White Paper

It Is Easy to Drive and Protect SiC MOSFET

Introduction

More than ten years ago, we started seeing increasing Silicon Carbide (SiC) Metal–Oxide–Semiconductor Field-Effect Transistors (MOSFETs) activities and a splash of product launches from key power semiconductor suppliers like Cree and Infineon. At the same time, many new suppliers were trying to dethrone the incumbent silicon and change the gameplay in their own ways. However, this is a mammoth task as Insulated-Gate Bipolar Transistors (IGBTs), which have been around for more than 40 years, are entrenched in every power electronics engineer's design.

Although SiC MOSFETs can bring forth many benefits, it took more than ten years for suppliers to consolidate and align SiC MOSFET specifications and standards, including definitions for driving and protecting the SiC MOSFET. Engineers faced many challenges. For example, the normally ON SiC Junction-Gate Field Effect Transistor (JFET) needed a negative gate voltage to turn it off. The more acceptable normally OFF switch could be used, but it required a very high gate voltage of 20V to ensure low conduction loss. That meant engineers had to redesign their power supply, which had been optimized for the IGBT at 15V gate-emitter voltage, V_{GE}. Common problems also included challenges like high-speed operation and dv/dt noise when SiC MOSFETs switch faster.

Today, most of the disparities have been aligned with how we will drive IGBTs. Most importantly, gate drive technologies have also improved tremendously to enable the adoption of SiC MOSFETs. Broadcom recently released a 10A gate drive optocoupler, the ACPL-355JC. It is able to fulfill the demanding requirements of driving and protecting SiC MOSFETs.

At the same time, most of the major suppliers in the power semiconductor industry are ramping up their SiC MOSFET production with packages and pinouts that can easily replace existing IGBTs. This drives the costs of SiC MOSFETs to a very competitive level, which is likely the most important factor to facilitate SiC MOSFET adoption.

The Standardization of SiC MOSFET Specifications

The Broadcom® gate drive optocoupler has evolved to meet the demand of SiC MOSFETs. Similarly, SiC MOSFETs have also evolved to be easily driven and protected by gate drivers. This section highlights some of the important changes in the specification, which enable the growing adoption of SiC MOSFETs.

The first specification is gate-source voltage, V_{GS}. Over the years, the optimum V_{GS} for SiC MOSFET operations has reduced from 20V to 18V and finally settled at 15V, the same level as the V_{GE} of IGBTs. This has made definitions of the gate driver power supply and under voltage lockout (UVLO) threshold more definite. The ACPL-355JC gate drive optocoupler has a wide supply range from 0V to 30V, which makes it very versatile for either unipolar gate driving or bipolar gate driving. These ensure the SiC MOSFETs are firmly switched on or off. The UVLO of the ACPL-355JC is set to 13V, which is suitable to drive most of the latest SiC MOSFET gates, which are designed to operate at 15V V_{GS}.

The second specification is the total gate charge, Q_G. The Q_G of SiC MOSFETs is more than two times smaller than their equivalent IGBT counterparts. This allows SiC MOSFETs to switch very quickly, reducing switching losses and increasing operating frequency. A lower Q_G also implies a lower gate current requirement, which helps eliminate an additional current buffer stage. The ACPL-355JC has a 10A peak driving current that can help overcome input capacitance and quickly charge up the gate of the SiC MOSFET. This optimizes the potential of the SiC MOSFET and improves the overall system efficiency.

The third specification is the slew rate, dv/dt, which measures how fast the SiC MOSFET switches from zero to the BUS voltage within the shortest time. Although fast switching is critical to reducing switching losses, the high dv/dt generated can be a nuisance and can cause noise to the SiC MOSFET control. The ability for the gate driver to reject the dv/dt noise is specified by the common mode transient immunity (CMTI). SiC MOSFETs are capable to switch 100 V/ns and the ACPL-355JC has a CMTI rating to guarantee a noise immunity of more than 100 kV/µs.

The last specification is the short circuit withstand time (SCWT) of the SiC MOSFET. Silicon IGBTs in general have superior SCWTs to SiC MOSFETs. Hence, any short circuit fault current in the SiC MOSFET needs to be extinguished quickly before the switch is destroyed; typically, the rule of thumb is 1 µs to 3 µs for SiC MOSFETs, as compared to 5 µs to 10 µs for IGBTs. In terms of short circuit protection, the ACPL-355JC uses the same methodology as the DESAT sensing of the IGBTs. The ACPL-355JC monitors the drain and source of the SiC MOSFET and triggers a soft shutdown when a high fault current increases the drain source voltage. To address the difference in time regarding how fast the SiC MOSFET and IGBT need to be protected, the detection voltage, detection time, and shutdown time of the ACPL-355JC can be adjusted using external discreet components.

Driving and Protecting SiC MOSFET Modules in Standard Packages

This section will look into driving 1200V SiC MOSFETs from two major suppliers, in standard module packages for low and high current.

Table 1: 1200V SiC MOSFET Modules in Standard Packages for Different Current Classes

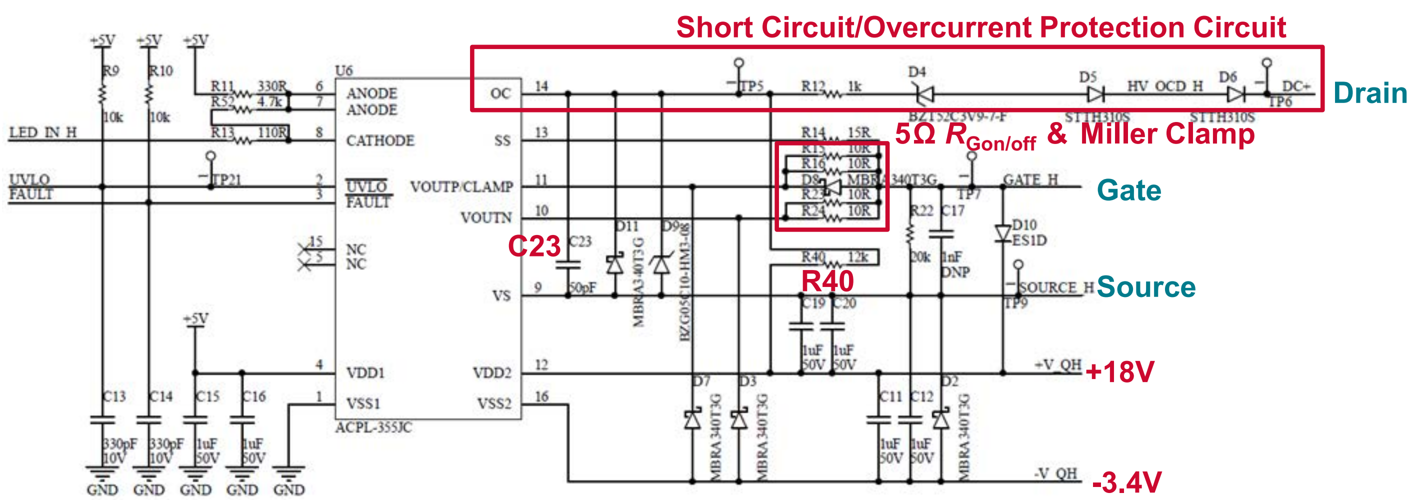
Supplier	Part Number	Package	Current Class
Infineon	FF11MR12W1M1	EasyDUAL 1B	100A
Wolfspeed	WAB300M12BM3	62 mm	300A

Infineon FF11MR12W1M1 1200V/100A SiC MOSFET Module

Figure 1 shows the driver board, which features two ACPL-355JC gate drive optocouplers for driving a SiC MOSFET module in an EasyDUAL 1B package. The board has an integrated capacitor DC bus, isolated switch mode power supplies (SMPS) for the gate drivers, and access to pulse width modulated (PWM) inputs and short circuit fault signals.

Figure 1: Infineon EasyDUAL 1B SiC MOSFET Module Driver Board

Figure 2: Infineon EasyDUAL 1B SiC MOSFET Module ACPL-355JC Gate Driving Circuitry



The isolated SMPS, which serves as the ACPL-355JC secondary-side power supply, is designed for bipolar driving of the gate at +18V and -3.4V. This is recommended for high frequency switching in the Infineon application note *AN2018-09*.

The ACPL-355JC has two outputs, VOUTP and VOUTN, which are connected to 5Ω gate resistances for positive and negative gating. The 5Ω gate resistances are realized with two parallel resistors to increase the power dissipation capability. The resulting peak current is approximately 4A, which is lower than the ACPL-355JC peak limit of 10A. In addition, the Schottky diode D8, placed between gate and VOUTP pin, is used together with the CLAMP function to shunt parasitic Miller current during the off cycle.

Using this driving circuit, the switching waveforms of the Infineon FF11MR12W1M1 are measured using the double pulse test at 600V V_{DC_BUS}. Figure 3 and Figure 4, show the turn-on and turn-off switching transients at different drain current levels (I_{DS}).

Figure 3: Infineon FF11MR12W1M1 SiC MOSFET Module Turn-On Switching Waveforms

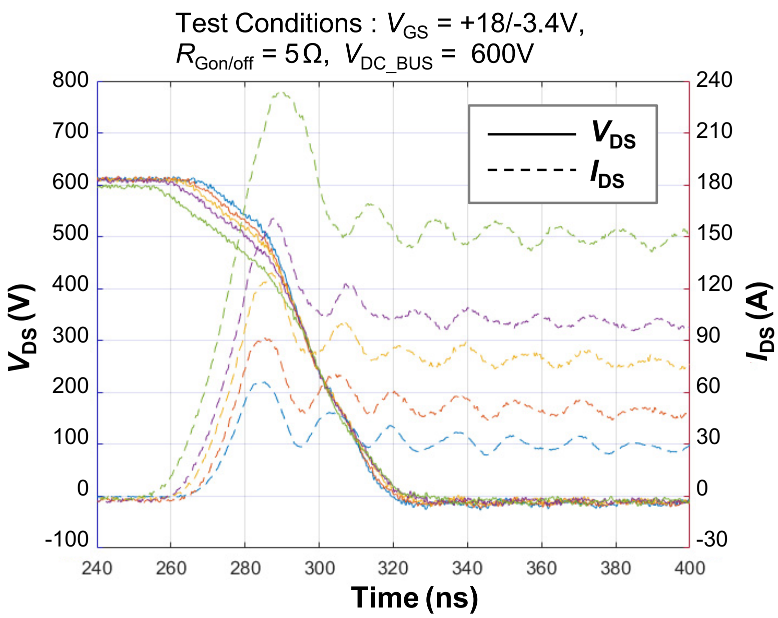
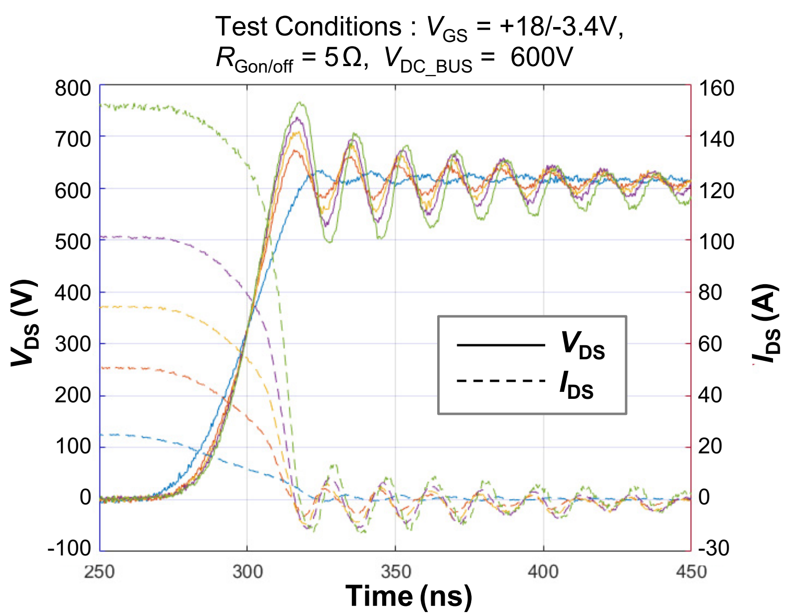


Figure 4: Infineon FF11MR12W1M1 SiC MOSFET Module Turn-off Switching Waveforms



The instantaneous power during switching and the resulting switching energy losses can be calculated as shown in Figure 5 and Figure 6. Based on the switching energies of 1.8 mJ (E_{on}) and 0.6 mJ (E_{off}) at 100A, the switching performance measured is on par with what is specified in the Infineon data sheet.

Figure 5: Infineon FF11MR12W1M1 SiC MOSFET Module Turn-On Switching Energy Losses

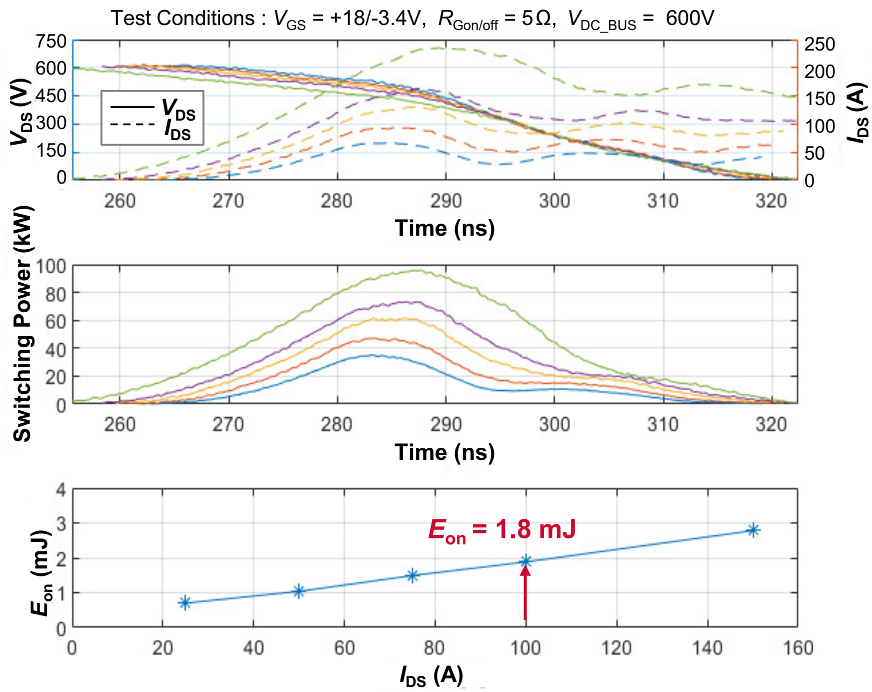
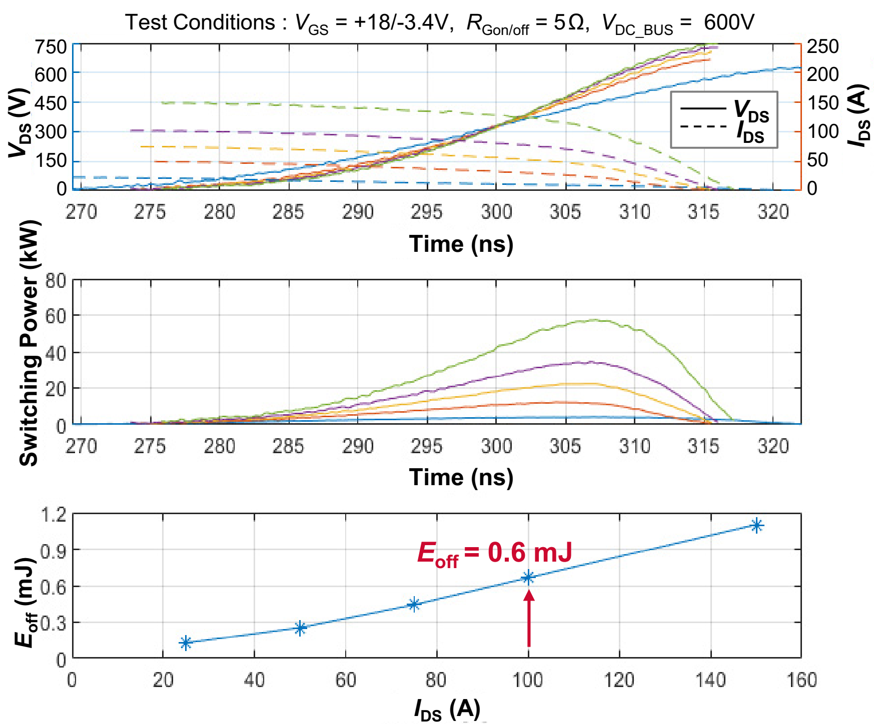


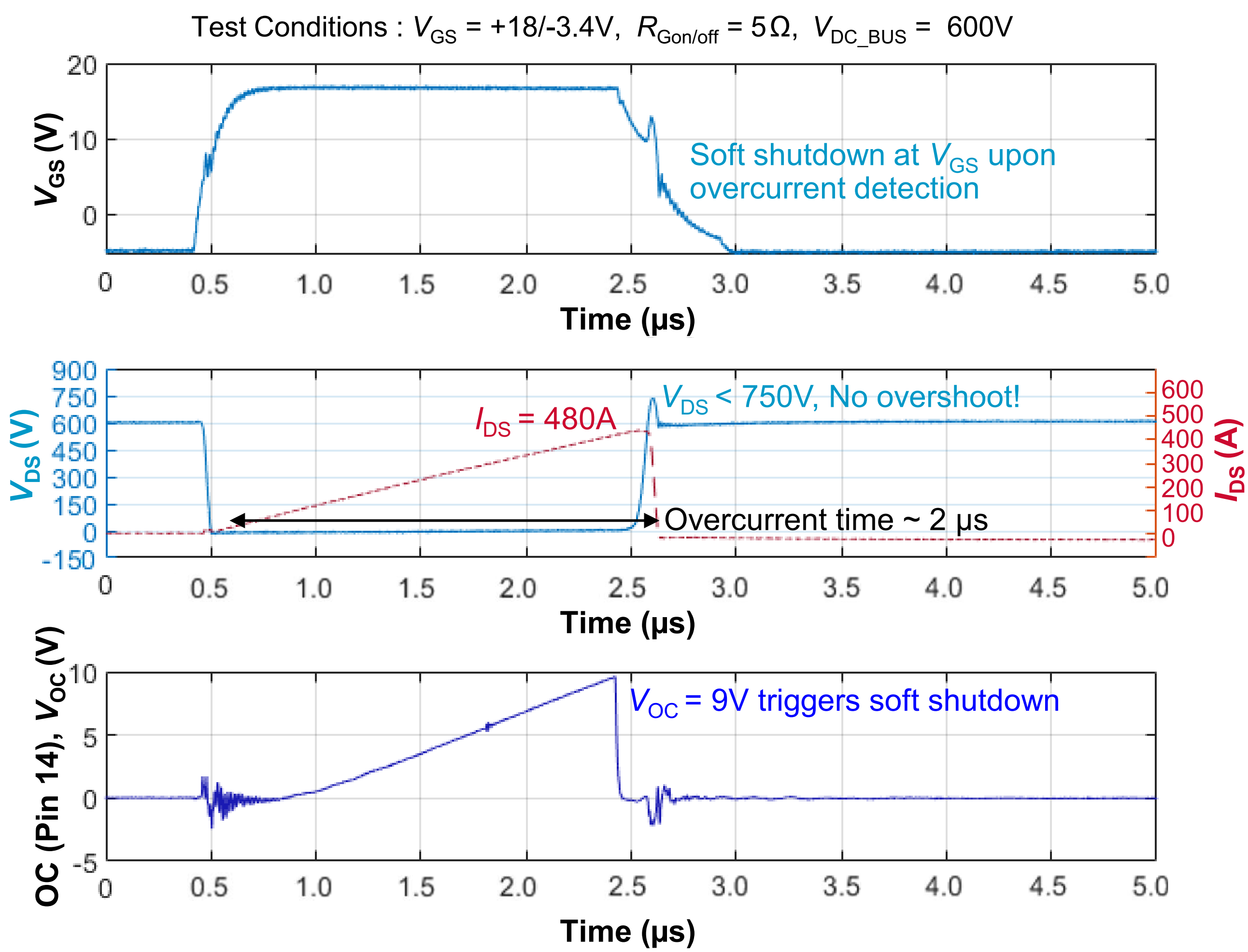
Figure 6: Infineon FF11MR12W1M1 SiC MOSFET Module Turn-Off Switching Energy Losses



In Figure 2, the ACPL-355JC and its short circuit and overcurrent protection circuit, made up of OC (Pin 14), Zener diode (D4), and high voltage blocking diodes (D5 and D6), is connected to the drain of the SiC MOSFET module. Using this connection, the ACPL-355JC senses if there is an increase in the V_{DS} over the SiC MOSFET in the event of a short circuit or overcurrent condition. Depending on the blanking time, which can be adjusted by C23 and R40, the speed of the high current fault detection can be adjusted. For example, the Infineon data sheet states that the short circuit duration should be kept under 2 µs to prevent the SiC MOSFET module from exceeding its package thermal dissipation.

Figure 7 shows the overcurrent protection waveforms done with a loop inductance of 2.5 µH. The current surged almost five times above the rated current of 100A before being brought down to 0A quickly - within 2 µs. The shutdown at V_{GS} 18V is completed softly via the ACPL-355JC softshut (SS) pin 13, to minimize the SiC MOSFET V_{DS} overshoot that governs by $V_{DS} = V_{DC\_BUS} – L_{par} \times di \div dt$ (see item 7 in Related Documents). The soft shutdown lowers the negative di/dt, which causes the overshoot.

Figure 7: Infineon FF11MR12W1M1 SiC MOSFET Module Overcurrent Protection



Wolfspeed WAB300M12BM3 1200 V/300 A SiC MOSFET Module

This driver board also features two ACPL-355JC for driving SiC MOSFETs in a 62-mm housing. The board has an isolated SMPS for gate drivers and access to PWM inputs and short circuit fault signals.

Figure 8: Wolfspeed 62-mm Half-Bridge SiC MOSFET Module Driver Board

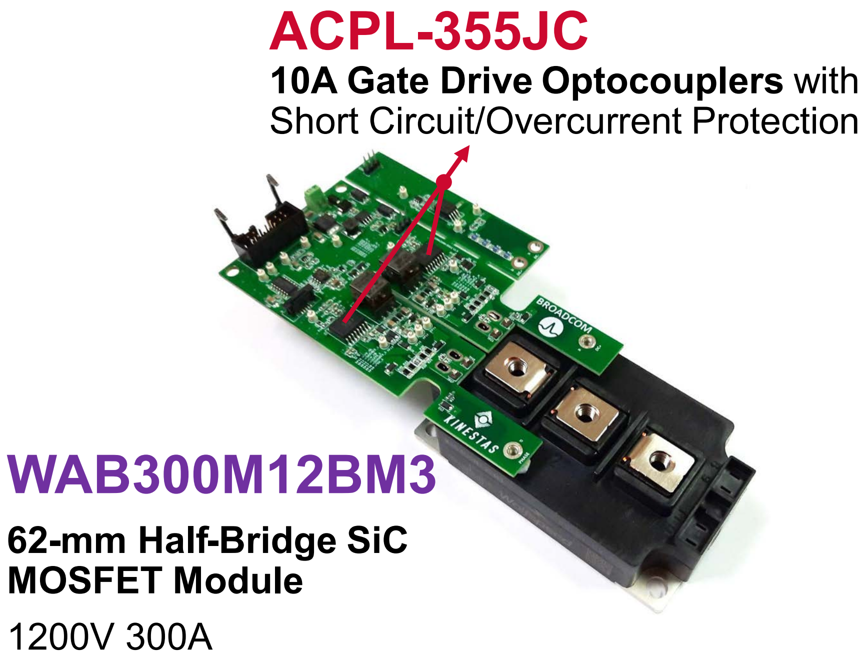
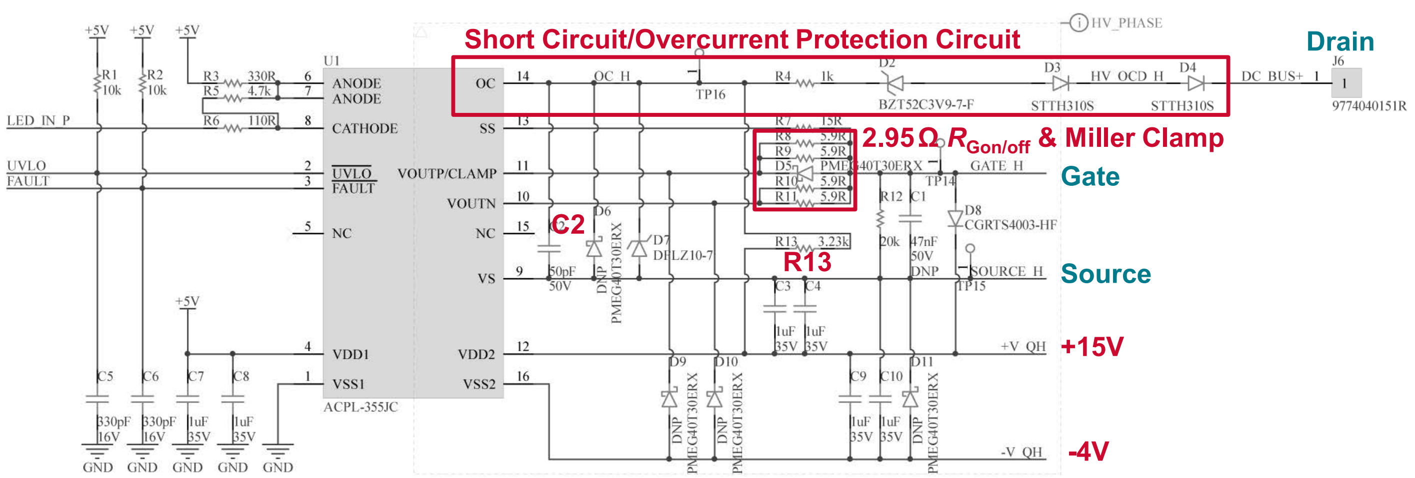


Figure 9: Wolfspeed 62-mm SiC MOSFET Module ACPL-355JC Gate Driving Circuitry



WAB300M12BM3 has a higher current rating than FF11MR12W1M1. As such, a larger peak gate current is required to overdrive the Q_G of the SiC MOSFETs. The isolated SMPS is designed for bipolar driving of the gate at +15V and -4V, as recommended in the WAB300M12BM3 data sheet. To achieve a larger gate current, 2.95Ω gate resistances are used for positive and negative gating. The 2.95Ω gate resistances are realized with two parallel 5.9Ω resistors to increase the power dissipation capacity. The resulting peak current is approximately 6A, which is lower than the 10A peak limit of ACPL-355JC.

Using this driving circuit, the switching waveforms of the Wolfspeed WAB300M12BM3 are measured using the double-pulse test at 600V V_{DC_BUS}. Figure 10 and Figure 11 show the turn-on and turn-off switching transient at different drain current levels (I_{DS}).

Figure 10: Wolfspeed WAB300M12BM3 SiC MOSFET Module Turn-On Switching Waveforms

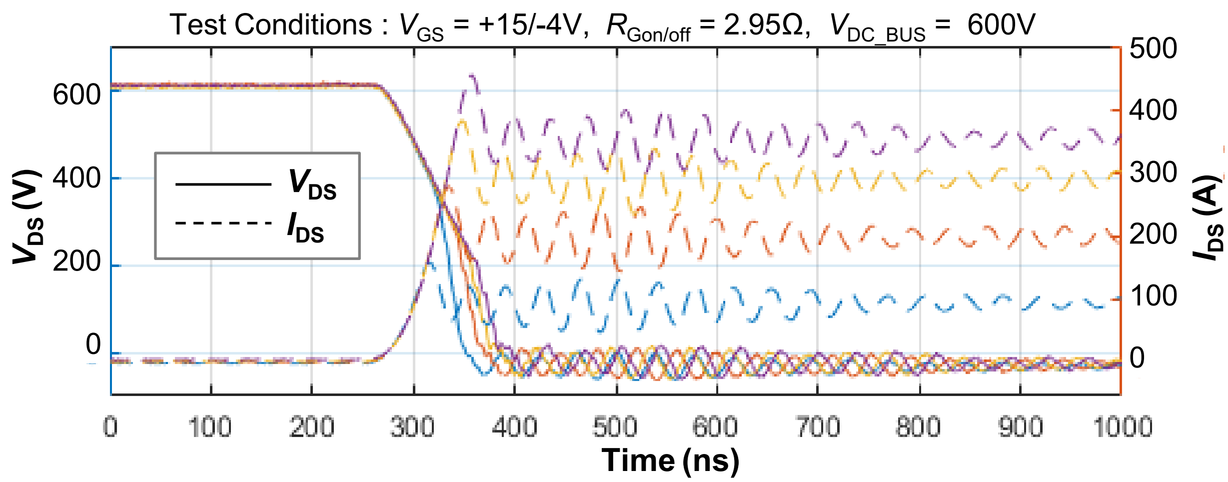
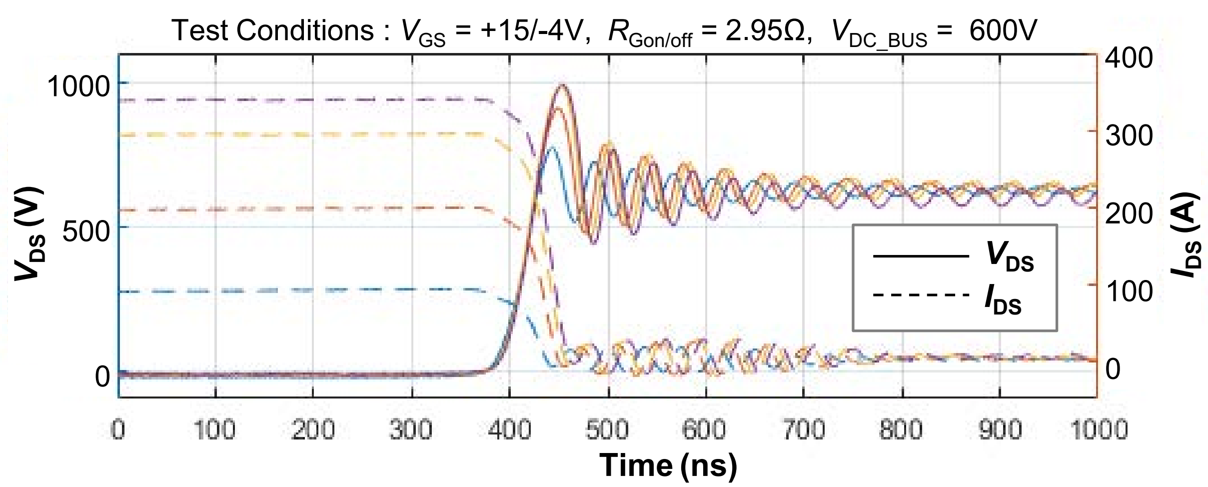


Figure 11: Wolfspeed WAB300M12BM3 SiC MOSFET Module Turn-Off Switching Waveforms



The instantaneous power during switching and the resulting switching energy losses can be calculated as shown in Figure 12 and Figure 13. Based on the switching energies of 5.8 mJ (E_{on}) and 5 mJ (E_{off}) at 300A, the switching performance measured is on par with what is specified in the Wolfspeed data sheet.

Figure 12: Wolfspeed WAB300M12BM3 SiC MOSFET Module Turn-On Switching Energy Losses

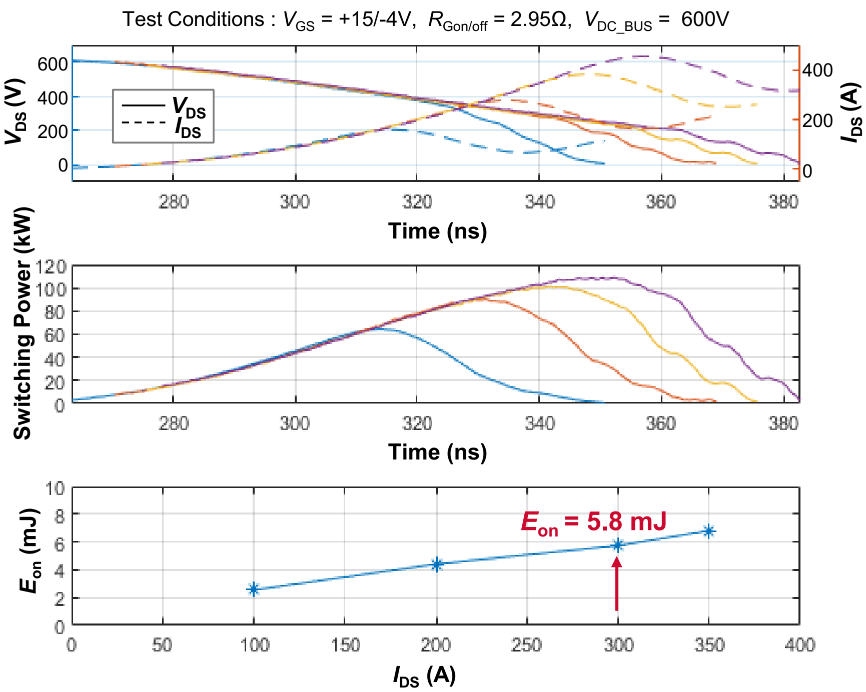
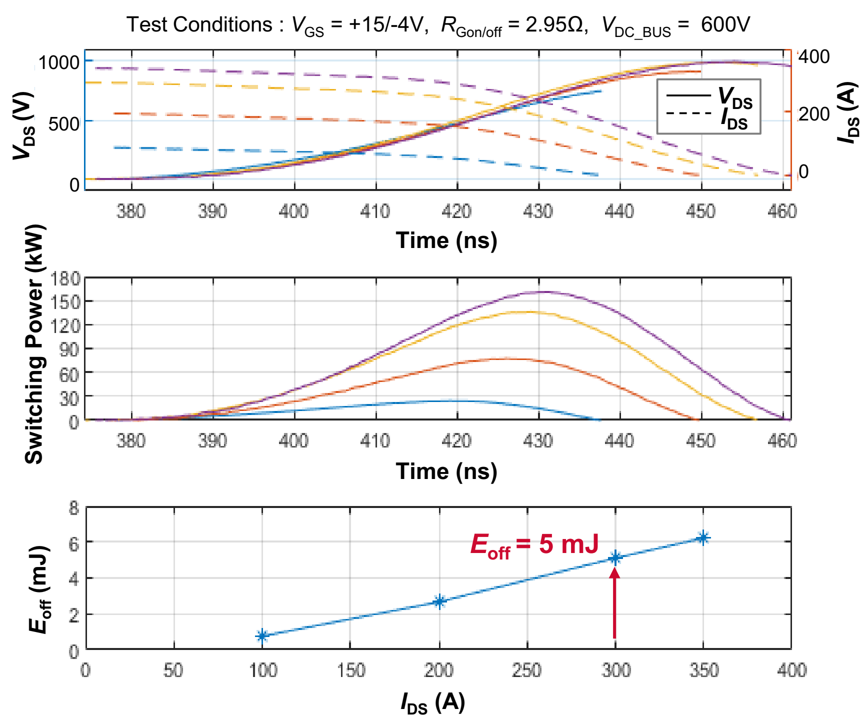


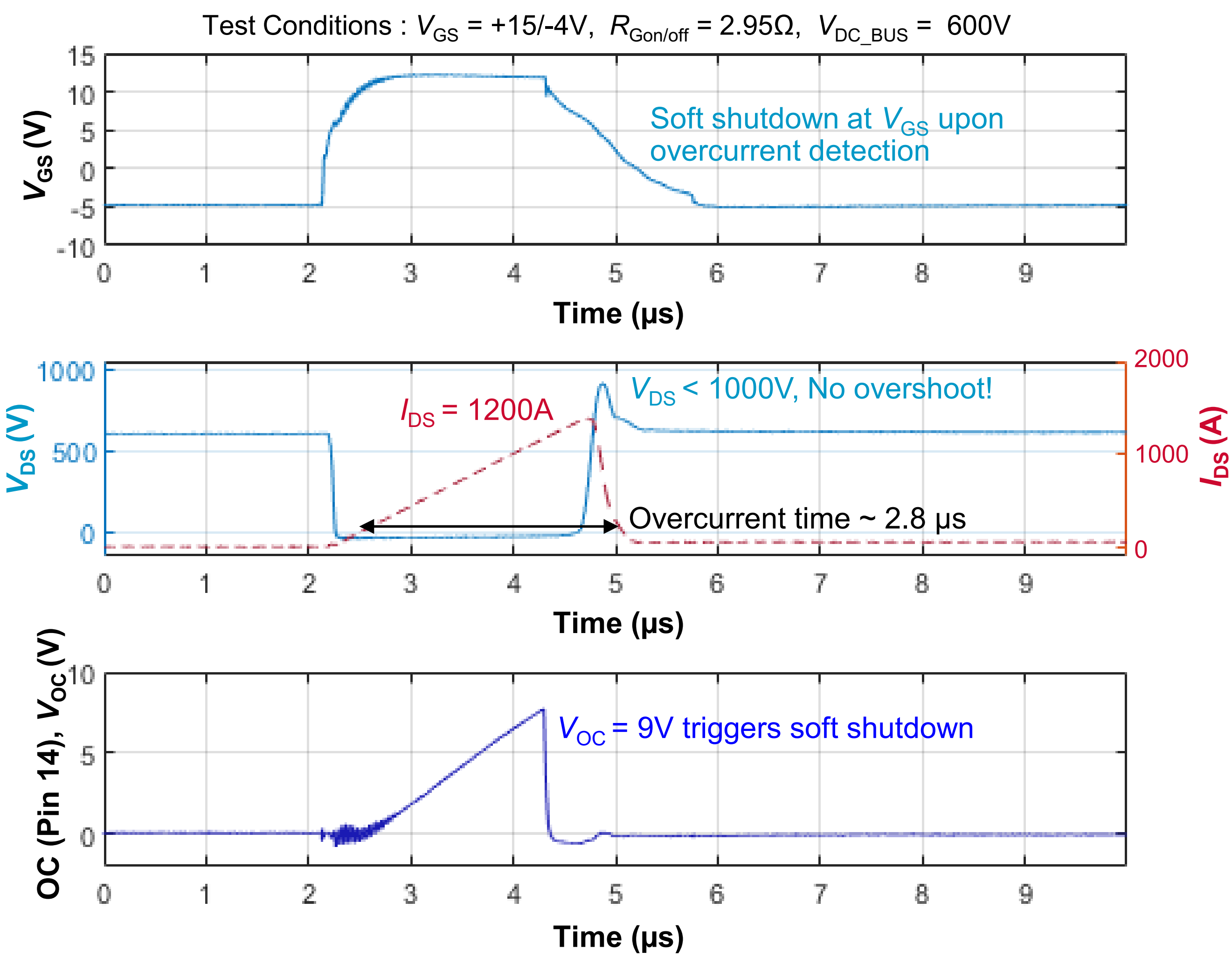
Figure 13: Wolfspeed WAB300M12BM3 SiC MOSFET Module Turn-Off Switching Energy Losses



In Figure 9, the ACPL-355JC and its short circuit and overcurrent protection circuit, made out of OC (Pin 14), Zener diode (D2), and high voltage blocking diodes (D3 and D4), is connected to the drain of the SiC MOSFET. Using this connection, the ACPL-355JC senses if there is an increase in V_{DS} over the SiC MOSFET in the event of a short circuit or overcurrent condition. Depending on the blanking time, which can be adjusted by C2 and R13, the speed of the high current fault detection can be adjusted.

Figure 14 shows the overcurrent protection waveforms done with a loop inductance of 1.5 µH. The current surged to four times above the rated current of 300A before being brought down to 0A quickly within 3 µs. The shutdown at V_{GS} 15V is completed softly via the ACPL-355JC softshut (SS) pin 13, to minimize the SiC MOSFET V_{DS} overshoot.

Figure 14: Wolfspeed WAB300M12BM3 SiC MOSFET Module Overcurrent Protection



Conclusion

This article demonstrates the driving and protection of 1200V SiC MOSFETs from two different suppliers with different current ratings and module packages. With the unification of SiC MOSFET specifications and the versatility of ACPL-355JC in terms of output gate voltage, driving current and adjustable short circuit or overcurrent detection time, it is now easy to drive and protect SiC MOSFETs.

Related Documents

1. *FF11MR12W1M1_B11 EasyDUAL™ Modul mit CoolSiC™ Trench MOSFET und PressFIT / NTC Data Sheet*, Infineon Technologies AG, V2.2 2018-07-18
2. *Guidelines for CoolSiC™ MOSFET Gate Drive Voltage Window*, Infineon Technologies AG, AN2018-09 version 1.2
3. *WAB300M12BM3 1200 V, 300 A All-Silicon Carbide THB-80 Qualified, Switching Optimized, Half-Bridge Module Data Sheet*, Cree Inc., Rev A, 2020-05-20
4. *ACPL-355JC 10A IGBT and SiC MOSFET Gate Drive Optocoupler with Integrated Overcurrent Sensing, FAULT, and UVLO Status Feedback Data Sheet*, Broadcom Inc., ACPL-355JC-DS101
5. *ACPL- 355JC DUAL 1B SiC Module EB1200-355JC Evaluation Board Reference Manual*, Broadcom Inc., ACPL-355JC-Dual1B-RM101
6. *ACPL-355JC 62-mm SiC Module EB1200M62-355JC Evaluation Board Reference Manual*, Broadcom Inc., ACPL-355JC-62mmSiC-RM100
7. *Ruggedness of High-Voltage IGBTs and Protection Solutions*, Thomas Basler, Universitätsverlag Chemnitz, 2014.