GaN & SiC Technologies for Power Electronics

RichardsonRFPD
An Arrow Company

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SiC MOSFETs produce much lower switching losses compared to Si IGBTs, as shown in the yellow-highlighted areas below:

SiC Schottky diodes have near-zero reverse recovery losses compared to Si FREDs and are stable over temperature:

SiC MOSFETs have a much more stable $R_{DS(on)}$ over temperature than Si MOSFETs.

SiC MOSFETs include a robust body diode with much lower reverse recovery charge ($Q_{rr}$) and reverse recovery time ($T_{rr}$) than Si MOSFETs.
Use SiC Performance Advantages to Reduce Total Cost

Design in SiC to substantially reduce switching and conduction losses, while minimizing heat sink size and cost:

Lower losses lead to higher efficiencies and lower energy consumption, resulting in lifelong savings:

- $200 cost differential between Si and SiC Module.
- Motor operated for 16 Hrs daily every day.
- Assuming 0.8% improvement in operational efficiency for the SiC motor drive.

Use SiC products to restructure, not increase overall system cost.

<table>
<thead>
<tr>
<th>Need to transfer 10kW</th>
<th>IGBT + Si Diode</th>
<th>SiC MOSFET + SiC Diode</th>
<th>SiC MOSFET + SiC Diode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Switching Frequency</strong></td>
<td>20kHz</td>
<td>60kHz</td>
<td>100kHz</td>
</tr>
<tr>
<td>Inductors</td>
<td>$62</td>
<td>$35</td>
<td>$20</td>
</tr>
<tr>
<td>Capacitors</td>
<td>$65</td>
<td>$65</td>
<td>$65</td>
</tr>
<tr>
<td>Cooling</td>
<td>$45</td>
<td>$30</td>
<td>$38</td>
</tr>
<tr>
<td>Power Semiconductors</td>
<td>$10</td>
<td>$40</td>
<td>$40</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$182</td>
<td>$170</td>
<td>$163</td>
</tr>
</tbody>
</table>

Comparison based on:
- 10kW interleaved boost converter
- Input Voltage Range: 300VDC - 450VDC
- Output/DC-Link Voltage: 640VDC

Design Options using SiC to reduce $ per Watt

**Option 1**
50 HP instead of 30 HP

**Si**
Drive

**SiC**
Drive

\[ F_{SW} = 8\ kHz \]
\[ R_{HS} = 0.16\ ^\circ C/W \]
\[ P_{loss} \text{Total} = 369\ W \]
\[ n = 99.0\% \]
\[ T_J = 127\ ^\circ C \]

**Option 2**
Smaller Cooling at same 30 HP

**Si**
Heat Sink

**SiC HS**

\[ F_{SW} = 8\ kHz \]
\[ R_{HS} = 0.55\ ^\circ C/W (1/3\ size) \]
\[ P_{loss} \text{Total} = 153\ W \]
\[ n = 99.3\% \]
\[ T_J = 135\ ^\circ C \]

**Option 3**
Smaller Cooling + Higher Frequency at same 30 HP

**Si**
Drive

**SiC**
Drive

\[ F_{SW} = 35\ kHz (>4x) \]
\[ R_{HS} = 0.4\ ^\circ C/W (2/3\ size) \]
\[ P_{loss} \text{Total} = 204\ W \]
\[ n = 99.1\% \]
\[ T_J = 136\ ^\circ C \]
Gallium Nitride (GaN)

Gallium Nitride, a wide band gap semiconductor, is rapidly displacing Silicon as the material of choice for power transistors. With their superior material properties and simplicity of use, Gan Systems’ GaN E-HEMTs allow designers to set new standards for efficiency, power density, size and weight.

GaN E-HEMTs are easy to use
• Voltage driven, like MOSFETs
• True enhancement-mode, normally off
• Easily driven by Si or GaN-specific gate driver
• Conventional slew rate control using RG
• Simple paralleling

GaN E-HEMT’s Key Properties - Benefits
• ZERO reverse recovery – Low power loss, high efficiency
• High switching frequency – Size reduction, high power density
• Bi-directional conduction – New high efficiency topologies
• Intrinsically stable paralleling – Broad power range

Zero Reverse Recovery

Turn-on loss comparison @ 400V/22A

GaN Systems vs Si IGBT: Switching loss comparison- Eon/Eoff

Eon/Eoff switching loss

GaN E-HEMTs have 10× lower Eon/Eoff switching losses compared to Silicon IGBTs.

- Eon/Eoff measurement (20 ns/div), 400V/15A, 100kHz, Half Bridge
GaN Systems Enables Compact, Inexpensive, High Power Wireless Charging

Semi-bridgeless PFC

Reduce system cost by 15% and part count by 33% by using GaN over Si.

GaN enables smaller, more efficient, lower cost PFC solutions
- Zero Reverse Recovery
- Reverse conduction
- Anti-Parallel Diode not required

Wireless Power – A Comparison of Key Technologies

<table>
<thead>
<tr>
<th>TECHNOLOGY</th>
<th>INDUCTIVE</th>
<th>MAGNETIC RESONANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer Standard body</td>
<td>Wireless Power Consortium</td>
<td>AirFuel Alliance</td>
</tr>
<tr>
<td>Frequency range</td>
<td>80-300kHz</td>
<td>6.78MHz</td>
</tr>
<tr>
<td>Max transfer range</td>
<td>5mm</td>
<td>50mm</td>
</tr>
<tr>
<td>Multi-device charging</td>
<td>No</td>
<td>Yes - At different power levels</td>
</tr>
<tr>
<td>Spatial Freedom</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Power Range</td>
<td>Low &amp; limited - 30W max</td>
<td>Broad &amp; versatile - 20W to 20kW+</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Limited to 80%</td>
<td>High: up to 95%</td>
</tr>
</tbody>
</table>

PFC System Cost Comparison: GaN Systems E-HEMT vs Si MOSFET

GaN enables smaller, more efficient, lower cost PFC solutions
- Zero Reverse Recovery
- Reverse conduction
- Anti-Parallel Diode not required

Your source for GaN & SiC news and innovation for power electronics
gan-sic-power.richardsonrfpd.com
<table>
<thead>
<tr>
<th>Systems</th>
<th>GaN-on-Si E-HEMT Discrete</th>
<th>SiC MOSFET Discrete</th>
<th>SiC MOSFET Module</th>
<th>SiC/Si Hybrid Modules</th>
<th>SiC Diode Discrete</th>
<th>SiC Diode Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>100V, 650V</td>
<td>—</td>
<td>700V, 1200V, 1700V</td>
<td>900V, 1200V, 1700V</td>
<td>500V, 600V, 800V, 900V, 1000V, 1200V</td>
<td>700V, 1200V, 1700V</td>
</tr>
<tr>
<td>Current</td>
<td>3.5A - 120A</td>
<td>—</td>
<td>700V, 1200V, 1700V</td>
<td>900V, 1200V, 1700V</td>
<td>500V, 600V, 800V, 900V, 1000V, 1200V</td>
<td>700V, 1200V, 1700V</td>
</tr>
<tr>
<td>Rds(on)</td>
<td>5mΩ - 500mΩ</td>
<td>—</td>
<td>700V, 1200V, 1700V</td>
<td>900V, 1200V, 1700V</td>
<td>500V, 600V, 800V, 900V, 1000V, 1200V</td>
<td>700V, 1200V, 1700V</td>
</tr>
<tr>
<td>Packages (mm)</td>
<td>4.5x5, 7x4, 7.5x4.6, 6.6x5, 5.5x4.5, 7x4.4, 8.4x7, 9x7.6, 11x9, 11.8x5.3, 12.7x5.6, 5x6 PDFN</td>
<td>—</td>
<td>700V, 1200V, 1700V</td>
<td>900V, 1200V, 1700V</td>
<td>500V, 600V, 800V, 900V, 1000V, 1200V</td>
<td>700V, 1200V, 1700V</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>—</td>
<td>—</td>
<td>1200V</td>
<td>600V, 1200V, 1700V</td>
<td>600V</td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>—</td>
<td>—</td>
<td>1200V</td>
<td>600V, 1200V, 1700V</td>
<td>600V</td>
<td></td>
</tr>
<tr>
<td>Rds(on)</td>
<td>—</td>
<td>—</td>
<td>15A - 800A</td>
<td>20A - 1200A</td>
<td>20A</td>
<td></td>
</tr>
<tr>
<td>Packages (mm)</td>
<td>—</td>
<td>—</td>
<td>15A - 800A</td>
<td>20A - 1200A</td>
<td>20A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.6mΩ - 3.1mΩ</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>—</td>
<td>—</td>
<td>900V, 1200V</td>
<td>1200V, 2400V</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Current</td>
<td>—</td>
<td>—</td>
<td>20A - 140A</td>
<td>100A - 150A</td>
<td>100A</td>
<td>—</td>
</tr>
<tr>
<td>Rds(on)</td>
<td>—</td>
<td>—</td>
<td>17mΩ - 80mΩ</td>
<td>8mΩ - 27mΩ</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Packages (mm)</td>
<td>—</td>
<td>—</td>
<td>flow 0, flow 1,</td>
<td>flow 0, flow 1</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>flow 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>—</td>
<td>—</td>
<td>600V, 1200V</td>
<td>1200V, 1700V</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Current</td>
<td>—</td>
<td>—</td>
<td>5A - 90A</td>
<td>20A - 325A</td>
<td>1A - 50A</td>
<td>—</td>
</tr>
<tr>
<td>Rds(on)</td>
<td>—</td>
<td>—</td>
<td>16mΩ - 1000mΩ</td>
<td>3.7mΩ - 80mΩ</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Packages (mm)</td>
<td>—</td>
<td>—</td>
<td>TO-247-3, TO-247-4, TO-263-7</td>
<td>45 x 108, 62 x 108, High Perf (65 x 110)</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

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High-speed Gate Drivers for GaN & SiC

Microsemi offers gate drive modules to maximize the performance of their SiC products. The MSCSICMDD/REF1 is a universal SiC driver with adjustable output that can be used on most modules. The MSCSICSP3/REF2 is specifically designed for easy mounting to SiC offerings in the SP3 package. The MSCSICSP6/REF3 is designed for SiC in the all new, high performance SP6LI package, featuring ultra-low 2.9nH of stray inductance.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Outputs</th>
<th>Device Voltage</th>
<th>Peak Current</th>
<th>Products</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSCSICMDD/REF1</td>
<td>2</td>
<td>700V/1200V</td>
<td>30A</td>
<td>Universal</td>
<td>400kHz</td>
</tr>
<tr>
<td>MSCSICSP3/REF2</td>
<td>2</td>
<td>1200V</td>
<td>30A</td>
<td>SP3 package</td>
<td>400kHz</td>
</tr>
<tr>
<td>MSCSICSP6/REF3</td>
<td>2</td>
<td>1200V</td>
<td>30A</td>
<td>SP6LI Package</td>
<td>400kHz</td>
</tr>
</tbody>
</table>

pSemi’s UltraCMOS® technology enables integrated circuits to operate at much faster speeds than conventional CMOS technologies. With a switching frequency up to 40 MHz (PE29102), pSemi’s GaN FET drivers deliver the industry’s fastest switching speeds, empowering design engineers to extract the full performance advantages from GaN transistors, resulting in significantly smaller power converters with increased power density.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Max Gate Drive</th>
<th>Peak Output Current</th>
<th>Frequency</th>
<th>Propagation Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE29101</td>
<td>6.5V</td>
<td>2A/4A source/sink</td>
<td>40MHz</td>
<td>11ns</td>
</tr>
<tr>
<td>PE29102</td>
<td>6.0V</td>
<td>2A/4A source/sink</td>
<td>40MHz</td>
<td>9ns</td>
</tr>
</tbody>
</table>

Tamura’s 2DM180506CM and 2DM180206CM gate driver modules feature the characteristics – low common-mode noise and high-speed response – required for driving silicon carbide modules. Additional features of this series include:

- Integrated DC/DC converter with gate driver
- Low common mode noise (parasitic capacitance: 15pF typical)
- 5V logic input
- Dielectric withstand voltage: AC 2500Vrms
- Fast response (100ns typical)
- Over current protection by DESAT detection

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Output Voltage</th>
<th>Peak Output Current (A)</th>
<th>Max Switching Frequency (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2DM180506CM</td>
<td>+18 V / -5 V</td>
<td>18A source/sink</td>
<td>200</td>
</tr>
<tr>
<td>2DM180206CM</td>
<td>+18 V / -2 V</td>
<td>18A source/sink</td>
<td>200</td>
</tr>
</tbody>
</table>

Wolfspeed offers a range of gate driver products for their discrete and module SiC devices with 1, 2 and 6 channel outputs. These products are designed to maximize performance and feature isolated power supplies, and module products also feature short circuit, over temperature and under voltage protection in direct mount, low inductance designs.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Outputs</th>
<th>Device Voltage</th>
<th>Peak Output Current</th>
<th>Products</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>CGD15FB45P1</td>
<td>6</td>
<td>1200V</td>
<td>9A</td>
<td>CCSxxxM12CM2</td>
<td>250kHz</td>
</tr>
<tr>
<td>CGD15HB62P1</td>
<td>2</td>
<td>1200V</td>
<td>9A</td>
<td>CASxxxM12BM2</td>
<td>64kHz</td>
</tr>
<tr>
<td>CRD-001</td>
<td>1</td>
<td>1200V, 1700V</td>
<td>9A</td>
<td>C2M/CMF</td>
<td>—</td>
</tr>
<tr>
<td>CGD15HB62LP</td>
<td>2</td>
<td>1200V</td>
<td>14A</td>
<td>CAS325M12HM2</td>
<td>115kHz</td>
</tr>
<tr>
<td>CGD15SG0002</td>
<td>1</td>
<td>900V, 1200V</td>
<td>9A</td>
<td>C3M</td>
<td>—</td>
</tr>
</tbody>
</table>
Isolated gate drivers provide electrical isolation as well as strong gate drive capability, which is often required for safety and robustness in many system architectures. The isolated gate driver portfolio from Analog Devices offers designers performance and reliability advantages over optocouplers or pulse transformers by utilizing ADI’s proven iCoupler® technology. The isolated gate driver family offers the advantage of a maximum propagation delay of 50 ns, less than 5 ns channel-to-channel matching, up to 150kV/usec Common Mode Transient Immunity (CMTI), and output voltages to cover all SiC and GaN drive levels.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Outputs</th>
<th>Max output</th>
<th>Peak Current</th>
<th>CMTI</th>
<th>Miller Clamp</th>
<th>UVLO</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADuM4120</td>
<td>1</td>
<td>35V</td>
<td>2A</td>
<td>150kV/usec</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>ADuM4121</td>
<td>1</td>
<td>35V</td>
<td>2A</td>
<td>150kV/usec</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>ADuM4135</td>
<td>1</td>
<td>30V</td>
<td>4A</td>
<td>100kV/usec</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>ADuM4136</td>
<td>1</td>
<td>35V</td>
<td>4A</td>
<td>100kV/usec</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

In addition to driving conventional Si-based power devices like IGBTs and MOSFETs, SCALE-2, SCALE-2+ gate driver cores and SCALE-iDriver gate driver ICs are also capable of driving SiC MOSFET power switches. However, SiC switches often require turn-on and turn-off voltage levels which are different from those required by Si-based devices. Application Note AN-1601 on the Power Integrations website outlines how to modify the devices below in order to provide correct drive levels and control of SiC based modules.

- SID1182K
- 2SC0115T-12
- 2SC0435T-17
- 2SC0535T-17
- 2SC0635T-45
- 2SC0650P-17
- 1SC2060P-17
- SIC1182K
- 2SC0650P-17
- 2SC0435T-17

RECOM offers DC/DC converters designed for GaN and SiC gate drive applications. The modules are available with input voltages of 5, 12, 15, or 24VDC with two asymmetric outputs of +20V/-5V and +15V/-3V for SiC and single +6V output for GaN. The modules offer 3kVDC to 6.4kVDC isolation and operating temperature range of -40°C to +100°C (with derating) to meet harsh environmental requirements.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Output Voltage</th>
<th>Input Voltage</th>
<th>Power</th>
<th>Short Circuit Protect</th>
<th>Iso Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPxx065</td>
<td>6</td>
<td>5, 12, 15, 24</td>
<td>2W</td>
<td>No</td>
<td>5.2kV</td>
</tr>
<tr>
<td>RKZxx2005D</td>
<td>+20/-5</td>
<td>5, 12, 15, 24</td>
<td>2W</td>
<td>Yes</td>
<td>3kV, 4kV</td>
</tr>
<tr>
<td>RxxP21503D</td>
<td>+15/-3</td>
<td>12, 15, 24</td>
<td>1W</td>
<td>Yes</td>
<td>6.4kV</td>
</tr>
<tr>
<td>RxxP22005D</td>
<td>+20/-5</td>
<td>5, 12, 15, 24</td>
<td>2W</td>
<td>Yes</td>
<td>6.4kV</td>
</tr>
</tbody>
</table>
Ceramic Capacitors for Fast Switching GaN & SiC

TDK CeraLink™ capacitors are a highly compact solution for the snubber and DC links of fast-switching converters based on SiC and GaN semiconductors. These capacitors are based on a PLZT ceramic material (lead lanthanum zirconate titanate). In contrast to conventional ceramic capacitors, CeraLink™ capacitors have their maximum capacitance at the application voltage, and this even increases proportionately to the share of the ripple voltage. The capacitors are designed for an operating temp from -40°C to +125°C and can withstand brief exposures up to +150°C.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Cap</th>
<th>Rated Voltage</th>
<th>Optimal Voltage</th>
<th>Peak Voltage</th>
<th>Current 85°C 100kHz</th>
<th>ESR 25°C 1MHz</th>
<th>ESL 5nH</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>B58031I5105M062</td>
<td>1.0uF</td>
<td>500V</td>
<td>400V</td>
<td>650V</td>
<td>11.4A</td>
<td>12mΩ</td>
<td>2.5nH</td>
<td>L-lead</td>
</tr>
<tr>
<td>B58031I7504M062</td>
<td>0.5uF</td>
<td>700V</td>
<td>600V</td>
<td>1000V</td>
<td>7.1A</td>
<td>29mΩ</td>
<td>2.5nH</td>
<td>L-lead</td>
</tr>
<tr>
<td>B58031I9254M062</td>
<td>0.25uF</td>
<td>900V</td>
<td>800V</td>
<td>1300V</td>
<td>5.1A</td>
<td>45mΩ</td>
<td>2.5nH</td>
<td>L-lead</td>
</tr>
<tr>
<td>B58031U5105M062</td>
<td>1.0uF</td>
<td>500V</td>
<td>400V</td>
<td>650V</td>
<td>11.4A</td>
<td>12mΩ</td>
<td>2.5nH</td>
<td>J-lead</td>
</tr>
<tr>
<td>B58031U7504M062</td>
<td>0.5uF</td>
<td>700V</td>
<td>600V</td>
<td>1000V</td>
<td>7.1A</td>
<td>29mΩ</td>
<td>2.5nH</td>
<td>J-lead</td>
</tr>
<tr>
<td>B58031U9254M062</td>
<td>0.25uF</td>
<td>900V</td>
<td>800V</td>
<td>1300V</td>
<td>5.1A</td>
<td>45mΩ</td>
<td>2.5nH</td>
<td>J-lead</td>
</tr>
<tr>
<td>B58033I5206M001</td>
<td>20uF</td>
<td>500V</td>
<td>400V</td>
<td>650V</td>
<td>41.3A</td>
<td>3.5mΩ</td>
<td>3.5nH</td>
<td>Solder-Pin</td>
</tr>
<tr>
<td>B58033I7106M001</td>
<td>10uF</td>
<td>700V</td>
<td>600V</td>
<td>1000V</td>
<td>32.6A</td>
<td>11mΩ</td>
<td>3.5nH</td>
<td>Solder-Pin</td>
</tr>
<tr>
<td>B58033I9505M001</td>
<td>5uF</td>
<td>900V</td>
<td>800V</td>
<td>1300V</td>
<td>25.6A</td>
<td>18mΩ</td>
<td>3.5nH</td>
<td>Solder-Pin</td>
</tr>
</tbody>
</table>

KEMET’s KC-LINK™ surface mount capacitors are designed to meet the growing demand for fast-switching wide bandgap (WBG) semiconductors that operate at higher voltages, temperatures, and frequencies. By utilizing KEMET’s robust and proprietary C0G/NPO base metal electrode (BME) dielectric system, these capacitors are well suited for power converters, inverters, snubbers, and resonators, where high efficiency is a primary concern. With extremely low effective series resistance (ESR) and very low thermal resistance, KC-LINK™ capacitors can operate at very high ripple currents with no change in capacitance versus DC voltage, and negligible change in capacitance over temperature of -55°C to 150°C. Available in AEC-Q200 automotive grade.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Capacitance</th>
<th>Rated Voltage</th>
<th>Peak Voltage</th>
<th>Current (85°C/100kHz)</th>
<th>ESR (25°C/300kHz)</th>
<th>ESL 5nH</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>CKC33C224KCGAC</td>
<td>220nF</td>
<td>500V</td>
<td>750V</td>
<td>19.3A</td>
<td>4mΩ</td>
<td>1nH</td>
<td>SMT</td>
</tr>
</tbody>
</table>

Transformers Optimized for GaN & SiC

Payton Planar offers standard and custom planar transformers for automotive, defense, industrial, medical, space & aviation, and telecom applications. Transformers made of the planar principle eliminate virtually all the shortcomings of old-fashioned wire wound types. In a planar design, the windings are made of copper foil lead frames or printed circuit boards. (Flat copper spirals laminated into thin dielectric substrates). These windings are then sandwiched, along with appropriate insulators, between large area, yet thin, state-of-the-art ferrite cores. This construction technique yields a host of benefits including high power density, high efficiency, good thermal conduction, low profile, low leakage inductance and high repeatability.
Inductors for High Frequency Power Applications

SiC and GaN Power Semiconductors deliver greater efficiency while operating at much higher frequencies than regular Si semiconductors. Power magnetics used in these designs must be able to handle high current and fast-switching speeds that can exceed 1MHz. Eaton FP and HC series are designed to deliver high power density by using high frequency core materials, which can significantly improve system efficiency.

<table>
<thead>
<tr>
<th>Series</th>
<th>Frequency</th>
<th>RMS Current</th>
<th>Inductance</th>
<th>DC Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP</td>
<td>1kHz - 2MHz</td>
<td>13A - 110A</td>
<td>22nH – 950nH</td>
<td>0.05 mΩ - 0.65mΩ</td>
</tr>
<tr>
<td>HC</td>
<td>1kHz – 1MHz</td>
<td>11A – 78A</td>
<td>0.047uH – 10.5uH</td>
<td>0.24mΩ - 8.7mΩ</td>
</tr>
</tbody>
</table>

Thermal Management

ATS High-Performance Cold Plates

According to research published by SatCon, The University of Kiel and Wolfspeed, direct liquid cooling via cold plates is an effective way to cool SiC Power Modules. ATS cold plates have more than 30% better performance compared to other commercially-available cold plates. An internal, mini-channel fin structure enhances the surface area to maximize heat transfer with low pressure drop characteristics and provides uniform cold plate surface temperature. ATS cold plates can be quickly customized to fit different mounting configurations.

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<tr>
<th>Part Number</th>
<th>Dimensions (L x W x H)</th>
<th>Flow Rate (L/min)</th>
<th>∆T @ 1kW between the cold plate base and inlet fluid temperature</th>
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<td>ATS-CP-1000</td>
<td>202 x 130 x 20mm</td>
<td>4 L/min</td>
<td>5.50°C</td>
</tr>
<tr>
<td>ATS-CP-1001</td>
<td>198 x 147 x 20mm</td>
<td>4 L/min</td>
<td>5.00°C</td>
</tr>
<tr>
<td>ATS-CP-1002</td>
<td>162 x 136 x 20mm</td>
<td>4 L/min</td>
<td>7.00°C</td>
</tr>
<tr>
<td>ATS-CP-1003</td>
<td>162 x 147 x 20mm</td>
<td>4 L/min</td>
<td>6.80°C</td>
</tr>
<tr>
<td>ATS-CP-1004</td>
<td>162 x 172 x 20mm</td>
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Standard and Custom Thermal Solutions

Wakefield-Vette designs and manufactures a wide array of thermal management products, including extrusions, LED heat sinks, heat frames, heat pipes, fan assemblies, heat exchangers, coolant distribution units and liquid cold plates. This means Wakefield-Vette has the most complete thermal solution toolbox to solve customers' heat density challenges. Standard and custom products are available to fit any need. Richardson RFPD stocks many standard extrusion profiles as well as rolled tube, exposed tube and full buried tube cold plates.

(1) Leo Casey, Bogdan Borowy, and Gregg Davis, “High Power Silicon Carbide Inverter Design – 100kW Grid Connect Blocks” (2005, presented at Sandia National Labs)
**GaN-on-Si E-HEMT Evaluation Platforms and Reference Designs**

- **Part Number: GS61008P-EVBHF**
  Half bridge using GS61008P 100V, 7mΩ and pSemi PE29101 high speed gate driver.

- **Part Number: GS61004B-EVBCD**
  Class D amp using GS61004B 100V, 15mΩ and pSemi PE29102 high speed gate driver.

- **Part Number: GS665MB-EVB**
  650V universal motherboard for GS665XXX-EVBDB.

- **Part Number: GS66508B-EVBDB1**
  1.5kW Half bridge daughter board.

- **Part Number: GS66508T-EVBDB2**
  2kW Half bridge daughter board.

- **Part Number: GS66516T-EVBDB2**
  2.5kW Half bridge daughter board.

- **Part Number: GS66516B-EVBCD**
  Half bridge using GS66516B 650V, 25mΩ.

- **Part Number: GSP65R25HB-EVB**
  1-3kW half bridge IMS using GS66516B 650V, 25mΩ.

- **Part Number: GSP65R13HB-EVB**
  4-6kW half bridge IMS using 2x GS66516B 650V, 25mΩ (13mΩ).

- **Part Number: GSP65MB-EVB**
  Motherboard for GSP65R13HB-EVB and GSP65R25HB-EVB.

- **Part Number: GS665BTP-REF**
  3kW High 99% efficiency bridgeless totem pole PFC using GS66516B 650V, 25mΩ.

**SiC Evaluation Platforms and Reference Designs**

- **Part Number: CRD-060DD17P-2**
  48W Aux power supply using C2M1000170J.

- **Part Number: CRD-060DD12N**
  60kW 4-phase interleaved boost using C2M1000120D.

- **Part Number: CRD-02AD09N**
  2.2kW, 98.5% efficiency Bridgeless Totem Pole PFC using C3M0065090J.

- **Part Number: CRD-20DD09N**
  20kW full bridge resonant LLC using C3M0065100K.

- **Part Number: CRD-066012P**
  6kW Bi-directional EV on-board charger. using C3M0065100K.

- **Part Number: CRD-15DD12P**
  15W wide input aux supply using C2M1000170J.

- **Part Number: CRD-60DD12N**
  60kW 4-phase interleaved boost using C3M0075120K.

- **Part Number: CRD-060DD12N**
  60kW 4-phase interleaved boost using C3M0075120K.

**Reference Design**

- **Part Number: MSCSICPFC/REF5**
  For qualified opportunities. Reference design files only, no hardware.
  30kW Vienna PFC Reference Design using Microsemi Next Generation SiC diodes and MOSFETs.
  Vin: 380/400Vrms, 3-Phase • Vout: 780VDC.
Package Styles Dimensions in millimeters (mm)

GaN Systems

GS61004B (4.6 x 4.4)
GS61008P (7.0 x 4.0)
GS61008T (7.0 x 4.0)
GS-010-120-1-T (7.0 x 4.0)
GS66502B (5.0 x 6.6)
GS66504B (5.0 x 6.6)
GS66506T (5.6 x 4.5)
GS66508B (7.0 x 8.4)
PD FN (5 x 6)
GS66508P (10.0 x 8.7)
GS66508T (6.9 x 4.5)
GS66516T (9.0 x 7.6)
GS-065-120-1-D1 (12.7 x 5.6)

Microsemi

TO-220-2
D3PAK (TO-268)
TO-247-2
TO-247

SOT-227 (Isotop)
41x52 (SP1)
43x73 (SP3F)
62x108 (SP6P)

62x108 (D3)
62x108 (SP6)
62 x 108 (SP6L)

Mitsubishi Electric

TO-220-2L

56x110
62x108
48x94
80x110
SuperMini DIP
130x140
62x122
67x131
50x120

*Available only in NA.

Vincotech

GS61004B (4.6 x 4.4)
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