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Development Tools Aim to Overcome Designers' Hesitation About SiC MOSFETs

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Thanks to marked improvements in material quality and device maturity, credible additions to the supplier base, and falling prices, it is now generally accepted that wide-bandgap materials, such as silicon carbide (SiC), will play a major role in the future of power electronics. Because SiC device technology is comparatively new, however, some power converter designers remain hesitant to incorporate these devices into their products.

At the heart of the hesitation is a reality that implementing SiC devices requires changes in techniques used to design a power converter—changes that are manifestations of the very benefits SiC technology brings to bear. Silicon carbide MOSFETs support higher operating voltages than their silicon (Si) MOSFETs, can switch up to five to ten times faster than bipolar Si IGBTs, and can operate at higher junction temperatures than Si devices.

The ability to switch at higher frequencies allows designers to shrink the size and weight of filter components, which can significantly improve power density without sacrificing—and in many cases, improving—system efficiency. Taking advantage of enhanced switching performance does not come for free. The side effects of fast switching, if not properly considered, can lead to new problems; one example is that noise (EMI) may be fed into the gate driving circuitry and lead to catastrophic shoot-through.

To counter designers' hesitation, a growing number of device suppliers are taking steps to encourage exploration of the technology's potential and accelerate its mainstream acceptance, including the development and release of a variety of reference designs and demo boards. For example, Littelfuse and Monolith Semiconductor have joined forces to develop comprehensive tools intended to help designers streamline the incorporation of SiC power devices into their systems.

This article describes two of these tools: the Dynamic Characterization Platform and the Evaluation Converter Kit. In addition, this article also touches on reductions in inductance and capacitance that can be achieved by raising the switching frequency over a range of power levels up to 5 kW with the Evaluation Converter Kit.

Evaluating SiC Switching Performance

The Dynamic Characterization Platform (DCP) allows circuit designers to evaluate a SiC device's switching performance with extreme accuracy on a per-cycle basis using a process called a double-pulse clamped inductive load (CIL) test. Fig. 1 shows the DCP, which performs the double-pulse clamped inductive load (CIL) test. This test involves turning on the MOSFET two times.

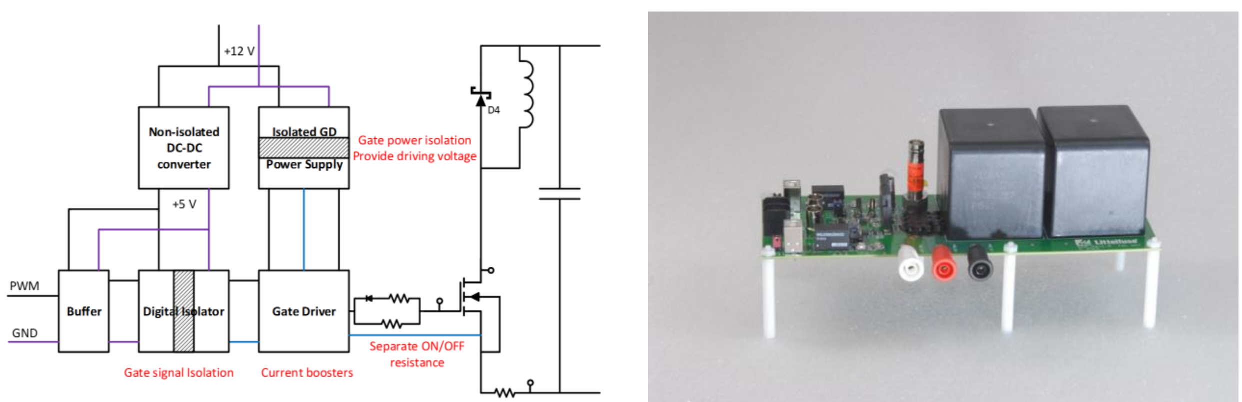


Fig.1. The Dynamic Characterization Platform (DCP) developed by Littelfuse and Monolith Semiconductor allows designers to evaluate the switching performance of the company's SiC MOSFETs.

The first pulse width, in conjunction with the inductor value and bus voltage, determines the current amplitude through the device during the turn-off event. During the time between the first pulse and second pulse, the energy stored in the inductor circulates through a free-wheeling diode. This allows the same set of operating parameters to be applied to the device during the rising edge of the second pulse, the turn-on event.

The waveforms of interest in this test are gate-source voltage (V_{GS}), drain-source voltage (V_{DS}), and drain current (I_{DS}) (Fig. 2). The primary time intervals of interest in these waveforms are the falling edge of the first pulse (turn-off) and the rising edge of the second pulse (turn-on). The V_{DS} amplitude is controlled by the dc bus voltage (from a dc power supply), which is programmed by the user and is typically 600 V or 800 V, in this type of test, for a 1200-V device. The user also controls V_{GS}; the recommended V_{GS} (driving) voltages are: on = 20 V, off = -5 V.

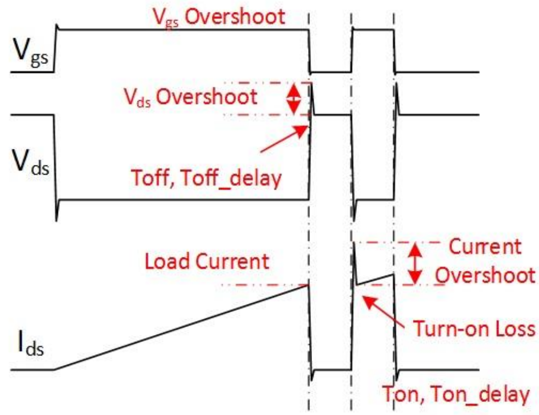
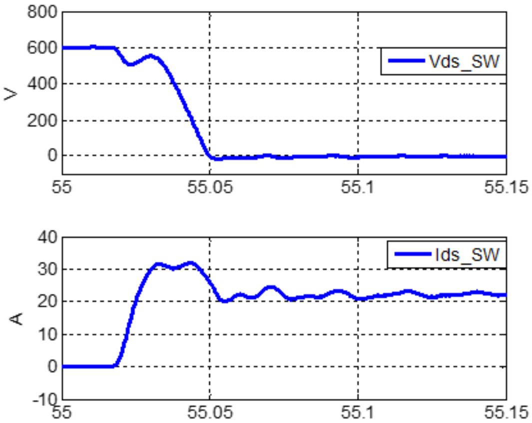
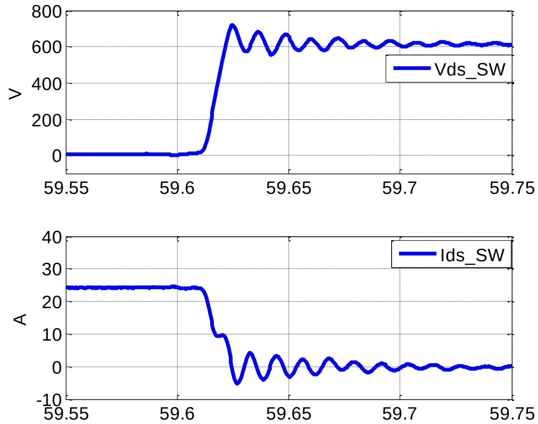


Fig. 2. The double-pulse test technique is useful for extracting data on SiC device switching performance.

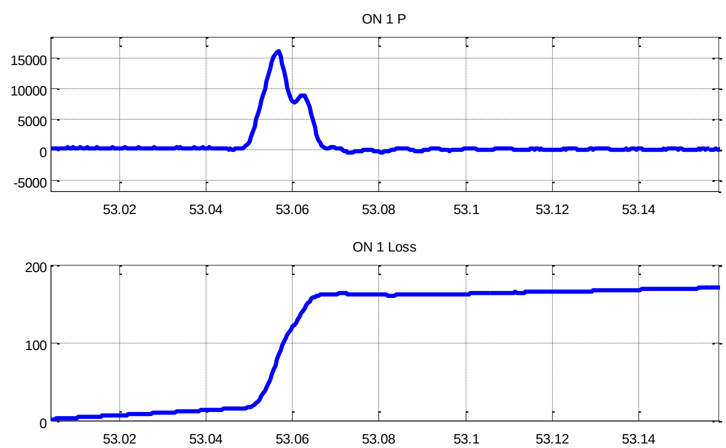
With the DCP, designers can extract a full suite of switching characteristics associated with a device, including gate charge, switching times, and switching energies. Switching test waveforms (Fig. 3) let them gain an in-depth understanding of the devices and exactly how they should be implemented in their designs to achieve optimal performance. For detailed instructions on how to use the DCP, specific devices that can be characterized, and guidance on how to obtain and interpret the results, consult the application note developed to accompany the DCP (see the reference.)





(a) Turn-On

(b) Turn-Off



(c) Switching energy: instantaneous power (top waveform) and integrated power loss (bottom waveform) for turn-on event shown in (a)

Fig. 3. Switching waveforms obtained using the DCP. They demonstrate that the DCP allows for accurate characterization of the device under test (DUT) with minimal concern regarding measurement error due to test platform and measurement circuit parasitics. The x-axis on all plots is in microseconds; the y-axis on the bottom chart of (c) is in millijoules.

Testing SiC Devices In Converter Circuits

The second tool, the 5-kW Evaluation Converter Kit (ECK), offers a flexible platform for converter-level testing that aids in testing buck and boost converter designs configured to specific application requirements. Although the DCP supports detailed evaluation of switching behavior under individual pulse conditions, it can't be operated in continuous mode because it doesn't include any thermal management capability. That's where the second design tool developed by Littelfuse and Monolith comes in.

Several important converter design and layout considerations are necessary to exploit fully the advantages SiC offers. For example, minimizing the amount of undesired parasitic inductance in the power loop is crucial. Careful gate-drive design and layout are also necessary to isolate the converter's control circuitry from noise. By leveraging a modular design strategy, the 5-kW Evaluation Converter Kit offers a highly versatile and adaptable platform for converter-level testing. It can be easily configured to emulate the operating characteristics of a specific application. With this kit, power converter designers can characterize performance metrics critical in actual converter operation, including converter efficiency, switch temperature, EMI, noise sensitivity, etc.

The 5-kW evaluation converter kit is designed with full flexibility in mind. Configurable operating characteristics include a choice of converter topology (synchronous or non-synchronous buck, synchronous or non-synchronous boost, which designers can readily reconfigure by rearranging the kit's MOSFETs and diodes), input/output voltage and current levels, operating frequency, and driving solutions.

The kit's flexibility makes it suitable for use in introductory converter design, power density studies, and control theory applications. It can also serve as a guide to proper layout techniques when dealing with SiC devices and is useful for evaluating the effect of different driving techniques.

Designers can configure the evaluation kit with their choice of operating parameters to emulate the operating characteristics of a specific real-world application (see the table.)

Table. Configurable Parameters for 5-kW Evaluation Kit.

Parameter	Minimum spec.	Maximum spec.
Input voltage	200 V	800 V
Output voltage	200 V	800 V
Switching frequency	25 kHz	200 kHz
Power	1 kW	5 kW
Conversion ratio (duty cycle)	25%	75%

When properly configured, the 5-kW Evaluation Converter Kit can simplify the process of designing a wide range of power electronics applications, including automotive EV/HEV and charging systems, solar and wind power generation and energy storage systems, data and communications power and uninterruptible power systems, and industrial drives, HVAC and welding products.

A converter capable of achieving higher switching frequencies offers greater power density. The capacitance and inductance values of the components that go into these converters can be substantially reduced at higher switching frequencies. In Fig. 4, note the silver cubes (inductors) on the top of the 5-kW Evaluation Converter Kit platform and the light blue cubes on the bottom of the platform (capacitors). The following equations determine the minimum values required of these components.

$$L = \frac{D * V_{in} * (1 - Dtyp)}{\Delta I_L * f_{sw}}$$

$$C_{out} = \frac{\Delta I_L}{16 * f_{sw} * \Delta V_{out}}$$

To get a feel for how switching frequency influences these components' size, let's consider an example of a nonsynchronous buck converter that converts an 800-V input to 400-V output. If we calculate the inductance and output capacitance values required to maintain critical conduction mode (CCM) over a range of specified frequencies and power levels, we obtain the results shown in Fig. 5. As the inductors' and capacitors' values get smaller, so do their physical volumes, which increases the converter's power density.

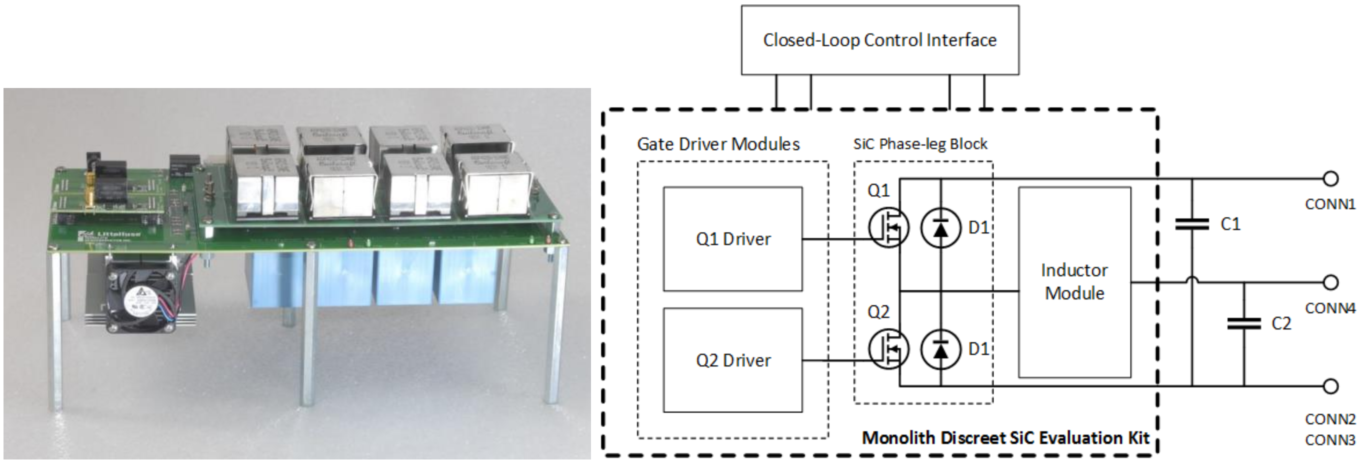
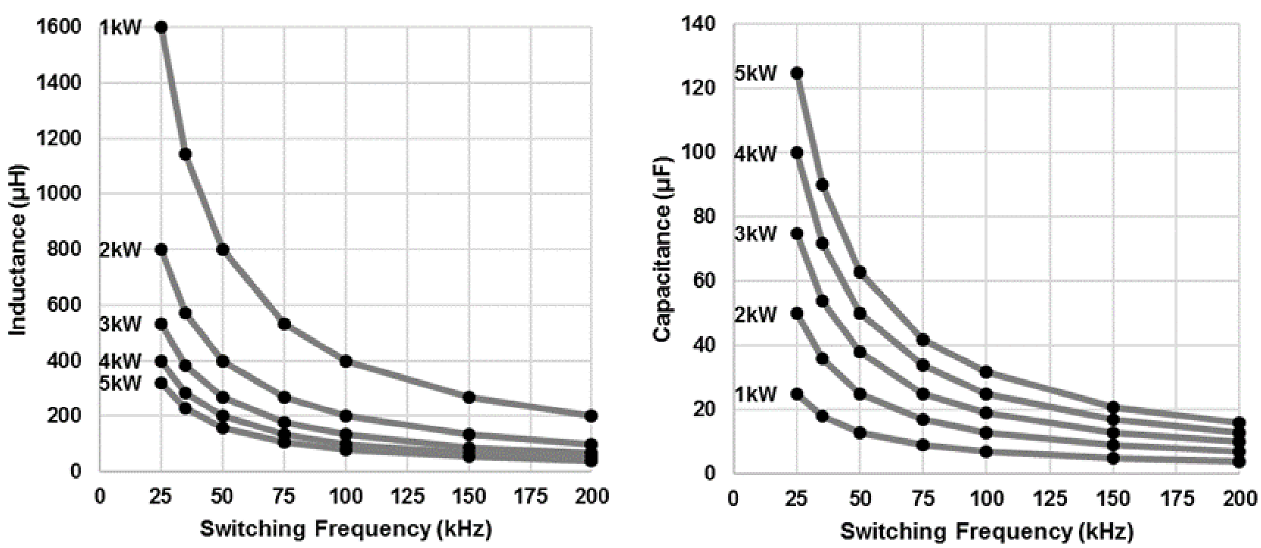


Figure 4. A 5-kW Evaluation Converter and its design. Silver cubes are inductors; light blue cubes are capacitors.



(a) (b)

Fig. 5. Minimum inductance (a) and minimum capacitance (b) values are graphed (using the equations shown previously) for a non-synchronous buck converter topology with an 800-V input voltage and a 400-V output voltage, which implies operation at 50% duty cycle.

Substituting physical components readily available off the shelf for their theoretical counterparts requires a measure of compromise with component values that are "a close enough match" (Fig. 6) to the theoretical values previously calculated. It should also be noted that the minimum filter component values have a co-dependent relationship when it comes to satisfying output voltage ripple requirements. In other words, if there exists a maximum off-the-shelf capacitor value (due to volume, cost, voltage rating, etc.), the designer can simply increase the inductor value and, in turn, maintain the output voltage ripple specification.

In the example presented in Fig. 6, a maximum value of 50 µF was enforced. Note the lines on the plot in Fig. 6(b) that were affected by this limitation (3 kW, 4 kW, and 5 kW); accordingly, there is also a noticeable increase on the corresponding minimum inductor value lines in Fig. 6(a) when compared to those shown in Fig. 5(a).

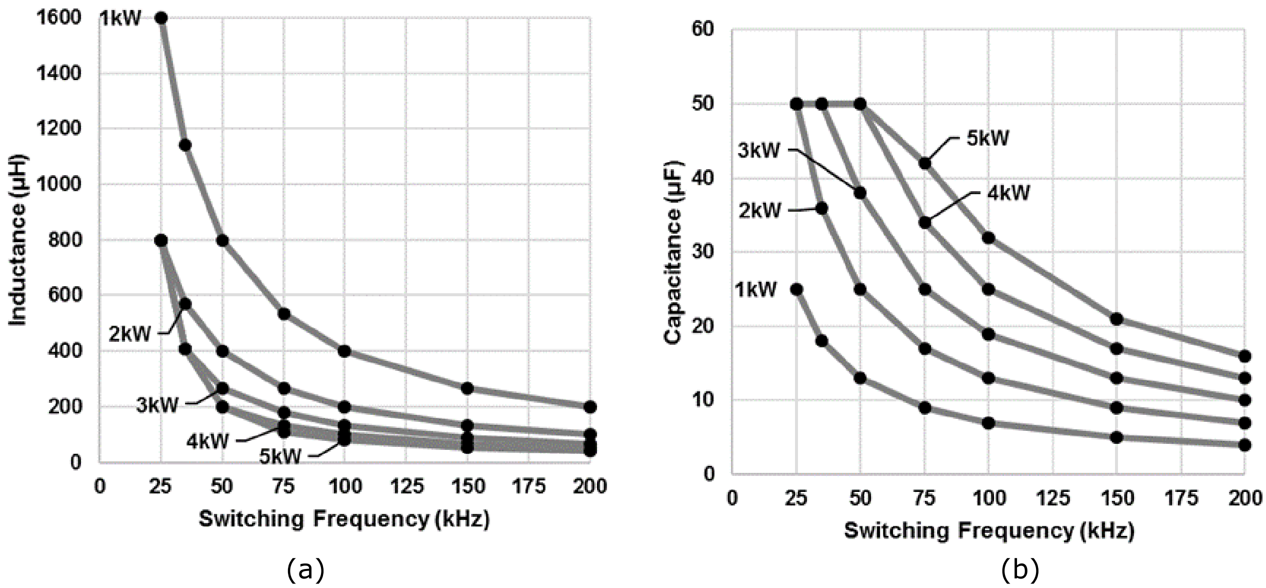


Fig. 6. Practical values for off-the-shelf inductors (a) and output capacitors (b) that can be used in place of the values calculated in Fig. 5.

Fig. 7 shows the correlation of the capacitance and inductance values of the off-the-shelf components directly to the volume that they occupy in the system. Relating Fig. 6 to Fig. 7 shows that as the component values decrease, generally so does the volume.

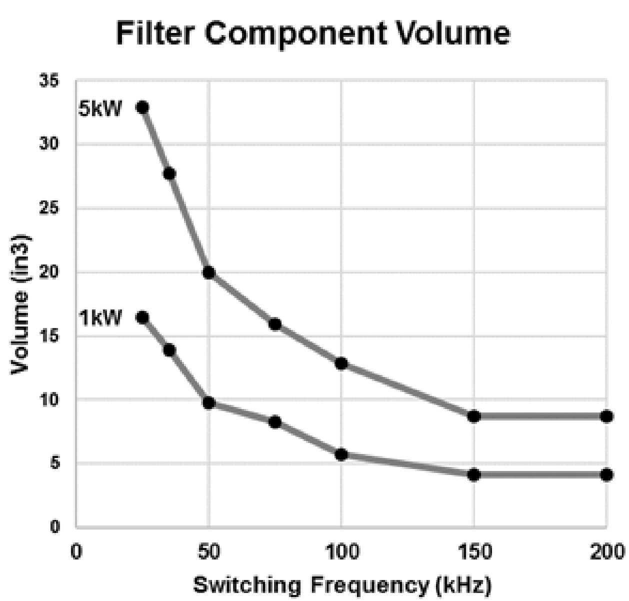


Fig 7. Total volume of implemented filter components from previous figure.

Given that it is now widely acknowledged that the question is not *if* but *when* SiC and other wide bandgap devices will enter the mainstream market and become dominant players in the industry, a new question arises from the perspective of suppliers. "What can be done to accelerate this inevitable trend?" Monolith and Littelfuse believe that one major answer to this question is alleviating any concerns designers may have about integrating this new technology into their designs. Not coincidentally, the kits discussed in this article offer excellent platforms that allow designers to gain a wealth of understanding of how SiC devices behave.

Reference

An application note for the DCP is available from the company.

About The Authors

Levi Gant is an application engineer at Monolith Semiconductor, focused on commercializing and enabling widespread adoption of silicon carbide power semiconductors. He attended The University of Alabama, where he received his BS in 2015 and his MS in 2016. Levi joined Monolith in August 2016, where he specializes in the characterization of SiC devices and the design of SiC application converters.

Kevin Speer joined Littelfuse in January 2015 as the business development manager responsible for providing strategic direction for the growth of IGBT and wide-bandgap power semiconductor business at Littelfuse. In addition to promoting and developing multi-chip IGBT module technology, Kevin has been involved in SiC materials, devices, and applications research since 1999. He earned a BSEE from the University of Arkansas in 2004, an M. Eng. from Case Western Reserve University (CWRU) in 2007, and a PhD in electrical engineering from CWRU in 2011.

For further information on SiC power devices, see How2Power's Silicon Carbide and Gallium Nitride section.