

# Accelerating Adoption of SiC Power

## *Practical, Ready-to-Use SiC Devices and Circuit Solutions for Better, More Efficient Power Systems*

*The market has heard for many years about wide bandgap product roadmaps and concepts, touting that many possibilities could be available. However, you can't design in a PowerPoint presentation or a preliminary datasheet, so this article will reinforce that Wolfspeed SiC power has moved way beyond any hype, talk, and fake news and has pioneered the widespread adoption of silicon carbide power devices in the customer base - today.*

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We showcase SiC devices that are widely used, and how they solve real issues: system-level examples adopted and working in the market -- today.

The practical, real, and ready-to-use circuit solutions discussed will span watts to hundreds of kW. Each solution will highlight our commercially available, fully qualified SiC devices, proven within the market to enable significant value to systems with regards to efficiency, power density, and cost.

SiC is not in the future tense, it's not just tomorrow's possibility – with Wolfspeed SiC is all around, proven and here today.

### Example 1: 2kW Totem pole PFC

The advantage of SiC diodes in traditional server power PFC boost circuits are well known and understood with full market adoption for many years. Recently though, akin to the increased pressure to achieve new higher efficiency energy star and 80+ power supply regulations, power supply designers are faced with yet more challenges to increase system efficiency & increase power density whilst working with ever reducing BOM budgets.

The tried and tested single or interleaved PFC boost, a main stay of any standard PFC circuit, works hard to achieve the 80+ bronze, silver or gold server power supply standards but falls well shy of the more stringent efficiency regulations set to obtain the 80+ Titanium efficiency challenge, so more creative topologies and wide band gap device technologies are now more than simply "interesting studies".

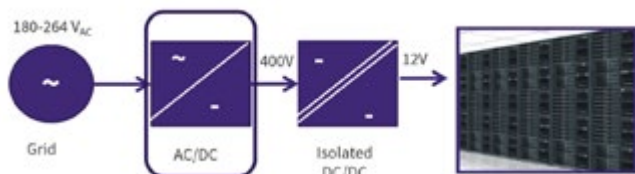


Figure 1: Functional block diagram of a typical Server power supply system

With regards to server power system architecture, Figure 1 shows a power block diagram of a typical single-phase server or Netcom switch mode power supply, breaking out by specific circuit function.

The circuit function in debate during this article is the AC-DC boost, also known as the PFC. An incumbent design approach would contain the bridge rectifier, single switch or interleaved boost circuit followed by an isolated dc-dc stage.

### Design Challenge

Higher efficiency power regulation in server systems is a very well known requirement as server farms are functioning 24/7 and are subject to energy regulations and legislation. The 80+ standard is a voluntary certification program intended to promote efficient energy use in computer power supply units. Despite being voluntary it is widely adopted and industry accepted. The 80+ standard comes now in 6 levels of efficiency achievement from 80+ as the basic to 80+ Titanium – being the most stringent. Titanium standard is the latest requirement that server power supply makers strive to reach. For Titanium, efficiency points are 94% at half load and 90% at full load for 115V input and 96% at half load and 91% at full load for 230V input - for a combined PFC plus dc-dc stage so just addressing the PFC alone then the efficiency targets or budget need to be 96.4% at half load and 93.8% at full load for 115V input and 98.5% at half load and 94.8% at full load for 230V input

Achieving this PFC efficiency budget with conventional silicon boost topologies is beyond reach with most silicon MOSFET devices and, although achievable, with enhanced performance devices the cost budget increases to such a level that it becomes impractical to implement.

So, the design challenge is how to achieve the required Titanium efficiency budget whilst increasing power density and maintain a cost neutral power system to typical lower performance silicon approaches.

### Design Specification

System requirements for single phase PFC boost circuits are reasonably generic with regards to voltages, currents, harmonics and EMI considerations, so Figure 2 shows a typical PFC parameter specification.

2kW was chosen as typically the higher power systems require the higher efficiency standards. In addition, as increasing circuit power density is also a strong consideration, a surface mount power device adoption was taken as part of the design challenge.

Bridgeless power factor correction topologies are not necessarily new concepts, whether single or 3-phase in approach, and the advantages of higher efficiency, higher power density and lower component count are compelling; however often the inadequate performance of the silicon incumbent technology for power switch combined with unusual control implementation have limited any practical adoption.

Now, with a business as usual approach a designer would construct a 4-switch totem pole circuit based off the simulation results with the best performing SiC MOSFET's available, however with the price neutral budget criteria also in place it was evaluated to approach the totem pole with two SiC MOSFETs in the high frequency leg and two low Vf silicon diodes in the low frequency leg to significantly reduce the BOM cost. This approach significantly reduces the semiconductor content and cost plus also significantly simplifies the circuit control and associated IC costs. The C3M0065090J was chosen specifically for its surface mount capability – hence reducing overall board size thus increasing circuit power density plus the fact that the device

Parameter	Specification
$P_{OUT}$	2 kW
$V_{in}$	90-264 V
Switching Frequency	85 KHz
THD <sub>i</sub>	< 5 %
MOSFET Package	Surface Mount
$V_{OUT}$	400 V <sub>DC</sub>

Figure 2: PFC design specification

offers the user a separate kelvin source connection which when utilized correctly significantly reduces device switching loss versus conventional D2PAK or 3 lead TO type devices. **Two-Switch Totem Pole Results**  
Operating at 85kHz, the two-switch totem pole PFC circuit designed to the specification shown in figure 2 achieved exemplary results. At 230V input the totem pole 50% load efficiency was 98.61% and the full load efficiency was 98.54%, both of which were above the target efficiency budgets of 98.5% and 95% respectively. This efficiency includes the losses generated from the auxiliary power supply and fan. Figure 3 shows the hardware board

Board size is 213mm x 112mm showcasing the totem pole power density. Single fan and surface mount MOSFET's and Diodes. This board is equal to or smaller than existing off the shelf silicon based 80+ gold solutions but achieves titanium level efficiency. The two-switch circuit is practical to implement and therefore commercialize. The entire design is based off power devices that are fully released, fully qualified and manufactured in substantial volumes.

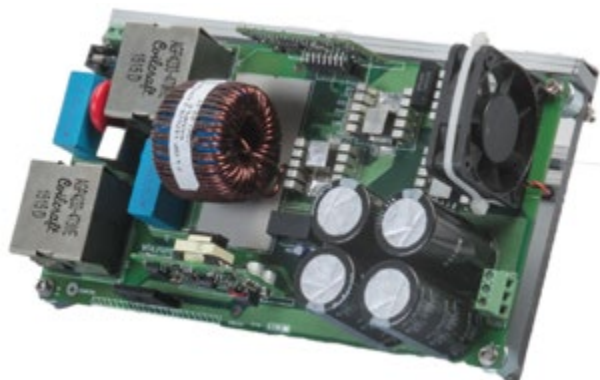


Figure 3: Hardware board and entire efficiency plot against output power

**Example 2: 20kW Bi-Directional 3 phase AC-DC converter**

Grid-connected three-phase AC/DC (or DC/AC) power conversion is required in a wide range of industrial applications – from power electronic interfaces of renewable energy systems (solar, wind, and batteries), industrial and mass transport vehicle charging, to regenerative motor drives (elevators, mills, etc.). A practical example of such a 3-phase grid-tied AC-DC system would be fast charging stations for electric vehicles. Figure 1 shows a functional block diagram of a 3-phase fast off-board charger for battery electric vehicles (BEVs). With Bidirectional functionality of the converter, it is possible to deliver power from vehicle to grid (V2G).

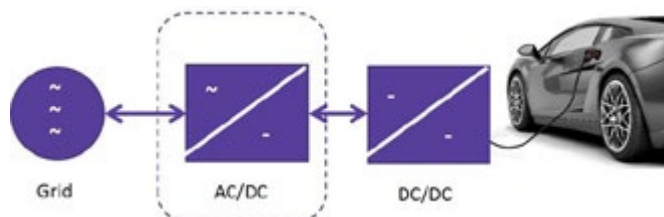


Figure 4: Functional block diagram of 3-phase AC/DC system.

**Design Challenge**

For PFC bidirectional applications, two-level topologies using 1200V IGBTs or three-level topologies using SJ FETs are typically used. Two-level topologies with 1200V IGBTs offer simplicity, low semiconductor cost, and high-power capability (>20kW) but switching frequency limited to <20kHz – yielding systems with lower power density, lower efficiency, and expensive inductors. Multi-level IGBT topologies such as the neutral point clamped (NPC) rectifier offer higher power density and efficiency (lower switching losses) at the expense of higher circuit complexity. For unidirectional power flow complex approaches are also seen with 650V silicon MOSFET's. The Vienna or

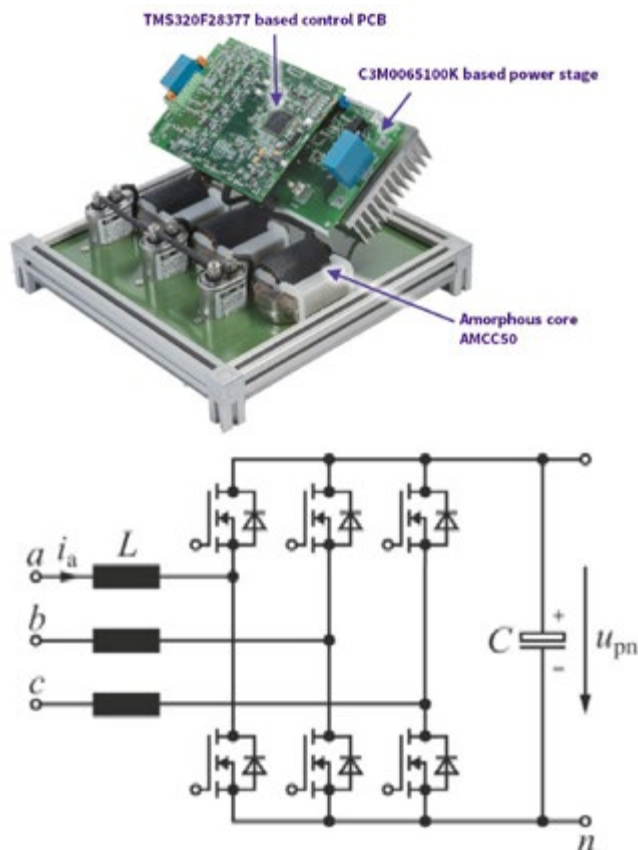


Figure 5: 20kW Active Front End Circuit and Hardware

modified Vienna circuit can achieve reasonable unidirectional power efficiency but lacks acceptable power density, is complex in design and component count and lacks any bidirectional capability.

An alternative approach designers today, utilizing SiC MOSFETs, are drastically reducing switching losses and significantly extending the usable switching frequency range of the two-level six-switch converter, while maintaining higher full-load and part-load efficiency. With SiC MOSFETs, power density of the system is significantly increased by shrinking the size of magnetic components and reducing the size of the heatsink. Additionally, when utilizing SiC MOSFETs, the device's body diode can be used as the anti-parallel diode, reducing circuit complexity and cost.

Figure 5 shows the two-level SiC MOSFET converter power stage. This example showcases a cost-effective, highly efficient design alternative for an industrial PFC application with the entire design based on SiC power MOSFET devices that are fully-qualified, and in volume production. Challenging the traditional 1200V Si-IGBT two-level system, this approach meets the same system-level specifications but offers higher efficiency, significant increase in power density and reduction in system cost. For this power level, the 1000V/65mΩ SiC MOSFET was selected. This part delivers extremely low switching losses thanks to a 4-lead TO-247 package with dedicated Kelvin source connection. In addition, the optimized 1000V blocking and rugged body diode capability allows for minimum die cost while supporting up to 800VDC link operation. This example again shows a real solution using Wolfspeed's commercially available SiC MOSFETs (C3M0065100K) which meets new market requirements for bi-directional functionality, in a simple two-level topology - switching at 48KHz. The design at full power shows measured results ~1% efficiency improvement over Si IGBT systems.

### Example 3: 250kW 3 phase inverter

It is without question that electric vehicles provide one of the largest opportunities for power semiconductors for the next decade and beyond and whilst silicon has proved itself to be adequate in the early Hybrids and BEV's, the power conversion circuits that charge the vehicles battery and drive the vehicles motor need significant improvements in relation to efficiency and power density to meet the market demands of increasing mileage range, lighter vehicles and cost effective end products.

The automotive industry itself has evaluated and proven the value of incorporating SiC into On Board Chargers (OBC) and drivetrain inverters. It is an incredible result to see that replacing a 250kW EV drive inverter from silicon IGBT to Wolfspeed SiC MOSFET's reduces the inverter losses by ~80% across the combined driving cycle! Details

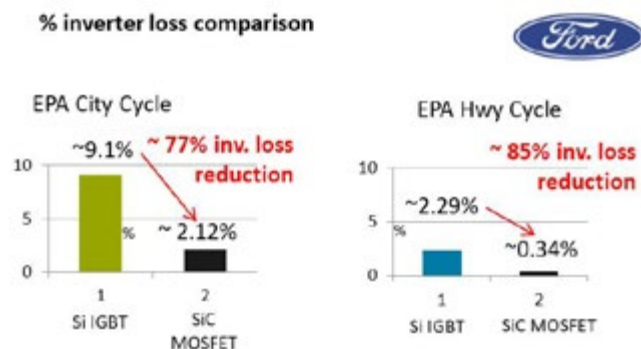


Figure 6: Inverter loss reduction by implementing Wolfspeed 900V 10mO SiC MOSFETs

shown in figure 6. For the OBC, using SiC can increase system level efficiency by >1.5% whilst increasing power density by over 30% when compared to traditional silicon approaches.

To shorted customers design cycles and quantify the SiC value proposition Wolfspeed developed a high performance 250kW three-phase evaluation kit targeted at the EV drive train. The kit is designed to enable customers to prove the real-world benefits of SiC devices, in an optimized inverter stack-up, in their own laboratory environment with a minimal amount of resource investment in proof-of-concept system design. Wolfspeed's 250 kW Evaluation Units weigh in at just under 16 kg with a volume of 26.3 L (44 mm long, 39.8 mm wide, and 15 cm tall) as shown in Figure 7.

Utilizing the CAS module optimized packaging Wolfspeed has focused on developing high gravimetric- and volumetric- density solutions, which also maintain incredibly low parasitic inductance - boasting just 7.5 nH of inductance, while weighing in at only 180 grams and occupying nearly the same space as your average smart phone. The inverter design can deliver up to 250 kW continuous power at 850-900 VDC bus at 20 kHz PWM switching – with ~ 80% reduction in inverter loss (over the combined operation cycle) than an equivalent Silicon IGBT inverter.



Figure 7: The Wolfspeed 250kW EV drive train inverter

### Conclusions

The tipping point for SiC availability and adoption has occurred and in many markets today the customer base is harvesting the advantages SiC gives. Wolfspeed has been pioneering the SiC revolution and with the largest most proven product portfolio in the industry – by far, the design community has real SiC solution – today that increase system level efficiency, reduce overall system board size, increasing system power density and last, but by no means least, lower power BOM cost verses conventional inefficient silicon based topology approaches.

Say adieu to preliminary datasheets, power point roadmaps, and fake news as through leveraging its 30 years of experience in SiC design, optimization and high volume manufacturing Wolfspeed has developed high performance reference designs, built around their SiC-optimized power discrete and module product line, which are targeted at ensuring that end-system designers invest minimal effort in learning the best-practices associated with achieving optimized performance for SiC-based system design.