

ACPL-W346 and ACPL-339J

SiC MOSFET Gate Drive Optocouplers

Introduction

Silicon Carbide (SiC) power semiconductors are rapidly emerging into the commercial market. They deliver several benefits over conventional Silicon-based power semiconductors. SiC MOSFETs can improve overall system efficiency by more than 10% and the higher switching capability can reduce the overall system size and costs. The technical benefits coupled with lower costs have increased the fast adoption of SiC power semiconductors in applications like industrial motor control, induction heating, industrial power supplies, and renewable energy.

Broadcom[®] gate drive optocouplers are used extensively in driving silicon-based semiconductors like IGBT and power MOSFETs. Optocouplers are used to provide reinforced galvanic insulation between the control circuits from the high voltages and the power semiconductors. The ability to reject high common mode noise (CMR) will prevent erroneous driving of the power semiconductors during high frequency switching. This paper describes how the next generation of gate drive optocouplers can be used to protect and drive SiC MOSFETs.

Advantages of SiC MOSFET

Silicon carbide is a wide bandgap (3.2 eV) compound made up of silicon and carbon. Wide-bandgap SiC, besides being able to operate at high voltage, frequency and temperature, exhibits on-resistance and gate charge by an order of magnitude lower than silicon material. In an evaluation conducted by Cree Inc. to compare the second generation 1200V/20A SiC MOSFET with a silicon high speed 1200V/40A H3 IGBT using a 10 kW hard-switching interleaved Boost DC/DC converter. The results showed that even with five times the switching frequency, the SiC solution was able to achieve a maximum efficiency of 99.3% at 100 kHz, reducing losses by 18% from the best efficiency of the IGBT solution at 20 kHz.

Cree's recent release of the C2M family of MOSFETs provide engineers a wide range of competitively priced 1200V and 1700V SiC MOSFETs for a wide range of applications. Cree has been able to bring the cost down significantly while providing improved switching performance and lower $R_{ds(on)}$. Increasing the switching frequency can significantly reduce the size of the inductor. The lower conduction and switching losses allow engineers to reduce the size of the heat sink or potentially remove fans and move to passive cooling solutions. The smaller inductor and heat sink can reduce the system size significantly. Although a SiC semiconductor costs more than Si, the overall system BOM costs can be lower than Si technology by 20%.

SiC MOSFET Market and Adoption

SiC technology is now widely recognized as a reliable alternative to silicon. More than 30 companies worldwide have established SiC technology manufacturing capability with related commercial and promotional activities. Many power module and power inverter manufacturers have included SiC in their roadmaps for future products.

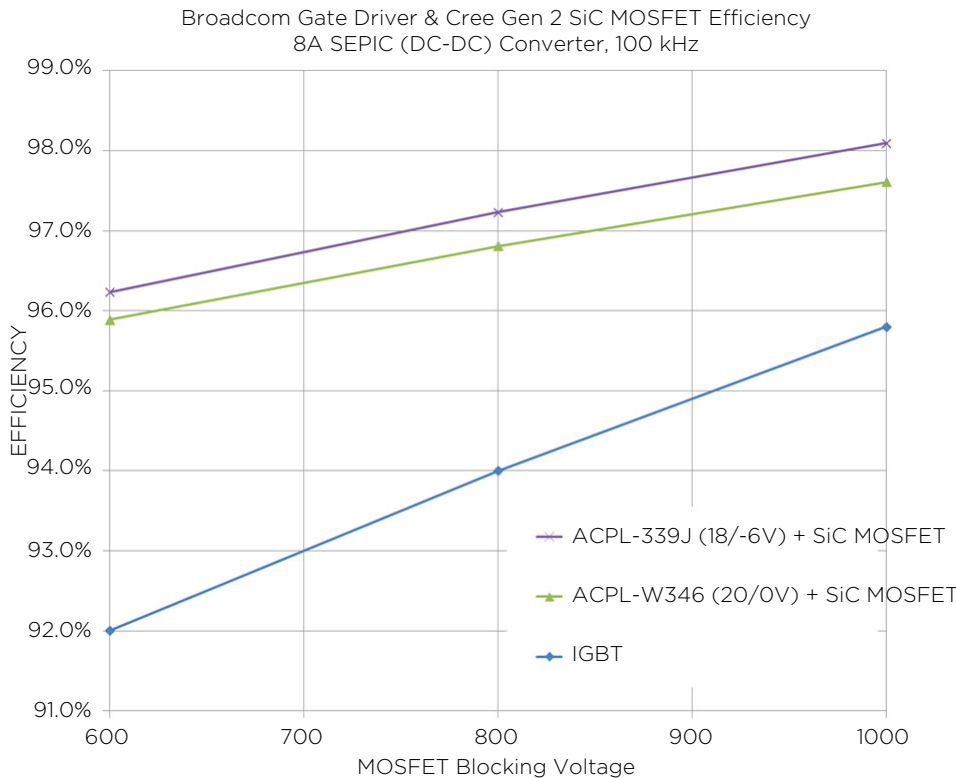
Solar inverter manufacturers and server power supplies are the earliest adopters of SiC semiconductors as efficiency is critical in their technological ranking. In 2013, Europe’s top solar inverter makers, REFU, SMA and Delta announced a new model with SiC inside. Photon magazine evaluated SMA SiC inverters and efficiency increased from 98% to 99% and inverters physical weight reduced by 30% as compared to equivalent IGBT inverter. SiC semiconductor production volume will increase due to increased availability, higher voltage variety, and lower costs. This increase results in greater adoption in applications like motor drives, railway traction industrial UPS, and even hybrid vehicles.

Broadcom gate drive optocouplers have been used extensively in driving silicon-based semiconductors like IGBT. This paper describes how the improvements in the next generation of gate drive optocouplers can also be replicated to drive and protect SiC MOSFET.

SiC MOSFET Gate Drive Optocouplers

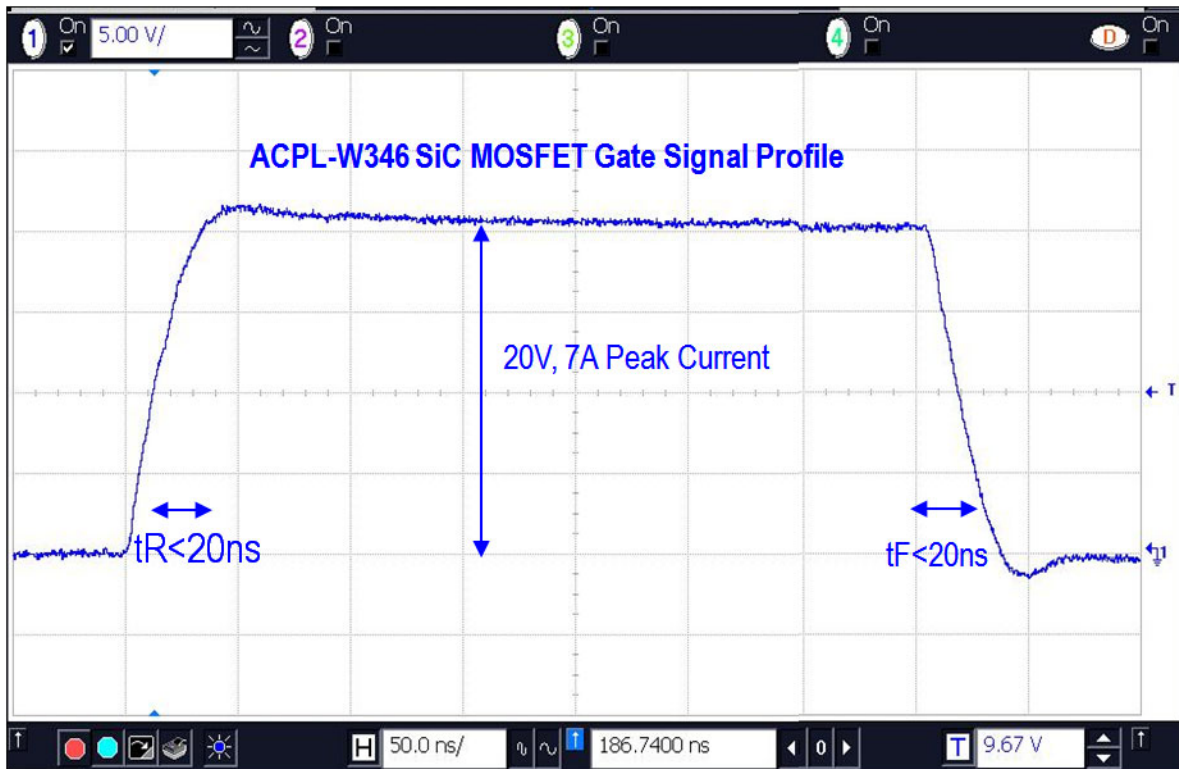
Broadcom has been working closely with the SiC market leader Cree Inc. to determine suitable gate drive optocouplers for SiC MOSFET operations. We have evaluated the gate drive optocouplers ACPL-W346 and ACPL-339J with Cree C2M SiC MOSFET operations using an 8A SEPIC DC-DC converter at 100 kHz. The gate driving capability of these two optocouplers met Cree’s efficiency requirement of 98% as indicated in the following figure.

Figure 1: Achieving High Efficiency with Broadcom Gate Drive Optocouplers and Cree C2M0080120D SiC MOSFET



To match the low switching loss of Cree SiC MOSFET operations, the gate driver must be able to deliver high output current and voltage with fast slew rate to overcome the gate capacitance of the SiC MOSFET operations. The scope capture shown in the following figure shows an ACPL-W346 gate drive optocoupler with a 20V fast rise and fall time signal profile at the gate of the SiC MOSFET operation. This fast rise and fall time signal is necessary to switch the SiC MOSFET operation efficiently.

Figure 2: ACPL-W346 SiC MOSFET Gate Signal Profile

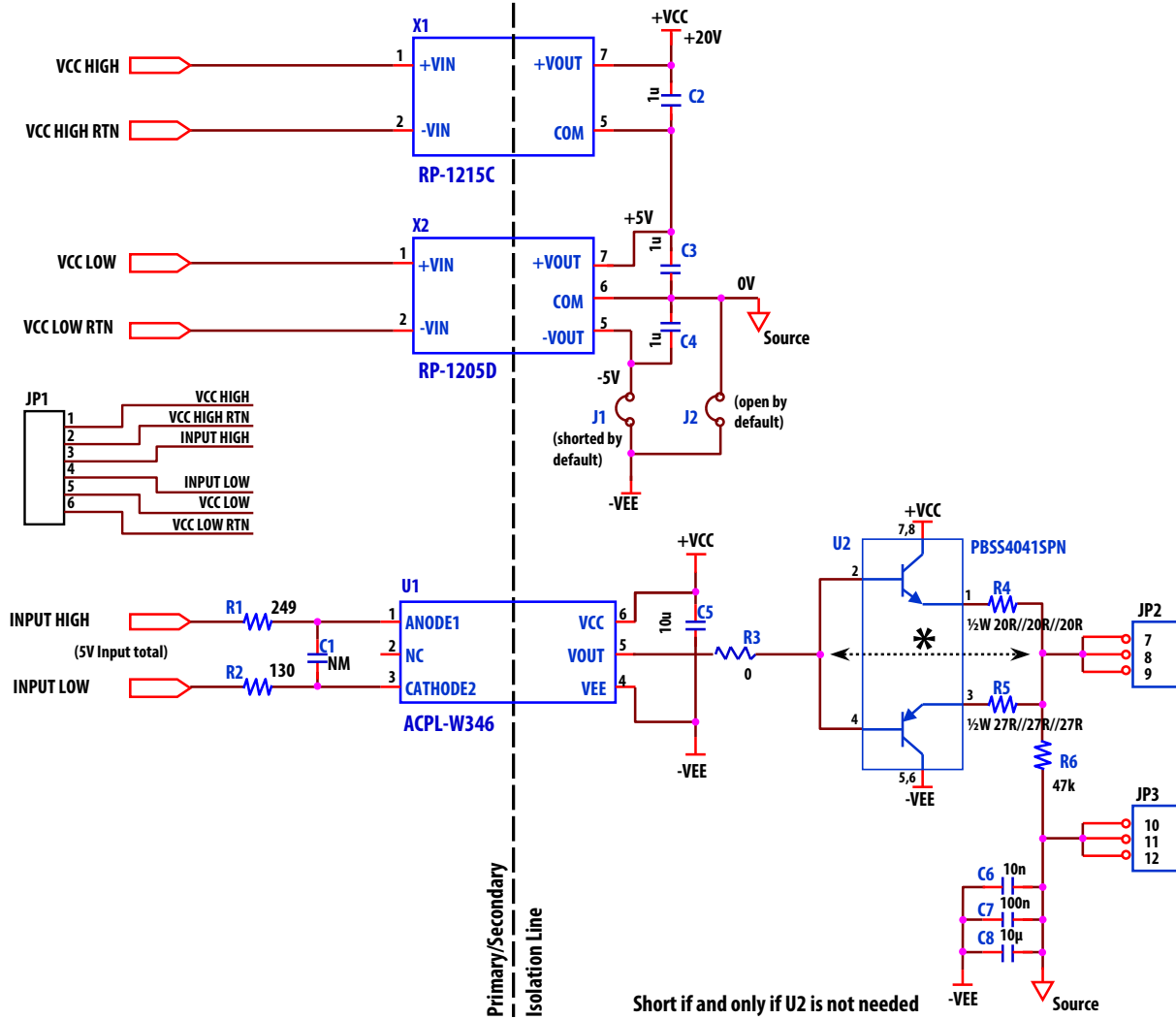


The ACPL-W346 is a basic gate driver optocoupler. It is used to isolate and drive the SiC MOSFET operations at high DC bus voltage. It has a rail-to-rail output with 2.5A maximum output current.

The unique feature of the ACPL-W346 gate drive optocoupler is the speed, which is the industry's fastest in its class. The maximum propagation delay is 120 ns, and typical rise and fall times are around 10 ns.

The very high common mode rejection (CMR) of 100 kV/ μ s is required to isolate high transient noise during the high frequency operation from causing erroneous outputs. The ACPL-W346 gate drive optocoupler when coupled with a bipolar current buffer stage provides fast switching high voltage and high driving current. This combination allows the SiC MOSFET gate drive optocoupler to turn-on and off efficiently and reliably. The older reference designs used a dedicated MOSFET driver with proprietary circuitry. Compared to the older reference designs, the ACPL-W346 gate drive optocoupler and the generic off the shelf bipolar current buffer offer an easy to implement and cheap gate drive solution. The following figure shows the ACPL-W346 and Cree SiC MOSFET reference design.

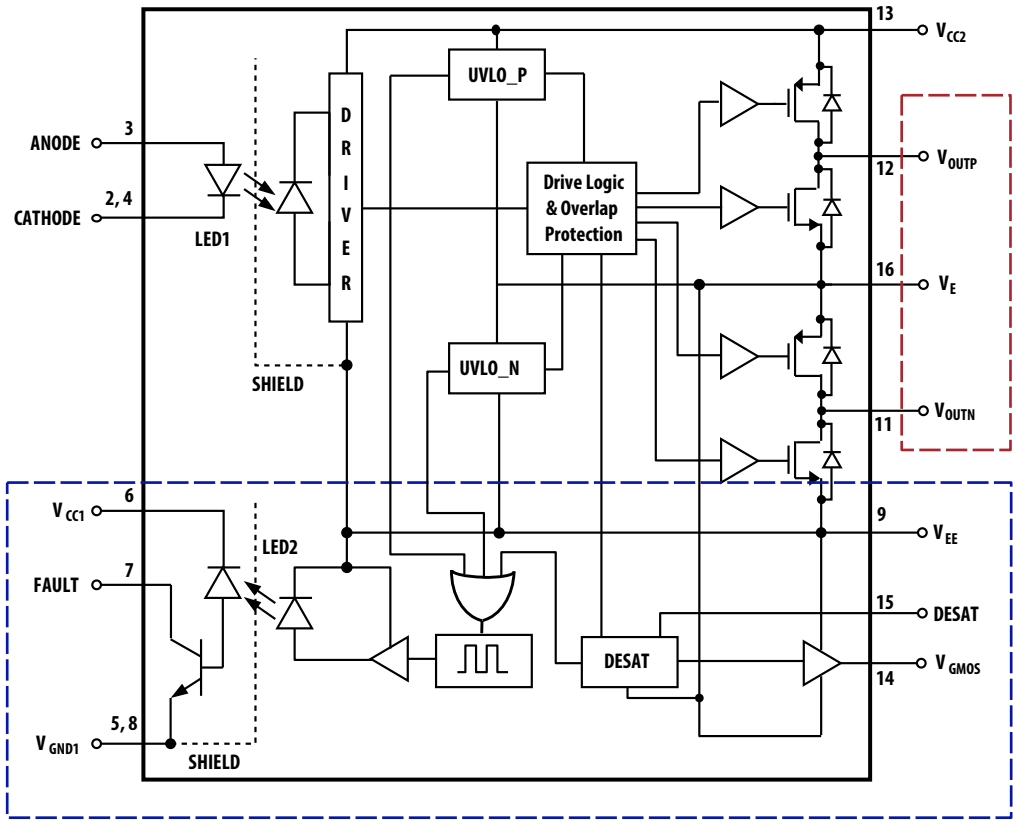
Figure 3: ACPL-W346 and Cree SiC MOSFET Reference Design



Driving and Protecting SiC MOSFET

The ACPL-339J is a “smart” gate drive optocoupler that can isolate, drive, and protect SiC MOSFET operations in a single chip solution. The following figure shows the integrated SiC MOSFET short circuit detection and faults feedback features are highlighted in *blue*.

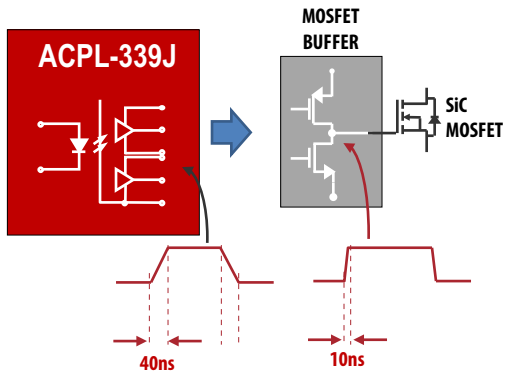
Figure 4: Functional Diagram of the ACPL-339J Gate Drive Optocoupler



The area highlighted red shows the ACPL-339J gate drive optocoupler's dual-output, which is industry's first, uniquely designed to support the MOSFET buffer. The device has a minimum output peak current of 1A optimized for driving both high-side and low-side MOSFET buffer stages. It features an internal active timing control circuitry which prevents cross conduction and minimizes switching losses in the MOSFET buffer stage.

The main reason for using MOSFET buffers (which are made PMOS and NMOS) is because they are voltage controlled devices. The output of the MOSFET is able to switch very fast once its input threshold voltage (typically 1V) is crossed. In this way, the MOSFET buffer's level switching speed is independent of the previous gate drive optocoupler stage's level switching speed as shown in the following figure.

Figure 5: Achieving Fast Switching Time with MOSFET Buffer



The scope capture in the following figure shows the ACPL-339J gate drive optocoupler with a bi-directional fast rise and fall time signal profile at the gate of the SiC MOSFET. The bi-directional fast rise and fall time signal is necessary to switch the SiC MOSFET efficiently.

Figure 6: ACPL-339J and MOSFET Buffer SiC MOSFET Gate Signal Profile

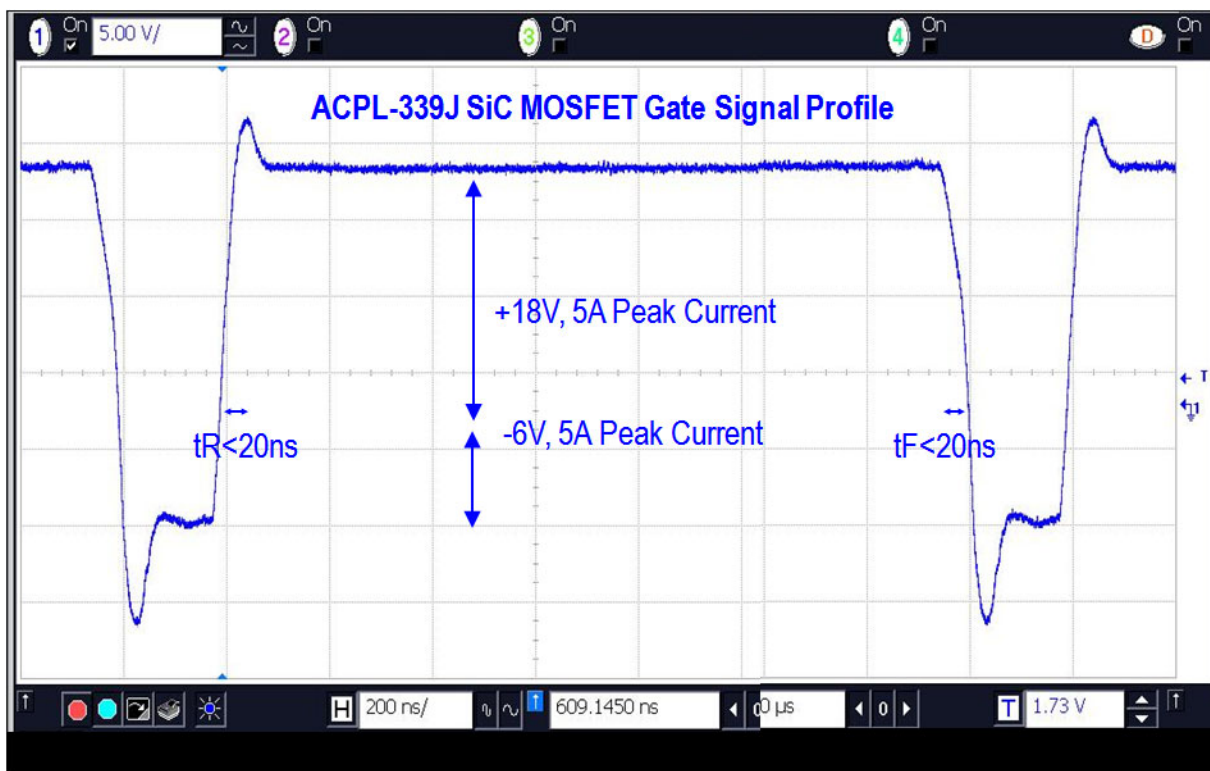
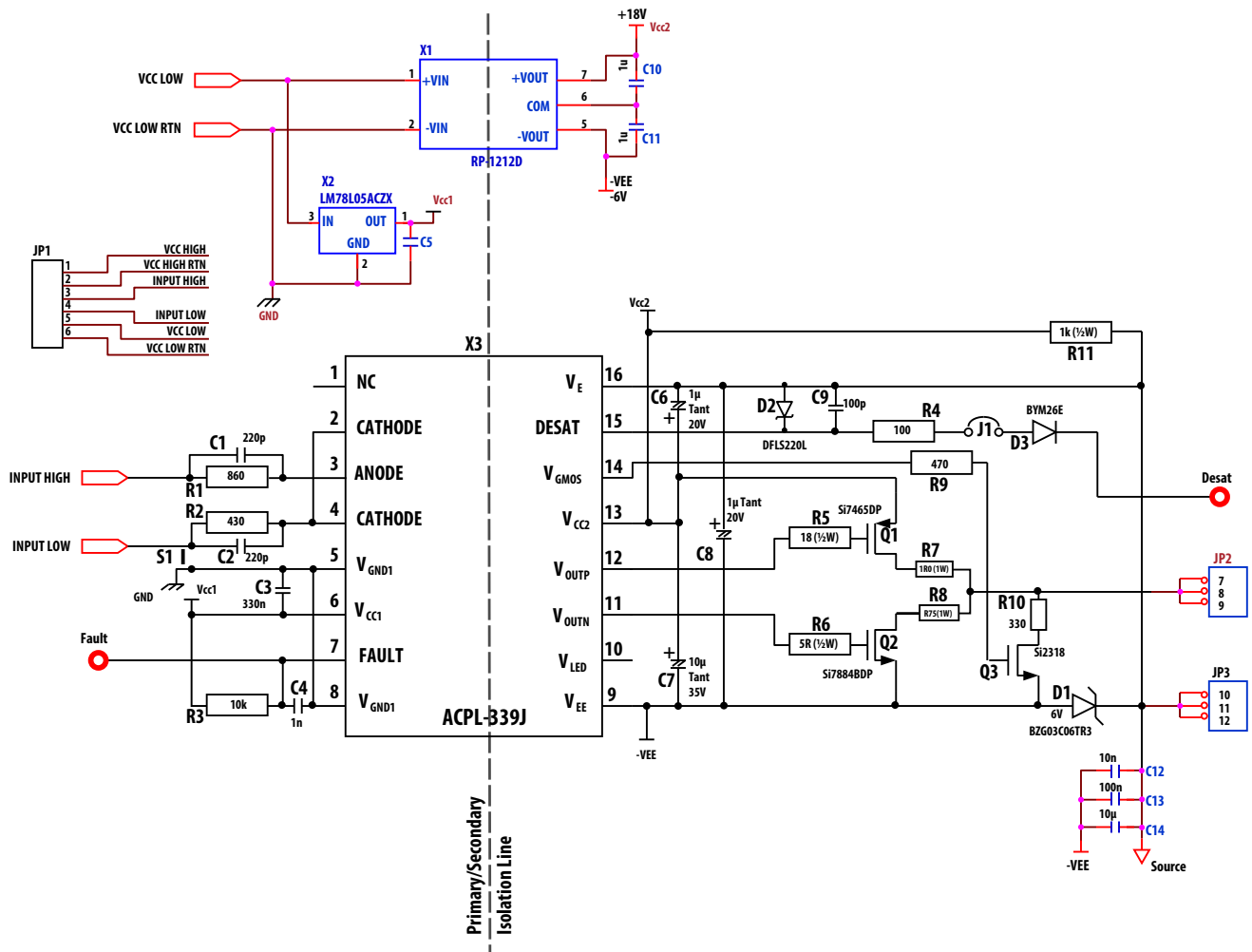


Figure 7: ACPL-339J and Cree SiC MOSFET Reference Design

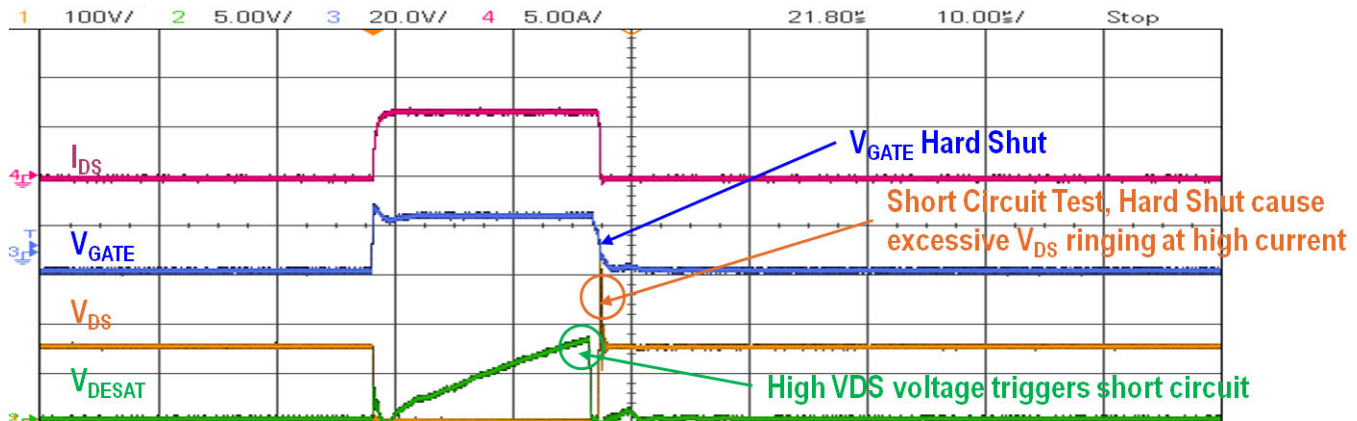


To execute the short circuit protection, the drain-source voltage of the SiC MOSFET is monitored by the ACPL-339J gate drive optocoupler during normal operation. When a short circuit occurs, high current flows through the SiC MOSFET and causes drain source voltage to increase rapidly. Once it crosses the ACPL-339J gate drive optocoupler’s threshold of 8V, a short circuit fault is registered and soft shutdown is triggered. The ACPL-339J gate drive optocoupler’s V_{GMOS} pin will switch on an external transistor to slowly discharge the gate of the SiC MOSFET to achieve the soft shut effect. The entire short circuit protection is completed by reporting the FAULT through the insulated feedback path to the controller.

If the SiC MOSFET is shutdown abruptly during a short circuit, a high overload current combined with any parasitic induced current can result in high overshoot voltage. This high overshoot voltage could exceed the SiC MOSFET breakdown voltage. To minimize such damaging overshoot voltage, the ACPL-339J gate drive optocoupler does a soft shutdown when a short circuit is detected. The SiC MOSFET gate voltage is slowly reduced to a low level off-state. The rate of soft shutdown can be adjusted through external MOSFET and resistance (see section Q3 and R10 in Figure 7) to reduce the overshoot voltage level.

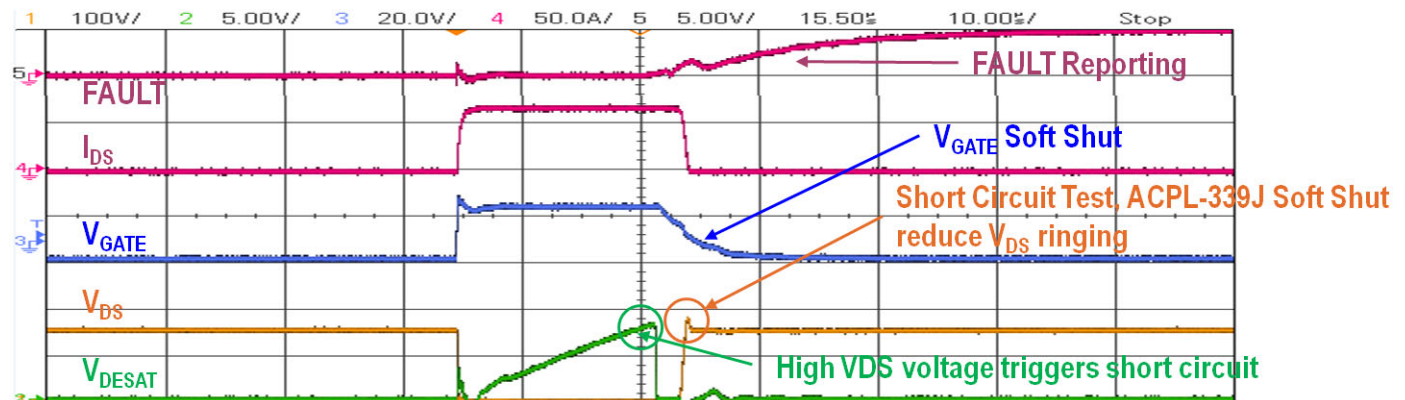
The following figure shows the high overshoot and ringing voltage across the drain-source of the SiC MOSFET when a hard (or abrupt) shutdown occurs during a short circuit. (A low BUS voltage is used to prevent excessive damage to the SiC MOSFET during the experiment.)

Figure 8: Hard Shutdown Causing Excessive VDS Ringing During High Current Short Circuit



The following figure shows how the high overshoot voltage can be suppressed when the short circuit detection is triggered and gate is shutdown “softly”.

Figure 9: Soft Shutdown Reduces VDS Ringing During High Current Short Circuit



Related Documents

- Dr Scott Allen, “Silicon Carbide MOSFETs for High Powered Modules,” Cree Inc., March 19, 2013.
- Jimmy Liu, Kin Lap Wong, Scott Allen, John Mookken, “Performance Evaluations of Hard-Switching Interleaved DC/DC Boost Converter with New Generation Silicon Carbide MOSFETs,” Cree Inc.
- “SiC Market 2013,” I-Micronews, May 25 2013.
- Alexandre AVRON, “Overview of Wide Band Gap semiconductors in power electronics,” YOLE Développement, April 17, 2013.
- “ACPL-P346 and ACPL-W346 2.5 Amp Output Current Power & SiC MOSFET Gate Drive Optocoupler with Rail-to-Rail Output Voltage in Stretched SO6 Package,” Broadcom, AV02-4078EN.
- “ACPL-339J Dual-Output Gate Drive Optocoupler Interface with Integrated DESAT Detection, FAULT and UVLO Status Feedback,” Broadcom, AV02-3784EN.

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