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PURPOSE

This application note provides design guidance for properly selecting gate-source voltages for Microchip's SiC MOSFET products, along with related device performance and behavior. This note applies to Microchip part numbers of the type MSCXXXSMAXXX.

SPECIFYING GATE DRIVE VOLTAGES FOR SIC MOSFETS

The way gate drive voltages are specified on data sheets varies by manufacturer, but most will have some form of Table 1. We begin by defining some terms:

- VGS is the applied voltage between the MOSFET's gate and source terminals.
- VGSon is the steady-state VGS applied to turn the MOSFET on.
- VGSoff is the steady-state VGS applied to turn the MOSFET off.
- VGSmax is the manufacturer's maximum allowed steady-state VGS, shown for both negative and positive extremes.
- VGS,OP is the manufacturer's recommended steady state values for VGSon and VGSoff.

Some data sheets do not specify VGSon and VGSoff; similar to silicon MOSFETs, different applications may call for different optimal values.

MICROCHIP RECOMMENDATIONS

For optimal device performance and system stability, Microchip SiC MOSFETs are best driven using VGSon = +20V and VGSoff = -5V. Microchip SiC MOSFETs still perform well at lower absolute values of VGSon and VGSoff, but as with any design, the additional losses associated with sub-optimal drive conditions should be analyzed and understood. To this end, the reasoning behind optimal VGSon and VGSoff are different, and the expected trade-offs for each case are described in the following sections.

ON STATE GATE DRIVE VOLTAGE, VGSon

Driving Microchip SiC MOSFETs with a lower VGSon will exhibit:

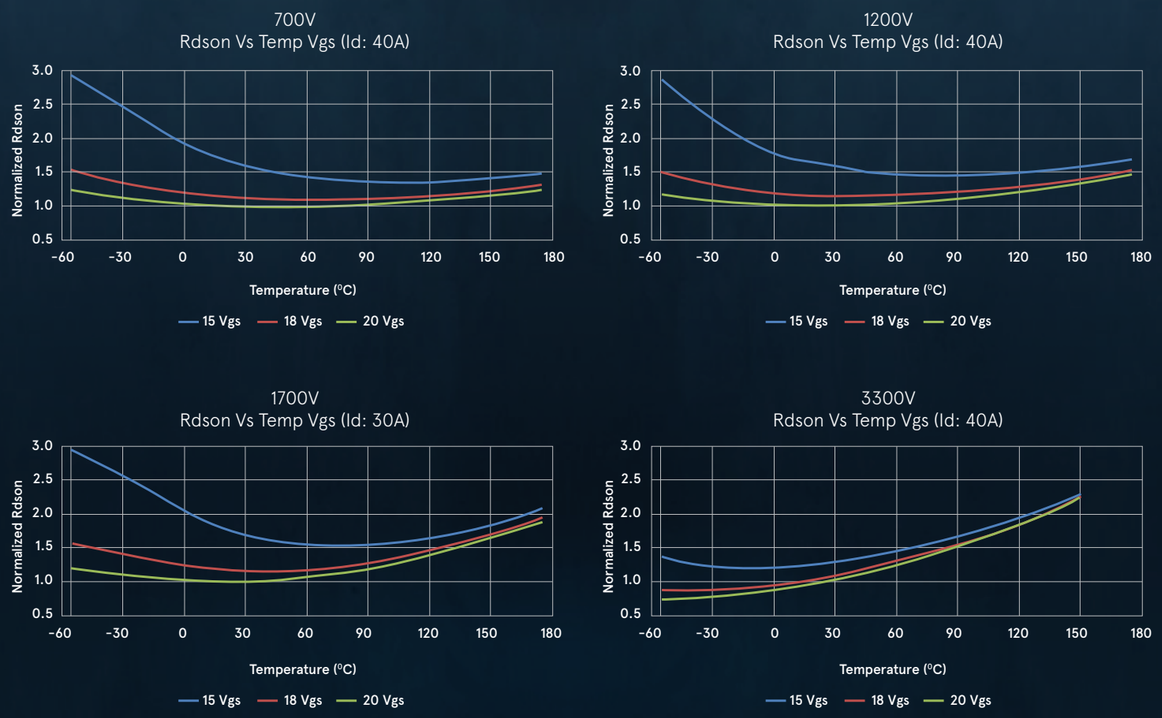
- Increased on-state resistance, resulting in higher conduction loss
- Reduced peak (saturation) current capability
- Longer short circuit withstand time
- Extended gate oxide lifetime
- Increased switching loss under the same gate resistance.

ON STATE RESISTANCE, RDSon

The four curves in Figure 1 show how the normalized RDSon (normalized to RDSon at 25°C and 20V gate voltage) increases with junction temperature, Tj. Data is shown for Microchip's largest SiC MOSFET die at each of four voltage classes: 700V, 15 mΩ; 1200V, 17 mΩ; 1700V, 35 mΩ; and 3300V, 25 mΩ. Some general observations include:

- The increase of RDSon for SiC MOSFETs with temperature is much lower than that of silicon MOSFETs.
- Microchip SiC MOSFETs show a lower increase of RDSon at elevated Tj than other SiC MOSFET suppliers.
- At VGSon = 18V, RDSon shows a minor shift which gets even smaller at higher Tj.
- At VGSon = 15V, the increase of RDSon is more substantial, particularly at lower Tj.

Figure 1: Temperature Dependency of RDSon Under Different Gate Voltage of Different Voltage Families.



DESIGNING FOR VGSon < 20V

Due to SiC's wide band gap, a higher electric field is required to invert the semiconductor of a MOS-gated transistor than is required for silicon. The electric field can be increased either by raising the applied VGSon or by reducing the thickness of the gate oxide. Raising VGSon may call for a new gate driver design, while reducing the oxide thickness could make the device more susceptible to failure. A third way to get more current is to increase die size, but this increases cost. Clearly the best technical and commercial choice is a new gate driver design, but what compromises are made if the ideal VGSon = 20V is impossible to achieve?

EFFECT ON RDSon

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EFFECT ON RDSon

When driving at lower values of VGSon, designers should analyze how RDSon changes across the junction temperature range of interest. If the RDSon across relevant Tj is consistently within a close range of the RDSon at VGSon = 20V, the final design can accommodate these small differences and be extremely robust. For Microchip SiC MOSFETs, production measurement of RDSon shows VGSon = 20V is an excellent predictor of RDSon at VGSon = 18V; in the case of a 1200V SiC MOSFET at Tj = 175°C, RDSon at VGS = 18V is only 4% higher than RDSon at VGS = 20V.

In contrast, the comparison of RDSon at VGSon = 20V and VGSon = 15V requires careful consideration. The variance is approximately 4x higher for VGSon = 15V and dependent upon device threshold voltage, VGS(th). For this reason, Microchip does not recommend driving SiC MOSFETs of type MSCXXXSMAXXX at VGSon = 15V. If they must be driven with 15V, a sufficient design margin for RDSon should be considered. Contact your local Microchip sales office for support.

PARALLEL-CONNECTED SIC MOSFETS

There is a final point to be made about parallel-connected SiC MOSFETs and VGSon < 20V. One can observe from the charts that the temperature coefficient of RDSon may not be positive across the entire range of relevant Tj. In an extreme example, consider the 700V SiC MOSFET at VGSon = 15V. This gate drive situation results in a SiC MOSFET with a negative temperature coefficient up to Tj = 80-100°C. Ensuring that paralleled devices will evenly share current is a risk against which the design should be safeguarded. However, much as in the previous paragraphs, using VGSon = 18V is the simplest solution and is well-suited for most applications.

PEAK CURRENT CAPABILITY

When driving with a lower VGSon, the MOSFET channel is not fully enhanced, and the maximum current is reduced.

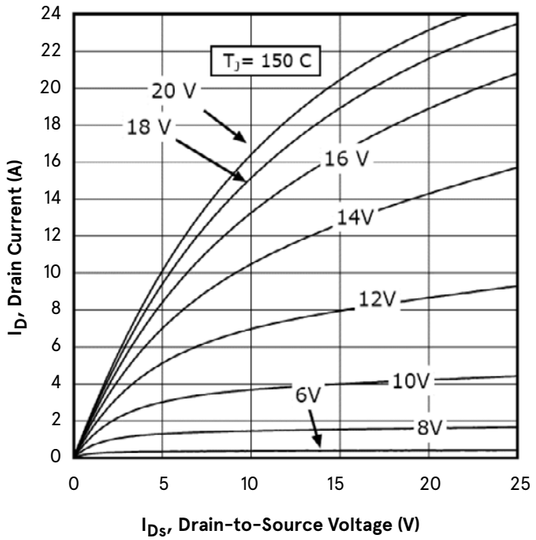


Figure 2: I-V Curve of MSC360SMA120B Under Different Driving Voltages at Tj = 150°C.

Figure 2 shows the I-V curve of MSC360SMA120B under different driving voltages at Tj = 150°C. Note the small separation between the RDSon curves at VGSon = 20V and VGSon = 18V, and compare this to the bigger differences in RDSon as VGSon drops increasingly below 16V. Some important considerations include:

- An over-current protection scheme based upon the maximum current may fail to trigger. Designers should account for the higher variability of RDSon at lower VGSon.
- The small-signal transconductance, gm, is higher at lower VGSon. This effect can lead to switching instability, since VGS may be in a middle range in the presence of high drain-source voltage – resulting in a short circuit event. (The peak short circuit current will be governed by the precise value and duration of VGSon. See the next subsection.)

SHORT CIRCUIT WITHSTAND TIME

When driving with lower VGSon, the maximum current will be lower under short circuit conditions, which can lead to a longer short circuit withstand time.

The following plot shows the short circuit withstand time (SCWT) in relation to gate and drain voltage for MSC035SMA070B measured with VDS = 350V, 470V and 560V and VGSon = 20V, 18V and 15V. It can be seen that the drain voltage is the most significant factor affecting SCWT, followed by VGS.

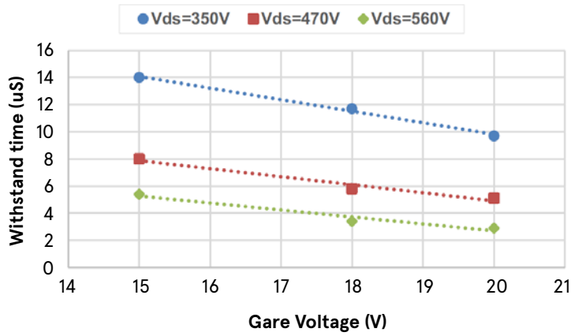


Figure 3: Short Circuit Withstand Time of MSC035SMA070B.

In applications where short circuits may occur, the following considerations should be made:

- The SCWT specified in the data sheet is the typical time to failure, as defined by the device no longer exhibiting proper electrical function. In reality, the failure occurs after the device is switched off, when the latent heat generated causes irreversible damage. In essence, the delay does not happen when the measurement says it happens. Because of this delay, data sheet's SCWT can only be seen as a typical number.
- A more reasonable requirement would be that a specified number of devices are still operational after a specified number of short circuit events.
- Short circuit withstand time can be extended by increasing the device size or using multiple devices designed to drive at a reduced current level with source degeneration.

For additional guidance and insight, please contact your local Microchip sales team.

PROJECTED LIFETIME

The below graph indicates that for every 2.5V increase in VGSon, the projected lifetime of the gate oxide is reduced by an order of magnitude. This relationship applies over a wide range. It is a wear out mechanism due to accumulated damage over time.

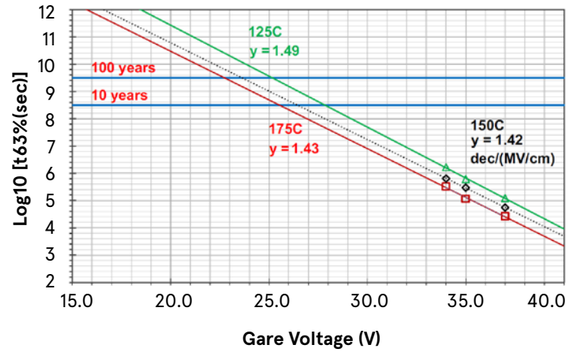


Figure 4: Projected Device Lifetime Under Different Gate Voltage.

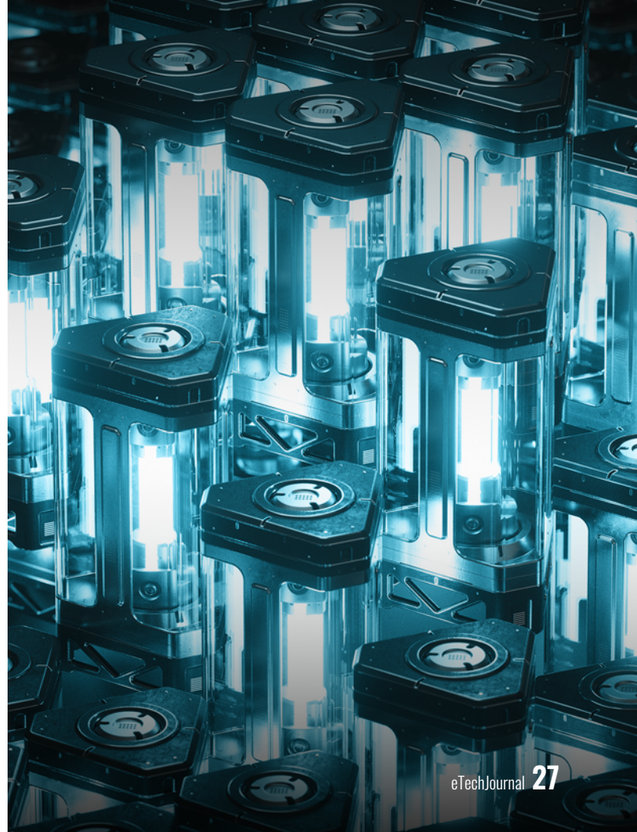
The lifetime of the gate oxide is mostly determined by the steady state gate ON drive voltage. The +23V maximum rating on the gate is a recommendation for steady state gate voltage based on the projected lifetime of the device. Transient overshoots in VGSon do not materially affect the device lifetime because of their brief duration. As an example, assume a rectangular overshoot for 20 ns at 25V with a nominal gate voltage of 20V. Per the oxide lifetime graph, the rate of degradation of the oxide during the pulse is 80 times higher. However, with a switching frequency of 100 kHz, the duty factor is 20/100,000 = 0.002. The relative stress, then, is only 80 × 0.002 = 16%.

It should be noted that transient VGS is not observable at the package pins. The gate and source lead inductances make it difficult to measure the actual gate voltage overshoot. Due to the high capacitance of the gate, the gate drive is normally over-dampened, and overshoot is rarely a problem. This is easiest to determine in simulations.

SUMMARY OF VGSon

Microchip SiC MOSFETs can operate at +18V drive voltage with little loss in performance compared with the recommended +20V drive voltage. As can be seen in the above graphs, the increase in RDSon is much larger at 25°C than at 100°C–150°C. A system generally is penalized less by conduction loss than would be implied by the difference at 25°C if the die is hot. While the switching losses may be slightly higher under the same gate resistance, and saturation current will be lower, the positive trade-off is a longer short circuit withstand time.

Operation at VGSon < 18V gate drive comes with elements of risk and should only be used if there is sufficient margin in RDSon. Current sharing between paralleled devices can be problematic at colder junction temperatures. If VGSon < 18V is needed, please contact your Microchip team for design support.



OFF STATE DRIVING VOLTAGE, VGSoff

Microchip SiC MOSFETs are normally OFF power transistors. A negative VGSoff is not required to keep the switch OFF during steady state. Rather, it is used to minimize switching loss and enhance switching stability.

- The presence of source inductance can slow the device turn-off process. A negative VGSoff is used to overcome this effect.
- A negative VGSoff provides more margin to avoid false turn on (also called shoot-through or cross conduction) during switching transients.
- A negative VGSoff has been used for decades with silicon IGBTs. Negative gate drive is not unique to SiC.
- More complex modules with distributed transistors need a higher (more negative) VGSoff to avoid instability. Single transistor discrete designs can get by with very little negative VGSoff.

Third Quadrant Conduction Performance Unlike a silicon IGBT, SiC MOSFETs can conduct current in both directions. The figure below shows the so-called "third quadrant" performance of Microchip's MSC360SMA120B; simply put, this is the drain current when the drain voltage is reversed. The body diode carries reverse drain current if the MOSFET's channel is turned OFF. In the case of VGSoff = -5V, all current flows through the body diode. As VGS is increased, the channel begins to form but maintains a substantial voltage drop even at VGS = 0V, meaning the body diode still carries most of the reverse current. Following the switching transient, the channel can be turned ON to also conduct the reverse current to further improve conduction losses in a technique known as synchronous rectification.

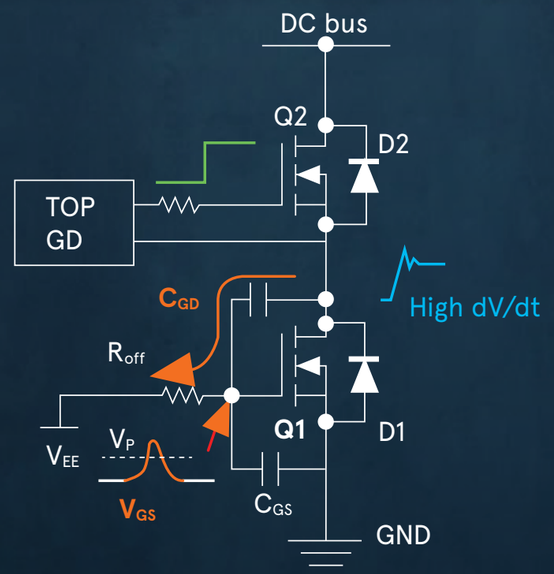


FIGURE 6: Switching Induced False Turn ON in a Half Bridge Configuration.

SUMMARY OF VGSoff

Due to the previous discussion, Microchip does not recommend the use of VGSoff = 0V. For single-ended topologies with no danger of shoot-though (e.g., flyback, buck, or boost topologies), it is possible to use VGSoff = 0V. Should VGSoff = 0V be absolutely required, attention should be given to proper gate-source loop design.

Specifically, designers should try to minimize three things: (i) parasitic drain-gate capacitance, (ii) gate-source loop inductance, and (iii) shared inductance between the gate-source loop and main current commutation loop.

CONCLUSION

This application note provides guidance on Microchip SiC MOSFET gate-source voltage specifications and design considerations for making the most effective gate driver circuit. The following are key takeaways.

1. For the best possible switching and conduction performance, Microchip recommends driving with VGSon = +20V and VGSoff = -5V.
2. It is permissible to deviate from these recommendations. Microchip SiC MOSFETs can operate at +18V with slight reductions in current capability and turn-on efficiency, but comes with the benefit of longer short circuit withstand time.
3. Driving current-generation Microchip SiC MOSFETs using VGSon = 15V is not recommended. If this situation cannot be avoided, please contact icrochip for design assistance.
4. Microchip guarantees turn-off with VGS = 0V at Tj = 175°C. That said, using a negative VGSoff provides greater margin around Vp, which enhances switching stability and is the most certain way to prevent false turn-on.

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