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.

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

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

**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.

- **APU**
- **Traction/Propulsion Unit**
- **Propulsion**
- **HVAC**
- **Battery charging**
- **Lighting**
- **Doors**
- **Outlets**

1500 VDC
3000 VDC
About Transportation APUs

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

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

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

IGBTs limit APU switching frequency to the audible range.

Possible solution:

Main traction unit

Auxiliary power supplies unit

Catenary AC or DC

Traction Transformer → PWM Rectifier → Traction Inverter → M

DC-DC Converter → DC-3AC Converter → 3AC-DC Converter

Charger+ Battery Pack 110V → HVAC Loads
Why SiC for APUs?

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

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

Your APU using:

<table>
<thead>
<tr>
<th>3.3 kV silicon IGBT</th>
<th>1.7 kV SiC MOSFET</th>
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</thead>
<tbody>
<tr>
<td>• Noisy to passengers and circuits</td>
<td>• Smaller, lighter, less expensive transformers</td>
</tr>
<tr>
<td>• Higher conduction losses at light loads</td>
<td>• Smaller heat sinks</td>
</tr>
<tr>
<td>• Switching losses 4-5x higher; must switch in audible range</td>
<td>• Less noise and greater passenger comfort</td>
</tr>
</tbody>
</table>

Large, heavy isolation transformer limited by IGBT’s switching losses and, hence, switching frequency.
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)

Not rugged?

- Avalanche ruggedness
- Short circuit withstand

If you want your transportation APU to:

- Not rugged?

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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*

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**Oxide predicted to last more than 100 years at recommended $V_{GS}$ and $T_j = 175^\circ C$**

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**Application benefits**

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

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**Predicted Oxide LIFETIME @ 175 °C**

- $y = 1.43 \text{ dec/(MV/cm)}$
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 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)

Application benefits

Safely ride through harmful electrical transients

Microchip

10 us comparable to IGBTs
**Ruggedness | Avalanche / R-UlS**

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

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*

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

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**Application benefits**

- Safely ride through harmful electrical transients
Low Inductance Power Packaging

SP6LI from Microchip
Low-inductance Package | The Importance

Sources of inductance

Common source, $L_{CSI}$
- Inductance coupling the gate and power circuits
- Inhibits edge rates and increases switching losses

Power loop, $L_{pwr}$
- Parasitic inductance of the circuit flowing through the power device(s) and load
- Responsible for voltage spikes during turn-off transient

Gate, $L_g$
- 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

Where did my SiC value go?

3

Gate Voltage
Current (Ids)
Voltage (Vds)
Standard double-pulse test circuit

$V_g$, $R_g$, $L_g$, $V_{dc}$, $L_{CSI}$, $L_{pwr}$, $I_L$
Low-Inductance Package | SP6LI

Parasitic loop inductance: 2.9 nH

- AlN or Si$_3$N$_4$ 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

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Current $Tc=80^\circ$C</th>
<th>RDSon Typ $Tj=25^\circ$C</th>
<th>RDSon max. $Tj=25^\circ$C</th>
<th>SiC parallel diode ratings</th>
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<tbody>
<tr>
<td>700 V</td>
<td>538 A</td>
<td>2.5 mΩ</td>
<td>3.2 mΩ</td>
<td>300 A</td>
</tr>
<tr>
<td>1200 V</td>
<td>754 A</td>
<td>2.1 mΩ</td>
<td>2.6 mΩ</td>
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<td>1200 V</td>
<td>641 A</td>
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<td>394 A</td>
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<td>180 A</td>
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<td>1700 V</td>
<td></td>
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<td></td>
<td>Coming soon</td>
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Total SiC Solution for APUs | *Layout Elegance*

Low-inductance bus bar design for 3-phase inverter
Intelligent Gate Drivers

AgileSwitch® Digital Gate Drivers from Microchip
Intelligent Gate Driver | Digital and Programmable

**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

Augmented switching

- Lower overshoot
- Lower losses
- Greater confidence

- V_{soff} = N2LTO
  - V_{ds} = 600 V; I_{ds} = 400 A; R_{g, ext} = 1.1 \Omega
  - E_{off} = 11.1 mJ

- V_{soff} = 0 V; t_{soff} = 50 ns
  - V_{ds} = 600 V; I_{ds} = 400 A; R_{g, ext} = 1.1 \Omega
  - E_{off} = 9.9 mJ
Intelligent Gate Driver | Safer Short Circuit

DUT: D3 SiC MOSFET
Vdc = 1000V

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

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

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

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<th>Client B</th>
<th>Client C</th>
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Total SiC Solution for APUs | Power Density

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