650V Silicon Carbide MOSFETs and Diodes: Expanding the Market for Silicon Carbide Power

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Cree | Wolfspeed 650V Technology Leadership

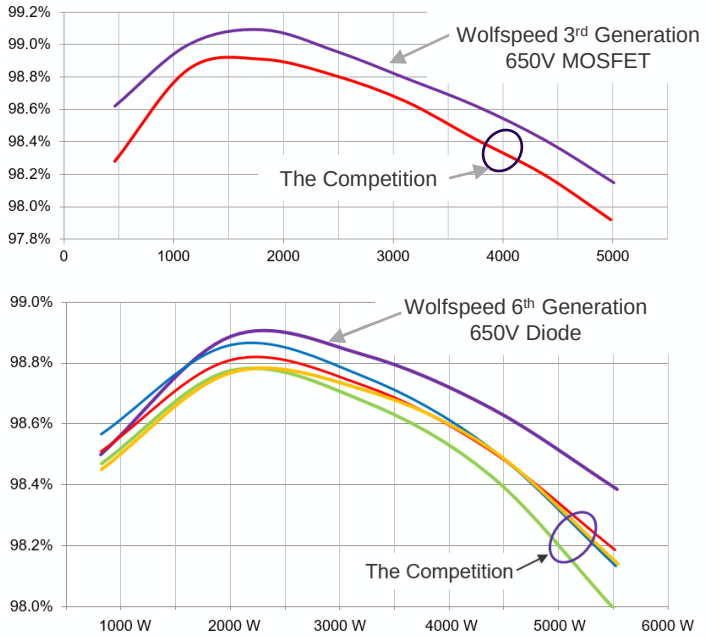
Wolfspeed's 650V Silicon Carbide MOSFETs offer the ***lowest*** conduction and switching ***losses*** in the industry for users who need ***smaller, lighter, and highly efficient*** power conversion in their products.

Compared with silicon, our 650 V Silicon Carbide MOSFETs enable:

- **75% lower switching losses**
- **½ the conduction losses**
- **3x higher power density**

When coupled with Wolfspeed's industry-leading 6th-generation (C6D) Schottky diodes, power supply designers can realize performance levels that meet or exceed the requirements of even the most demanding applications.

Enabling Highest System Efficiency



Top: Synchronous Boost Converter
Bottom: PFC Boost Converter

650V MOSFET Portfolio

Enabling Industry-Leading Power Supply Efficiency and Power Density

Part Number	V_{DS}	$I_{D\ MAX\ (25°C)}$	$R_{DS(on)\ (25°C)}$	$R_{DS(on)\ (175°C)}$	Sample Date	Release Date
C3M0015065D/K	650 V	120 A	15 mΩ	20 mΩ	Now	3/30/2020
New C3M0025065D/K	650 V	69 A	25 mΩ	32 mΩ	Now	1/8/2021
New C3M0045065D/K	650 V	50 A	45 mΩ	58 mΩ	Now	1/8/2021
C3M0060065D/J/K	650 V	36 A	60 mΩ	80 mΩ	Now	3/30/2020
New C3M0120065D/J/K	650 V	20 A	120 mΩ	156 mΩ	Now	2/1/2021

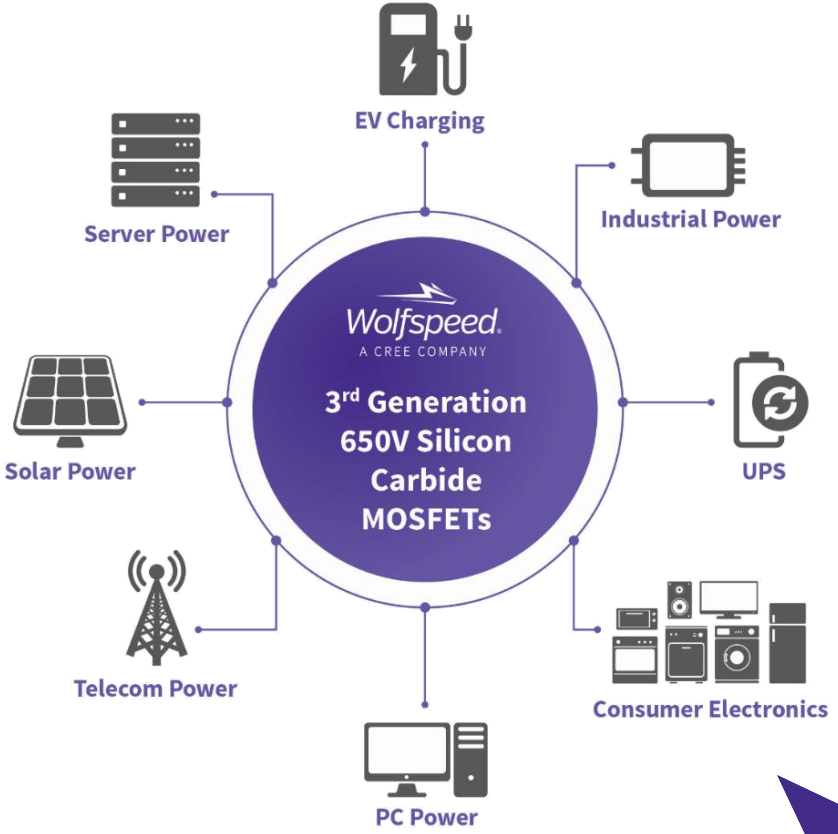
650V Schottky Diode Portfolio

Enabling Industry-Leading Power Supply Efficiency and Power Density

Part Number	Package	V_{RRM}	$I_{F\ (25°C)}$	$V_{F\ (25°C)}$	$V_{F\ (125°C)}$	Release Date
C6D04065E	TO-252-2	650 V	4 A	1.27 V	1.35 V	Available Now
C6D06065A	TO-220-2	650 V	6 A	1.27 V	1.35 V	Available Now
C6D06065E	TO-252-2	650 V	6 A	1.27 V	1.35 V	Available Now
C6D08065A	TO-220-2	650 V	8 A	1.27 V	1.35 V	Available Now
C6D08065E	TO-252-2	650 V	8 A	1.27 V	1.35 V	Available Now
C6D10065A	TO-220-2	650 V	10 A	1.27 V	1.35 V	Available Now
C6D10065E	TO-252-2	650 V	10 A	1.27 V	1.35 V	Available Now
C6D16065D	TO-247-3	650 V	16 A	1.27 V	1.35 V	Available Now
C6D20065D	TO-247-3	650 V	20 A	1.27 V	1.35 V	Available Now

Applications for 650V Silicon Carbide MOSFETs & Diodes

- Market Segments
  - Industrial
  - Energy
  - Electric Vehicles / “Electrification”
- Applications
  - Power Supplies (AC/DC, DC/DC, DC/AC)
  - Solar, UPS/Battery Backup, Energy Storage
  - Auxiliary Power in EV
  - EV Charging ***(400V Batteries)***
- System Voltages and Power Levels
  - AC line power
  - ***DC above 200V***
  - ***Batteries at 400V***
  - ***Anything measured in kW***



650V MOSFET Competitive Position

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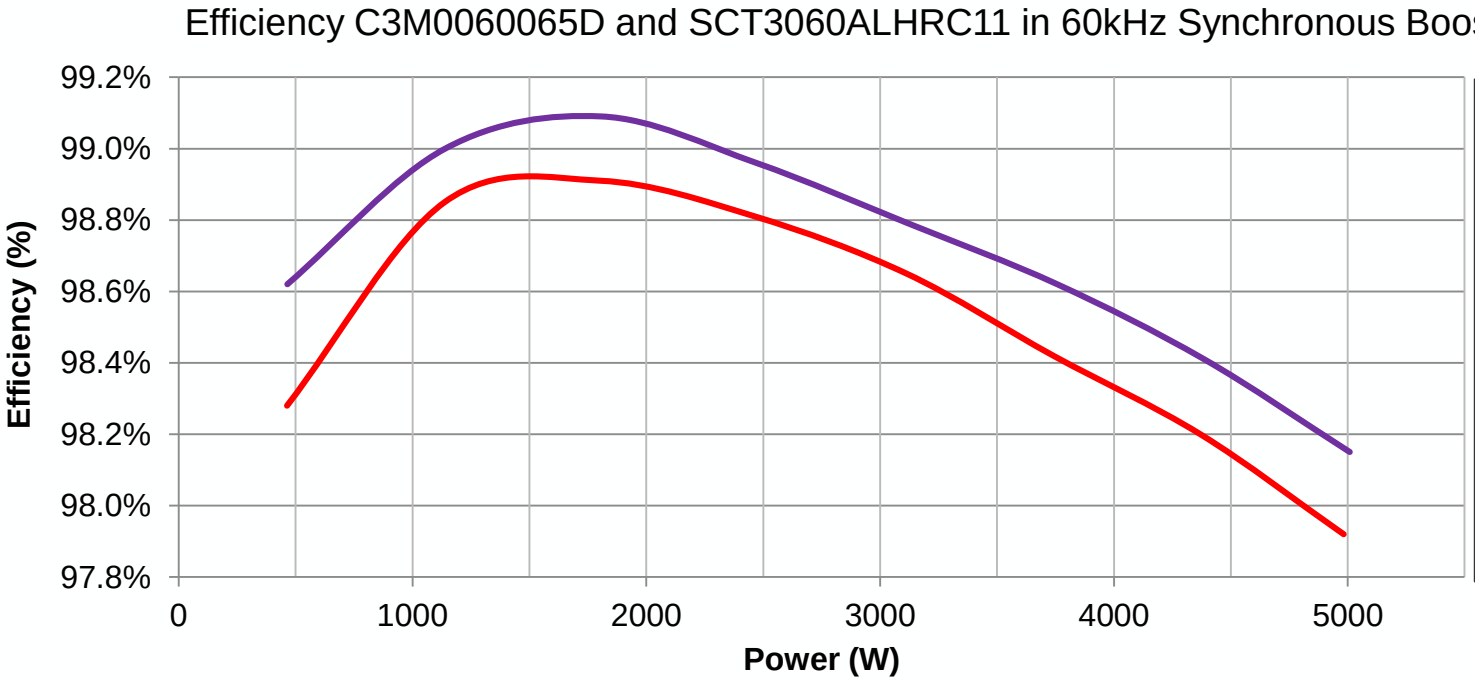
…Continuing with 650V Silicon Carbide MOSFETs

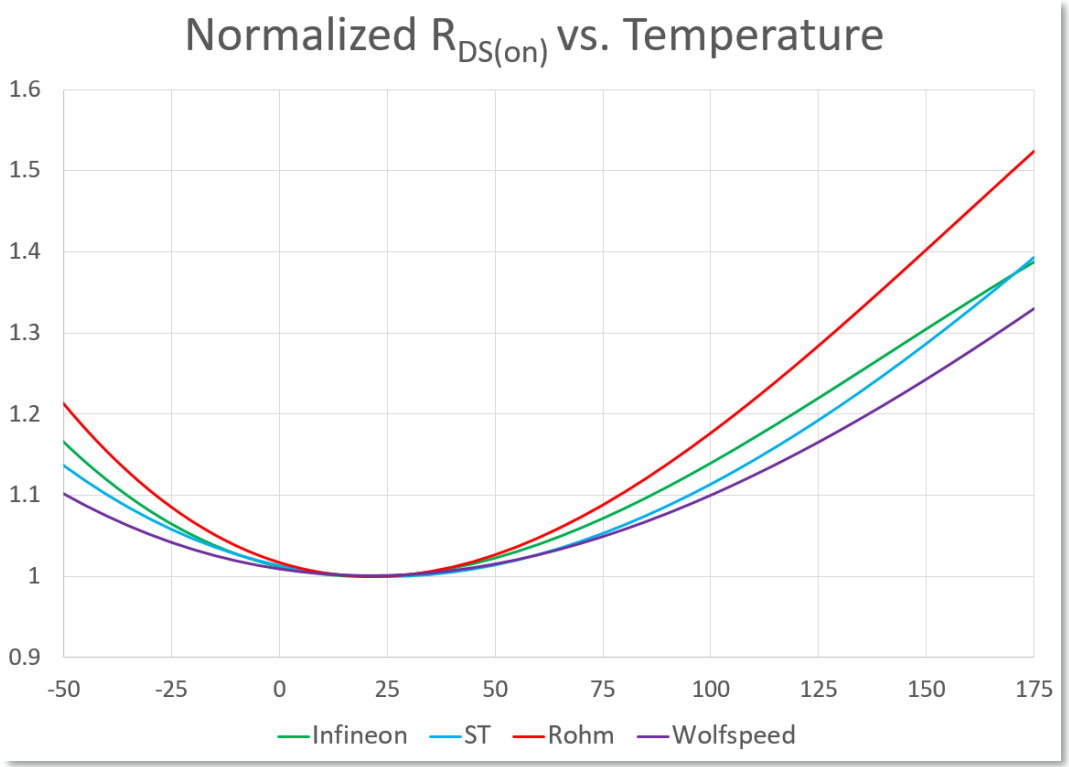


Test Platform:
Buck/Boost Board -
Sync. Boost Mode

Test Conditions:
60 kHz, 5kW,
V_{IN} = 200 VDC
V_{OUT} = 400 VDC
Wolfspeed V_{GS}: -3V/+15V
Rohm V_{GS}: 0V/+18V

Wolfspeed 650V MOSFET has both lower switching loss and lower conduction loss

Industry-leading 650V MOSFET Performance



650V MOSFET Application Example

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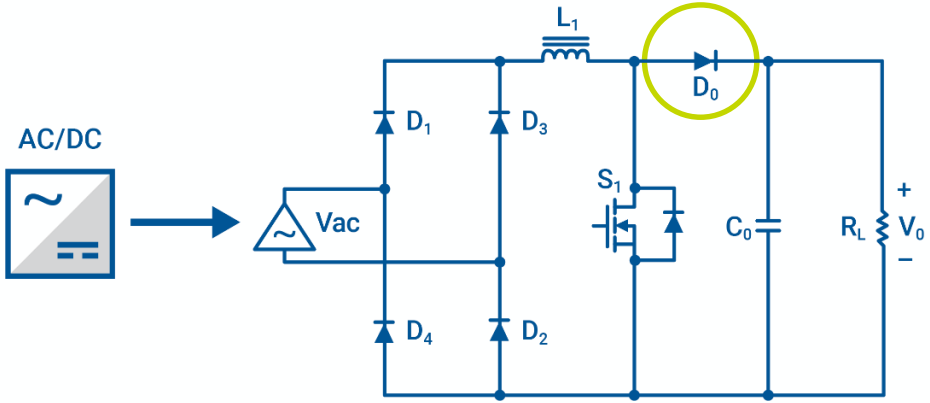
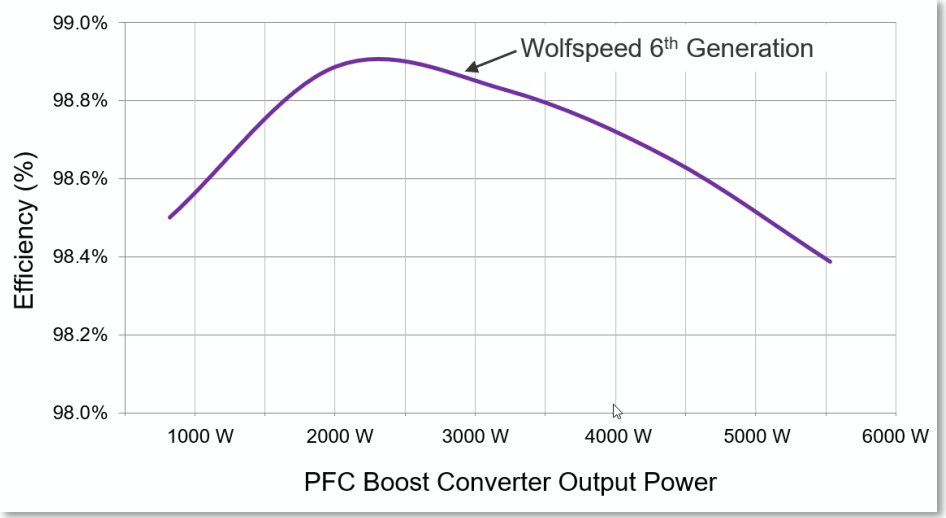
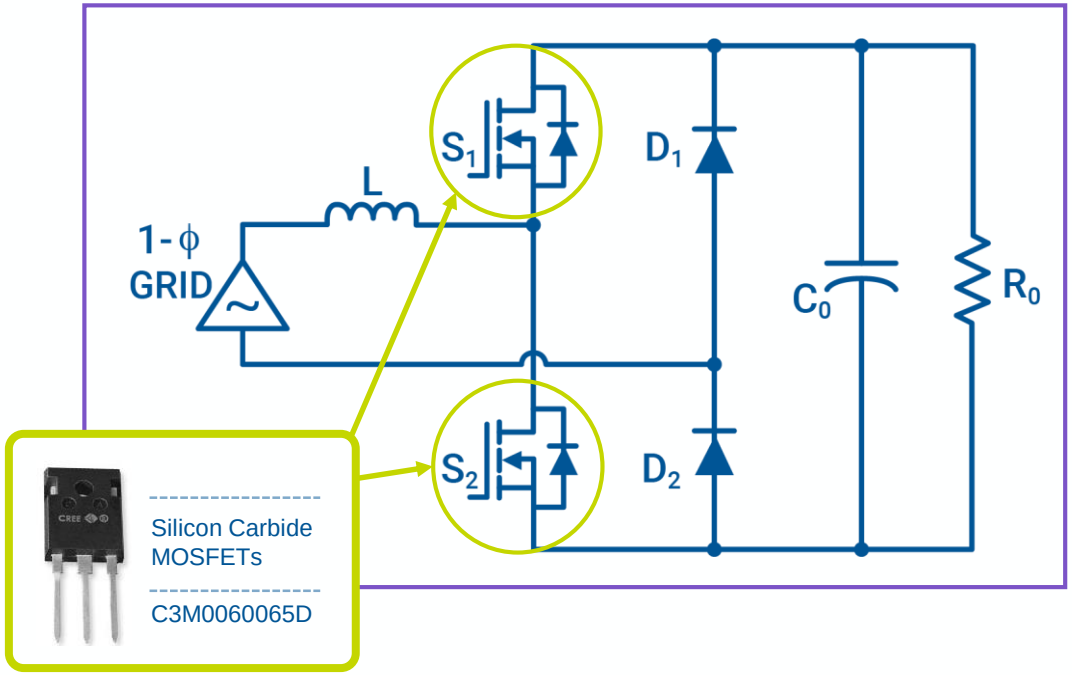
First Silicon Carbide Diodes in Traditional PFC Boost Converter





Maximizing Efficiency with MOSFETS: Totem Pole PFC



PROs

- Most cost effective “hybrid” approach with two SiC MOSFETs and two low-cost PIN diodes
- Fewest total number of components
- Enables higher power density

CONs

- Light load efficiency slightly lower (approximately 0.5%) compared to full-bridge totem-pole implementation

Industrial 2.2kW PFC Reference Design

Features

- Demonstration of highly efficient and cost-effective bridgeless totem-pole PFC topology solution by using Cree's 3rd Generation (C3M™) 650V, 60mΩ SiC MOSFETs
- Achieve 80+ Titanium standard with >98.5 % efficiency and THD<5%
- Innovative resistor based current sensing solution
- Reduced Bill of Material (BOM) cost with general purpose diodes in place of low frequency switches
- Digital Package include bill of materials (BOM), schematic, board layout, presentation and the application note

C3M0060065J
TO-263-7

C3M0060065K
TO-247-4

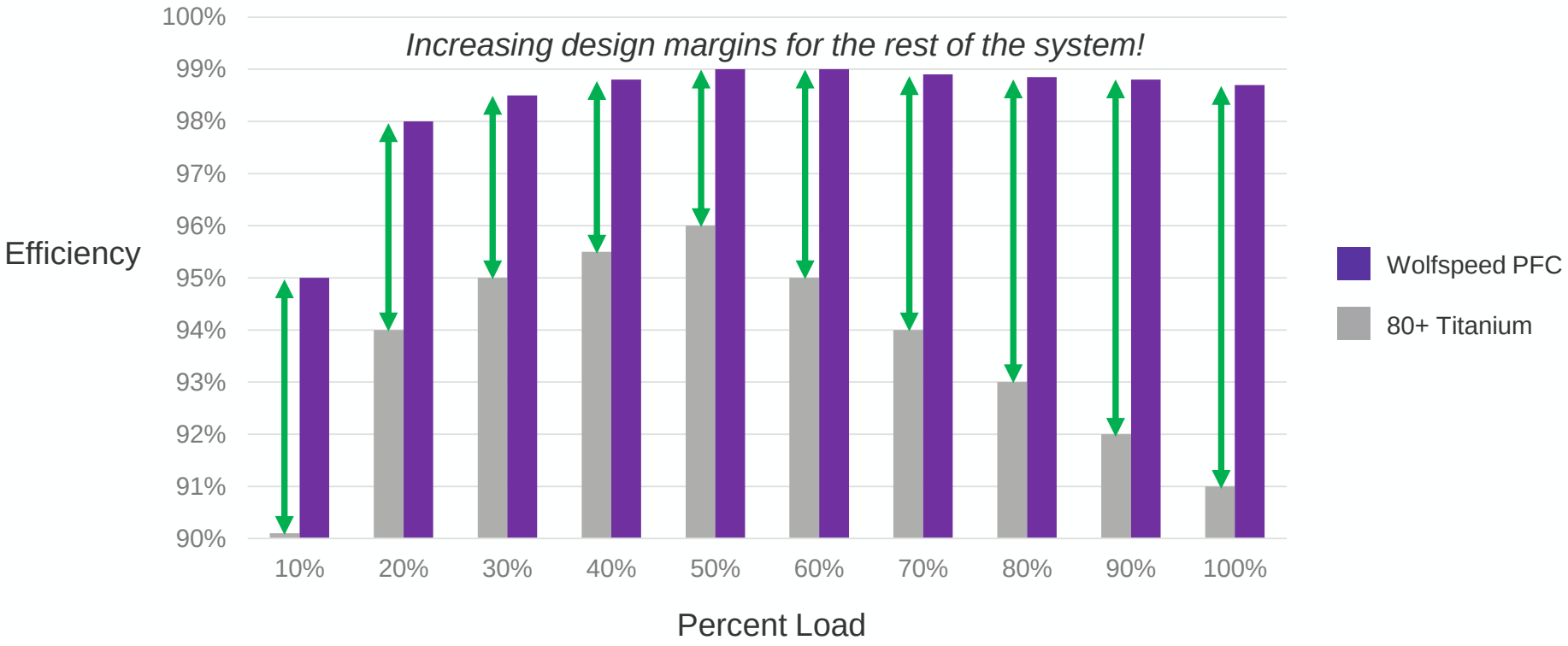
C3M0060065D
TO-247-3

Input Voltage	180 VAC – 264 VAC
Output Voltage	400 VDC
Output Power	2.2 kW
Switching Freq.	100 kHz
Efficiency	> 98.5 %
MOSFET Package	K, D, & J Packages

Applications

- Industrial Power Supply
- EV Charger
- Server/Telecom Power Supply

Beating the Standard with Silicon Carbide: C3M0060065K



Upgrading from Silicon to Silicon Carbide

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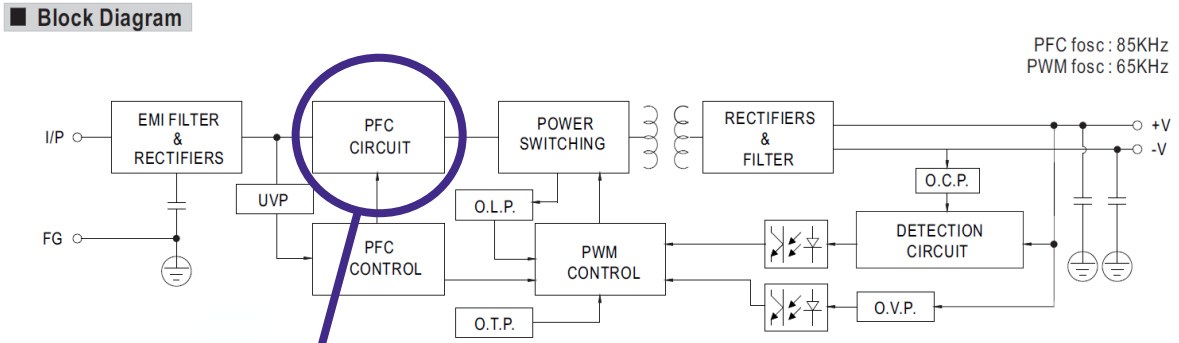
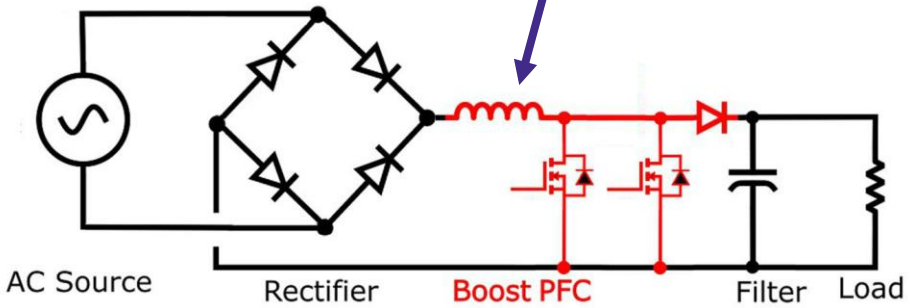
More Power, Same Form Factor: PFC Boost Converter

480W Single Output Industrial DIN RAIL



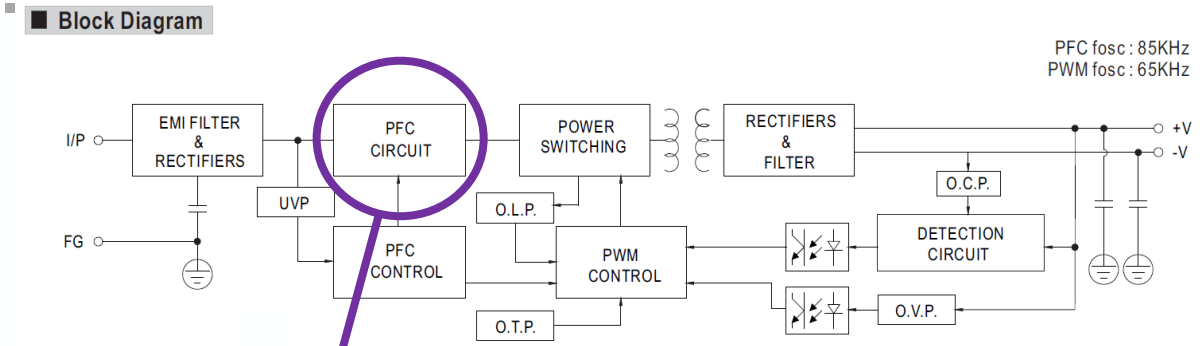


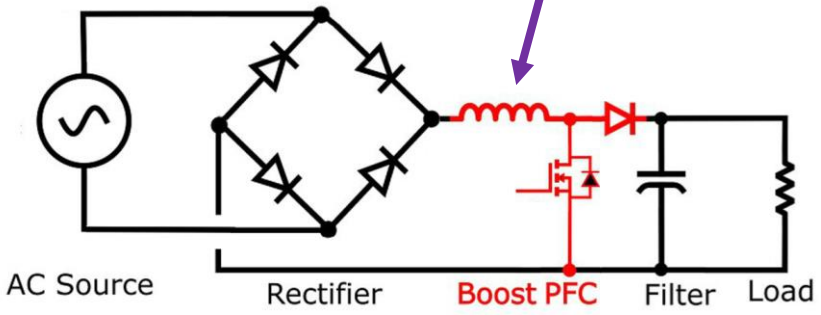
PFC MOSFETs:

2x 600V 160mΩ Silicon SJ

More Power, Same Form Factor: PFC Boost Converter

480W **+75W** Single Output Industrial DIN RAIL





PFC MOSFETs:

1x C3M0060065K 650V 60mΩ

Same Power, Smaller Form Factor: Resonant LLC DC/DC Converter

Silicon Carbide Solution

f_s = 500 kHz

Integrated Transformer and Resonant Inductor

Volume: 24500 mm^3

Weight: 200 g

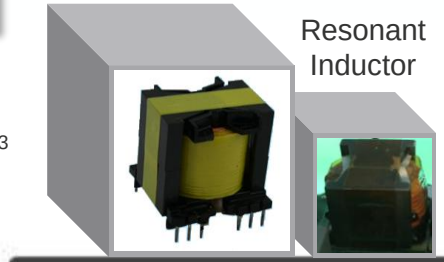
Silicon Solution

f_s = 150 kHz

Transformer

Resonant Inductor

Volume: 47710 mm^3



Weight: 416 g

Same Power, Smaller Form Factor: Resonant LLC DC/DC Converter

Silicon Carbide Solution

f_s = 500 kHz

50% Reduction in Size, Weight, & Cost!

Silicon Solution

f_s = 150 kHz

Volume: 47710 mm^3

Weight: 416

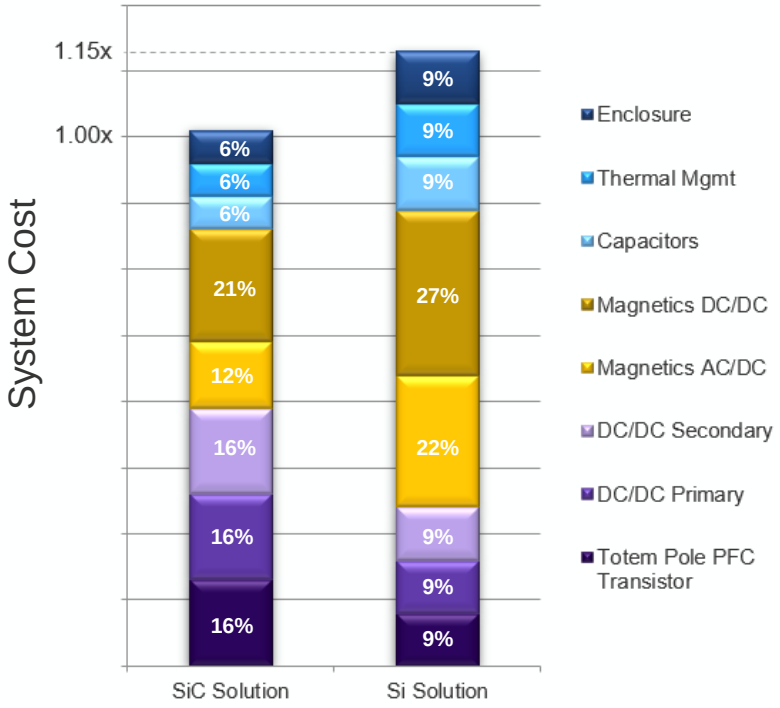
Volume: 24500 mm^3

Weight: 200 g

6.6kW High-frequency LLC DC/DC Converter Reference Design

Maximize Power Density: 6.6kW Bi-directional AC/DC + DC/DC

System Cost Breakdown



System Benefits Breakdown

	SiC System	Si System
System cost comparison[1]	1.00x	1.15x
Peak system efficiency	97%	94%
Power density	>3kW/L	<2kW/L[2]

[1] for power stage components only (power switches, passives, thermal management, etc.) Other components such as gate drivers, controllers, sensors, etc. are assumed to be similar in cost

[2] Examples:
https://www.onsemi.com/pub/Collateral/TND6320-D.PDF
file:///C:/Users/jlamar/Downloads/AnAutomotiveOn-Board3.3kWBatteryChargerforPHEVApplication_%20(2).pdf

Design Support

Reference Designs & Evaluation Kits

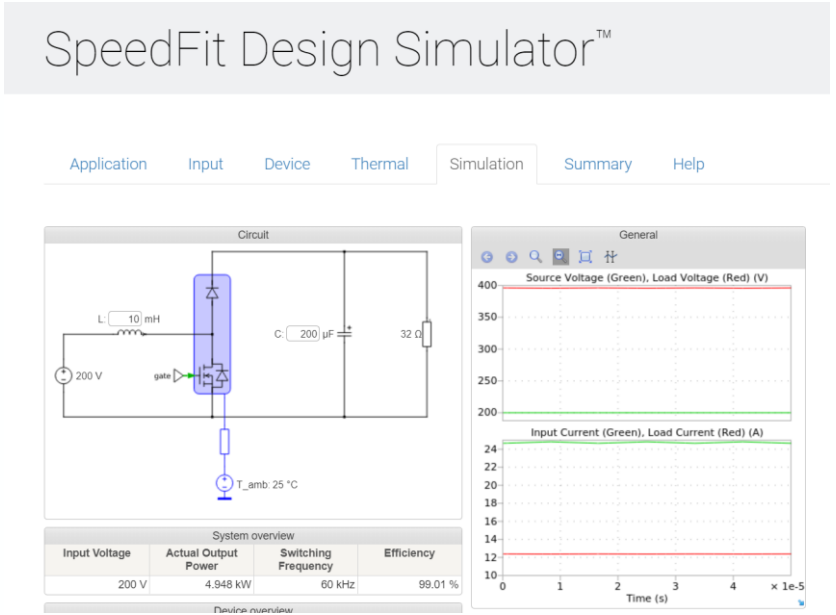
- 2.2kW **AC/DC**
  Power Factor Correction

- Buck/boost **DC/DC** eval kit

- 6.6kW high-frequency **DC/DC**

- 6.6kW Bi-directional
  AC/DC + DC/DC + DC/AC

Online Simulation Tool



Leading the Adoption of Silicon Carbide

Why Wolfspeed SiC?

- **Wolfspeed invented the SiC MOSFET in 2011**
  30+ years of SiC power with 6+ trillion installed field hours
- **Wolfspeed is Investing for the Future**
  #1 market share in SiC technology, 30X capacity by 2024
- **17+ Years of Diode and MOSFET Production**
  Thousands of customers with BILLIONS of MOSFETs and diodes
- **Focused Development and Customer Support**
  ALL resources dedicated to developing SiC capacity, devices, packages, and to providing superior applications support

We provide

- **SiC power devices**
- **SiC expertise – this is *all* we do**
- **Application reference designs**
- **Systems expert engineering support**
- **Online simulation platform**