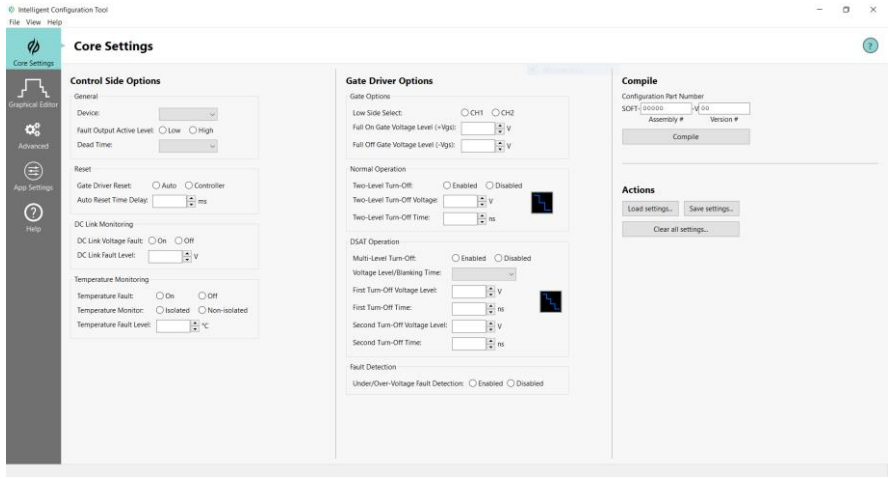
- 3x 2ASC-12A1HP 1200V Cores
- 1x 62CA1 1200V 62mm Module Adapter
- 1x Device Programmer Kit
- 1x AgileSwitch Intelligent Configuration Tool Software

MODULE COMPATIBILITY

- Standard 1200V 62mm Style Modules

MORE INFORMATION | STORE





ICT Intelligent Configuration Software optimizes:

- Augmented Switching™ profiles
- Fault reporting
- On and off gate voltages
- DC link and temperature trip levels

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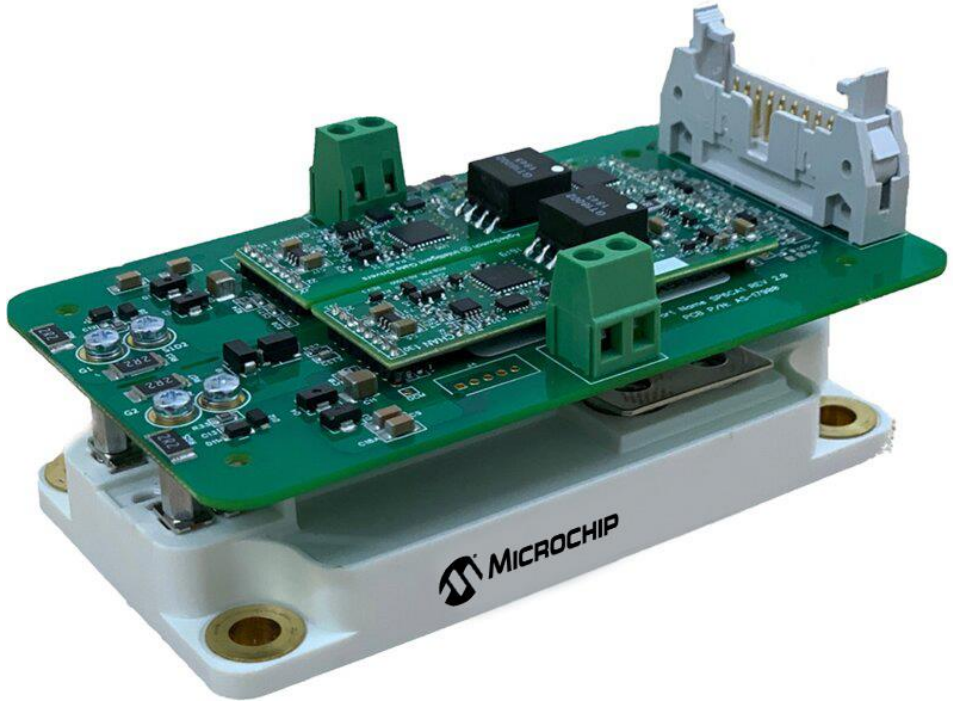
SiC SP6LI + Gate Driver Combo Kit (ASDAK+)

Each Kit Contains:

- Gate Driver
  - 2ASC-12A1HP Core
  - SP6CA1 Adapter Board
- Power Module
- Programming Kit
  - PicKit™ 4
  - Programming Adapter

Power Module Options for Kit

- MSCSM70AM025CT6LIAG
- MSCSM120AM02CT6LIAG
- MSCSM120AM03CT6LIAG
- MSCSM120AM042CT6LIAG



Seamless total system solution from evaluation to production

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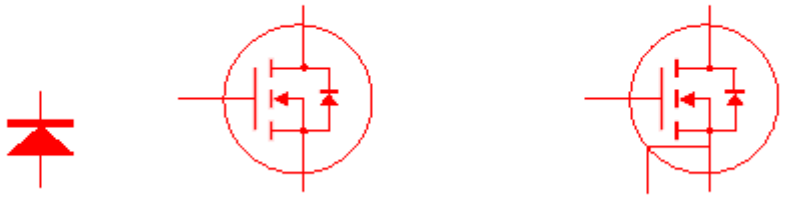
SPICE Simulation Tool and Models

- **MPLAB® Mindi™ Analog Simulator**
  - Microchip's free circuit simulation software is available for download at www.microchip.com/Mindi
  - Uses SIMetrix and SIMPLIS simulation environment for SPICE and piecewise-linear modeling respectively

- **SiC MOSFET and SBD SPICE Models (PLECs models also available)**
  - SiC MOSFET and Schottky Barrier Diode models available at www.microchip.com/SiC
  - Future release of Mindi will include SiC models
  - Two levels of simulation categories

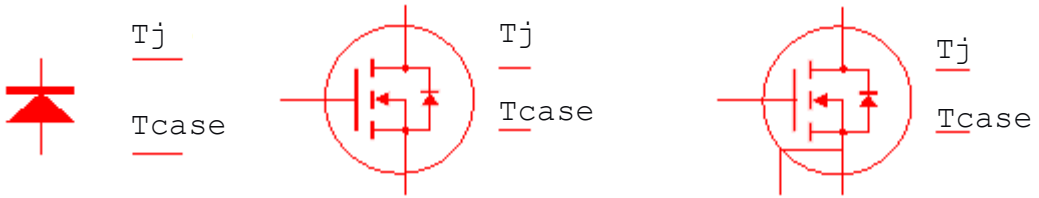
Level 1 (L1) – Electrical Models



3 lead model

4 lead model
(includes Kelvin sense)

Level 2 (L2) – Electrical and Thermal Models



3 lead model with
temperature

4 lead model with
temperature

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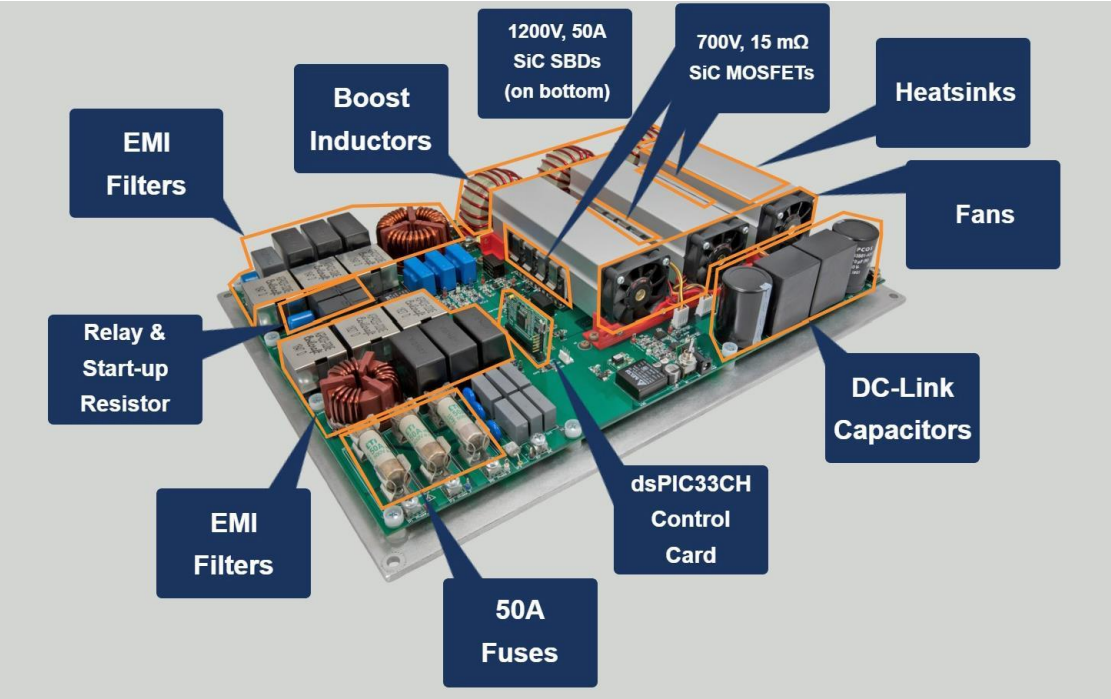
Vienna PFC Reference Design



Part Number: [MSCSICPFC/REF5]

- Design files, dsPIC33CH code and user's guide
- Simulate before design with SiC SPICE and PLECS PFC simulation models
- Hardware not included

- 30 kW Vienna rectifier topology
- 98.6% peak efficiency
- 3-phase 380/400 V, 50/60 Hz AC input with 700 V DC output voltage
- Design for 20% over voltage on the line
- 700 V SiC MOSFETs and 1200 V SiC Diodes
- 140 kHz PWM switching frequency
- dsPIC® DSC 3-level modulation digital control
- < 5% current THD at half and full loads
- IEEE Publication
  - S. Chen, W. Yu, D. Meyer, "Design and Implementation of Forced Air-cooled, 140kHz, 20kW SiC MOSFET based Vienna PFC"
- Video Overview
  - "APEC 2019: Here's How to Build an EV Charger with SiC Transistors" (https://www.youtube.com/watch?v=pBTqJI-4pKA)

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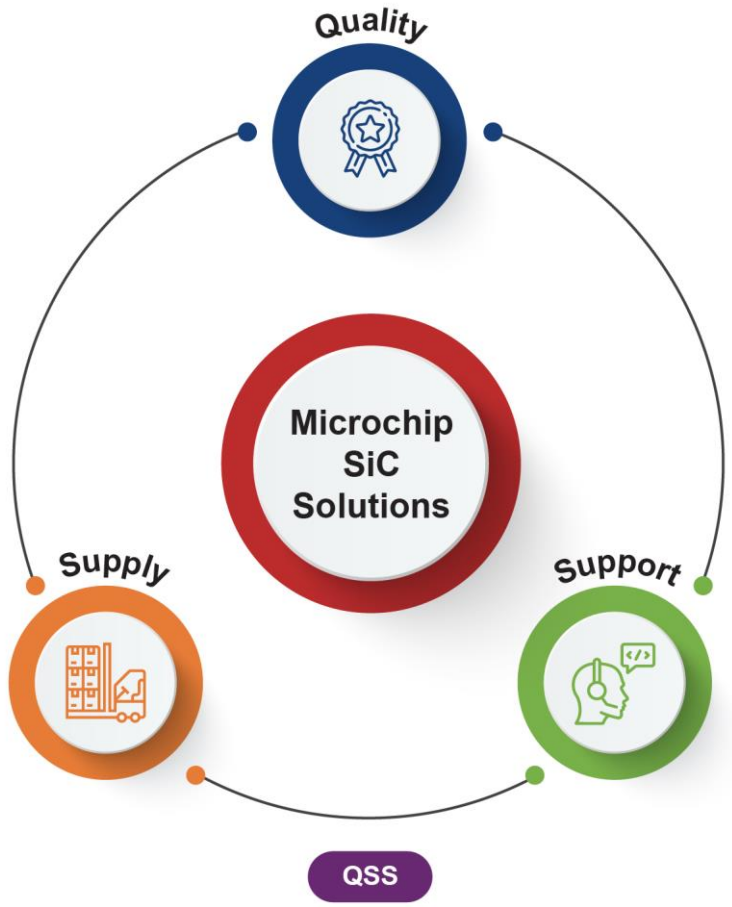
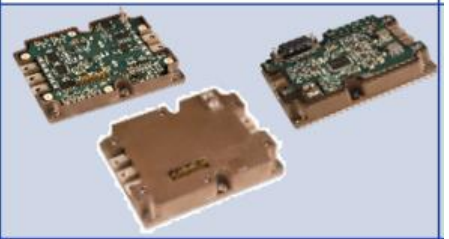
Microchip Quality, Supply and Support (QSS)

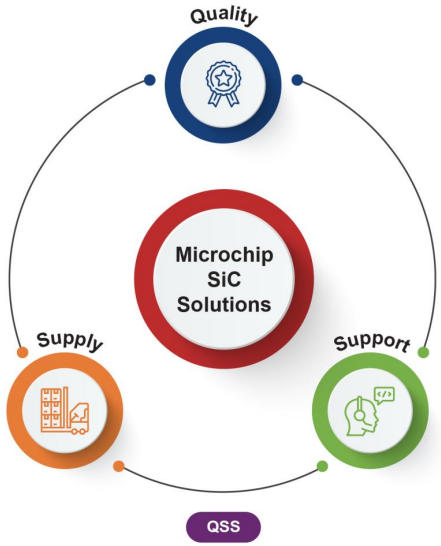


- **<u>Quality</u>: Proven reliability and ruggedness**
  - Refer to earlier slides
- **<u>Supply</u>: Risk averse throughout supply chain**
  - Qualified and secured long-term substrate and epi supply with multiple vendors; not reliant on competitor substrate/epi material
  - Dual fab location strategy protecting supply chain from natural disasters or major yield issues
  - Microchip's well-established no EOL policy
  - Competitive lead times of less than 16 weeks in most cases
- **<u>Support</u>: Standard and custom die, discrete, module and gate driver solutions for small to large customers**

Key Takeaways

- **Broad portfolio of SiC die, discrete, power module and gate driver solutions with component models**
- **Microchip Total System Solutions approach supports solution ecosystems**
- **Designed for ruggedness with Microchip's Quality, Supply and Support (QSS)**
- **SiC resources**
  - www.microchip.com/sic (including SiC Brochure)
  - www.microchip.com/pfc
  - www.microchip.com/treelinktool

Product Family	Product Packages
Power Discretes	
Power Modules	
Integrated Power Solutions	
Digital Programmable Gate Drivers	



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Thank You

www.microchip.com/sic