Empowering High-Power Designs with Microchip Silicon Carbide Solutions

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A Leading Provider of Smart, Connected and Secure Embedded Control Solutions

SMART | CONNECTED | SECURE

Presented by:
Douglas Min, Principal Embedded Solutions Engineer
Oct 24, 2023

About Microchip Technology

Microchip is a leading provider of:

- High-performance standard and specialized Mixed Signal Microcontroller (MCU), Digital Signal Controller (DSC) and microprocessor (MPU) solutions
- Power, mixed-signal, analog, interface and security solutions
- Clock and timing solutions
- Wireless and wired connectivity solutions
- FPGA solutions
- Non-volatile EEPROM and Flash memory solutions
- Flash IP solutions

$8.4 Billion Revenue for FY2023

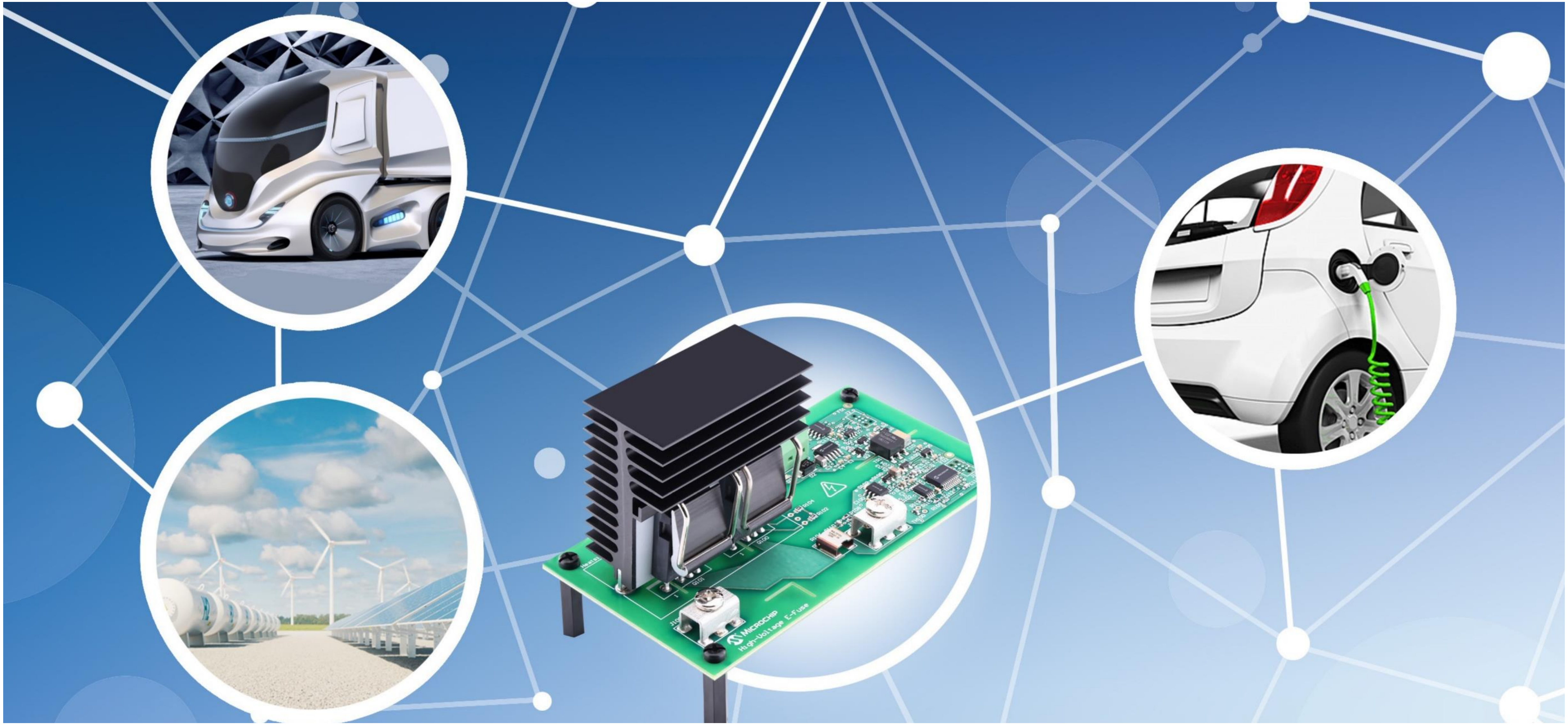
Headquartered Near Phoenix in Chandler, AZ

>22,500 Employees

125,000+ Customers

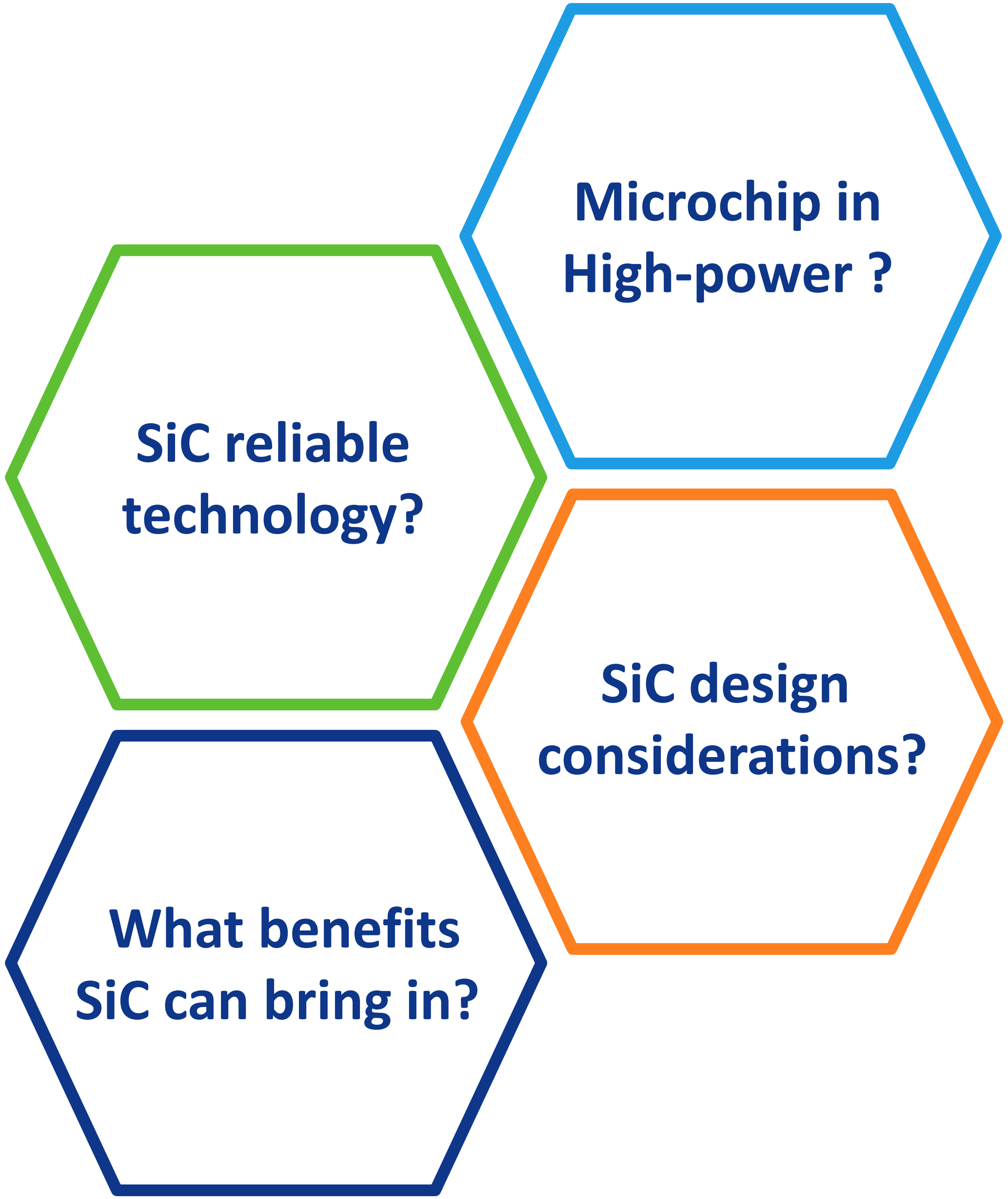
Electrification of Everything

Adopt Silicon Carbide with Ease, Speed and Confidence



Agenda

- **Why Silicon Carbide (SiC)?**
- **Introduction to mSiC™ MOSFETs**
  - Why SiC?
  - The physics behind SiC
- **Microchip Portfolio**
  - Why Microchip SiC?
  - Reliability and ruggedness considerations
- **SiC Gate Drivers**
  - Gate characteristics & challenges
  - Microchip SiC driver solutions
- **SiC Design support**
  - Reference design overview
  - E-Fuse design
  - MPLAB® SiC Power Simulator



Why SiC ?

- **Designers are present with new challenges brought by the ever-increasing demand in power electronics with improved capabilities including:**
  - Higher efficiency
  - Reduced cooling
  - Decreased size and weight
  - Stricter EMI/RFI
  - Better power quality requirements

Applications :
- **High-efficiency inverters in DC/AC converters for solar and wind power**
- **Power converters for electric and hybrid vehicles**
- **Power inverters for industrial equipment and air conditioners**

→ All of these requirements are greatly influenced by the properties of Power Switch.

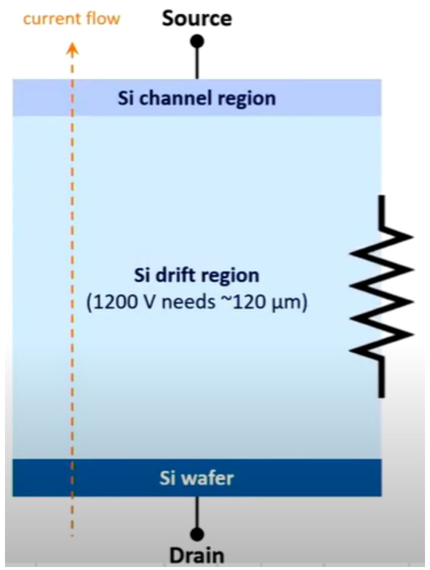
- **What are such critical properties of Power Switch ?**

- **Low RDSON & low switching losses**
- **Power density**
- **Capability to switch in very high frequency**
- **Better thermal conductivity**

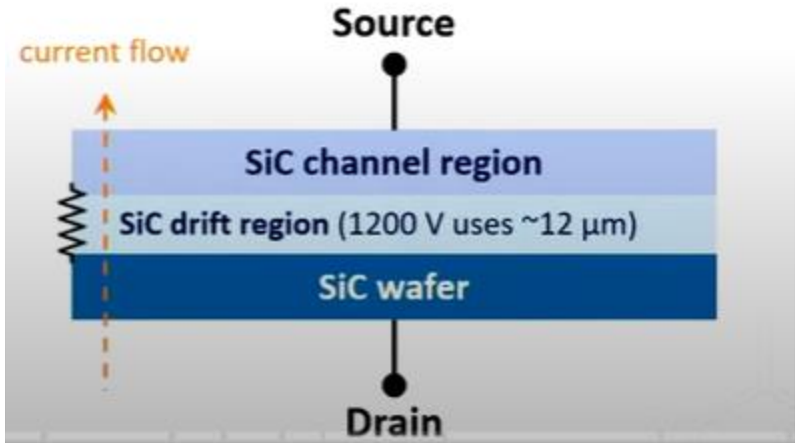
Wide-bandgap devices

SiC
& GaN

SiC Power FETs



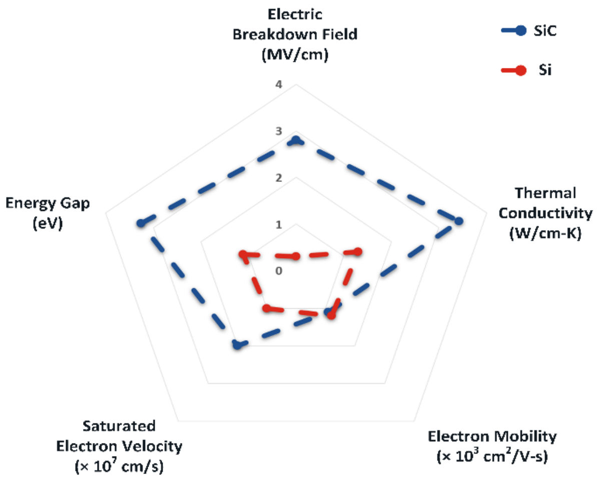
Si



SiC

	Si	GaN	4H-SiC	Diamond*
Band gap (eV)	1.1	3.4	3.3	5.5
Breakdown field (MV/cm)	0.3	~5	3 to 5	1 to 10
Carrier mobility (cm^2/V-s)	*n*: 1450 *p*: 370	*n*: 900 *p*: 200	*n*: 948 *p*: 99	*n*: 2000 *p*: 2100
Saturation velocity ($\times 10^7$ cm/s)	1.0	2.5	2.0	2.7
Thermal conductivity (W/cm-K)	1.6	1.3	3.7	8.0

- **Higher voltage**
- **Faster switching**
- **Almost zero reverse recovery**
- **Low RDSON**



Microchip SiC Products

Portfolio Overview , Ruggedness and Reliability Characteristics

Microchip SiC Timeline

2004 | 2006 | 2008 | 2010 | 2012 | 2014 | 2016 | 2018 | 2020 | 2022 | 2024

First SiC Device Shipped (Q4/2003)

PowerSicel acquired by Advanced Power Technology (APT)

ADVANCED POWER TECHNOLOGY

APT Acquired by Microsemi

SiC Process and Technology Transfer for SIT/JFET

NORTHROP GRUMMAN

Internal SiC Fab in Bend, OR

Gen 2 SiC SBDs Released (700V – 1700V)

Power Matters.

Gen 1 SiC MOSFETs Released (650V & 1200V)

SiC Modules Released

Dual Fabs (Internal & External)

Microsemi

Microsemi Acquired by Microchip

AgileSwitch® Acquisition

AgileSwitch

Process Transfer, Expansion to Fab 5

Gen 2 SiC Release (700V – 1700V)

AEC Release of SiC MOSFETs and SBDs

3.3 kV SiC MOSFETs and SBDs Released

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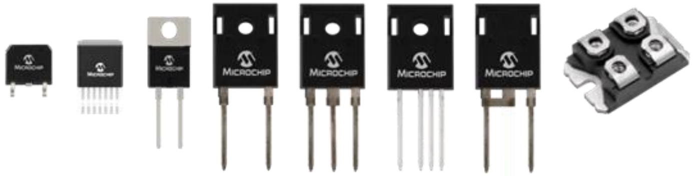
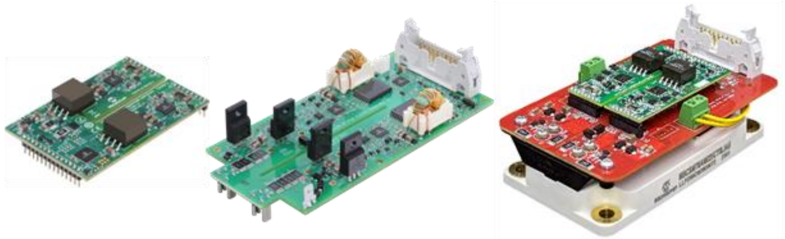
mSiC™ Solutions: 700V – 3.3 kV

Product Family	Packaging	Key Differentiation
Die		Unrivaled Ruggedness and Performance
Discretes		Widest Breadth
Modules		Lowest Inductance Standard and Custom-Tailored
Gate Drivers		Fastest to Market Highest Efficiency

Unrivaled Ruggedness and Reliability

Gate Oxide Integrity

- Rock-solid threshold voltage
- Lifetime >100 years

Robust Body Diode

- Degradation-free
- Eliminate freewheeling Schottky

Avalanche Rugged

- Stable performance after 100k pulses
- Optimized cost and efficiency

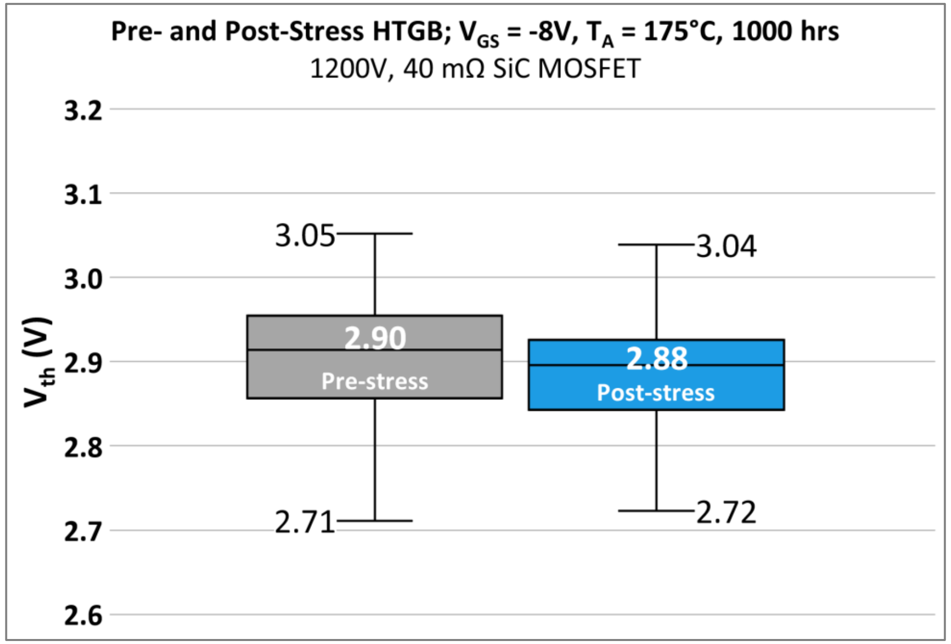
"IGBT-like" Short Circuit Performance

- Safely ride through unexpected system transients

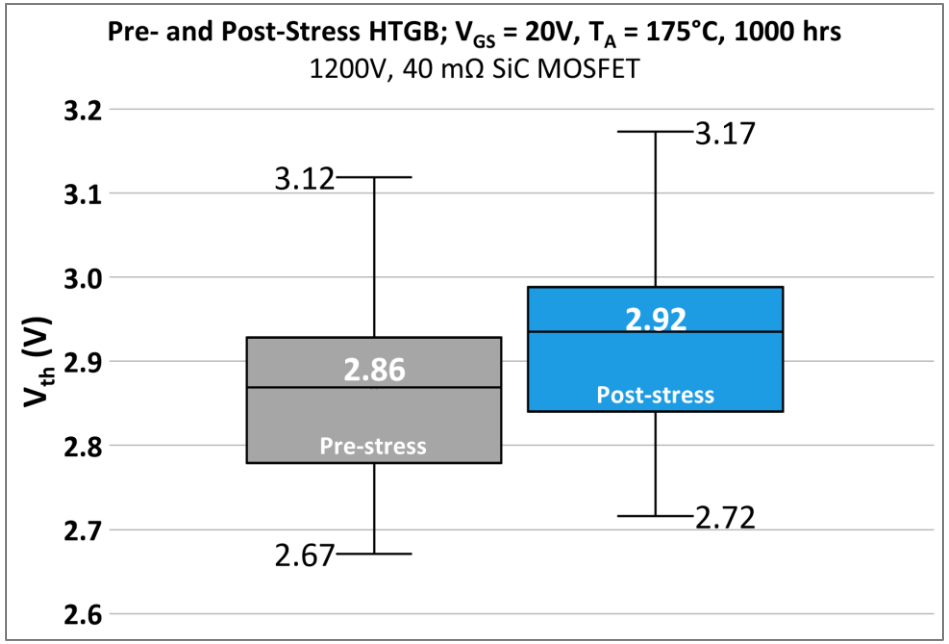
Ruggedness

Gate Oxide Stability

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



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



V_{th} measurements before and after 1000 hours of High-Temperature Gate Bias (HTGB) stress show negligible shift

Application Benefits ✓ Reliable routine operations ✓ Meet (exceed) desired service lifetime

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Ruggedness

Body Diode Stability

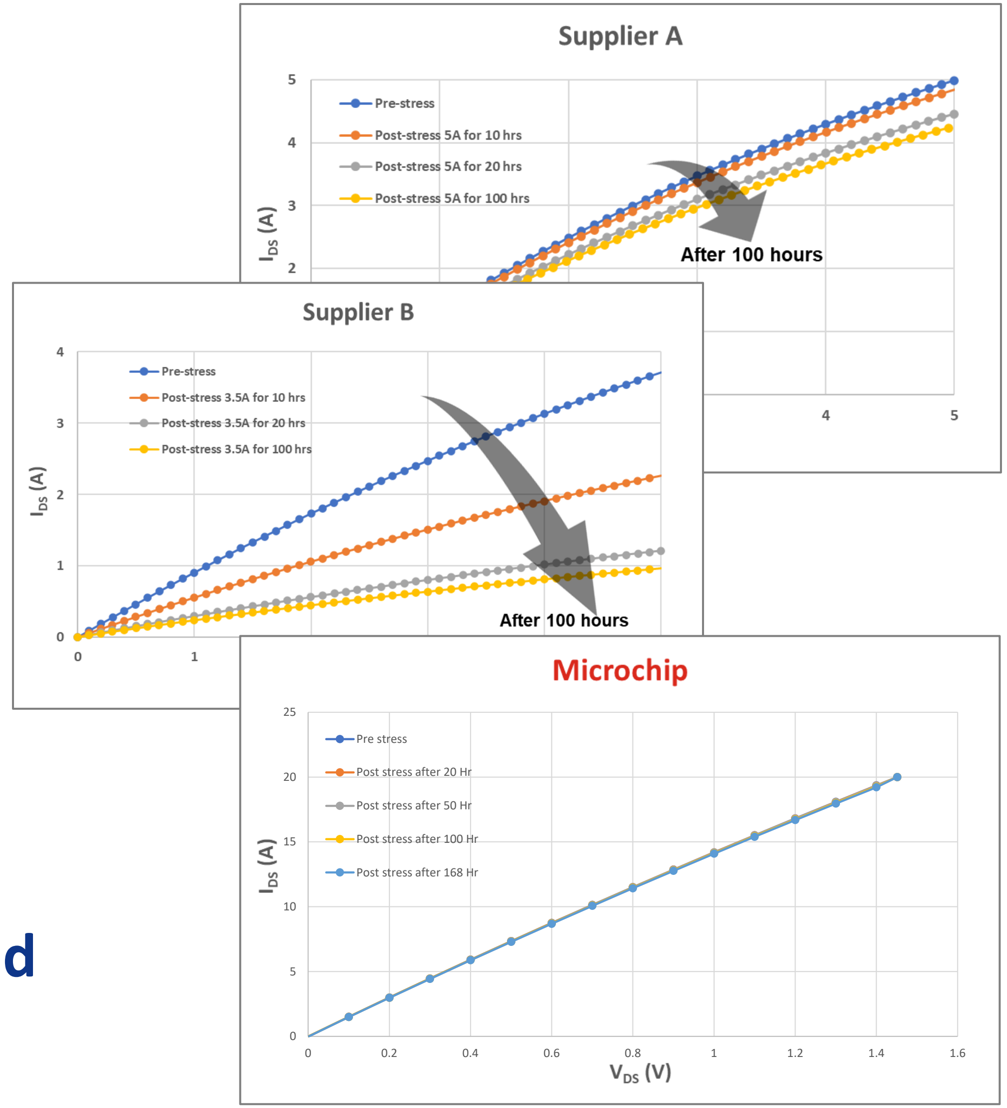
i. **SiC MOSFET body diodes stressed with a constant forward current**

ii. **Body diode I-V curves and $R_{DS(on)}$ measurements made before and after stress**

Data from commercially available 1200V, 80 mΩ SiC MOSFETs*

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

M. Kang *et al*, *2019 IEEE 7th Workshop on Wide Bandgap Power Devices and Applications (WiPDA)*, 2019, pp. 416-419, doi: 10.1109/WiPDA46397.2019.8998940.



No degradation observed in Microchip body diodes

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

Application Benefits ✓ Reliable routine operations ✓ Meet (exceed) desired service lifetime

Ruggedness

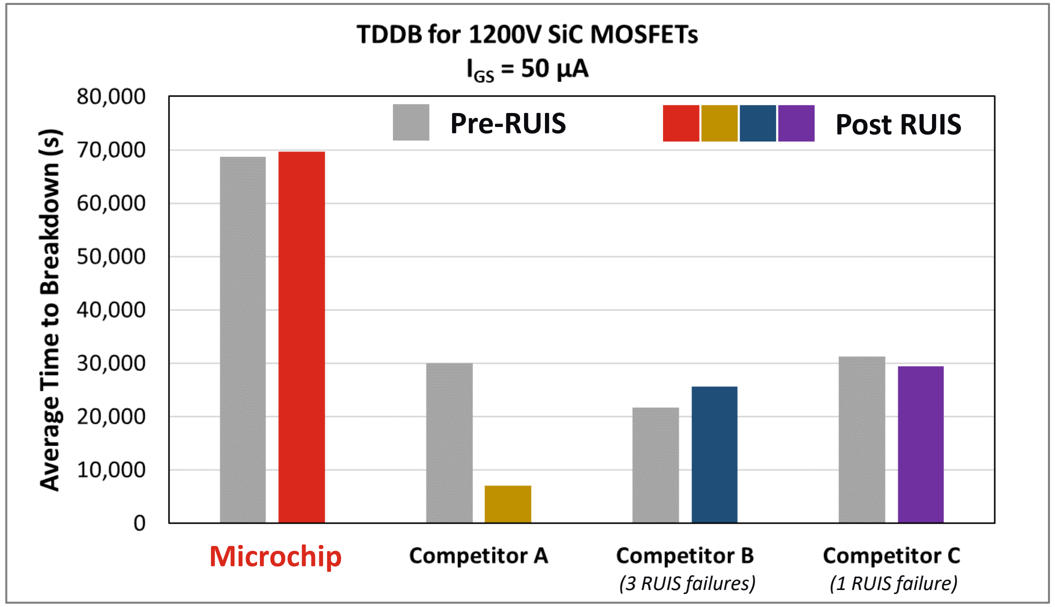
Avalanche/Repetitive UIS

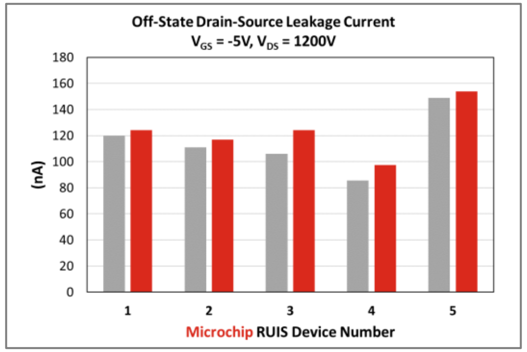
i. **Measures the MOSFET's ability to repetitively sustain an avalanche current being switched off from an unclamped inductive load (RUIS)**

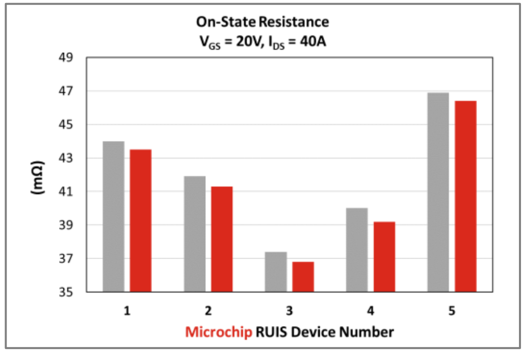
ii. **Cells are not enhanced (MOSFET is OFF); peak current increases rapidly until $V_{DS} = V_{BR}$; avalanche current likely to crowd around die edge**

Data from commercially available 1200V, 40 mΩ MOSFETs

> **Microchip devices exhibit excellent avalanche ruggedness and parametric stability following 100k pulses of RUIS**







Pre-RUIS Post RUIS

Application Benefits ✓ Safely ride through harmful electrical transients

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Ruggedness

Short Circuit Capability

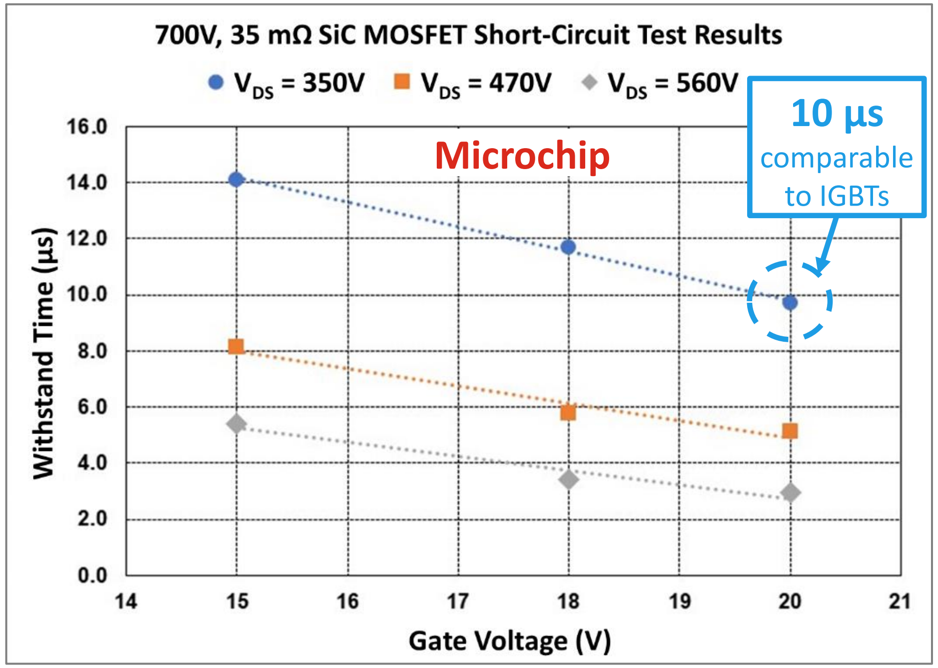
i. **Short circuit emulates the application condition of shorting the MOSFET's drain-source across the DC link**

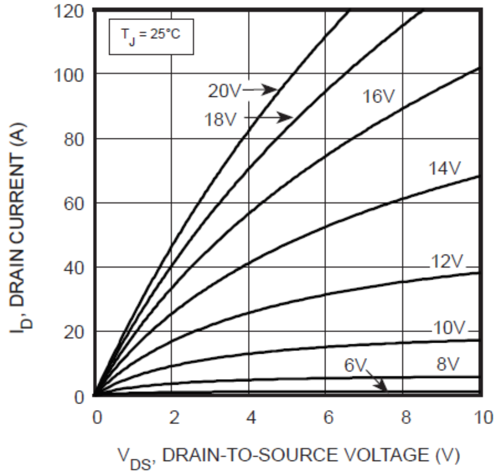
ii. **Cells are enhanced (MOSFET is ON); peak current intended to distribute uniformly across die**

Data from production-grade 700V, 35 mΩ SiC MOSFETs

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

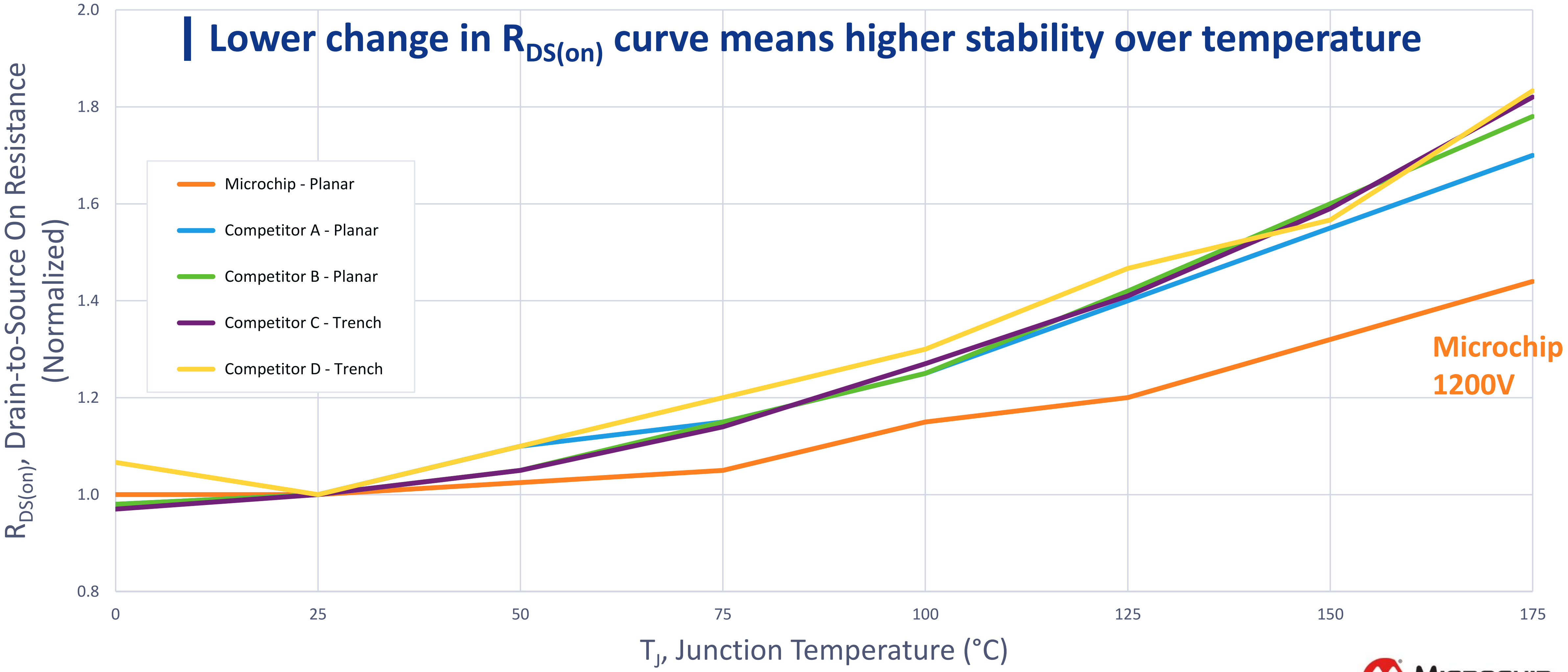
Application Benefits ✓ Safely ride through harmful electrical transients

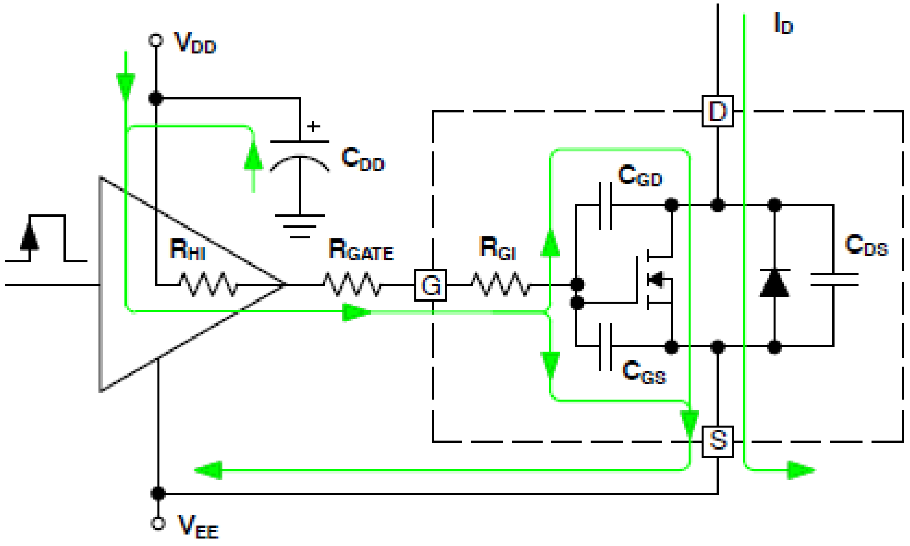




Ruggedness

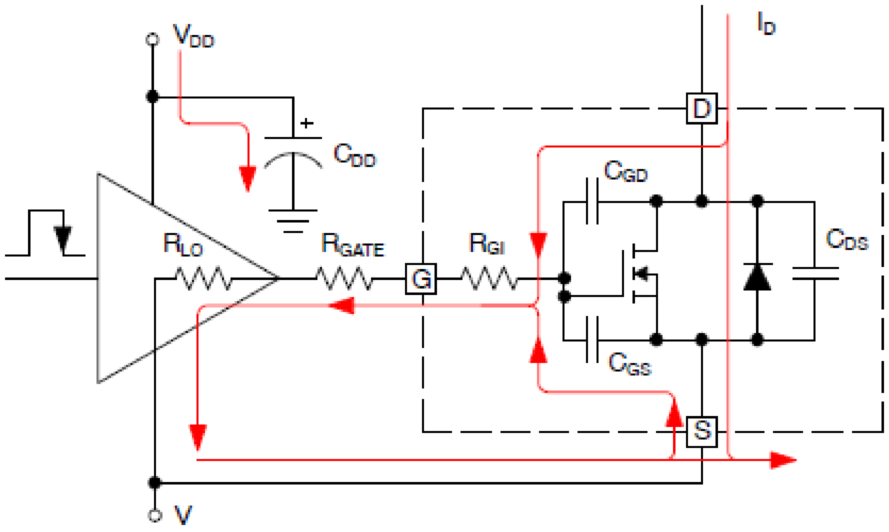
$R_{DS(on)}$ vs. Junction Temperature





SiC Gate Characteristics

The roadway to design a reliable driver



SiC Gate Characteristics

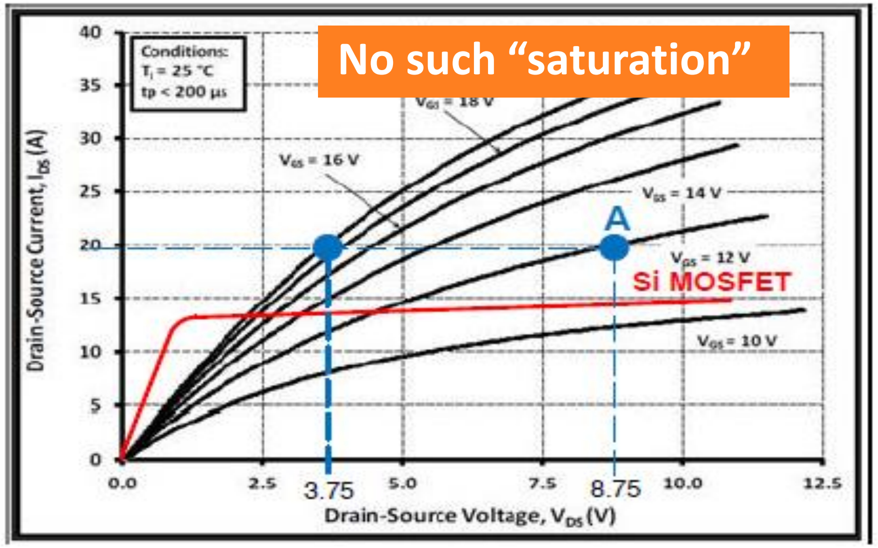
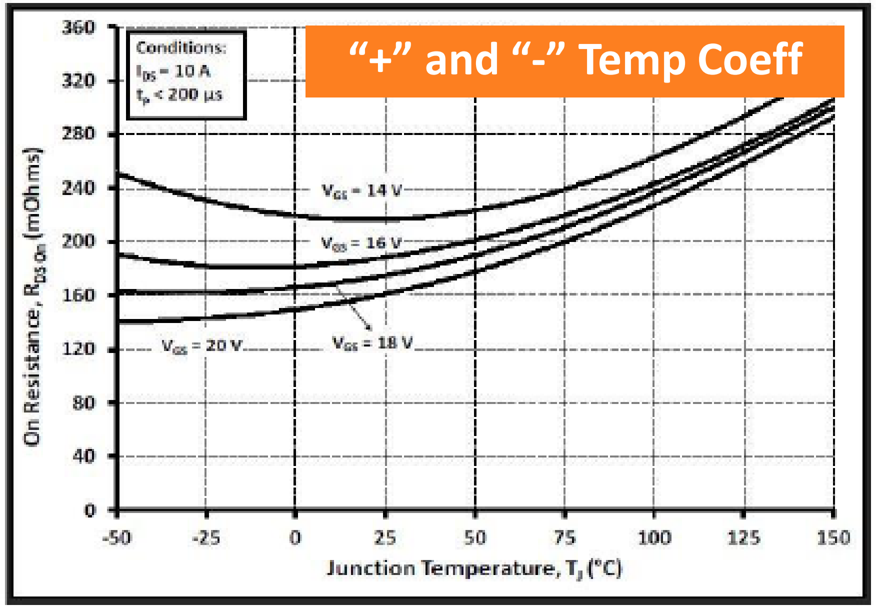
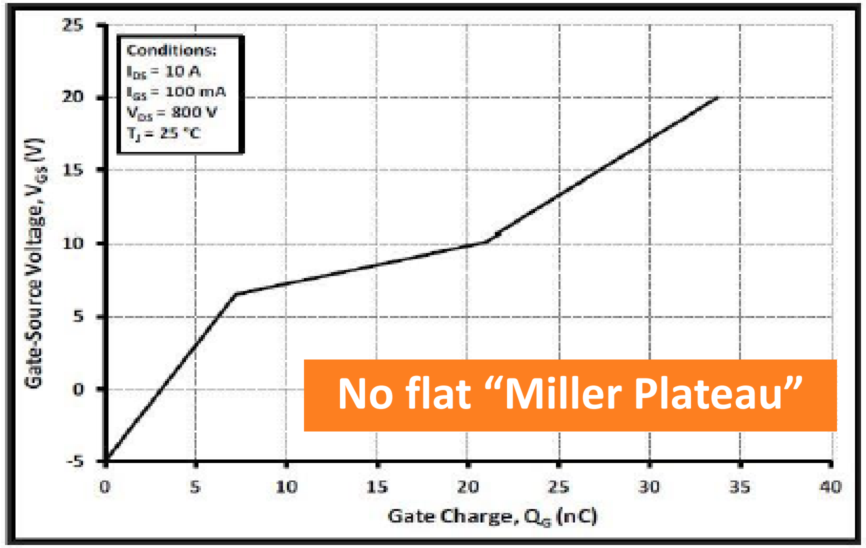
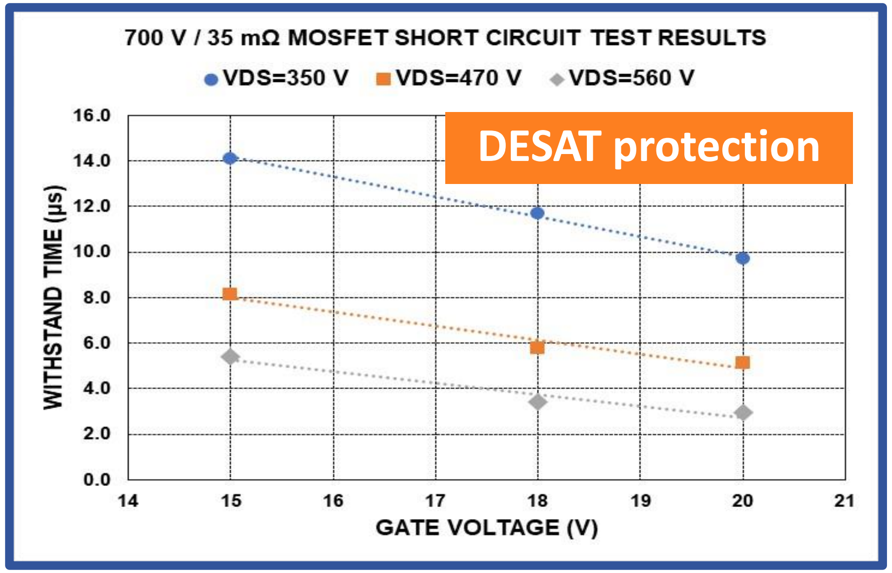


Figure 1. SiC MOSFET Output Characteristics







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SiC Gate Driver Solutions

The new way to rugged, reliable, flexible drive design

SiC Runs Faster Than Silicon

But Often With Nasty Secondary Effects

- **Noise/EMI**
- **Short Circuit**
- **Overvoltage**
- **Overheating**

A digital solution, **with Augmented Switching™** technology, is required to address these impacts

Without Augmented Switching   With Augmented Switching

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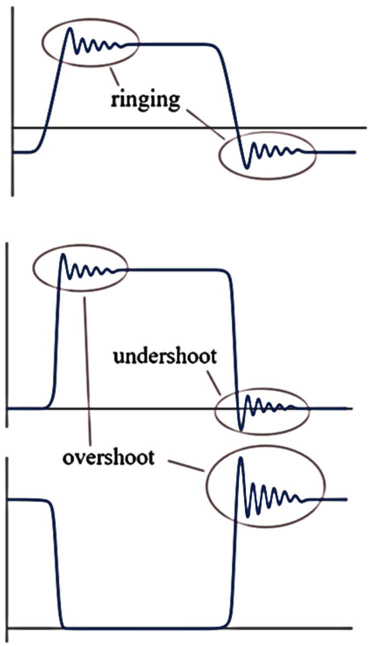
Superior SiC Digital Programmable Gate Driver Solution Over Analog Solution

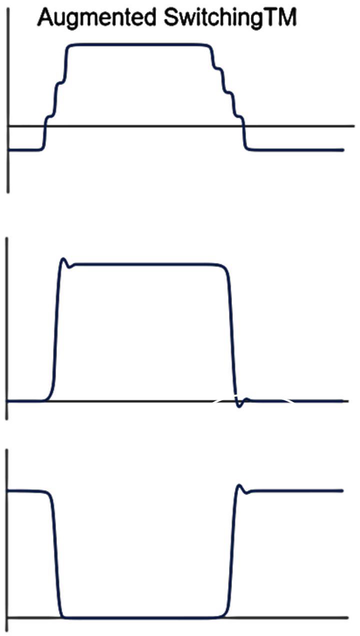
Standard Analog Drivers vs. **AgileSwitch® Gate Drivers featuring Augmented Switching™**



Gate Voltage

Current

Voltage

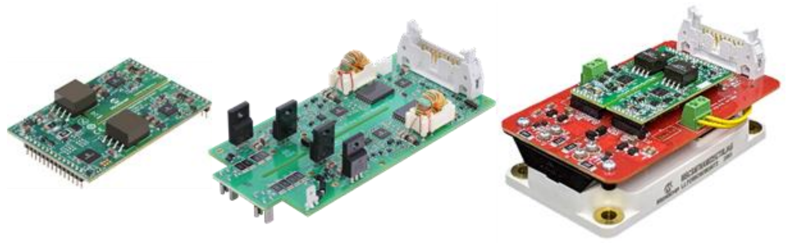


- ✓ No False Faults
- ✓ Mitigates Ringing
- ✓ Lowers EMI
- ✓ Reduces Overshoot
- ✓ Reduces Undershoot

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

Adopt SiC With Ease, Speed and Confidence

SiC Gate Drivers – Fastest to Market, Highest Efficiency

Product Family	Packaging	Portfolio
Gate Drivers		• 700V – 1700V Gate Drivers • Augmented Switching™ (Patented) • Development Kits

Lowest System Cost

- Higher efficiency
- Reduces design and evaluation time
- No supply interruption of production

Fastest to Market

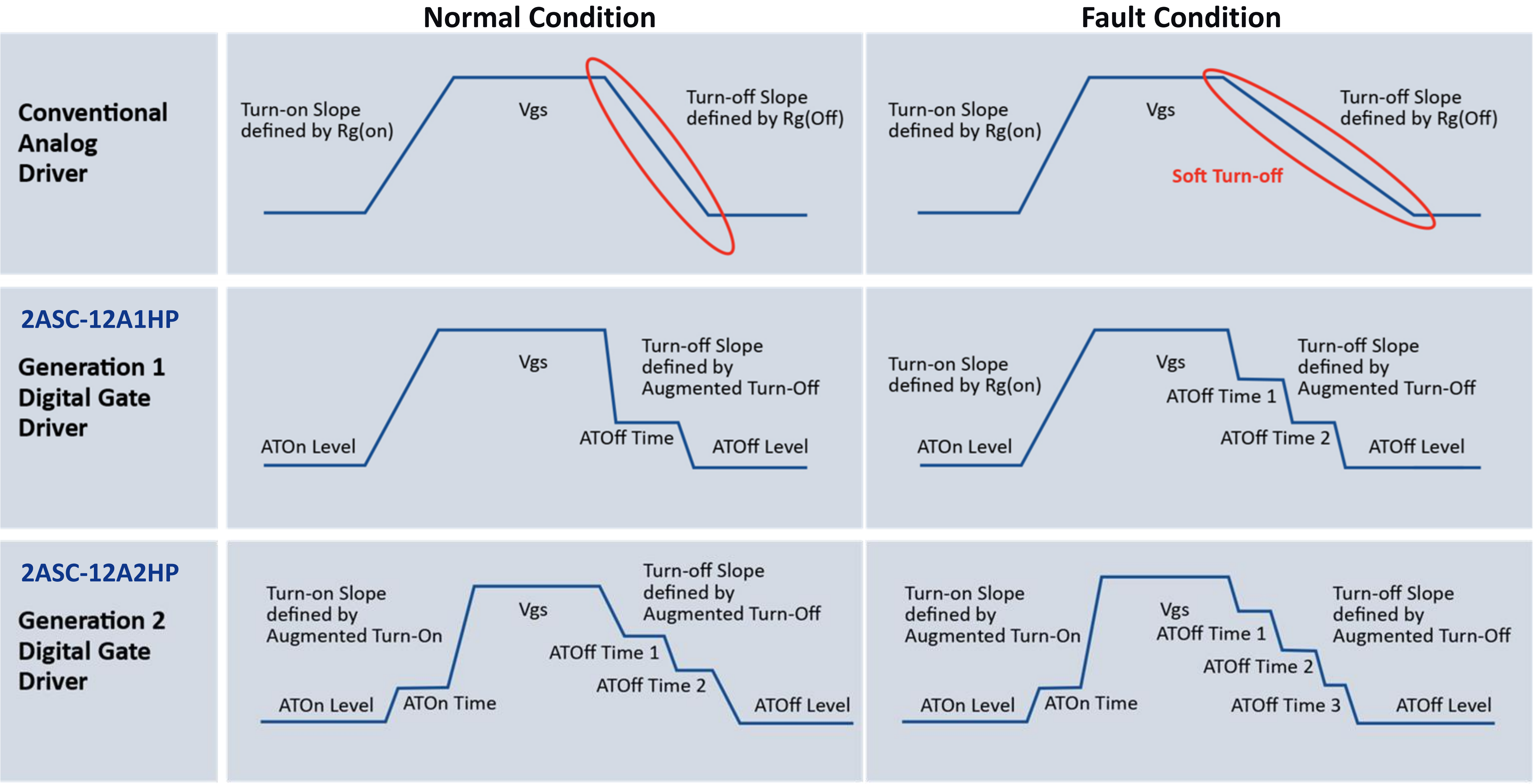
- Reduces design and evaluation time
- Earlier and more revenue
- Accelerate your innovation process

Lowest Risk

- Increased power system reliability
- Reduces design and evaluation time
- Runs cooler

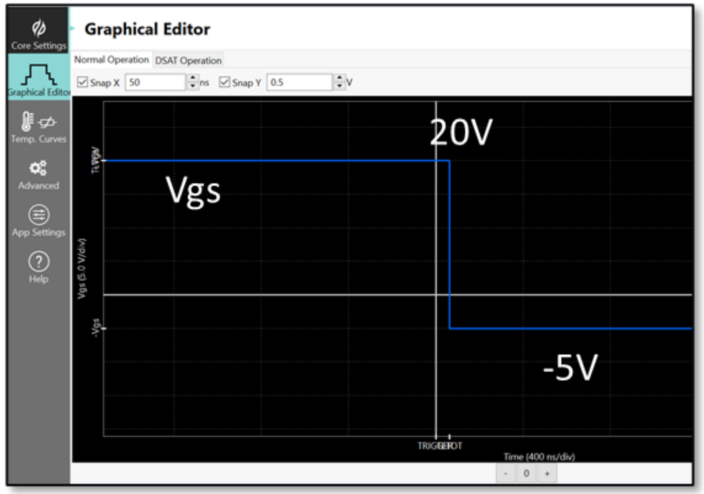
Unleash the Full Capability of Silicon Carbide

Quickly Optimize with Configurable Digital Control



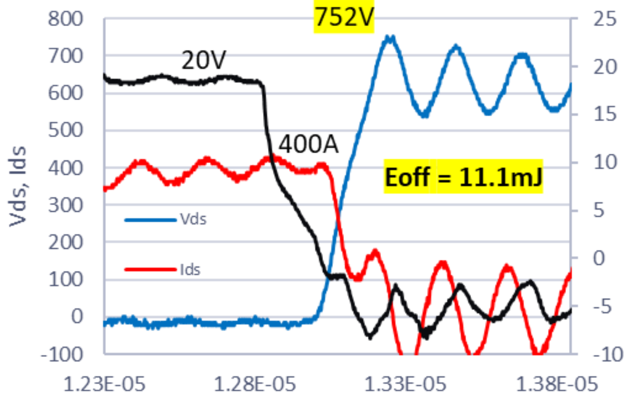
Augmented Switching™ Technology

Augmented Turn-Off Disabled



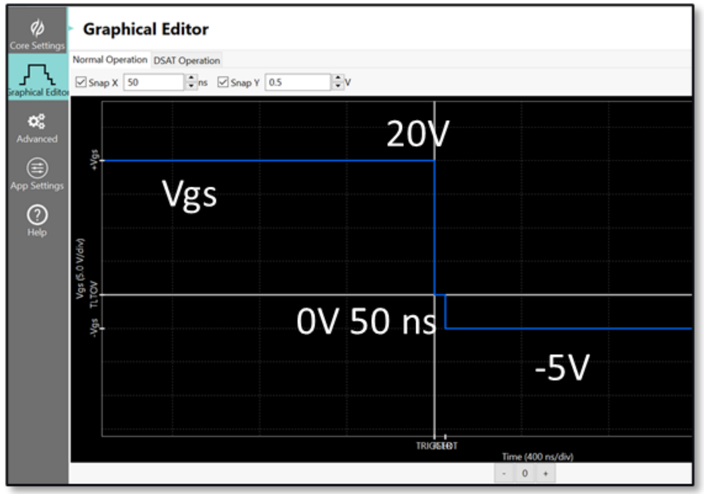
Vsoff = N2LTO

Vds = 600V; Ids = 400A; Rg,ext = 1.1Ω



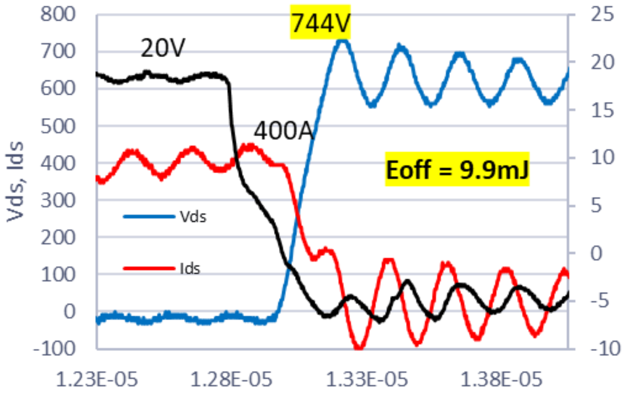
Base Case

Augmented Turn-Off Setting (0V; 50 ns)



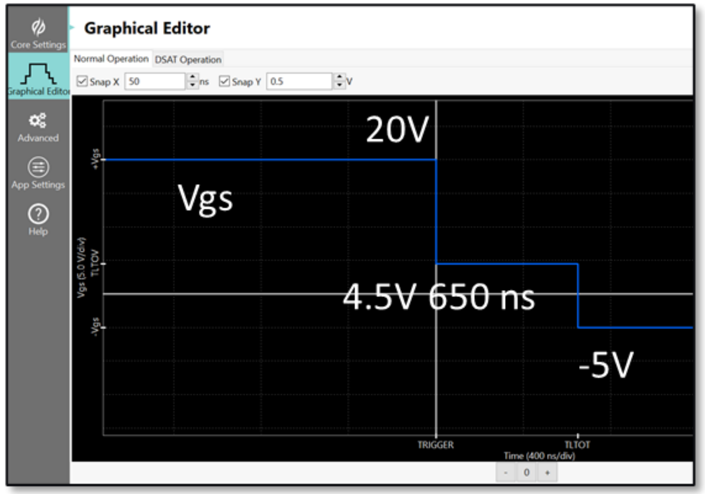
Vsoff = 0V; tsoff = 50ns

Vds = 600V; Ids = 400A; Rg,ext = 1.1Ω



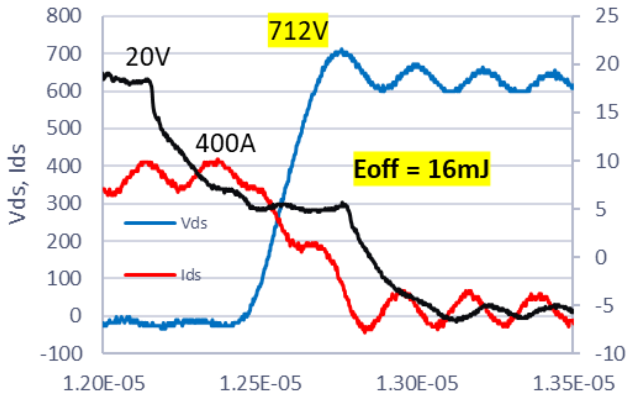
Reduce Eoff

Augmented Turn-Off Setting (4.5V; 650 ns)



Vsoff = 4.5V; tsoff = 650ns

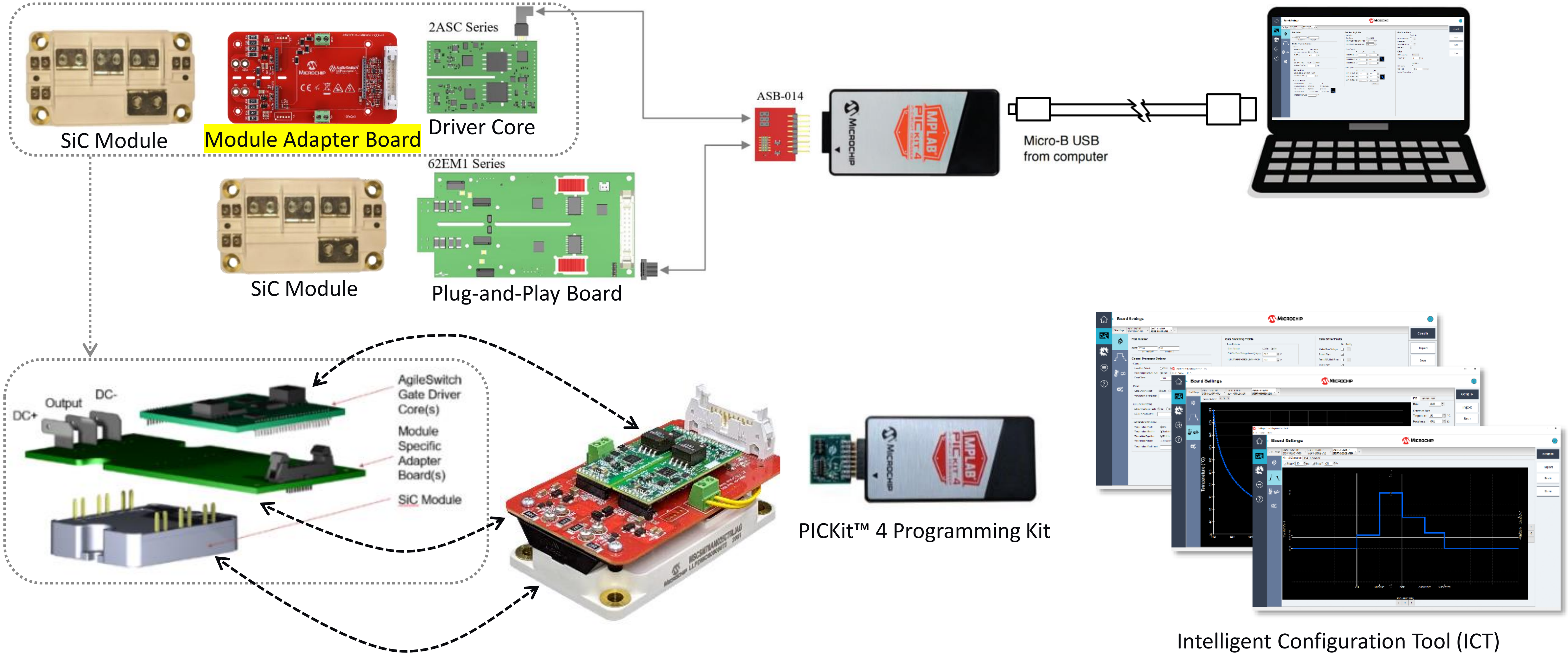
Vds = 600V; Ids = 400A; Rg,ext = 1.1Ω



Reduce Vovershoot, EMI

Connect and Configure

Saves up to Six Months of Development for New Designs



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SiC Design Support

Reference designs , Development Ecosystem, Tools

SiC Design Support

- **Hardware Tools**
  - 30 kW 3-phase Vienna PFC Development/EvalBoard
  - 30 kW Dual PSFB DC-DC Development/EvalBoard
  - 150 kVA 3-phase SiC Power Stack Development/EvalBoard
  - 400/800V_{DC}, 30A Solid State Circuit Breaker Development/EvalBoard
  - 60W Auxiliary Power Supply with 250 – 1000V_{DC} input Reference Design
  - Half bridge ASD2 gate driver and SiC MOSFETs in TO-247 Development/EvalBoard
  - SP6LI Module Development/EvalBoard
  - More available at **SiC Design Resources:**
    - www.microchip.com/SiC

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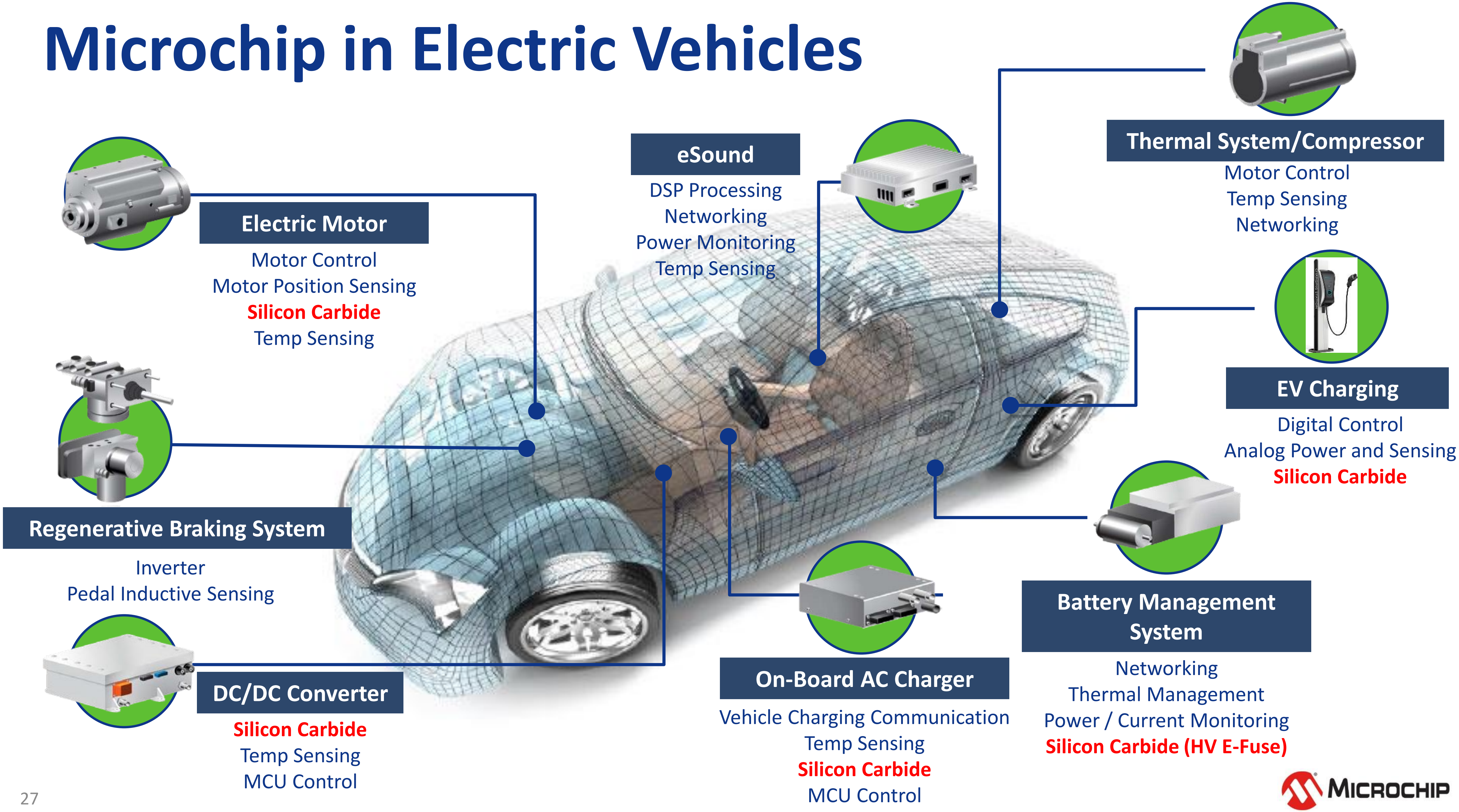
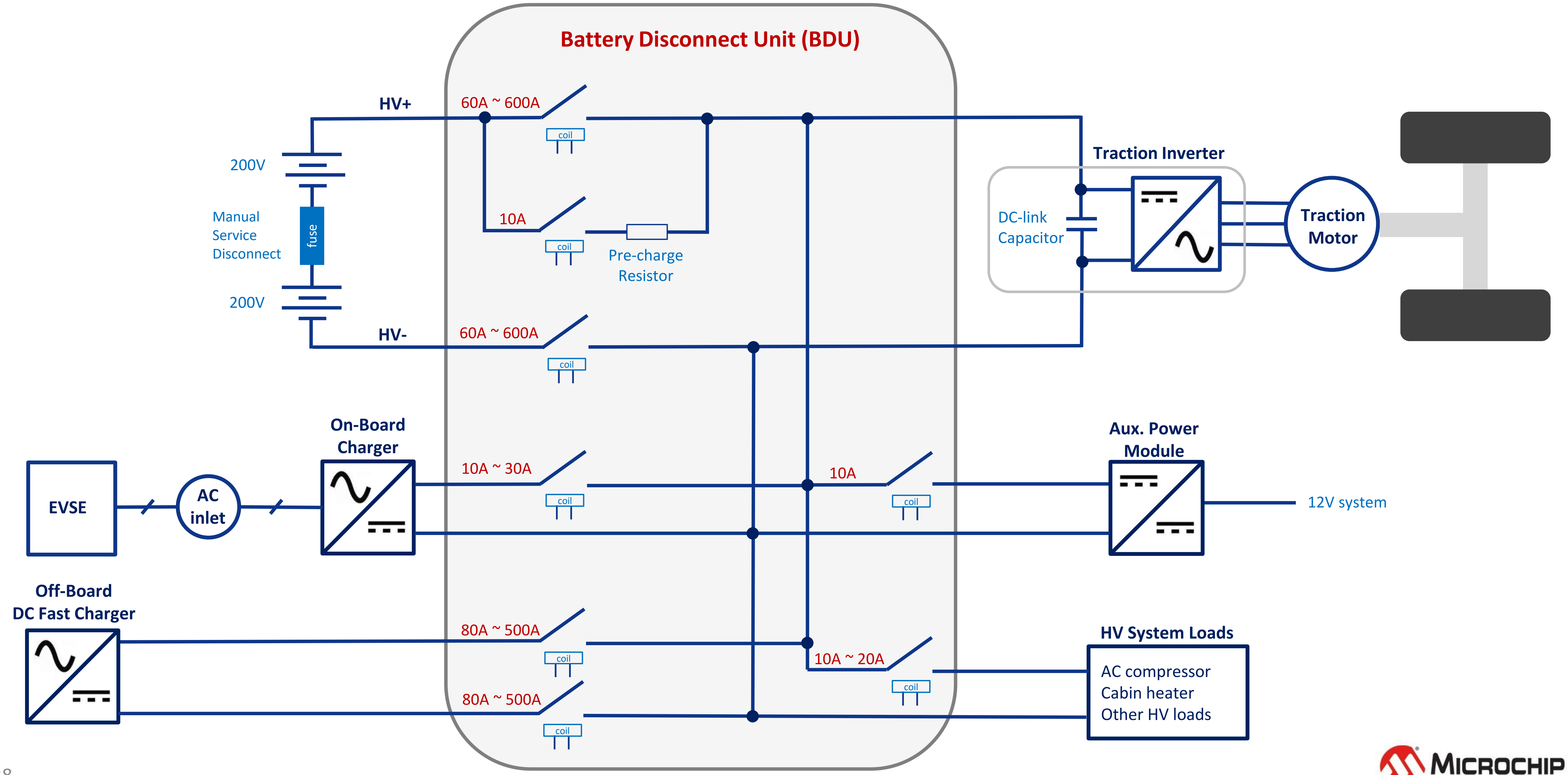
Microchip in Electric Vehicles



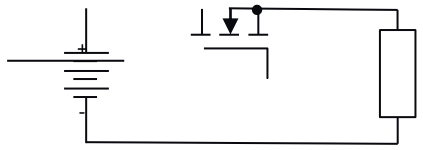
EV Battery Disconnect Unit



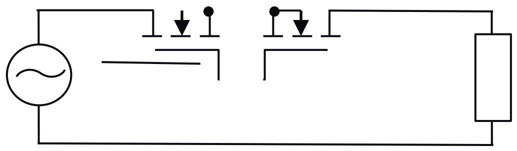
Electromechanical Relays and Solid-State Comparison

Performance, Reliability, and Safety	Relays	Solid-State
Resistance	Contact resistance	$R_{(DS)ON}$
Operating current	Coil, economizer	Gate drive
Response time	Milliseconds	Microseconds
Controllability	No	Yes
PWM operation	No	Yes
DC systems	Yes	Yes
Temperature	T_{AMB} = 85°C	T_{JUNC} = 175°C
Aging, wear-out	Contact erosion, corrosion	No
Mechanical durability	Vibration, mechanical shock, drop	n/a
Overshoot, ringing	-	Controllable
Galvanic isolation	Yes	No
Electric arc	Inductive loads	No
Hazardous environments	Sealed	Yes

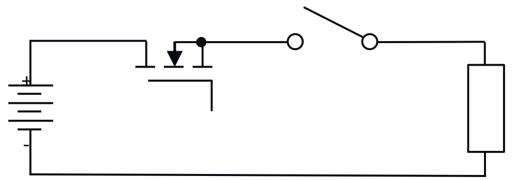
- **DC system**



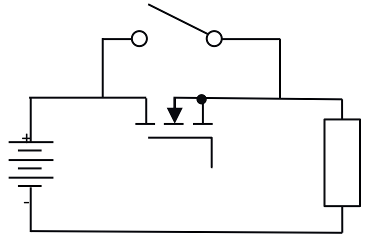
- **AC system**



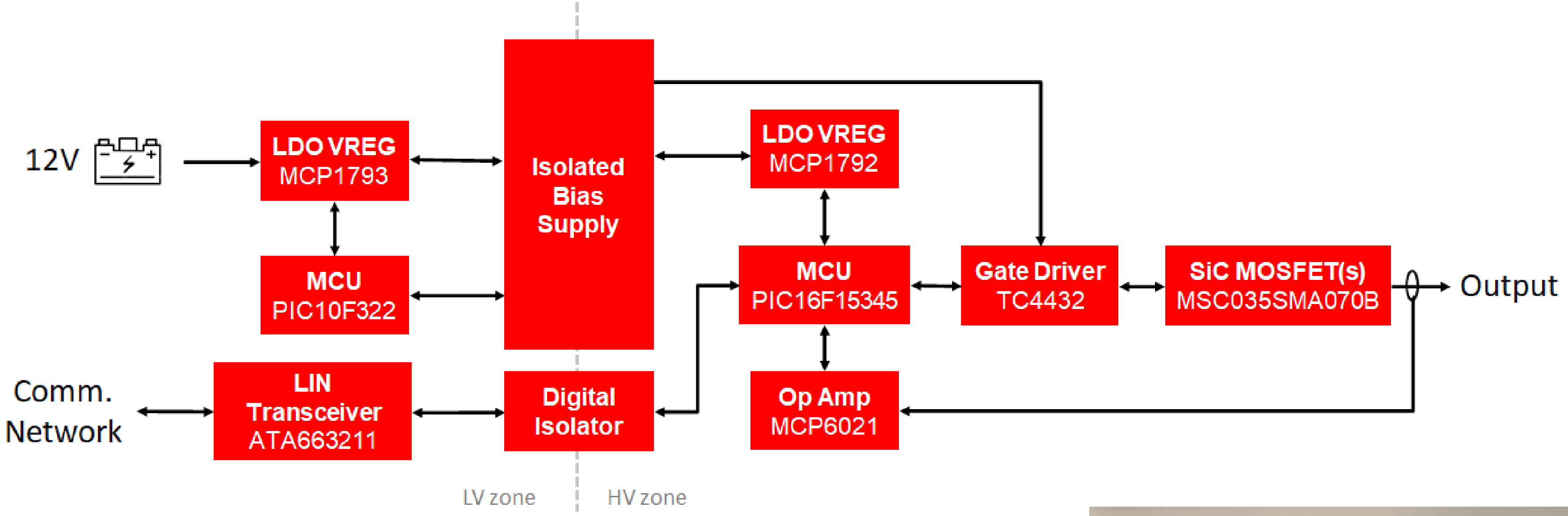
- **Hybrid - Series configuration**



- **Hybrid - Parallel configuration**

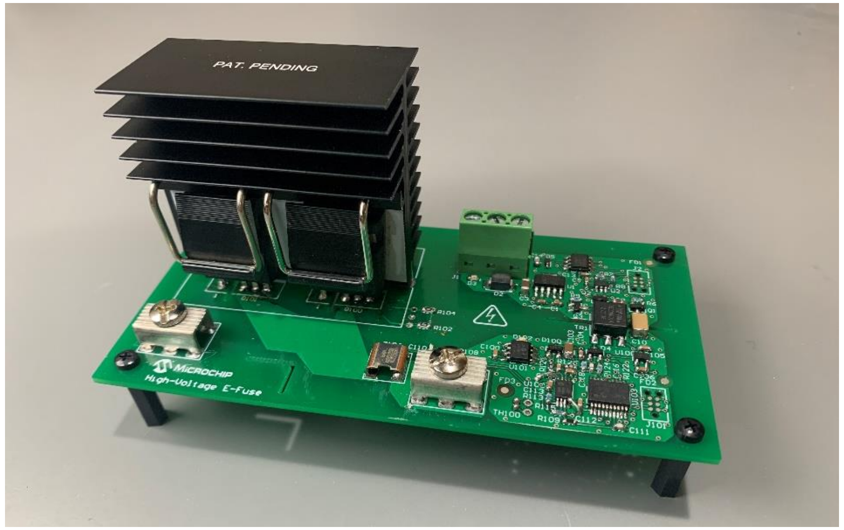


E-Fuse Design – Broad System Solution



Target Specifications

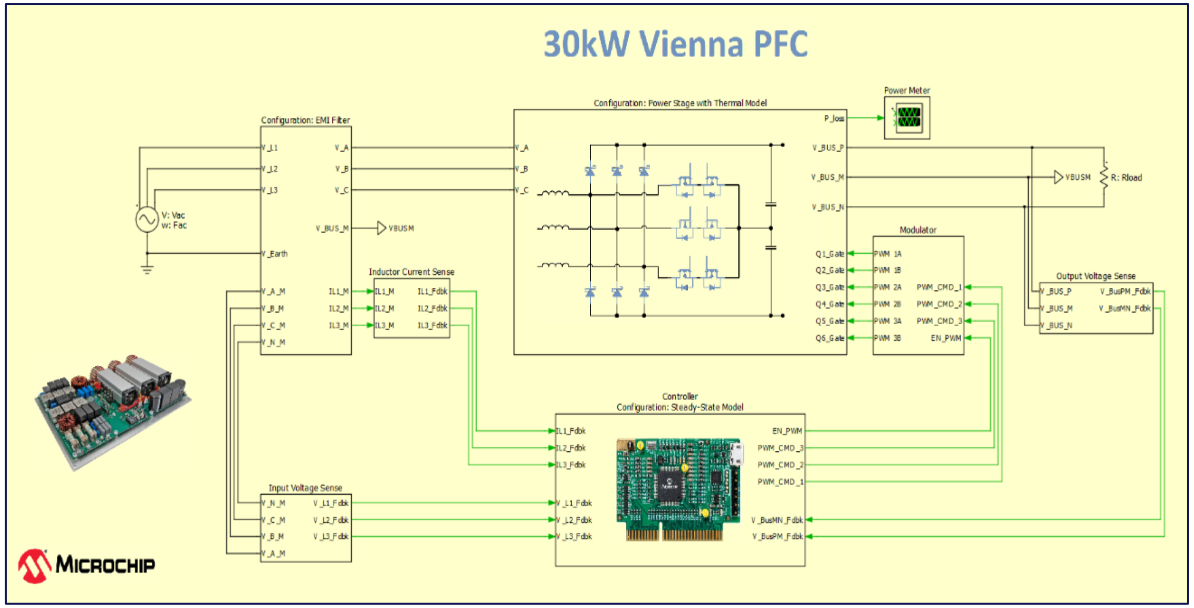
- 400V and 800V DC battery system
- Up to 30A continuous load
- Short-circuit withstand time up to 10 µs
- Configurable current limit profile
- Communication interface for configurability and diagnostics



SiC Design Support

Software Tools

Vienna PFC PLECS Model for electrical and thermal modeling



SiC Simulation Models

- SiC SPICE models (MOSFET and SBDs)
- SiC PLECS models (MOSFETs and SBDs)

MPLAB® SiC Power Simulator

- Free PLECS-based online power simulation tool
- Quickly evaluates Microchip SiC power devices and modules across various topologies

MPLAB® Mindi™ Analog Simulator

- Microchip's free circuit simulation software available for download at www.microchip.com/Mindi
- Uses SIMetrix and SIMPLIS simulation environment for SPICE and piecewise-linear modeling, respectively

Adopt SiC With Ease, Speed and Confidence

Lowest System Cost | *Unrivaled ruggedness and performance—**No Redundancy***

Fastest to Market | *Gate drivers and broad system solutions—**Rapid Development***

Lowest Risk | *Multi-source epi wafers and dual fabs—**Supply Certainty***

Questions

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Thank You!
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