



SKYWORKS®

How to Solve the Three Most Common SiC Issues in Electric Vehicles

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Introduction

Electrification is transforming the automotive industry, forcing designers who once worried about fuel economy to now think about charge times, range, and power converter efficiency. Electric vehicles (EVs) represent a radical shift from the internal combustion engines (ICE) that have dominated vehicle sales for nearly a century. Manufacturers are hunting for disruptive technology to make their EVs stand out. Silicon carbide (SiC) is positioned to be one of those technologies. When used properly, SiC FETs significantly improve the efficiency of the high voltage power conversion systems. However, like any new technology, SiC has its own nuances. Skyworks latest gate driver technology solves three of the most common SiC FET design issues with industry leading immunity to common mode transients, parasitic turn on prevention, and protection against shoot through.



SiC and EVs, like Chocolate and Vanilla

The advantages of silicon carbide lies in its electrons. In order to make a material conduct, electrons must be moved from the valence band to the conduction band. SiC is a “wide bandgap” material, where the energy required to move electrons to the conduction band is much greater than other materials like silicon. This allows SiC to have a much higher breakdown voltage for a given die size than silicon. The small die size yields other benefits, such as lower on-resistance (RDSON) and faster switching speeds, which are well suited to solve some of the biggest challenges with EVs.

EVs today have three big challenges: charge time, range, and cost. One way to address these challenges is to increase the DC link voltage to 800 V or even 1000 V. This lowers the current, which in turn reduces cable weight. However, these higher voltages come at a cost, requiring switching devices with higher breakdown voltages, often up to 1200 V. Reaching this breakdown voltage and maintaining high current capability becomes impractical for standard silicon MOSFETs, as the die size becomes prohibitive. Bipolar gate transistors (IGBTs), sacrifice switching speed to solve the die size issue. The unique properties of

SiC allow unipolar FET devices, with much smaller die sizes, to achieve or exceed the current and breakdown voltage ratings of traditional IGBTs and achieve high switching speeds. Because SiC FETs switch at much higher speeds than IGBTs, they improve power conversion efficiency which addresses additional EV challenges.

At first glance, improving EV range and reducing cost seem opposed to one another. Increasing the size of the battery pack certainly improves the range of the EV; however it adds size, weight, and cost. By using SiC FETs, designers can greatly improve the efficiency of the vehicle, which allows for longer range on smaller batteries and reduces the overall vehicle cost. SiC FETs accomplish this by allowing designers to increase the switching frequency, which increases efficiency and at the same time reduces the size of the magnetic components. In addition, highly efficient converters need smaller heat sinks and cooling systems, further reducing vehicle weight and cost. By dissipating very little energy in each charge/discharge cycle, SiC FETs make these high switching frequencies practical.



Table 1 – Comparison of Skyworks’ automotive grade isolation products to industrial isolation products.

Additional efficiency improvements from SiC come from high temperature performance and efficiency across the full range rated current. The material properties of SiC, combined with smaller die sizes, allow higher temperature operation with lower losses than IGBTs. As shown in Figure 1, the rated RDSON for SiC FETs varies little across temperature, which is key in EV systems that routinely operate at high temperatures. In addition, IGBTs are typically optimized for a specified current; below this current their conduction losses increase significantly. SiC FETs, however, maintain their efficiency across their current rating. Many automotive systems, like the traction inverter, operate at different load points for long periods of time, such as driving on a residential street versus driving on the highway. These benefits of silicon carbide help improve vehicle range, while decreasing cost. However, adopting SiC technology has several challenges, three of the most common can be address through selecting the correct isolated gate driver.

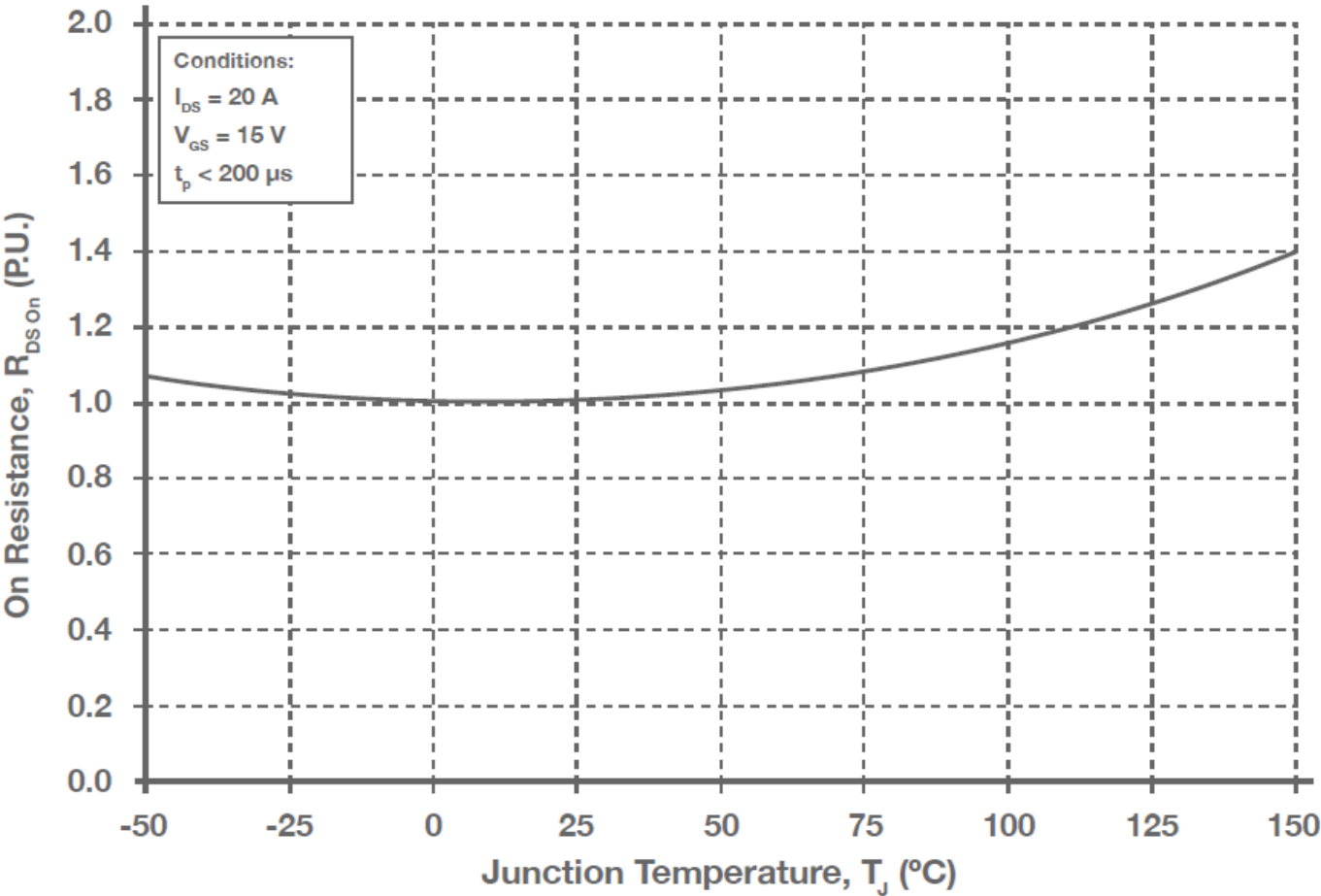


Figure 1 – Cree Wolfspeed E3M0065090D Automotive SiC FET $R_{DS(on)}$ change with temperature.

Problem 1: Handling High Switching Speeds and High Working Voltages

Most high voltage automotive systems require isolation devices to separate the low voltage controller from the high voltage portion of the system. The performance and specifications of the isolation devices, in particular the isolated gate driver, have a tremendous impact on a SiC design operating correctly. The high switching frequencies in most SiC FET designs subject the isolation devices to very fast transients. Specifically, the isolated gate driver seems many fast transients because it is driving the SiC FET. A gate driver with a common mode transient immunity (CMTI) of at least 100 kV/μs is needed to withstand these transients. Furthermore, the driver’s propagation delay and channel to channel skew generally need to be below 10 ns for the design to be stable at such high speeds. Finally, the isolated gate driver must also have sufficient maximum insulation working voltage (VIORM) to withstand the DC link bus voltages. The correct isolation device quietly eliminates many of the challenges from the higher switching speeds and higher voltages used in SiC designs. Table 1 summarizes the various features and performance of different Skyworks isolated gate drivers.

Isolated Gate Driver Family	Isolation Rating	Maximum Working Voltage	CMTI	Miller Clamp	Desaturation Detection	Integrated DC-DC Controller
Si872x	2.5 kV RMS	630 V	200 kV/μs	No	No	No
Si823Hx	5 kV RMS	891 V	125 kV/μs	No	No	No
Si828x	5 kV RMS	891 V	125 kV/μs	Yes	Yes	Optional

Table 1 Skyworks Isolated Gate Drivers

Problem 2: Miller Parasitic Turn On

Most power conversion systems use a half bridge or full bridge configuration, in which the switching devices are schematically stacked on top of one another, with one device pulling the load high and the other pulling the load low. In this configuration, the switching device on the lower half of the bridge experiences a very fast change in voltage on the drain when the upper device turns on. This induces a current in the gate to drain parasitic capacitance, which can discharge through the gate and turn on the lower device. This is known as “Miller parasitic turn on” and causes shoot through which will quickly damage a SiC FET. As shown in Figure 2, the integrated Miller clamp on the [Si828x](#) isolated gate driver discharges the gate to drain parasitic capacitance when it reaches a pre-configured threshold. This clamp prevents Miller turn on and damage to the SiC FET, even at high switching frequencies.

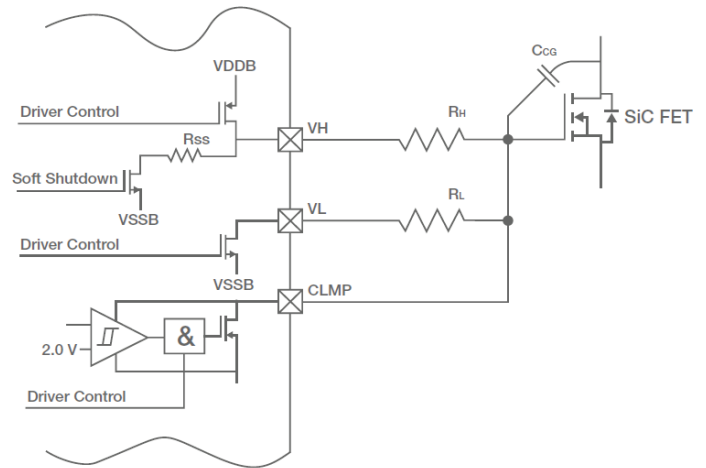


Figure 2 – Integrated Miller clamp on Skyworks’ Si828x isolated gate driver.

Problem 3: Desaturation

EV systems constantly experience changing load conditions. Even with a robust design, abnormal load conditions may cause the switching device to fall out of saturation and be damaged. As shown in Figure 3, the integrated desaturation detection circuit on the Si828x is able to turn off the SiC FET in under 1 μ s if the SiC FET starts to desaturate. The desaturation circuit detects the voltage across the switching device, and if it rises above a preconfigured threshold, the gate driver shuts the switching device off. In order to limit the induced shutdown voltage, the Si828x includes a soft shutdown circuit to gracefully turn off the SiC FET. The fast turn off speed and shutdown circuit ensure the SiC FET and system are protected.

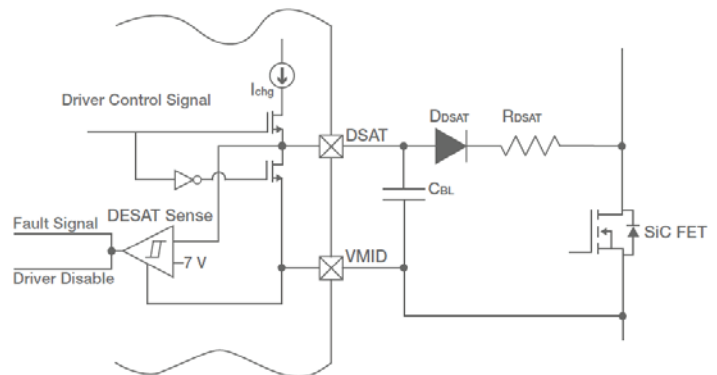


Figure 3 – Integrated desaturation circuit on Skyworks’ Si828x isolated gate driver.

Another problem that causes challenges for SiC FET designs is the need for a negative gate voltage. Many SiC FETs require a negative gate voltage to work in conjunction with the Miller clamp to secure the SiC FET in the off state. The methods to generate the negative voltage rail are best described in the context of generating an isolated, low voltage power rail needed to power the isolation devices.

Silicon carbide technology promises to drive the EV industry forward through making the high voltage power systems more efficient. The fast switching speeds, high breakdown voltages, and more linear thermal performance make SiC FETs a clear choice for EVs. As the market for EVs becomes mainstream, automotive manufacturers will rely on SiC to improve range, reduce weight, and lower vehicle costs. Skyworks automotive digital isolators and isolated gate drivers will be at the heart of these advances in EV technology.

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