ADVANCES IN APPLICATION OF SILICON CARBIDE FOR HIGH POWER ELECTRONICS
**Title:** Advances in Application of Silicon Carbide for High Power Electronics

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Outline

• Overview of SiC Advantages
• Prototype 150kW DC/DC Converter Description
• Initial Test Results / Requirements Compliance
• Test Plan / Schedule
• Conclusions
• Acknowledgements
SiC Advantages

- Size, Weight & Performance
  - Improved from Silicon:
    - Lower switching losses = substantially less waste heat
    - Higher operational switch junction temperatures = higher allowable coolant inlet temperature
    - Better thermal conductivity = better peak power capability
    - Higher switching frequencies = smaller capacitors & magnetics
    - Better radiation hardness = potentially simpler EMI/EMC design
System Advantages of SiC

• Cooling System Options
  – Increased top tank temperature allows:
    • Reduced radiator frontal area
    • Reduced cooling fan speed (proportional to fan power$^3$)
  – Reductions to sizing (flow, pump, power) of the power electronics circuit

• Integration Flexibility
  – Integration locations previously inhospitable for power electronics placement

• However: Cost currently a significant disadvantage

Vehicle System Designers Can Balance These Advantages for Significant System Improvements
Prototype 150kW DC/DC Converter

- **Bi-Directional 150kW Unit**
  - 180kW Peak for 20s (discharge)
  - 100°C Coolant Inlet
  - 90°C Ambient
  - Full-SiC MOSFET half-bridges
  - Fiber optic communication interface
  - 3.35 kW/liter, 1.8 kW/kg continuous ratings

- **High Voltage Conversion**
  - Galvanically isolated gate driver with gate voltage & over current monitoring, minimal recovery time, & failure memory
  - 580-640Vdc propulsion bus
  - 300-530Vdc “battery” bus
  - 1200V, 100A switches
  - 40-50kHz frequency used
Prototype 150kW DC/DC Converter Architecture

- Bi-Directional
- Eight power phases with 45° phase shift (4x2)
- Individual power chokes
- Dual compartment layout (hot & cool)
Key Design Challenges

- Two compartment design
  - Minimize development of new high-temp control electronics (scope, budget constraints)
  - Maintain a lower operating temperature for these items
  - Peltier heat pump power supply
  - Peltier heat pump controller (to improve part-power efficiency)

This development area retains significant room for future power density improvements as high temperature components become more readily available
Key Design Challenges (Cont.)

- Gate driver design
  - Must reside with switches in high-temperature compartment
  - Small board-mounted DC converters remain temperature sensitive – cool compartment air circulated
  - On/Off driver voltages of -8/+20 reduce conduction losses without need for adjustable output
  - Separate sub-circuit gate drivers used to avoid parallel issues associated with MOSFETs
Goal: 150kW Power, Up-Convert, 90°C ambient, 100°C coolant

Continuous power goal met
Goal: 180kW Peak Power, 90°C ambient, 100°C coolant

Peak power goal met, charge & discharge
Goal: Buck/Boost 150kW toggle, 90°C ambient, 100°C coolant

150kW Buck/Boost toggle goal met
Goal: Buck/Boost efficiency, 90°C ambient, 100°C coolant
Shown with and without Peltier heat pump power supply

All efficiency targets met for P>2kW, without Peltier power supply
Requirements Compliance

- 150kW continuous operation
- 180kW discharge operation for >20s
- Voltage maintained within high & low side ranges
- 100°C coolant inlet full power operation
- 90°C ambient full power operation
- \( \leq 12.5 \) liter/min & \( \leq 172 \text{kPa} \) \( \Delta \text{P} \)
- \( \geq 93\% \) efficiency, 2-30kW*
- \( \geq 97.5\% \) efficiency, 30-180kW*
- <45 liters
- 3.3kW/liter (continuous 150kW rating)
- X 81kg (goal 75kg) – due to added cooling complexity

*For lower temperatures when the Peltier cooling system is not operating

Ambitious Goals – Significant Achievements
Acceptance testing is underway at TARDEC labs
- Verify steady-state operation up to 150kW and up to 100°C coolant inlet temperature
- Verify peak operation at 180kW up to 100°C
- Perform 150kW load cycling: +/-150kW in 15sec intervals for 30 minutes at 100°C coolant inlet temperature
- Perform load-step testing to evaluate step response of DCC10

Further testing is planned with TARDEC’s Hybrid Electric Reconfigurable Moveable Integration Testbed (HERMIT) to evaluate the DCC10’s performance in a real vehicle environment under typical operating conditions
Conclusions

- Power electronics designs are achievable with high temperature coolant and elevated ambient temperature.
- The biggest drawback of this design has been the need for the Peltier cooling system, which can use up to 600W to cool the low-temperature electronics.
- High temperature alternatives have been identified for many of the devices that currently reside in the cool compartment of the DCC10.
- An improved design eliminating the need for the Peltier system would keep the efficiency of the next generation of converter above 98% down to about 10kW.
Questions?

• Additional questions can be directed to:
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