**Increasing Efficiency in Booster Power Modules with SiC Components**

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Two factors are shaping the development of advanced power conversion systems - increasingly stringent standards for energy efficiency, especially in solar and UPS applications, and the need to contain the overall system's costs for the customer. These two goals are rather ambitious, at least for power semiconductors based on conventional silicon technology and with limited switching capabilities. Instead, engineers often opt for SiC (silicon carbide) power semiconductors. This paper compares the efficiency of power modules based on a booster to see how pure silicon components stack up against silicon carbide components. It also discusses the benefits, drawbacks and challenges of using SiC technology.

## 1. Introduction

Intrigued by its special properties, researchers have been looking into SiC as a semiconductor material since the early '70s. It offers:

- High breakdown field strength (tenfold that of Si)
- A wide bandgap (threefold that of Si)
- High thermal conductivity (threefold that of Si)

These properties are conducive to applications that demand greater efficiency in a smaller footprint and operate at higher frequencies and temperatures. The properties of wafers, however, posed some obstacles to mass-manufacturing, so it wasn't until the early 2000s that single-crystal SiC wafers became a viable alternative. Although 4" wafers are the standard today, the next step up the evolutionary ladder is within reach. And when 6" wafers make it to market, device costs are sure to drop significantly. Today 12" Si wafers are commonplace, and if predictions are anything to go by, the next technological leap to 18" wafers will come in four or five years.

Vincotech successfully rolled out the first standard power modules with SiC Schottky diodes ten years ago. SiC Schottky diodes have practically no stored charge, which reduces switching losses in the diode itself and even in IGBTs when these transistors are used as commutation 'partners.' SiC Schottky diodes are the solution of choice for many of today's applications. However, the cost situation still needs to be improved to fully tap their market potential.

These days, researchers and developers are looking more into using SiC devices as active switches. The reverse voltage range below 4k V is the exclusive domain of unipolar switches configured with various types of circuits. The SiC MOSFET has prevailed over the SiC JFET in this arena. SiC MOSFETs exhibit excellent dynamic behavior because of their low tail current and superior static behavior because of their very low specific on-resistance ($R_{DSon}$). What's inhibiting large-scale commercialization of SiC MOSFETs is the relatively steep cost, which is proving to be an even greater obstacle than for SiC Schottky diodes. However, their impact on the overall system has to be considered when assessing their full potential for reducing costs. The comparisons made in this article between Si and SiC technologies' efficiency, switching losses and switching frequency aim to substantiate this impact.

## 2. A comparison of Si and SiC components in a booster power module

### 2.1. The basis for comparison

This assessment is based on a booster topology. One possible point of application is on the DC input side of inverters in photovoltaic systems. Figure 1 shows a schematic diagram of a booster.

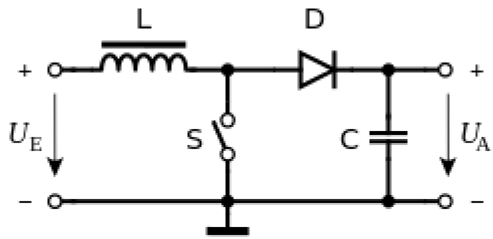


Figure 1: Schematic diagram of a booster

This example looks at a typical operating point of a photovoltaic system with 350 V input voltage and 700 V output voltage. The input current $I_{in}$ and the switching frequency f are varied. The calculations were performed using the simulation software Vincotech ISE [1]. It uses measurements obtained during the modules' characterization. This provides a fast, accurate way of comparing heat losses and temperature at various operating points. The best option for the given application may then be chosen without further ado.

This comparison examines the following standard Vincotech modules:

- IGBT switches and Si diodes
    - ***flow*****BOOST 0** (part no. V23990-P629-F72-PM) with a 40 A/ 1200 V Ultra Fast IGBT and a 30A/1200V STEALTH$^{TH}$ Diode. Although the *flow*BOOST 0 contains two parallel booster stages, this comparison looks at just one stage. The same goes for the other modules.
- IGBT switches and SiC diodes
    - ***flow*****BOOST 0** (part no. V23990-P629-F62-PM) with an 40 A/ 1200 V Ultra Fast IGBT and 3x5 A/ 1200 V SiC diodes
- SiC MOSFET switch and SiC diodes
    - ***flow*****BOOST 0 SiC** (part no. 10-PZ12B2A045MR-M330L18Y) with a 45 MΩ/ 1200 V SiC MOSFET and 4x10 A/ 1200 V SiC diodes

### 2.2. Assessing efficiency

The first step to improve efficiency is to replace the Si diode with an SiC diode. Figure 2 shows the efficiency curve as a function of the input current (power) in a comparison of modules with IGBT switches and Si or SiC diodes. Efficiency increases perceptibly with the SiC diode even at switching frequencies > 4 kHz. Losses can be halved from 1.6% to 0.8% at 16 kHz and 5A input current. Losses can be reduced again by 37% to 0.5% at the same input power and same switching frequency by using a SiC MOSFET in place of an IGBT. This is the second step to increase efficiency (see Figure 3). The benefits of the SiC MOSFET are even more striking at switching frequencies > 32 kHz. Given the same input current and a switching frequency of 64 kHz, efficiency increases and losses are reduced by just fewer than 35%. The effect is even more pronounced at higher input currents, but measures must be taken to ensure good cooling. These simulations were carried out with a constant heat-sink temperature of 80 °C. The physical limitations of Si technology are soon evident in applications demanding great efficiency and high switching frequencies. It is equally evident that SiC components will drive this market.

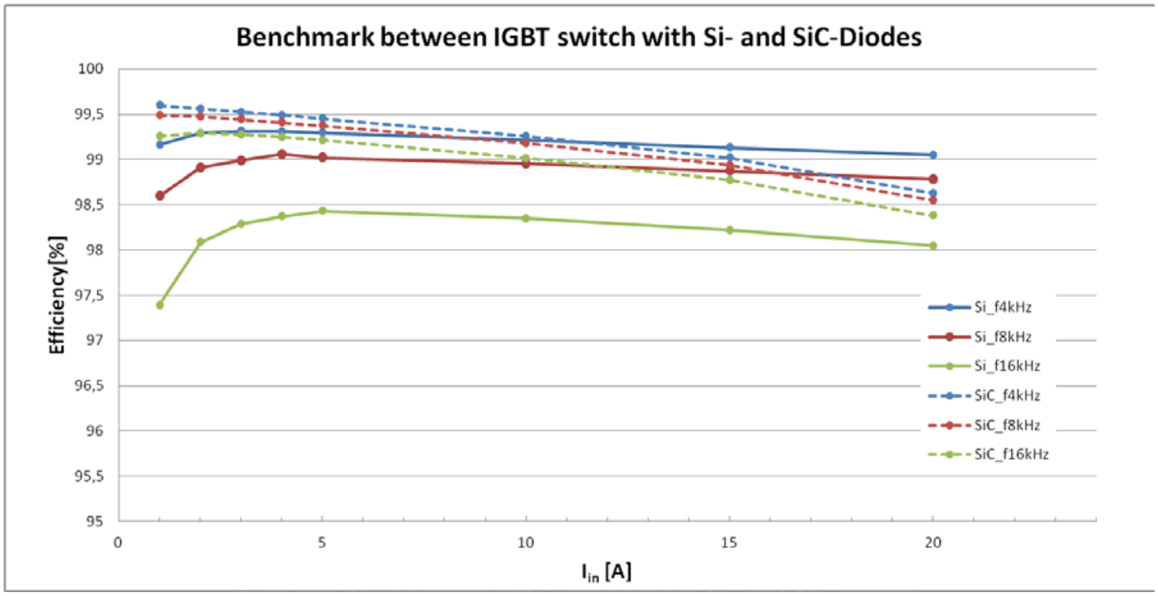


*Figure 2: A comparison of the efficiency curves of IGBT switches with Si and SiC diodes as a function of the input current at switching frequencies between 4 kHz and 16 kHz*

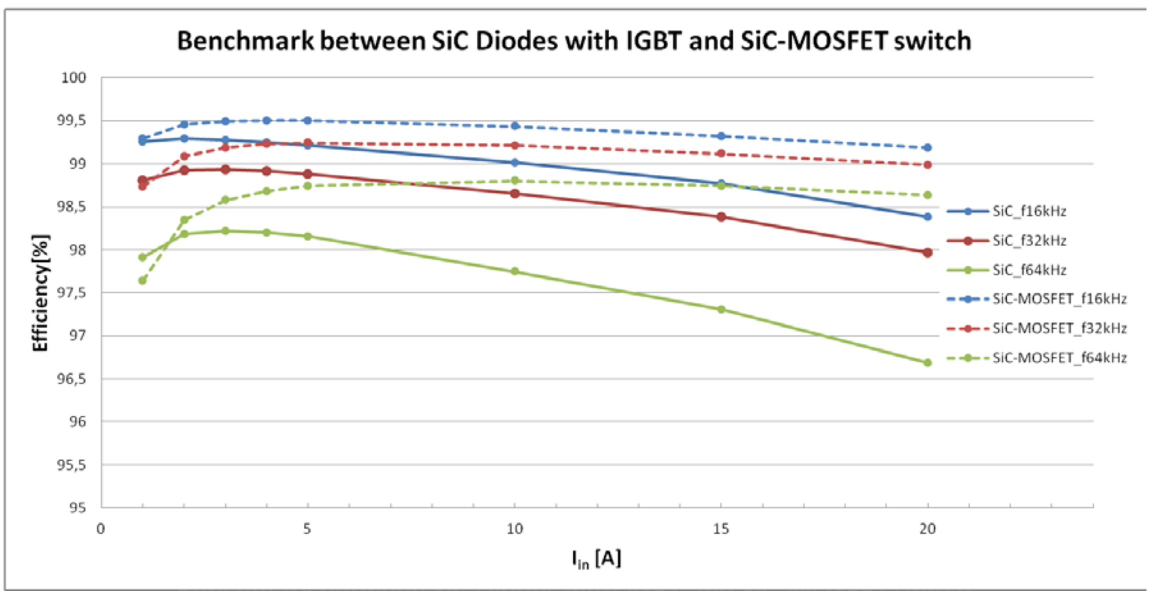


*Figure 3: A comparison of the efficiency curves of SiC diodes with an IGBT and an SiC MOSFET as a function of the input current at switching frequencies between 16 kHz and 64 kHz*

The following figures also show the benefits of using SiC components rather than Si components in performance-driven applications. Given the same losses – for example, 50 W of total dynamic and static losses – and a switching frequency of 16 kHz, output power can be increased by up to 85% when using SiC diodes instead of Si diodes. In this case, output power is commensurate with input current. Refer to Figure 4 for more on this. Given the same switching frequency, output power can be increased 50% by using a SiC MOSFET in place of an Si IGBT as shown in Figure 5. In this case, the combination of IGBT switch and SiC diode outperform the SiC MOSFET and SiC diode pairing because the IGBT's conduction losses are lower than those of the SiC MOSFET.

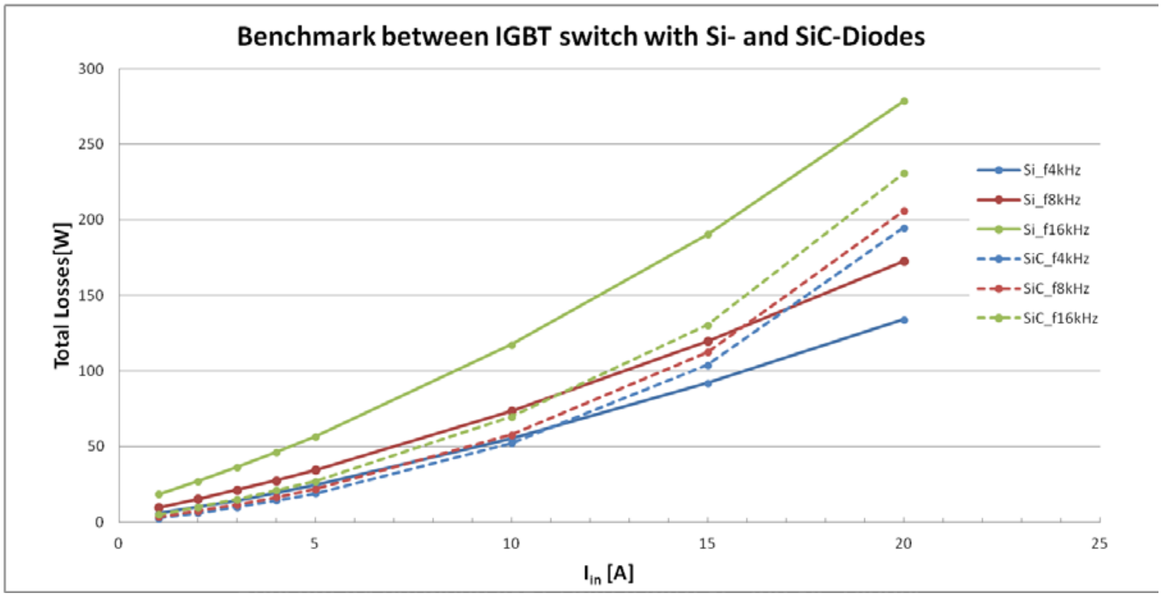


*Figure 4: A comparison of the total dynamic and static losses of IGBT switches with Si and SiC diodes as a function of the input current at switching frequencies between 4 kHz and 16 kHz*

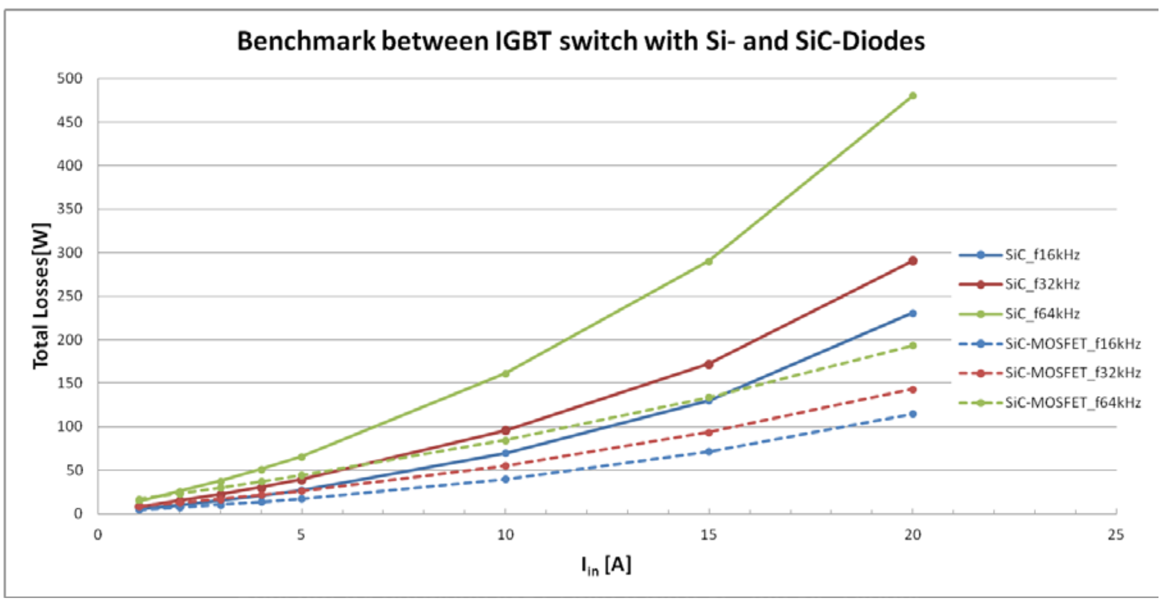


*Figure 5: A comparison of the total dynamic and static losses of SiC diodes with IGBTs and SiC MOSFETs as a function of the input current at switching frequencies between 16 kHz and 64 kHz*

Another interesting comparison looks at how total losses relate to switching frequencies. Compared to the Si diode with IGBT switch, the SiC-diode-with-IGBT combination's switching frequency can be increased from 16 kHz to 48 kHz with switching losses remaining the same. The SiC diode/ SiC MOSFET twosome's switching frequency may even be increased to over 100 kHz. And as the switching frequency rises, the size and cost of the inductance for the overall system can come down. In the final reckoning, losses can be decreased by more than 80% with SiC components rather than Si components. This, in turn, reduces the effort and cost of cooling. The benefits shown here also go a long way in helping engineers miniaturize end products and therefore cut costs. However, a quantitative assessment of the cost reduction also has to consider other factors and the challenges inherent in using SiC technology.

## 3. Challenges in using SiC components

In times when cost is the driving force behind new products' development, high price tags make it hard for new technologies to gain market share. This was the greatest barrier to SiC semiconductors' mass rollout. That barrier is gradually eroding as higher unit volumes and generational change bringing those steep initial costs down. For example, the price of 600 V SiC diodes dropped some 30% to 40% from 2011 to today. It is expected that it will come down another 10% or so in the next three years. The price of SiC MOSFETs is predicted to fall by more than 50% in the next three to four years, for example, for the 1200 V/ 80 MΩ model. At these prices, SiC components are sure to see widespread use in the years ahead.

Technical challenges also need to be addressed to make the most of SiC technology's benefits. Above all, assembly and bonding techniques have to be adapted to SiC components' higher performance capabilities. Devices with SiC components can operate at relatively high current densities with the heat-sink temperature remaining the same. This subjects bonding wires and solder joints to greater thermo-mechanical stress, which could influence the power module's lifespan. Then again, assembly and bonding techniques such as sintering, pressure sintering with silver powder, optimized bonding compounds, copper braiding or large-area foil contacts could counter such effects. SiC has a greater defect density than Si, which is why chips were kept small to obtain an acceptable yield. Until recently a rated current carrying capacity on the order of 5 to 10 A was typical for SiC diodes, but today the latest generations offer up to 50 A. To learn more about the benefits and challenges of using SiC diodes, read the paper indicated in [2] below.

## 4. Summary

This article discussed how the SiC diodes and switches used in Vincotech power semiconductor modules can increase efficiency and switching frequencies, while reducing losses in demanding applications such as solar inverters. These power modules were developed specifically to satisfy such applications' demanding requirements for symmetric control, heat dissipation and low-inductance connections. In addition to the *flow*BOOST 0 SiC module used for this comparison, Vincotech is gearing up the new *flow3x*BOOST 0 SiC for mass production. This module contains a three-channel booster topology with SiC diodes and the latest generation of switches. Designed for efficiency-driven applications, it caters to the solar market where companies are eager to reduce device size and cost with passive components such as inductors and transformers. It is also well-suited for inverters in machines that rotate at very high speeds and for applications where noise pollution is a problem.

Additional reading:

[1] http://www.vincotech.com/en/support/simulation-software.html
[2] Advantages of SiC Schottky Diodes in Fast Switching Power Electronics Solutions, Ernö Temesi, Development Engineer, Vincotech Hungary Ltd, Bodo's Power 2008