Silicon Carbide (SiC) Power Solutions for Transportation APUs

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SiC Power Solutions, Microchip

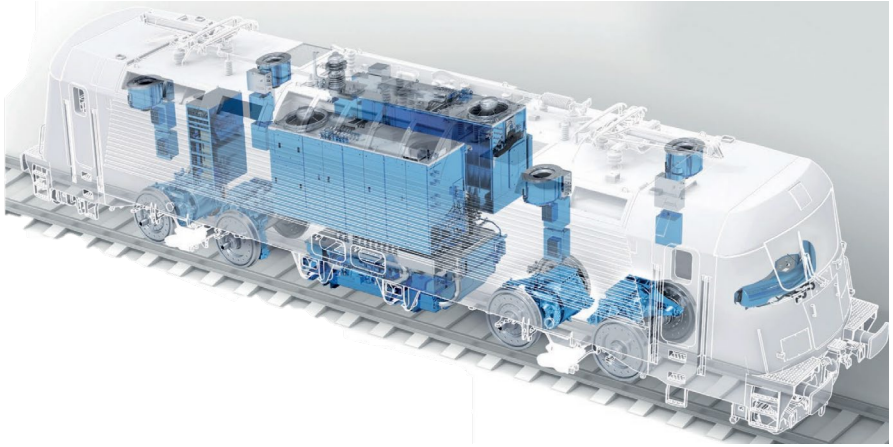
Overview

- Transportation APUs, in brief
- Microchip SiC for APUs
- Finding the “right” SiC
  - SiC MOSFET ***toughness***
  - ***Ultra-low inductance*** power package
  - Intelligent ***digital gate driver***
- SiC APU Solution: ASDAK+

Locomotive Electrical Systems

BATTERY CHARGER uses IGBTs or SiC MOSFETs switching at high frequency

AUXILIARY POWER supply is based on IGBT or SiC technology with integrated control for generating three-phase AC network



Images Source: Škoda Electric

PROPULSION with integrated traction control system. Independent inverters for four traction motors with 4Q input converters

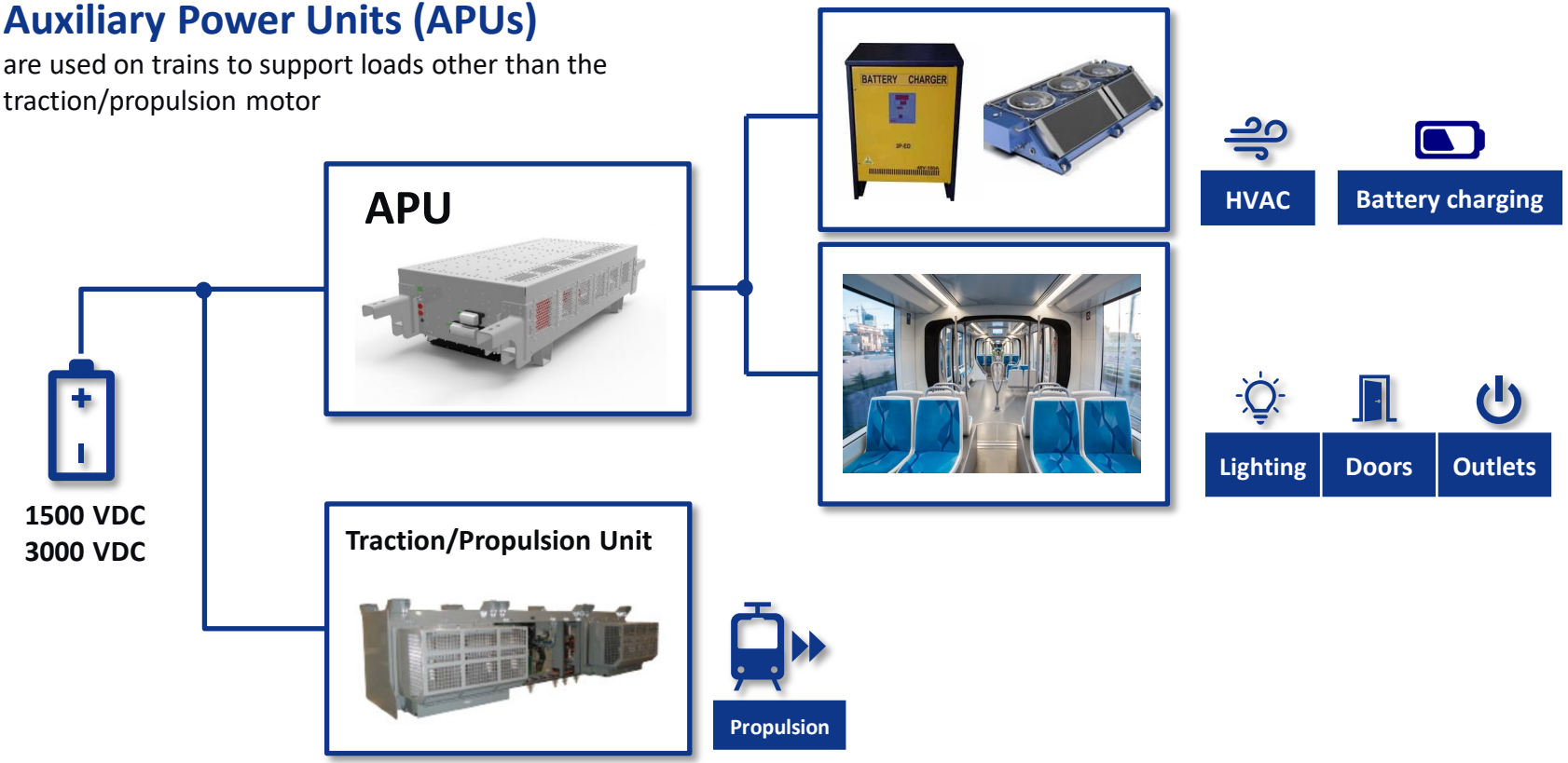
COOLING TOWER with fan contains the liquid-to-air heat exchangers

TCMS (Train Control and Monitoring System) uP-based train control algorithms, interfaces and control of local subsystems and remote diagnostics.

About Transportation APUs

Auxiliary Power Units (APUs)

are used on trains to support loads other than the traction/propulsion motor



About Transportation APUs

Converts 1500 VDC to 700 VDC, which is then turned into 3-phase 440 VAC for further distribution

HIGH VOLTAGE

Must operate continuously and often under light loads, unlike traction power unit

EFFICIENCY

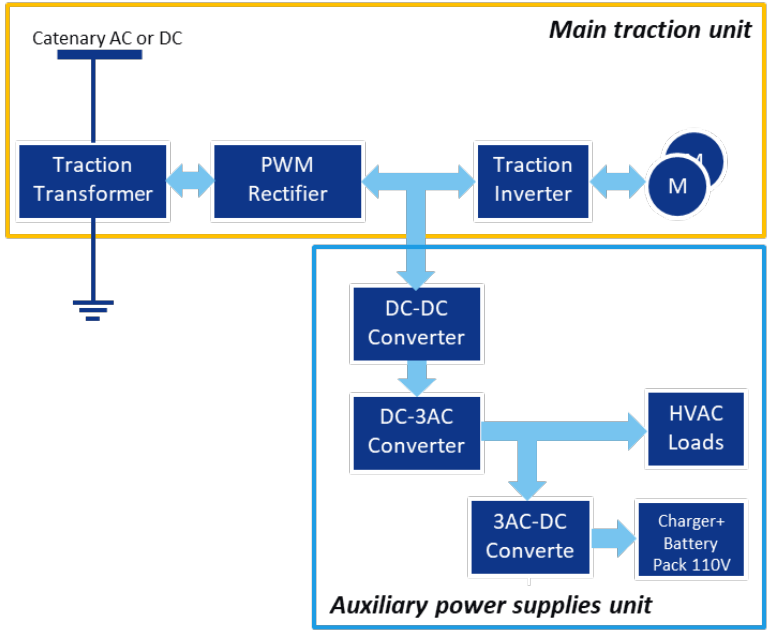
Need to downsize since these are installed in smaller trams where space is a premium

POWER DENSITY

IGBTs limit APU switching frequency to the audible range

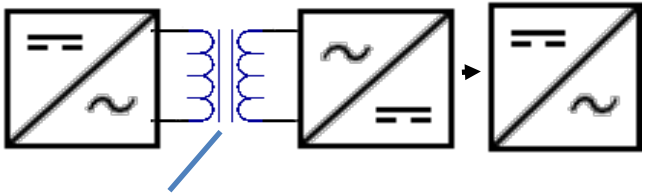
NOISY

Possible solution



Why SiC for APUs?

SiC Traction APU



Large, heavy Isolation transformer limited by IGBT's switching losses and, hence, switching frequency

Your APU using:	
3.3 kV silicon IGBT	**1.7 kV SiC MOSFET**
• Noisy to passengers and circuits • Higher conduction losses at light loads • Switching losses 4-5x higher; must switch in audible range	• Smaller, lighter, less expensive transformers • Smaller heat sinks • Less noise and greater passenger comfort

3 things are needed first!

Before we can successfully and confidently deploy SiC in APUs, we need three answers:

1. RELIABILITY & RUGGEDNESS
2. LOW INDUCTANCE
3. INTELLIGENT GATE DRIVER

1

Reliability & Ruggedness

SiC MOSFETs from Microchip

Why Does Ruggedness Matter in APUs?

If you want your transportation APU to:	Operate routinely & reliably	Meet or exceed desired service lifetime	Survive electrical transients
Then you care about:	Oxide stability Oxide lifetime Body diode stability Survivability	Oxide stability Oxide lifetime Body diode stability (also improves cost)	Avalanche ruggedness Short circuit withstand

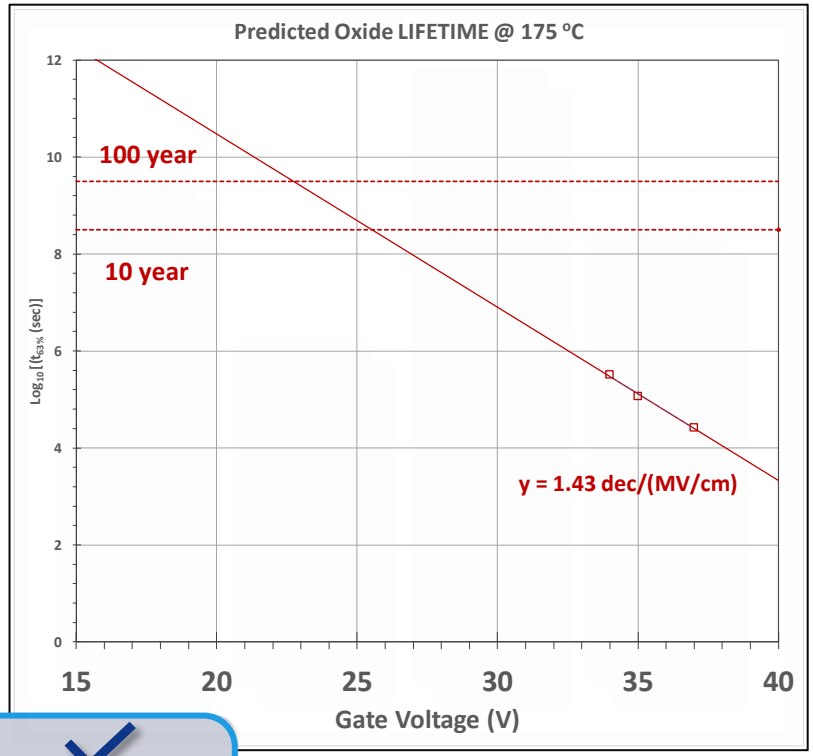
Not rugged?

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

Ruggedness | *Body Diode Stability*

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

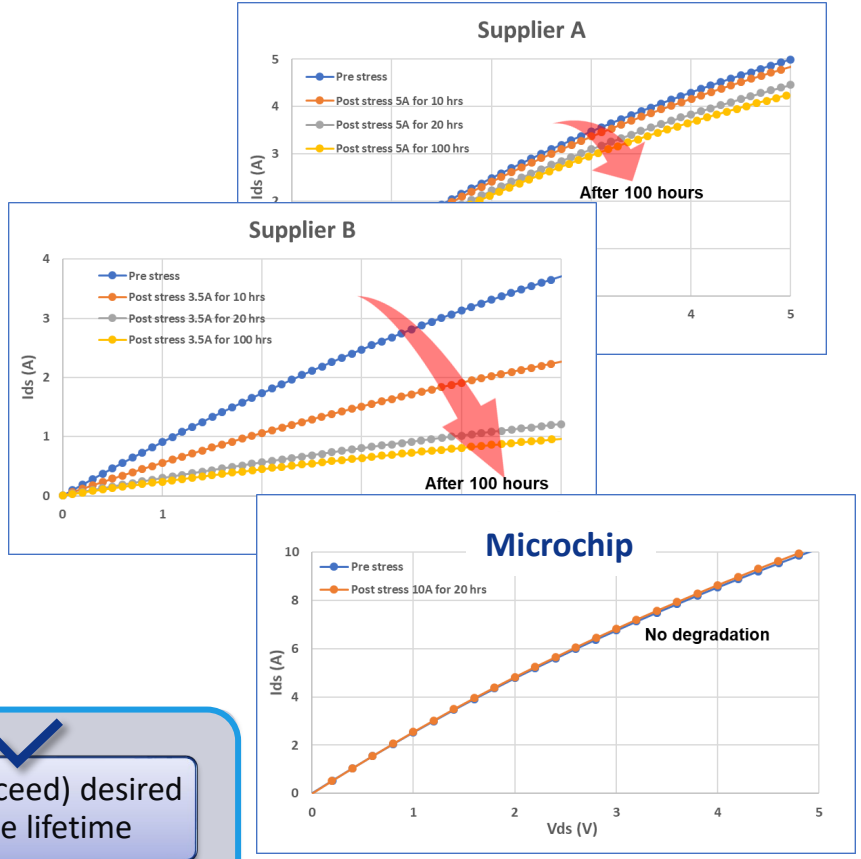
ii. Body diode I-V curves and R_{DSon} measurements made before and after stress

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

Ruggedness | *Short-Circuit Capability*

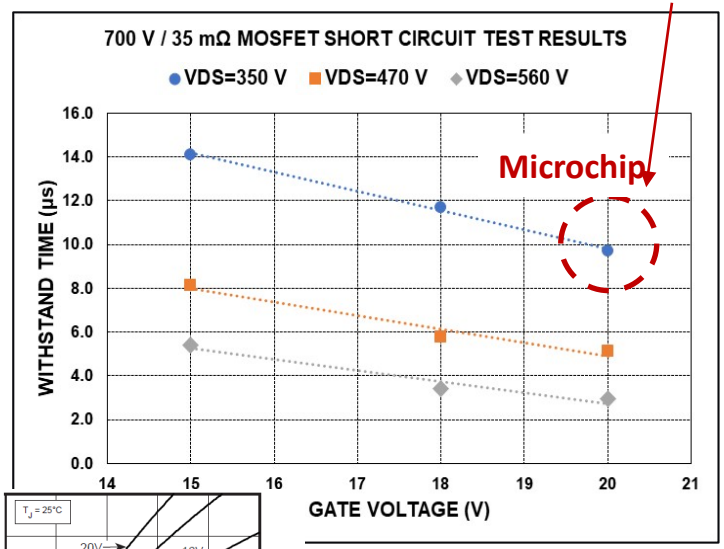
i. Short circuit emulates the application condition of shorting the MOSFET's drain-source across the dc link

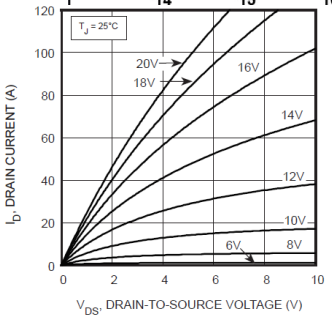
ii. Cells are enhanced (MOSFET is ON); peak current intended to distribute uniformly across die

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

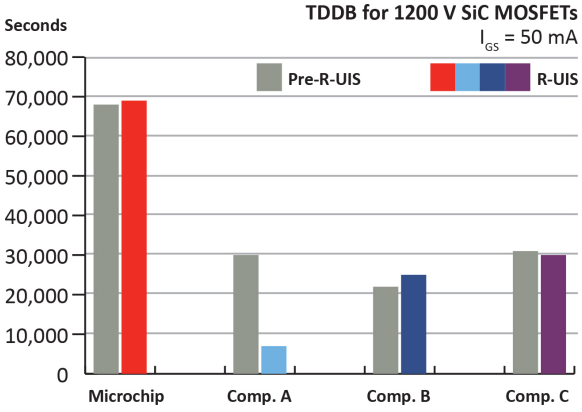
Safely ride through harmful electrical transients

Ruggedness | *Avalanche / R-UIS*

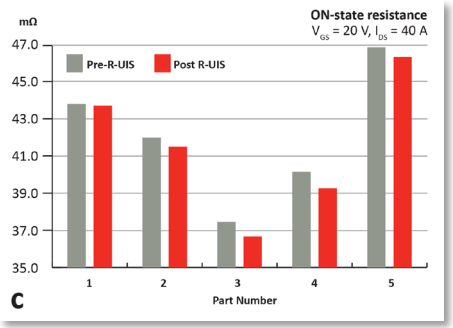
i. Measures the MOSFET's ability to repetitively sustain an avalanche current being switched off from an unclamped inductive load (R-UIS)

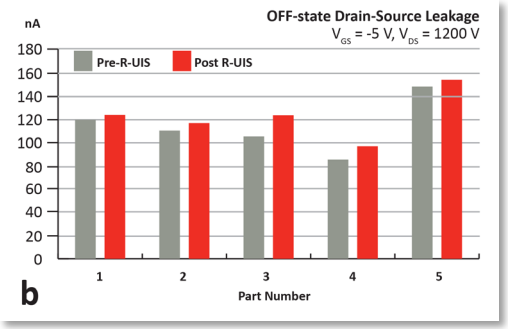
ii. Cells are not enhanced (MOSFET is OFF); peak current increases rapidly until $V_{DS} = V_{BR}$; avalanche current likely to crowd around die edge

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

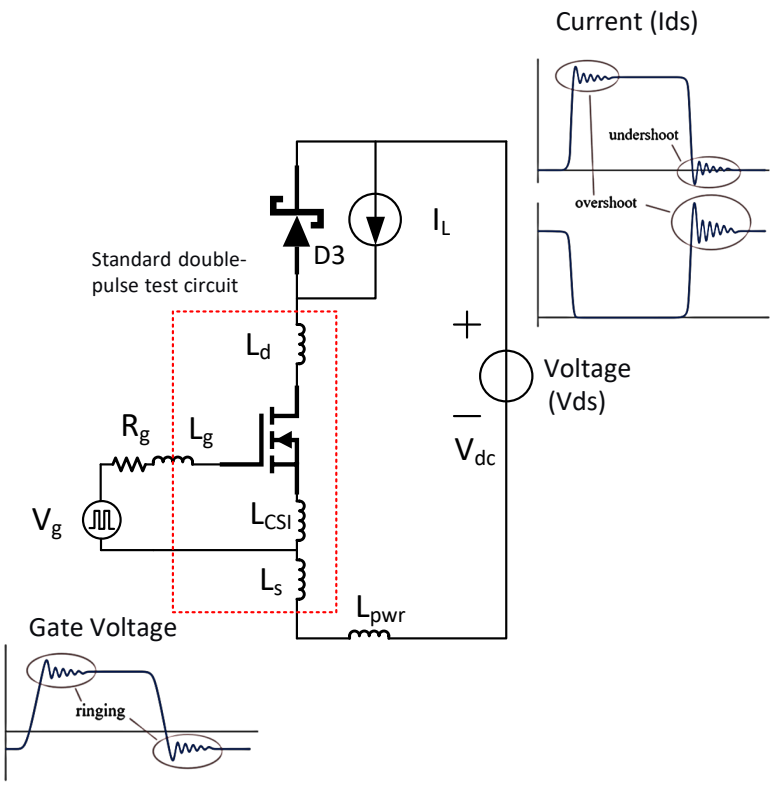
Safely ride through harmful electrical transients

2

Low Inductance Power Packaging

SP6LI from Microchip

Low-inductance Package | *The Importance*



3 Sources of inductance

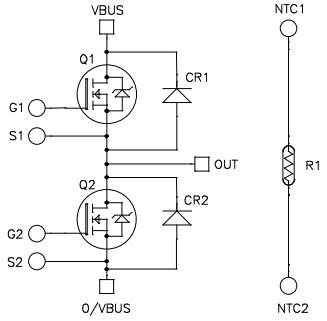
Common source, L_{CSI}	Power loop, L_{pwr}	Gate, L_g
▪ Inductance coupling the gate and power circuits ▪ Inhibits edge rates and **increases switching losses**	▪ Parasitic inductance of the circuit flowing through the power device(s) and load ▪ Responsible for **voltage spikes** during turn-off transient	▪ Gate inductance which can be part of the package or part of drive circuit ▪ MHz-range oscillations at turn-on, **creating EMI and potential system failure**
inefficient	**ineffective**	**incompatible**

Where did my SiC value go?

Low-Inductance Package | *SP6LI*

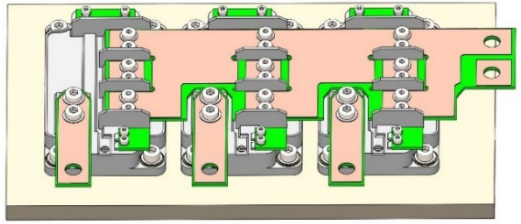
Parasitic loop inductance: 2.9 nH

- AlN or Si_3N_4 substrate with copper or AlSiC baseplate and NTC monitoring
- Easily paralleled and connected to DC link with minimal parasitic inductance
- Possibility to interconnect 3 modules together in vertical or horizontal position

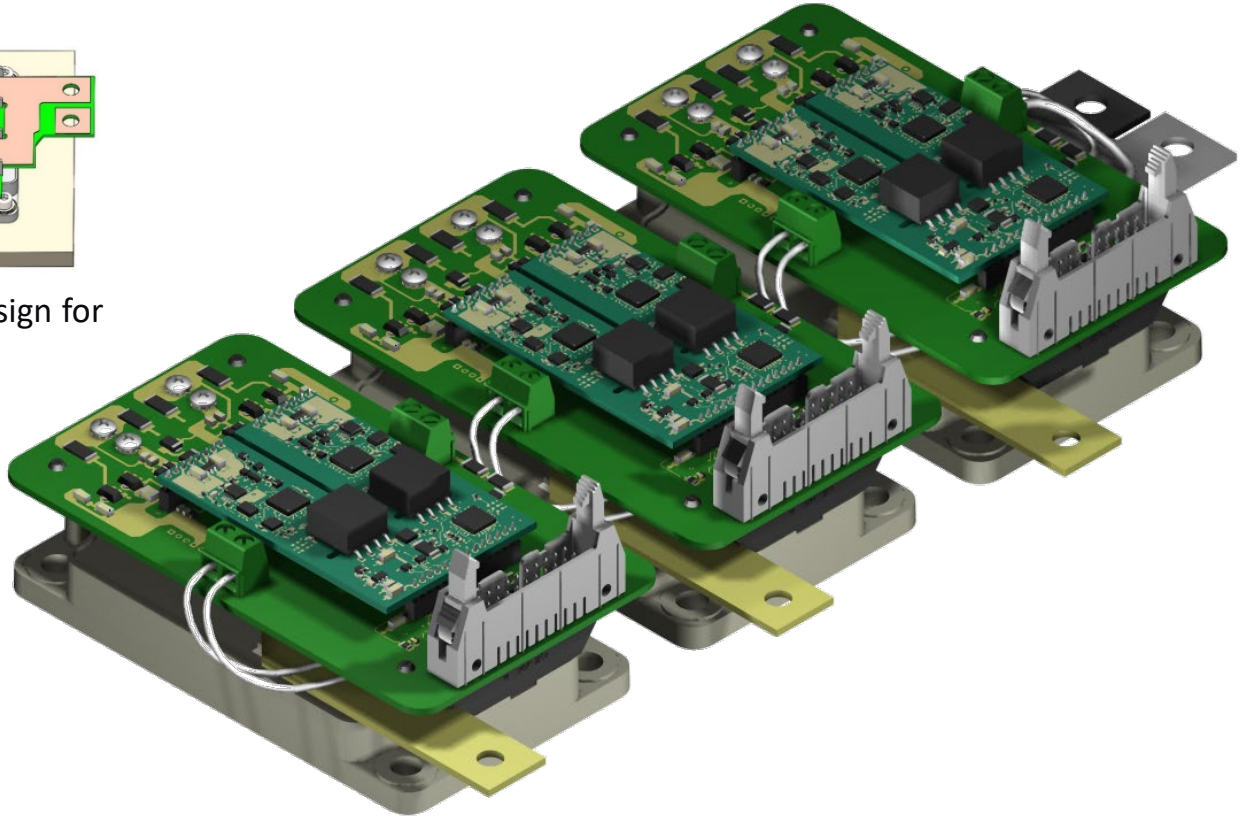


Voltage	Current Tc=80°C	RDSon Typ Tj=25°C	RDSon max. Tj=25°C	SiC parallel diode ratings
700 V	538 A	2.5 mΩ	3.2 mΩ	300 A
1200 V	754 A	2.1 mΩ	2.6 mΩ	300 A
1200 V	641 A	2.5 mΩ	3.1 mΩ	250 A
1200 V	394 A	4.2 mΩ	5.2 mΩ	180 A
1700 V	**Coming soon**			

Total SiC Solution for APUs | *Layout Elegance*



Low-inductance bus bar design for 3-phase inverter



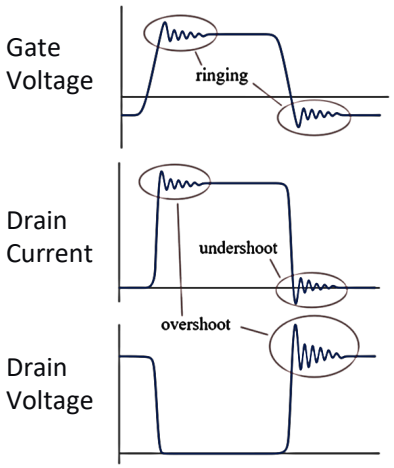
3

Intelligent Gate Drivers

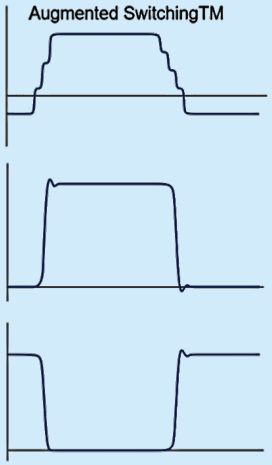
AgileSwitch® Digital Gate Drivers from Microchip

Intelligent Gate Driver | *Digital and Programmable*

Conventional switching



Augmented switching



- ✓ No false faults
- ✓ Mitigates ringing
- ✓ Lowers EMI

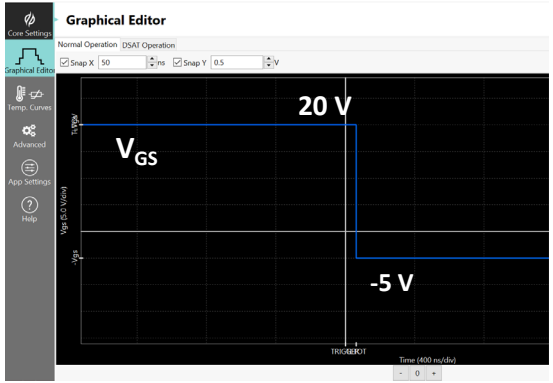
✓ Reduces overshoot

✓ Reduces undershoot

- Up to 80% lower V_{DS} overshoot
- Up to 50% lower switching losses
- Robust and fast short circuit protection
- Save countless hours of design tweaking

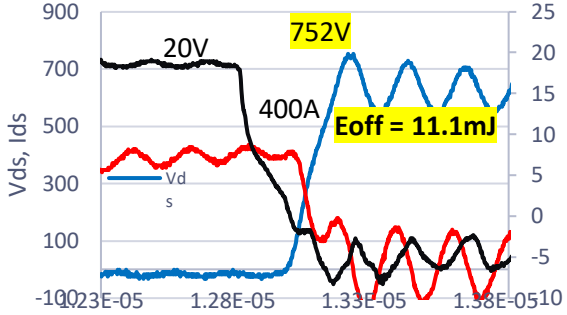
Intelligent Gate Driver | *The Impact*

Conventional switching

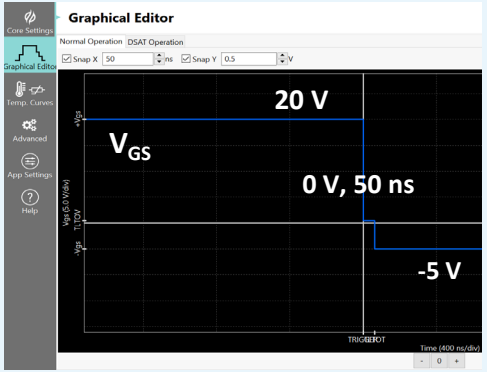


Vsoff = N2LTO

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

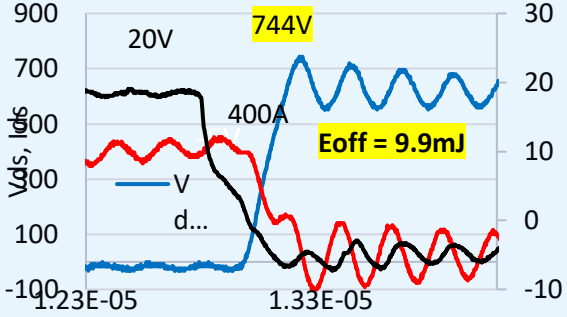


Augmented switching



Vsoff = 0V; tsoff = 50 ns

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



- ✓ Lower overshoot
- ✓ Lower losses
- ✓ Greater confidence

Intelligent Gate Driver | *Safer Short Circuit*

DUT: D3 SiC MOSFET
Vdc = 1000V

Pink = Vgs = 10V/div;
Yellow = Vds = 500V/div;
Green = Ids = 1kA/ div

Conventional switching

I_{sc} = 5 kA
$V_{overshoot}$ = 500 V

Augmented switching

I_{sc} = 4.5 kA
$V_{overshoot}$ = 200 V

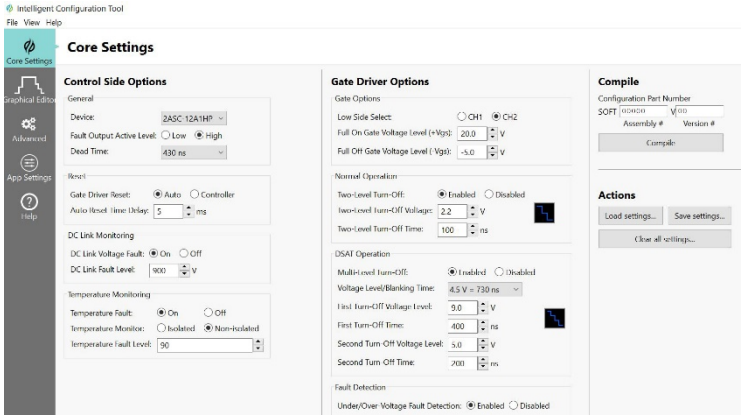
The Total SiC Solution for Transportation APUs

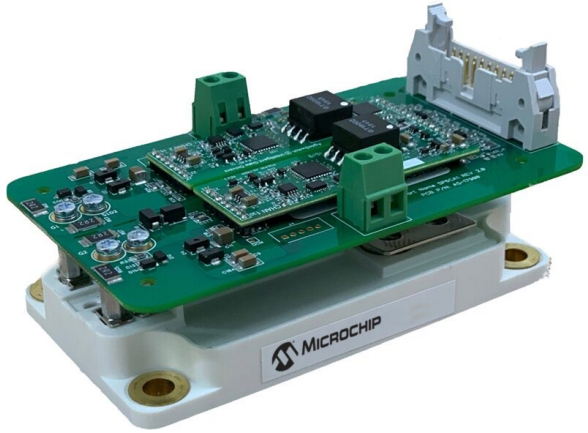
ASDAK+ Accelerated Development Kit

Microchip SiC Adoption in APUs

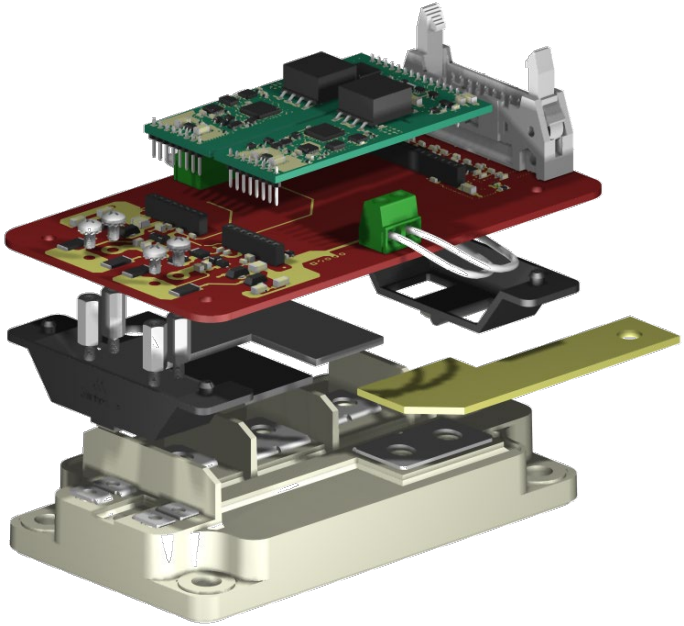
- Microchip offers total system solutions for transportation APUs
- Multiple APU customers in production with Microchip SiC solutions
- Total system solutions include all Microchip as well as competitor components
- **Microchip enhanced APU support means MORE:** controllers, timing, memory, and tailored products and services

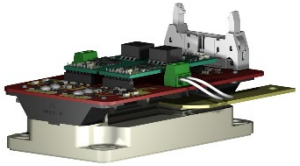
	Client A	Client B	Client C
Microchip SiC gate drivers	✓		✓
Microchip SiC power module	✓		
Microchip SiC discrete		✓	
Competitors' SiC modules/discretes			✓





Total SiC Solution for APUs | *Power Density*





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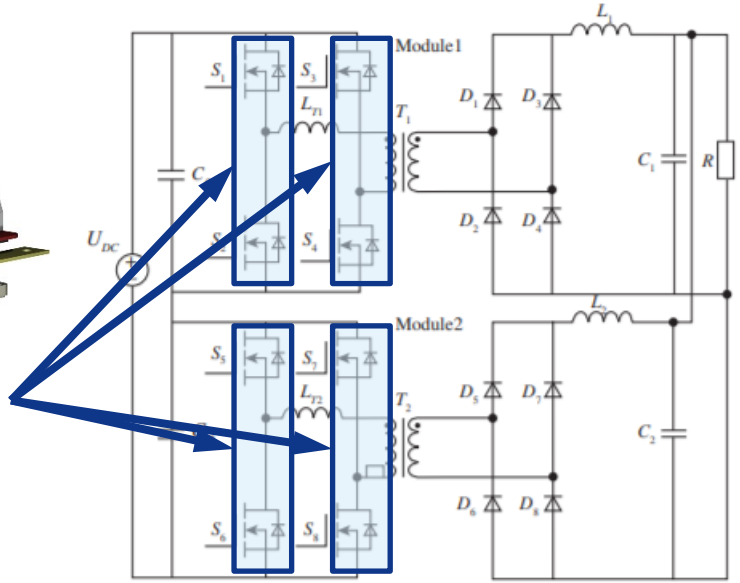
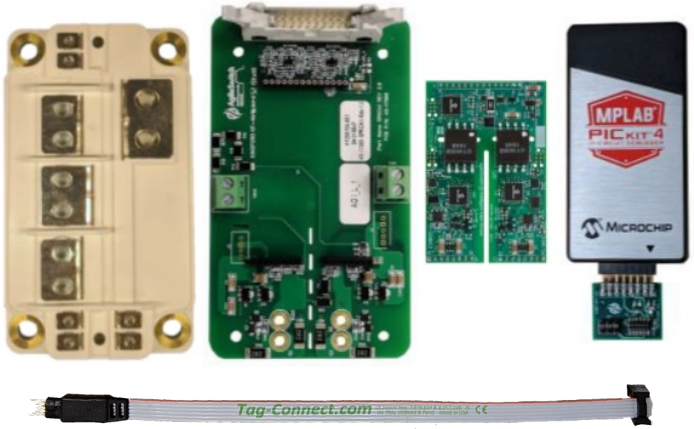
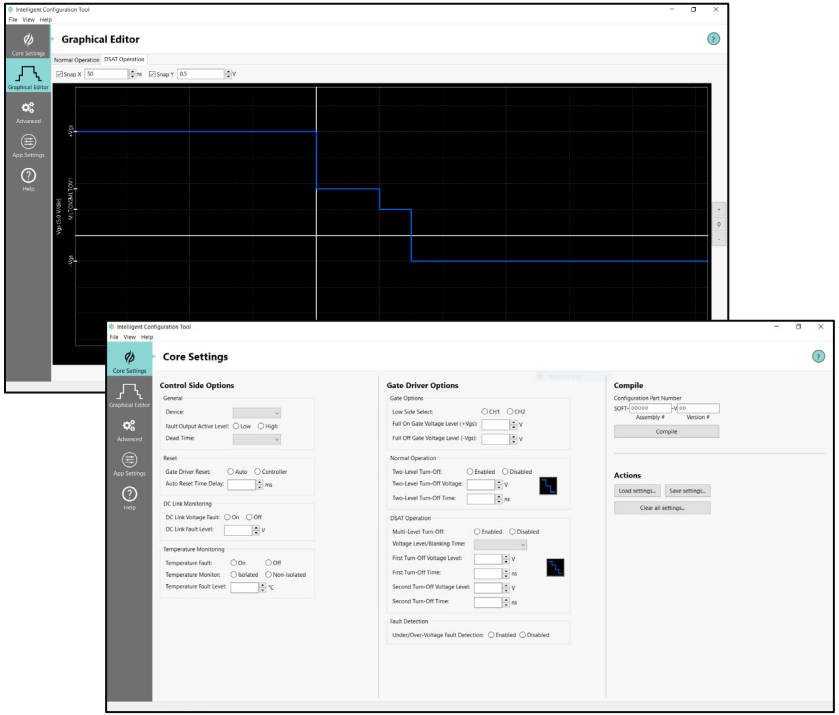


APU DC-DC converter using 1700 V SiC MOSFETs in phase-shifted full bridge topology

Huang et al., IEEJ J. Industrial Applications Vol. 8 (4), 2018

Total SiC Solution for APUs | *ASDAK+*





Each Kit Contains

Gate Driver

- *2ASC-12A1HP core*
- *SP6CA1 Adapter board*

SP6LI Power Module

- *Mounting hardware*

Programming Kit

- *MPLAB® PICkit™ 4*
- *Programming adapter*

Seamless total system solution:
from DPT evaluation to volume production

Solution Summary

Transportation APUs benefit from SiC power devices

- Higher power density *frees up valuable car space*
- Reduced losses mean *lighter, less expensive cooling*
- Less noise creates greater *system reliability (EMI) and passenger comfort (f_{sw} > 20 kHz)*

Harnessing these benefits requires the "right" SiC

- MOSFETs need *ruggedness and reliability*
- Power package needs *minimal inductance*
- Digital programmable gate driver needed to *fine-tune "in-system" performance*

Only Microchip offers a complete SiC solution for reducing the size, noise and field failures of transportation APUs

Thank you!

microchip.com/SiC